JEI JOURNAL OF ECONOMIC ISSUES
Vol. XXXVIII No. 3 September 2004

John Rae and Thorstein Veblen

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> All that the possessor of the luxury desires, is, to have a means of showing that he has acquired the command of a certain amount of the exertions of other men.
>
> —John Rae, *Statement of Some New Principles on the Subject of Political Economy*

Rae's "Accumulation"

Many of Thorstein Veblen's ideas in *The Theory of the Leisure Class* ([1899] 1998) are found in John Rae's *Statement of Some New Principles on the Subject of Political Economy: Exposing the Fallacies of the System of Free Trade, and of Some Other Doctrines Maintained in the "Wealth of Nations"* ([1834] 1964). Rae was born near Aberdeen in Scotland in 1796 and emigrated to Canada in 1821, to Boston and New York in 1848, and then to the Sandwich Islands in 1851; after a life of teaching, headmastering, writing, inventing, farming, and financial straits, he died in New York City in 1872. He was a freethinker and linguist who worked on the evolution of human language in general and the Polynesian language in particular. Rae influenced Nassau Senior, John Stuart Mill, W. Stanley Jevons, Eugen von Böhm-Bawerk, Alfred Marshall, Irving Fisher, Frank Taussig, and Joseph Schumpeter (Mixter 1905, xxxii; Edgell and Tilman 1991, 731).[1]

Rae's subjects were capital formation—accumulation as opposed to prodigality ([1834] 1964, 118–29, 199, 206; Mixter 1902)—and technological progress through knowledge and invention (Spengler 1959). Accumulation is of "instruments" of slower or quicker return according to the labor put into their formation, their capacity of return, and the "length of time . . . elapsing between their formation and exhaustion"

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(Rae [1834] 1964, 100–01, 278), as well as by their efficiency and absolute durability (109–17). Instruments include not only tools but also houses and arable fields (86–89, 170–171). (Veblen's "accumulation" is closer to mere "acquisition" [(1899) 1998, 25–41, 230]). For Rae "knowledge" and "provident forethought" distinguish us from "inferior animals," and together these cause a better future (Rae [1834] 1964, 81; Veblen [1899] 1998, 10, 20, 74, 93, 227). The genesis of economic stratification is that frugal people become richer than prodigal ones (Rae [1834] 1964, 198–207).

Rae took as human givens not only concern for offspring but also "the interests of society" and the ability "to provide for the wants of futurity" ([1834] 1964, 81, 89, 119–125, 158-160). These emotions aid the effective desire of accumulation, which satisfies future "real wants" (265, 271, 289, 290). Within terms of the central category of *time,* a cost is "the sacrifice of some smaller present good" and a benefit is "the production of some greater future good" (118, 121, 136, 138). By building a well-insulated dwelling, for instance, with good cupboards, this greater good is the fuel, food, wearing apparel, and metabolized body energy which is thereby not "wasted" (200–03, 313–19); for Veblen also, to say the least, waste is a crucial category ([1899] 1998, 15, 59, 83–85, 91, 97–101, passim).

Because it is truistic that "all men prefer a greater to a less" and the future good or saving is obviously greater, the time factor must be invoked to explain prodigality, or nonfrugality. Not only do we not live forever but the exact date of our demise is uncertain, and thus this "desire of accumulation" is contravened by our natural preference for present pleasure (time preference, discounting the future)—"to spend is easy, to spare, hard." That capital which does get formed is thus a function of a person's net factor of "the *effective desire of accumulation*" (Rae [1834] 1964, 118–21, 129, 206–07). Strengthening the hand of present over future enjoyment even more are both our covetous glances at the "rank immediately above" us (which we perceive as "rolling in superfluous extravagance") and our desire for the "articles . . . necessary to [our] condition" or "rank" (Rae [1834] 1964, 120; Veblen [1899] 1998, 1–3, 22–34, 140–41). Indeed, "merely personal considerations" can yield no more than a weak desire of accumulation (Rae [1834] 1964, 120; Veblen [1899] 1998, 89). Providing for some comfort in our own old age motivates us to some extent, but Rae is asking (128–29, 80–81), like Kenneth Boulding (1973), why we consider posterity at all.

"But man's pleasures are not altogether selfish"; Rae's empirical wisdom is that a person is also moved by "love" of others, "the conjugal and parental relations, the claims of his kindred, his friends, his country, or his race" ([1834] 1964, 121–22). This is equivalent to Veblen's "group solidarity" of the "peaceable savagery" phase ([1899] 1998, 7, 33, 219; [1914] 1964, 36) or to his "non-invidious impulses" serving the "generic life process" ([1899] 1998, 16, 259, 275, chap. 13), "parental bent" ([1914] 1964, 11, 25), or "other features of human nature . . .alien to . . . conspicuous consumption," without which no saving whatsoever would occur ([1899] 1998, 91). Thus for Rae the "uncertainty and worthlessness [of] future goods" is counterbalanced and a degree of effective

accumulation is after all achieved by these "social and benevolent affections" (122, 142) Further help comes from our "intellectual powers" (Veblen's "idle curiosity"?) because they strengthen invention (122, 275–76).

Vanity

Accumulation is thus the advancement of "the wealth of society, the capital and stock of communities," and it both enables the "consumption of utilities" and provides "additional supplies for the wants of futurity"; Rae's basic cleft is between "utilities" and "luxuries" ([1834] 1964, xv, 292, 275, 222, 238; also Boulding 1949–50). The main "check" on the "social affections and . . . intellectual powers" that promote accumulation is the "purely selfish . . . principle . . . of vanity," and Rae's term for "the expenditure occasioned by the passion of vanity" is "luxury." *Vanity* is "the mere desire of superiority over others" by whatever criteria; "a perfect being" can achieve de facto superiority purely through "pleasure in the good he does," but it is the (vain) pleasure in "surpassing others" that moves the rest of us (Rae [1834] 1964, 265–66, 271–72, 290–91; Edgell and Tilman 1991, 735–36). Vanity is also the "pride" moving a man to rise in the world, "placing himself on an equality with those to whom he was once inferior" (325); for Veblen it is "to rank high" in "invidious comparison" with our "competitors" ([1899] 1998, 31–34, 16–17, 25–27), recalling Rae's "desire . . . to rank high in the estimation of the world" (125, 120) and "It is invidious to run to expenses which others cannot follow" (282).

Veblen likewise contrasted the desire for "sustenance" ([1899] 1998, 103), "self-preservation" (110), "serviceability" (154), "physical necessities" (205), "the generically useful" (219), "subsistence" (24), "naïve" consumption (25), and so on, with *emulation,* which is "the stimulus of an invidious comparison which prompts us to outdo those with whom we are in the habit of classing ourselves" (103, 31). Similar to Rae's "real practical utility" ([1834] 1964, 338), he also opposed "economic" to "aesthetic and ethical" serviceability (262–63). And his discussion of noninvidiousness parallels Rae's social affections and shows the mistake of emphasizing his sarcasm and coolness: in contrast to consumption due to "the human proclivity to emulation" which—like Rae's dissipating laborers' "abilities to spend" (326)—fulfills only a "secondary utility as evidence of relative ability to pay," there are goods "consumed as a means to the fuller unfolding of human life," to the end of "the fulness of life . . . taken in absolute terms" (154, 24–26, 102–04).

These two categories of consumption are in terms of motivation, rather than the goods themselves. One is relative to others; the other is "absolute" or, better, relative to nature—"against the non-human environment" rather than the "human environment" (Veblen [1899] 1998, 220). Rae said that while many goods satisfy "real wants" ([1834] 1964, 289, 292), luxuries, seen in terms of the economy as a whole, "give no absolute enjoyment, it is all relative" (290, 275). John Maynard Keynes later contrasted "abso-

lute" needs for health and survival with "relative" ones "in the sense that we feel them only if their satisfaction lifts us above, makes us feel superior to, our fellows" (1930, 326). Veblen's corresponding two-tiered analysis is in terms of "higher" versus "lower" wants ([1899] 1998, 25, 103), or "physical want" versus "spiritual need" (85, 168).[2]

This dichotomy between absolute and relative, or intra- as opposed to intersubjective (Fullbrook 1998), is sociological, while the dichotomy in terms of needs and wants (Sanne 2002), or between subsistence and conspicuous consumption, requires physiological criteria, as in Veblen's "subsistence minimum . . . required for the maintenance of life" ([1899] 1998, 107, 25–26, 69, 92) or John Hobson's "biological utility" or "organic human standard" (1929, 309, 337). Better than dozens of later writers who build on some such distinction, Rae and Veblen avoided the conflation of subjective and objective criteria. Good overviews are McAdams 1992 and Jackson and Marks 1999. In the interests of thoroughness it should be added that Rae's taxonomy was actually three-tiered—necessaries, conveniences, and "amusements," or luxury ([1834] 1964, 12, 118, 253, 258, 272, 275)—presaging Marshall's "necessaries, comforts, and luxuries" ([1890] 1916, 67).

Of course vanity or emulation also come in nonpecuniary varieties. Rae mentioned "excelling in virtue" or even vice ([1834] 1964, 266, 122), while Veblen granted "invidious comparison in other respects than opulence; as . . . in the manifestation of moral, physical, intellectual, or aesthetic force" ([1899] 1998, 97). Like "knowledge of dead languages . . . and fancy-bred animals," though, much of this is reducible to the pecuniary strength evidenced by leisure (43–45, 25, 91, 223). But both were mainly interested in wealth, and other roads to status are indeed less relevant for economics (or justice, or environment problems).

For Rae, what counted was "to have what others cannot have" ([1834] 1964, 266), whereas for Veblen it was to own what "other persons . . . are compelled to do without" ([1899] 1998, 130) or, in a word, his delicious "spiritual need . . . of pecuniary decency" (85, 126). Rae's examples, like Cleopatra's drinking a precious pearl dissolved in water or Romans' eating nightingales' brains (an example from Pliny via Adam Smith), underline the costly and wasteful character of such consumption (266–67). Veblen's somewhat more plebian examples are "carpets and tapestries, silver table service, waiter's services, silk hats, starched linen, many articles of jewellery and dress" (99); these objects, as well as household furniture, lend themselves intrinsically to "honorific costliness" (131). And while for Rae it is true that "mere costliness" and having "what others cannot have" do heighten the pleasure attending the noncompetitive consumption of, say, wines and meats themselves, the motive of vanity is stronger than this pleasure from the object itself (266–68). Veblen concurred (38), and both, using examples of spoons, metals, gems, and jewels, knew that scarcity and price lend higher distinction than either serviceability or beauty (Rae, 269–73, 275, 307; Veblen, 126–30, 169).

Display

The kind of superiority that Rae examined was social, not secret; it must be shown and, if possible, acknowledged by people "accustomed to see and be seen" ([1834] 1964, 287). When "articles" are chosen to show superiority they must, in order to be capable of "gratifying this passion" of vanity, be "conspicuous" or "apparent" (267, 270, 287, 310); luxury objects give enjoyment because they "display superiority" (289, 271). The contrast is with things that "supply some real want," or things that become cheap, inconspicuous, and therefore unfit to "supply the demands of vanity" (289, 286). For such goods Veblen gives us the lovely term "humilific" ([1899] 1998, 155), and if the vintage Veblenism is "conspicuously wasteful honorific expenditure" (103), his "conspicuous consumption" is a household word. Rae, however, while often combining "wealth and honor" (209) lacked an explicit concept of "wealth-vanity" to correspond to Veblen's "pecuniary emulation" (34, 110).

To this common and central term (*conspicuousness*) Rae preferred *luxury* ([1834] 1964, 271–272, 252). This too conveys "visibility" (Veblen [1899] 1998, 16, 103, 112, 122) because if *luxe* is "light," and the light either shining on or emanating from an object serves its display, then *luxury* is indeed a good concept for consumption over and above basic wants. Rae thus translated Heinrich Friedrich von Storch's "*le luxe d'ostentation*" as "the desire to show"; for Storch, "luxury objects" must "display [or] attest the wealth" of the owner or consumer; display gratifies "the desire to appear rich" and thus superior to others (270–71; Veblen, 67–85, 73–74).

To further denote the exact things signifying possession of "a certain amount of wealth" or "such a rank in society," Rae used "inscription" and "mark," or "marks of distinction" ([1834] 1964, 287, 307), the latter term being common both in ethology and in more recent consumption literature. Again, the job that objects have of "marking superiority" can't be done by the unseen timber in your house or your fuel coal but rather by dress, furniture, marble chimneys, wines, and liquors (267–68). (For further examples see Rae, 200, 289; Veblen [1899] 1998, 74–75, 112; Frank 1985, 1999.) "Opulence" is also employed by Rae for that which sets one above (270), and Veblen's core theory is that the leisure class must show its "ability unproductively to consume . . . thereby putting in evidence [the] ability to sustain large pecuniary damage without impairing his superior opulence" (63).

Veblen's vocabulary of display includes "marks of expensiveness" ([1899] 1998, 132), "badge or insignia of honor" (44), "suggestion of leisure" (170), "signs of expenditure" (187), and more. Rae's "propensity to show" ([1834] 1964, 276) is Veblen's "propensity for emulation" (110), or "propensity for display of expenditure" (168). For Veblen wealth, leisure, and the ability to waste must be "manifest" (38, 91), "put in evidence" (36, 38, 61, 187), or, in language tantalizingly close to that of sexual selection theory (Darwin [1859] 1950, 75–77; 1871), "advertised" (85–88) or "displayed" (86,

167–68).[3] Indeed, for Charles Darwin, display was a decisive clue for this theory ([1871] 2003, 221–22, 314–19, 394–402, 567, 572–73).

For Rae, consuming what the vulgar masses consume lowers one's status; "costliness" or "dearness" itself and the "parade of riches" explain the character and quantity of goods possessed or consumed, a view he supported with a quotation from Smith, who observed also that "scarcity" and "great labor" make up an object's desirability ([1834] 1964, 268–70). Or, "it is not the thing itself,[4] but merely the quantity of labor embodied in it that vanity prizes" (285). This specific focus on labor-costliness is implicit in Veblen since labor is such a huge element of price. It is also explicit, as when he contrasts machine-made with hand-made goods ([1899] 1998, 127, 158–66). What's more, if labor's "irksomeness" (17–18) consists of a time-cost as well as an energy or annoyance one, Veblen's insistence that wealth means having time as well as goods—leisure as "the non-productive consumption of time" (43)—is an insight that goes farther than Rae.[5]

Exclusivity is explicit in both Veblen ([1899] 1998, 130, 235) and the work of Rae, who prosaically noted that "a very large share . . . of the expenditure of the wealthy consists of luxuries,—articles, the sole gratification afforded by which is, that they alone can afford to possess them" ([1834] 1964, 274). Certain consumption is "prohibited" for lower classes (269) or, in Veblen, is allowed only on the "sufferance" of the higher ones (72). It is a short step to Harvey Leibenstein's "snob" and "Veblen" effects wherein demand varies "non-additively" with others' demand and with price (1950). In illustrating this point with pearls—that when progress renders any hitherto expensive thing cheap, this effect is lost—Rae employed Veblenian humor (286).

Cost and Waste I

Once Veblen established the concept of status and its expression through ownership ([1899] 1998, 25–34, 46–47), his main economic concept was waste (15, 27, 116–20, 154–60, 175–81). Both leisure and consumption "for the purposes of reputability," have the "common element" of waste, and the pecuniarily decent life follows "the broad, fundamental canon of conspicuous waste" (85, 91). Repeatedly, he examined "usefulness," "utility," and "serviceability" on one hand, contrasted with "futility," "idleness," and the merely pecuniary or nonindustrial on the other (15–16, 24, 95, 128). Conspicuously consumed goods must above all be costly, "pecuniarily above reproach" (119, 126). This is waste, "expenditure [which] does not serve human life or human well-being on the whole" (97). In his later analysis of "pure waste" in gold, timber, and oil production, Veblen pointed to oil spills and "duplication of work and equipment" ([1923] 1964, 177, 199), described in detail for the case of the Oklahoma fields by Angie Debo as "enormous . . . tragic waste" (1949, 58–63, 69).

Rae also viewed the matter in terms of waste and nonutility. Because vanity demands the new and changing, it "destroys before its time, as Mr. Say complains, whatever it lays its hands on . . . 'destroyed . . . before having ceased to exist, and without hav-

ing supplied any real want'" ([1834] 1964, 271). He had another category of "loss to the society" or "pure economic loss," or, simply, "waste"; much industry and effort is "expended in vain" from the point of view of "the whole society as a body" (290, 307–308, 312–19, 338). ("Wasted" and "in vain" are common-usage synonyms.)

Thus such consumption is societal waste, and the "social and benevolent affections" represent it as "hurtful" (Rae [1834] 1964, 122, 275). Albeit without taking a stand himself, Rae described at length antiquity's attribution of immorality and "the suffering of others" to "the pursuit of wealth," drawing as well on St. Paul and Shakespeare (125–128), a tradition upheld in our day by, for example, Schumacher 1999 and Orr 1999. Vanity consumption "supplies no wants" (290) and indulgence in "acknowledged extravagances and real luxuries" makes one "guilty of inflicting an injury on the community" (282). For Veblen, similarly, "emulative efficiency" is "not directly serviceable to the community" ([1899] 1998, 262); invidious comparison succeeds group solidarity (27–28, 32–34, 219; also Rae, 96–98). Always movingly concerned about the future, Rae said that vanity consumption "brings no addition to the absolute capital [and] generates no provision for future wants" (290) and that ostentation is prodigality, an enemy of accumulation (121, 123, 199, 206, 273). Paralleling both writers very closely are Boulding's analysis of waste and stocks (1949–50) and Richard McAdams' argument that "Competitive consumption is a market failure" (1992, 69, 48–62).

However, like Veblen, Rae exonerated the individual for his vanity. Even in its "absurdities" and "follies," "no blame can attach to . . . compliance with the [vain] customs of the society"; it is "the business of the poor man . . . , too, to avoid a display of poverty" ([1834] 1964, 281). "The gentleman, the tradesman, the lady, the servant girl, must alike obey the laws which the strength of this principle imposes on the society" (287). Veblen would say that these customs or institutions have "prescriptive force" ([1899] 1998, 41, 105), and he likewise insisted that his term "invidious" is in no way intended to deprecate but is merely descriptive of "the process of valuation of persons in respect of worth"; this "rating and grading" offers each of us, to boot, a gauge of the "degree of complacency" with which we may regard ourselves (34). He also bends over backward to deny the deprecation that "the speech of everyday life" has for "waste"; for him it is "a technical term" (97–101). For "*the person incurring the expenditure,*" an expenditure "on the ground of invidious pecuniary comparison" is not wasteful (99, my italics). During this deep bow to "economic theory proper," of course, in which utility is proven by preference, with no questions asked, his tongue is securely in cheek (also Veblen [1914] 1964, 1; Gilman 1999).

In his chapter "Of Waste, or Pure Economic Loss," Rae specified a further category of economic losses to society, namely the cheating of debtors, simple theft, war, and deceit in salesmanship and advertising, in other words, "successful or unsuccessful attempts to pass off commodities for what they are not" ([1834] 1964, 314). Extravagance is the cause of "artifice and fraud" and "fraud and violence" (326), recalling Veblen's "force and fraud" as "prowess" ([1899] 1998, 14, 231). Not only is this the

"business" or "predatory" category in Veblen's dichotomy between it and industry (28, 208–09, 237–41, 259) but it constitutes as well the more current category of defensive expenditures which has taken on importance in measuring real welfare by subtracting such expenditures from gross domestic product (GDP). Daly and Cobb's index (1989) of sustainable economic welfare (ISEW) is one example. The spirit of this thought is captured, in turn, by Veblen's priceless characterization of the lawyer, who is "exclusively occupied with the details of predatory fraud, either in achieving or in checkmating chicane" and to whose profession "no taint of usefulness . . . attaches" (231).

Both men were looking at what is before and after preferences: at the motives or nature of them and their consequences or effects, for example, their hurtfulness to society. Veblen time and again contrasted wealth for display with our endeavors both for plain old "physical comfort" ([1899] 1998, 25–26, 102–03, 205) and for the "generically useful" (219) or "generic life process" (334)[6] or "fulness of life" (100); a good's utility is judged by its "efficiency as means to this end" (154), and the instinct of workmanship always resurfaces to fight predation and emulation (15, 93, 98). When Rae wrote that "if we inspect the dwelling-houses and furniture of rigid economists, we generally perceive that they have an air of both durability and efficiency" ([1834] 1964, 200), Veblen's parents' farm comes to mind; Rae's straightforward assertion is that an "indirect . . . effect . . . of luxury . . . is always to dissipate a part of the national funds proportioned to its strength" (292; also 126, 325–26). EdwardBellamy, for his part, taxonomized this societal waste into thirteen categories ([1887] 1917, 225–44; Edgell and Tilman 1989, 1010–14).

Cost and Waste II

The pursuit and display of wealth, then, assuming scarcity, is detrimental for society and by some criteria wasteful after all; material inequity and future want result, and if it is individually "rational," perhaps also tragedies of the commons. But a further, different question is possible: what is the situation of the individual? Is the societal or economic waste of luxury and pecuniary decency also waste in terms of the individual's economy of costs and benefits? During the last decades of the nineteenth century, evolutionary thought was teaching that preserved "derivations of structure or instinct" must be "profitable" (Darwin [1859] 1958, 389, 128, 170–74); were, for instance, in addition to the males, female deer and elephants to grow immense horns and tusks, this "would be a great waste of vital power" (Darwin [1871] 2003, 503; also 216, 496 on danger, 221–22 on energy expenditure, 338–39, 403, 514–15 on consumption of organized matter; also Ghiselin 1974; Gans 1991). Hobson later noted that "[g]etting and spending, we lay waste our powers" (1929, 309), also stressed by Juliet Schor (1992), Gary Cross (2000), and others, who ask why we might be so stupid as to work ourselves to death just to outdo the Joneses, who are trying to outdo us. My suggestion here is that it is this cost-benefit ratio that is often captured by Veblen's "efficiency": by "industrial"

efficiency and workmanship for the behavioral, economic realm ([1899] 1998, 15, 93, 110–11, 241, 259) and by "physical efficiency" for the internal economy of the organism (58, 69, 73, 203-05).[7] In terms common to economics and biology (utility, efficiency, waste, futility), Richard Dawkins elucidated this "economy assumption" with the examples of salmon, bone calcium, birdsong, firefly flashes, trees' height, cheetah-antelope races, elephant seals, work experts, and model T kingpins, all from the point of view of DNA, not of groups or even individuals (1994, 103–24).

Are the invidious, vain expenditures of time, effort, and material—high enough to be visible to others—wasteful for the individual, "too high," higher than benefits? Earlier, Veblen had defined conspicuous consumption as "displaying costly goods that afford no return to their owner, either in comfort or in gain" ([1894] 1997, 282). Yet in spite of this, and of course aside from competitive expenditure's not serving "human life or human well-being on the whole," it is not waste "from the standpoint of the individual consumer" because it was chosen ([1899] 1998, 97–98). This is close to evolutionary biology's working assumption that species-wide behavior could very well be adaptive. But to the extent that he was here joking, he was implying that perhaps, after all, costs exceed benefits, pecuniary emulation is stupid, maladaptive. At least for the "lower strata" he is clear that conspicuous consumption endangers their subsistence and energy economy: they endure "squalor and discomfort" and "this category of consumption [is] not given up except under the stress of the direst necessity" (84–85). Merely factoring in status-driven pecuniary utilities ignores exactly this part of the story (in addition to ignoring societal waste). To be sure, however, Veblen's guiding question is not the evolutionary biological one but rather the social one of the "economic conscience" (98).

Rae was also looking at luxury in contrast to real wants, sustenance, capital accumulation, provision for the future, and the common good, but of course without the idea that what has survived natural selection/elimination is usually adapted to conditions. But luxury does entail costs. In his example of Cleopatra's drinking the dissolved pearl, Rae says it must have tasted "disagreeable"; similarly, "a dish of nightingale's brains could scarcely be a very delicious morsel" ([1834] 1964, 266). In fact, it is the very disagreeable or at best neutral taste of these expensive things which, for Rae, proves that we consume them from some other motive other than just normal "pleasure" or "real wants"—this is his *derivation* of vanity. Another of his examples goes even further, namely that from Pliny of Roman men with many heavy rings on their fingers, "rather loading than adorning them" (277). And an example taken from Smith claims that, "in the wantonness of plenty," even great power and authority will be sacrificed for "frivolous and useless . . . diamond buckles" or other "trinkets and baubles" (274–75). Like Darwin ([1871] 2003, 573 ff.), he cited the "privations" that "savages" incur in order to ornament themselves in terms of the pain and expense of cuts, tattoos, and European imports; they also voluntarily relinquish "provisions . . . made for the future" (Rae, 276). Finally, just as Veblen exempted "no class of society, not even the most abjectly poor" ([1899] 1998, 85) from conspicuous consumption, Rae asserted that vanity expenditure

"falls on all classes of society," including "those who have difficulty in procuring absolute necessities" (271).

Veblen's own examples of perhaps *overly* costly consumer behavior are the "squalor and discomfort" suffered to buy "the last trinket" of the poor ([1899] 1998, 85), the "infirmities" and "dissipation [of] dram-drinking, 'treating,' and smoking" (70, 89–90; Rae [1834] 1964, 326), the wearing of uncomfortable, unprotective, even "incapacitating" clothing (170–72, 185)—in short, going "ill clad in order to appear well dressed" (168), "costly entertainments, such as the potlatch or the ball" (75), the "mutilations" and "debility" of the "constricted waist'" and "deformed foot of the Chinese" (147–49, 172), the "Polynesian chiefs, who, under the stress of good form, preferred to starve rather than carry their food to their mouths with their own hands" (42), and, finally, a French king who burnt to death rather than shifting his chair himself (43).

The mere acquisition of leisure class manners takes "strenuous discipline" and "laborious drill"—in short, "pains" (Veblen [1899] 1998, 49–50); "achievements of etiquette" are "difficult and costly" (76), and winning invidious comparisons entails an "arduous" learning of "the right kind of goods" to consume (74–75). Social duties are "irksome" (65), a man's workless wife requires his "assiduity" (81), and the "strain" of emulative consumption is in general "cumbrous" or "onerous" (65–66, 103, 111). The modern, leisure class scheme of life, which reduces to "waste, futility, and ferocity," has "pathological consequences" (70, 149); for "conspicuous decency" we pay with "comfort and fulness of life," and for pecuniary decency we give up "indolence and good-fellowship" (205, 351). Finally, were waste not necessarily defined in terms of life, we could, as Veblen did in the book's darkest passage (96), call this waste of life.[8]

I believe that Rae and Veblen were here onto something important for understanding conspicuous consumption, itself important for social justice and environmental quality. In terms of survival (Rae's sustenance, Veblen's subsistence), the conspicuous expenditures of the peacock's tail, the deer's antlers, the colors of birds and butterflies, and animals' "antics" in general had stumped Darwin, who then found their cause in same-sex combat and opposite-sex preference for certain traits. Rae and Veblen chose to look at human behavior and consumer goods, from antiquity to the Gilded Age, that was similarly puzzling (and odious), a perfect Darwinian example being Veblen's "decadent book," which is "costly and ill adapted to its ostensible use" ([1899] 1998, 164–65). They found its cause in vanity, emulation, status, and repute. But two questions then remain open. Why do we want status—why do we compete for rank, position, standing? And why is this so often on the basis of wealth—why is status expressed by *blue collar* and *silk stocking* (Hamilton 1973, 203; Brekke et al., 2003)?

Doing any justice to these questions would go far beyond this article. Yet it seems to me that in the two works examined here, status seeking itself is taken as a given. However, at least in Veblen, its pecuniary form is not. To be sure, Rae was open to the influence on behavior of "institutions" and "habits" ([1834] 1964, 95–96), and he hinted at "barbarian" or "savage" hunting societies preceding agriculture and pastoralism

(142–44), but where there are tools, the correlation between ownership of them and position on the "social scale" is self-evident (Mixter 1905, 235). More explicitly, Veblen imagined a "peaceable savage," "primitive," "perhaps sedentary," "ante-predatory" phase of culture where material classlessness reigns ([1899] 1998, 6–7, 16–21, 219, 351). But with the phase of "economic surplus" (20, 25, 205), perhaps even the earlier phase of "barbarism" (3–8), come emulation and the regime of status. That the rich, not the poor, set the standard, is likewise a given (104).

In his discussion of stratification according to material wealth, Rae only noted that people differ in "vigor of mind and body, as well as skill" ([1834] 1964, 98) and in their dispositions toward constructing instruments (129, 198–201). (When he added that vanity sometimes aids the "accumulative principle" (325), I think he meant that fortunes begin with somebody's working hard.) Very roughly put, Veblen's much fuller derivation of specifically pecuniary emulation relies on the concepts of predation, trophies, exploit, esteem, and ownership ([1899] 1998, 22–34, 44, 73, 349). It may be worth mentioning that Bellamy ([1887] 1917) assumed that rank and emulation are here to stay (68, 96–98, 123–31, 164–65, 170–71, 187–88, 197–98, 222, 259), but, by assuming material nonscarcity and moral improvement, eliminated its pecuniary variety from his utopia.

Moot and controversial questions remain, of course, as to the depth of Veblen's explanatory chain and his views on heredity and human nature, but his support of the premises of struggle within scarcity ([1899] 1998, 14, 24–25, 113, 220; Rae [1834] 1964, 96–97, 323–24) and of natural selection/elimination theory (13, 15, 188–89, 212, 215, 225, 246, 335) is beyond doubt. At any rate, the search for explanations of invidious pecuniary comparison remains topical. Michael Boyles and Rick Tilman, for instance, asked whether evolutionary theory (as sociobiology), has illuminated the "genesis of . . . power, class, and status" (1993, 1210–11). In spite of many attempts to extend the explanation back to Darwinian reproductive success, they find in the negative, but the question is on the table.[9]

During the late 1890s sexual selection theory was definitely on the table. Alfred Russel Wallace, Darwin, Thomas H. Huxley, and many others had debated it for years (Cronin 1991). In 1896 George Santayana reported that "[o]f late we have even learned that the forms of many animals are due to the survival by sexual selection of the colours and forms most attractive to the eye" (5). Rae's editor Charles Mixter devoted a footnote to the fact that Rae's remarks on the indirect utility of female dress were "written before the discovery of the principle of sexual selection" (1905, 252). And Veblen's silence on sexual selection is all the more puzzling because Bellamy, who influenced him, embraced it explicitly, even audaciously: women's power to mold men is Godly, improving within a mere three generations their efficacy, morality, and even their propensity for intergenerational justice, while selecting against their instincts for pecuniary prowess ([1887] 1917, 267–70). At any rate, one yearns to listen in on a conversation between Darwin and Veblen on their common topic: competition, conspicuousness, decoration, antics, status, and desirability.

Geoffrey Hodgson has recently noted the parallels between Veblen's idea of conspicuous waste and the "'costly' signaling between animals . . . to indicate, for example, fitness and availability to mate"; he referred to Amotz Zahavi and Ashivag Zahavi's handicap principle—that costliness proves fitness (1997)—but did not explicitly mention sexual selection (1998, 188–89, 194). He is also one who is asking questions of the heritability of behavior-guiding mechanisms (2001), suggesting that "habits," whether as feelings or institutions, are at least partly in human nature. Another is Edward Fullbrook (1998), whose explanatory chain leads to the nature of human psychology, positing, albeit without reference to evolution, an intentional theory of mind and our "existential lack."

Rae and Veblen gave us germs of the view that conspicuous consumption is costly for the individual in the way Darwin's peacocks' tails and deer's antlers were, that it is noncontributory, superfluous (Veblen [1899] 1998, 63, 155–56), or even detrimental to basic survival, and that it is hurtful and wasteful for (yet strangely tolerated by) society; in terms of natural selection, it makes little sense. But it exists and persists and thus, in the spirit of human ethology, the question must be faced: Is it an adaptation? Is it sexually, or otherwise socially, selected, thus indirectly enhancing reproductive success? For Rae it met one criterion of adaptations, namely human universality ([1834] 1964, 283, 129), and the case could be made that for Veblen, this is true once the predatory, pecuniary stage of society has been reached. For newer work on the possible adaptiveness of status consumption see Low and Heinen 1993, Buss 1994, Boone 1998, Hrdy 1999, Morrison 1999, Miller 2000, and Jackson 2002.

Insatiability

Pertinent to both equitable distribution and environmental quality is Veblen's insight that, because it is motivated by *relative* standing (status, rank, superiority), consumption will increase unlimitedly. His exposition is masterful and well-known: Because we are *comparing* ourselves with each other, it is not enough to reach the "normal pecuniary standard of the community." Our "chronic dissatisfaction" cries for an increasing "pecuniary interval" between us and others, and the "present pecuniary standard [is] the point of departure for a fresh increase of wealth" ([1899] 1998, 31, 90; Daly 1974; Scitovsky 1976). For Veblen, assuming a certain surplus above subsistence (20, 25), such an increase is realistic. But no matter how high or fairly distributed the "community's wealth, . . . the desire for wealth can scarcely be satiated. . . . If, as is sometimes assumed, the incentive to accumulation were the want of subsistence or of physical comfort, then the aggregate economic wants of a community might conceivably be satisfied at some point in the advance of industrial efficiency"; but since the "ground" of this "race for reputability" is "invidious comparison, no approach to a definitive attainment is possible" (32). Because the "need of conspicuous waste" is emulative, then despite "increased industrial efficiency" we don't work less but consume more (see Schor 1992);

the "increment of output" to meet emulative consumption is thus "indefinitely expansible" (110–11, 102). The sky is the limit.[10]

Rae started but did not finish this argument. He began with the point that the exact form of a particular person's "manifestation of . . . luxury" depends on his temperament: those leaning toward benevolent affection are extravagant in "sumptuous entertainments, and luxuries of the table," while those given to the intellectual powers indulge in "expensive buildings and decorations" ([1834] 1964, 279). In the altruistically inclined, furthermore, vanity gets steered toward frugality and thus toward "the welfare of others" and posterity, a combination bestowing great esteem (120–28). This recalls Veblen's jibe at charitable work, wherein he perceived the presence of "extraneous motives" ([1899] 1998, 339–40); as well, his taxonomy of exhibitions of "reputable waste" is fuller than Rae's, covering architecture, art, philanthropy, and leisure in the form of sports, spelling ability, and the knowledge of occult sciences (65, 259–63, 338–43, 363–67, 394–99).[11]

Rae then quoted Charles de Secondat, Baron de Montesquieu in support of the observation that vanity consumption increases with urbanity, population density, and anonymity, because "in the country, everyone is known" and deception impossible ([1834] 1964, 280). Correspondingly, Veblen noted that country gossip assures that "everybody's pecuniary status [is] known to everybody else"; in the country "home comforts and the leisure indulged in" count as consumption, but in the town or city, "advertisement" is far more necessary ([1899] 1998, 88–89). Contrasting examples are given by Knut Hamsun ([1917] 1978, 230–34, 285, 324–27). Rae also touchingly believed that city people have few options but consumption, whereas a country person has the ability and means to make or improve "instruments" like mending a fence, cultivating a plot, or "procuring food for his cow or his pig" (280).

Further following Montesquieu, where we are surrounded by numerous strangers, "vanity redoubles, because there are greater hopes of success. As luxury inspires these hopes, each man assumes the marks of a superior condition. But, by endeavoring thus at distinction, every one becomes equal and distinction ceases: as all are desirous of respect, nobody is regarded" (Rae [1834] 1964, 280). The competitive spiral begins anew at this higher absolute level. Again, the "industry employed [for] luxuries" is "in vain. . . . It gives no absolute enjoyment, it is all relative; as much as one is raised by it, another is depressed, the superiority of one man being here equivalent to the inferiority of another" (290).

This insatiability is banal in its role as assumption in neoclassical economics. But Veblen, and Rae with Montesquieu's help, looked behind the empirical fact of it, again using pecuniary emulation and vanity to explain it. For justice, environmentalism, and even psychological health, this fact—that happiness by means of material wealth is relative rather than absolute—is however not banal but bad news. The observed upward spiral has led many authors to bemoan the "irrationality" of the consumption "rat-race," "treadmill," "zero-sum game," "religion," and so on (Duesenberry 1949; Easterlin 1973,

9–10; Scitovsky 1976, 107–20; Leiss 1976, 7, 9, 29, 85, 100, 127; Schor 1992, 49, 122–25; Frank 1985, 17–30, 1999, 67–73, 111). However, if status seeking is a given, this behavior in the realm of wealth is no more irrational than that of a team's wanting to top the standings. The fact that, seen as a whole, the standings are a zero-sum game is irrelevant.

Rae did not make the point in so many words. He did say, however, that "[p]eople who regard appearances . . . can scarce expect that any improvement will materially diminish their yearly outlay for dress, for themselves or families" ([1834] 1964, 287). Bear in mind that improvement, successful efforts of invention, and increase in the facility of production (289) are Rae's terms for Veblen's industrial efficiency ([1899] 1998, 32, 110, 241). This is because lower prices do not lower the "proportion of their revenues" that people spend to maintain their "rank"; if improvement cuts prices by half, then "the quantity carried about must be doubled, or recourse must be had to some other material" (287). Rae quoted Adam Smith: "When by improvements in the productive powers of manufacturing art and industry, the expense of any one dress comes to be very moderate, . . . the rich . . . will naturally endeavor to . . . distinguish themselves . . . by the multitude and variety of their dresses" (270). Finally, "[s]hould the best flannel cost only two pence a yard, it would still be worn by all who now wear it, and by many who do not" (287). Other things, or more of the same, get consumed.

Regarding goods, though, that are "beyond the reach of vanity," greater efficiency in their production is "really felt"; iron, quarrying stone, bricks, flour, soap, glass, leather, and fabrics are thus subject to "real improvement" (Rae [1834] 1964, 289). When cheapness renders things less suitable in showing superiority, yet their use remains necessary, either "a greater quantity" is necessary, or else one must only "consume them when they are most scarce," as with green peas at Christmas or fish from very far away (287). For Rae, to be sure, most commodities exhibit a certain "strife between the two principles" of "vanity," or "luxury," and "utility" (286, 272, 310), equivalent to Veblen's caveat that consumable goods "may be useful and wasteful both," and "generally show the two elements in combination" ([1899] 1998, 100; Hamilton 1989). However, for goods apt to be used conspicuously, like "articles of furniture, of diet, [and] the equipage [SUVs, Mercedes (Joplin 1970)] of the rich," a "greater or less part of the effects of improvement, is absorbed by vanity in them all, and consequently lost" (288), just as for Veblen "pecuniary emulation . . . stands ready to absorb any increase in the community's industrial efficiency" (110–11).[12] Rae's "lost" also reminds one of Veblen's belief that fully half the monetarily measured economy is wasted and has nothing to do with the "collective good" ([1914] 1964, 193, 344, 350; [1899] 1998, 226–31).

Fashion

Veblen makes the questionable assertion that "[n]o explanation at all has hitherto been offered of the phenomenon of changing fashions" ([1899] 1998, 173). Indeed,

Marshall for instance seems to have contented himself with condemning—because of its wastefulness—"the baneful influence through almost every rank of society" of "the evil dominion of the wanton vagaries of fashion" ([1890] 1916, 288, 88). Like many after him (Foley 1893, 465, 466; Veblen [1899] 1998, 152–53; Scitovsky 1976, 137–38, 282–83), Marshall also fell back on the nonexplanatory observation that we want "variety for its own sake" (86). But he made a good start by saying that variety in dress has both "natural" and "conventional" causes—roughly Veblen's "naïve" versus "honorific" consumption (25, 70–74, 102–03)—and he hints that variety in housing may have to do with the fact that it gives both "shelter" and "social distinction" (87–88; Veblen [1894] 1997).

For Rae, too, fashion covers food, jewelry, precious metals, tattoos, clothes, feasts, and much else ([1834] 1964, 268–78) and is "in a state of ceaseless revolution" (271). The lace and colors of the country girl's bonnet are, again in an example of Storch's, "foreign to its utility" (271). The pleasure of the thing itself—its beauty or taste or texture—is "entirely distinct" from the pleasure deriving from its "rarity." Yes, the ornaments and sculptures in the dwellings of the rich really are beautiful, but, mainly, they are displayed (272–74). The exact mixture of "necessaries [and] conveniences" on one hand, and luxuries on the other, varies between the social classes (275). The pattern of most of Rae's examples is that invention and efficiency change both the nature and price of the supply, but the need for superiority stays, and therefore whatever serves this need must change (278).

Caroline Foley (1893) began similarly to Veblen by noting that "a residuum of variableness in wants [remains] not accounted for" in the fashion literature (461), and although she has understanding for its therefore being called "irrational," she is sure that it is not: "An errant instinct obtruding into the lines of motivated conduct is not unnaturally judged to be irrational, and the philosophy that identified the irrational with the shifting and impermanent has not died out since the day when it was put into the mouth of Nature attacking Fashion" (460). To relocate fashion in the realm of the rational, she explained it first by "love of distinction, imitation, and the effort after equalisation" (461). The motive for "social distinction" is "emulous within each caste, or class, or smaller group" (465, 463); "rainments" are "social symbols" just as for Veblen "no line of consumption" shows the canon of waste more aptly than "expenditure on dress" ([1899] 1998, 167). Then there is the motive for "change"—the variety, novelty, and waste implied in Shakespeare's "The fashion wears out more apparel than the man" (465, 466). Fashion cannot be defined as either "necessaries, comforts, or luxuries, but rather as a coefficient of any of these," greatest when "nature ceases to be preemptory" (462), as when, in Veblen, the "niggardliness of nature" loses its strictness (24).

Her survey of the literature quoted, among others, Rae himself, Joseph Fourier's characterization of fashion as "*la passion papillonne*," Thomas Macaulay, Storch, and John Locke on snob effects and Veblen effects, Jean-Baptiste Say on "unreal wants,"

Henri Baudrillart on four types of luxury (*de luxe* again, "not indispensable"), Darwin on the universality of fashion, and John Taylor, "the water poet," on exhaustion, overuse, and nonsustainability (1893, 461, 462, 463, 466, 468). Finally, she noted that dress must be "inconvenient" (467; Veblen [1899] 1998, 172), a point much more fully elaborated by Veblen in his examples of the walking stick (171, 265), the corset (149, 172), the high heel shoe, "feminine bonnets," and "the man's high hat" (171)—again, being simultaneously ill clad and well dressed (168; Rae [1834] 1964, 201, 203, 307). Veblen's inconvenience and discomfort show leisure and ability to pay by showing that one is "incapable of useful effort" (148–49, 182–83). Insofar as fashion and much other visible consumption are thus successfully explained by distinction or status, much consumption literature of the twentieth century here falls behind Veblen, Foley, and Rae in regarding it as irrational.[13]

Taste

Both Rae and Veblen applied two criteria for beauty or taste. Rae's first is that of the "beauties of feature or form . . . quite independent of their cost," which adhere to their simplicity or utility, like fabrics protective against heat and cold, the clean linen of the peasant, flowers, and even art works that are "well-executed," although here the border to beauty based on cost and vanity is hard to determine; this aesthetic experience is "real enjoyment" ([1834] 1964, 272–73, 282). But this standard of "real beauty" loses out in real life against a second one based on expensiveness (283), and many objects, such as "pearls, as ornaments, probably derive nearly their whole value from their scarcity" (286), an opinion echoed exactly by Veblen with the examples of gold and gems ([1899] 1998, 129, 130). For "dresses worn in public," for example, cheapness detracts from beauty (Rae, 289, 309), and very generally, "enjoyment" lies in "opulence" (270–71).

Similarly, Veblen's first category is of "popular taste" ([1899] 1998, 138), "middle-class tastes" (82, 138), "unsophisticated . . . intrinsic beauty" (128–30), of an "untrained sense" (149), and "beauty in the naïve sense" (150); these "underlying norms of taste are of very ancient growth, probably far antedating the advent of the pecuniary institutions that are here under discussion" (150–51). He spoke of a "taste for effective work" and a "distaste for futile effort" (15; [1914] 1964, 1). By this criterion beautiful things are "inexpensive" and straightforwardly suggest their serviceability ([1899] 1998, 151) and "the generic" (153). There is, however, an inherent "antagonism" between "native taste" in what is "beautiful or becoming," which abhors wastefulness, and the taste that has developed due to the "requirement of conspicuous waste" showing leisure and wealth (176–77). This "pecuniary and cultural beauty" guided by the "canon of pecuniary decency" may not be "bona fide" (149), but, as in Rae, it wins out over the simpler, "decorative and mundificatory character" of household beauty, which yields to the standard of "wasted effort" (82; Gilman 1999, 708). A pre-existing "popular sense of

beauty or serviceability" is at least supplemented by the sense of beauty depending "closely upon the expensiveness of the articles" (126–30). The doctrine is that of "pecuniary beauty" (133, 145, 153–54, 178).[14]

However, there are limits. For Rae, following the example of the "Roman moralists and satirists," just as the "benevolent affections" see vanity's "hurtfulness," the "intellectual powers" represent vain expenditures as "absurd"—like Veblen's "inanities" and "absurdities" ([1899] 1998, 94, 163); both "diminish the sway of this passion" ([1834] 1964, 269, 275). Unlike Veblen, he reserved the term "invidious" for that which goes too far—"to run to expenses which others cannot follow" or make others feel "too much outshone" (282). There are two lines, above one of which lies "acknowledged extravagance," and below the other of which lies "sordid parsimony" (282). This top end of extravagance is also aesthetically displeasing: a "very costly dress" reveals "want of taste"; or, a "disagreeable feeling" is caused by "the view of a profuse expenditure of animal power, bringing about only a small effect"—in other words, an efficiency criterion of beauty (283). For Veblen our conflicting aesthetic results from the instinct of workmanship, which has "an abiding sense of the odiousness and aesthetic impossibility of what is obviously futile" (93) and sees that "advertisements" or displays can be "cruder," as with a "loud dress" (186–87). Indeed, perhaps his ubiquitous concept of "decency" implies that a certain restraint is the mark of perfection in evidencing wealth through taste. At any rate, both writers offer us incipient objective criteria of beauty, in contrast, for example, to the subjectivism of George Santayana ([1896] 1988), and tying aesthetics and waste together is an idea with potential.

The Greater Good

Rae's example of too much horsepower claims the ugliness of disproportionality and sheer waste, the "absurdity" detected in it by the intellectual powers. This sense of absurdity is of course pervasive in Veblen. But I suggest that for him the outcome of this tension between popular taste and the "instinct of workmanship" on one hand ([1899] 1998, 93, 99, 158; [1914] 1964), and the canon of conspicuous, "honorific" waste on the other ([1899] 1998, 91–101, 140, 159, 259) is also very sad. The "régime of status" and waste has superceded that of "charity," "good-fellowship," and "solidarity"—of "non-invidiousness" (334–38, 218–21). Veblen's deliciously ambiguous disclaimer that he is using the term "waste" in any but a technical sense (97–101) is more than amusing. Emulation is hurtful, a view supported by Nils Gilman's (1999, 702–04) treatment of Veblen's "vitalism."

Again, just as Rae upheld "improvement and accumulation" ([1834] 1964, 285, 312), Veblen upheld workmanship, efficiency, industry, serviceability, and the generically humanly useful ([1899] 1998, 154, 219, 259, 334; 1914, 154–55). The "instinct of workmanship" favors "productive efficiency" and "whatever is of human use" ([1899] 1998, 93). This is "production" as opposed to "acquisition," the "industrial" as opposed

to the "pecuniary," or the "non-invidious" as opposed to the "invidious"; the former serve the "collective interest" through workmanship and "industrial efficiency" (99, 208–09, 227, 342; Mixter 1902) while the latter are "business." The leisure class is defined as the "propertied non-industrial" class, and so-called "industrial captaincy" exposes itself as merely predatory, astute, financial, and mercantile, concerned only with ownership (209, 230–31). Like Rae, for whom business was "representing things to be other than what they are" and "is so much dead loss to the community" ([1834] 1964, 312, 326), Veblen saw that it is only the contrasting noninvidious, industrial "feature of human nature" that makes "saving" (accumulation for the future) possible, however high the wages of the working classes might be (91; Duesenberry 1949).

Rae, to be sure, found a pinch of social benefit in vanity insofar as the rich man's monuments to himself exhibit "substantial . . . materials and workmanship" and thus "durability," and men of public affairs both should and do "pay . . . attention to the concerns of a distant futurity" through durable public works ([1834] 1964, 283–84). However, he quoted Smith's opinion that from the point of view of vanity small public works, "having nothing to recommend them but their extreme utility," would appear merely "mean and paltry" (284). For Veblen, too, architectural good works arise from surviving "non-invidious interests" but must also flatter the donor by showing some decorative, expensive "honorific waste" ([1899] 1998, 348–49). The theme that small useful works get neglected was developed by Paulette Olson (1998, "My Dam Is Bigger Than Yours") in her cogent application of conspicuous consumption theory to nations and their "interests of the collective good fame" (Veblen, 227). As shown in the sections on waste, Rae's main thrust is that the common good lies in accumulation of capital, or even economic growth, and that luxury, vanity, and dissipation thwart this (Rae, 318; Edgell and Tilman 1991, 742).

Conclusions

Rae's apex to his chapter "Of Luxury" is that "[t]o the loss thus occasioned by vanity the term dissipation may be applied. Its amount cannot . . . be easily ascertained, nor is it necessary for our purpose that it should. It is sufficient to observe, that, in all societies which have hitherto existed, it has been considerable; and that it seems to be determined, in every society, by the strength of the selfish, and weakness of the intellectual powers and benevolent affections; and, consequently, that it is inversely as the strength of the accumulative principle" ([1834] 1964, 290).

To irrationalize, and thus perhaps trivialize, conspicuous consumption means to ignore the nineteenth century contributions of John Rae and Thorstein Veblen. Their sociology of relative standing, achieved through putting wealth into evidence, with its attendant high social as well as personal cost as well as the corollary of inherently unlimited consumption, is indispensable for even addressing the hoary problem of social inequity as well the newer one of high environmental impact. Future work must extend the

explanatory chain, and in particular test the thesis that insatiable consumption behavior could be, in the strict Darwinian sense, sexually and socially selected.

Notes

I first read of John Rae and Thorstein Veblen in Leibenstein 1950.

1. This John Rae is not the journalist of the same name, born in 1845, who wrote, for instance, a biography of Adam Smith; nor is he John Rae, M.D., who wrote on his arctic explorations.
2. This is the reverse of today's usage of "need" and "want."
3. Thorstein Veblen divined our age of visibility run amok, of neon signs high above the treetops, the single word FOOD as big as your house: "In order to impress . . . transient observers, and to retain one's self-complacency under their observation, the signature of one's pecuniary strength should be written in characters which he who runs can read" ([1899] 1998, 87).
4. Rae detached aptness for vanity consumption from the good itself, presaging a huge literature on the social meaning of consumption (Baudrillard 1988; Leiss 1976; McCracken 1988; Campbell 1995), but he does insist on the element of costliness.
5. Veblen's perhaps puzzling emphasis on leisure as opposed to consumption—as witnessed by the book's title, its placement of the leisure chapter before that on consumption, by the concept of "vicarious leisure" (59–66), as well as by the primacy of the "great economic law of wasted effort" (83)—carries a fuller flavor than our present-day emphasis on material consumption or, absurdly, money as such.
6. When Veblen used "generic," was he arguing from the good of the species?
7. Another example is Alfred Marshall's computation of the costs of luxury expenses for the poor; these render "their wages . . . less than are practically necessary for efficiency," i.e., for their ability to work and reproduce, and this he even defines as "waste." Just as Veblen said that what starts out as wasteful becomes a "habitual expenditure" ([1899] 1998, 99), Marshall said that things like tobacco, alcohol, and "fashionable dress" become "conventionally necessary" and thus rational and nonwasteful after all ([1890] 1916, 70) .
8. Rae's and Veblen's examples suggest that some consumption acts are indeed purely ceremonial or honorific, often even hurting the consumer or at least contributing nothing to his survival and comfort. In a contrasting view, Hamilton took eating caviar as an example of something mainly ceremonial or honorific but having "some nutritional value" and showing that "[b]oth aspects of behavior are always present" (1989, 1101; also Leiss 1976, 57–64, 101).
9. Wilson 1975, Alcock 1998, Chagnon and Irons 1979, Trivers 1985, Betzig et al. 1988, Barkow 1989, etc.
10. For a contrary view see Hamilton 1973, who saw competitive consumption as socially conditioned rather than deeply psychologically caused (201, 205) and therefore more amenable to change, in which case wants are really finite. Expanding "levels of living" are "technology making its own necessity" (205). Perhaps revealingly, his three examples of consumption—relieving a toothache, eating lunch, and fixing a flat tire (205)—come from the realm of basic, perhaps nonsocial, at any rate nonstatus consumption. See also the work of Christer Sanne (2002), for whom status signaling "does not presuppose commercial markers," which are "arbitrary" (285).
11. Zahavi and Zahavi 1997, Boone 1998, and Miller 2000 made this point about the altruistic nature of much conspicuous spending and its nature as a biological adaptation.
12. In 400 pages Veblen broke his rule ([1899] 1998, x) against quotations and source citation once, and that is here. The honor goes to John Stuart Mill—but of course without mention of book or page—who said that "hitherto it is questionable if all the mechanical inventions yet made have lightened the day's toil of any human being" (Veblen, 111). For my part, honor also goes to William Stanley Jevons ([1865] 1965). He saw the plausibility of thinking that

more efficient use of coal will decrease its use (137), and indeed efficiency advances due to invention were in his time being made; but "It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth. . . . [E]very. . .improvement of the engine, when effected, does but accelerate anew the consumption of coal" (140, 152–53).

13. In an overdue appreciation of Caroline Foley, Edward Fullbrook (1998) offered a demonstration that economics has not yet satisfactorily met her challenge of theoretically integrating nonadditive, intersubjective demand (Rae [1834] 1964, 306–307).
14. Rick Tilman noted that "Veblen, contrary to his own functionalist aesthetic, studs his writings with latinates and mordant wit" (1985, 892). Combining Veblen's broad theory of waste with Geoffrey Miller's applications of the theory of sexual selection (2000) could elucidate this phenomenon.

References

Alcock, John. *Animal Behavior.* Sunderland, Mass.: Sinauer Associates, 1998.

Barkow, Jerome. *Darwin, Sex, and Status: Biological Approaches to Mind and Culture.* Toronto: University of Toronto Press, 1989.

Baudrillard, Jean. *The Consumption Society: Myths and Structures.* London: Sage, 1988.

Bellamy, Edward. *Looking Backward: 2000–1887.* 1887. Reprint, Cambridge, Mass.: The Riverside Press, 1917.

Betzig, Laura, Monique Borgerhoff Mulder, and Paul Turke, eds. *Human Reproductive Behavior: A Darwinian Perspective.* Cambridge: Cambridge University Press, 1988.

Boone, James L. III. "The Evolution of Magnaminity: When Is It Better to Give Than to Receive?" *Human Nature* 9, no. 1 (1998): 1–12.

Boulding, Kenneth. "Income or Welfare." *The Review of Economic Studies* 17 (1949–50): 77–86.

——. "The Economics of the Coming Spaceship Earth." In *Toward a Steady-State Economy,* edited by Herman E. Daly. San Francisco: W. H. Freeman, 1973.

Boyles, Michael, and Rick Tilman. "Thorstein Veblen, Edward O. Wilson, and Sociobiology: An Interpretation." *Journal of Economic Issues* 27 (1993): 1195–1218.

Brekke, K. A., Richard B. Howarth, and Karine Nyborg. "Status-Seeking and Material Affluence: Evaluating the Hirsch Hypothesis." *Ecological Economics* 45 (2003): 29–39.

Buss, David. *The Evolution of Desire.* New York: Basic Books, 1994.

Campbell, Colin. "The Sociology of Consumption." In *Acknowledging Consumption: A Review of New Studies,* edited by Daniel Miller. London: Routledge, 1995.

Chagnon, Napoleon, and William Irons, eds. *Evolutionary Biology and Human Social Behavior.* North Scituate, Mass.: Duxbury Press, 1979.

Cronin, Helena. *The Ant and the Peacock: Altruism and Sexual Selection from Darwin to Today.* Cambridge: Cambridge University Press, 1991.

Cross, Gary. *An All-Consuming Century.* New York: Columbia University Press, 2000.

Daly, Herman E. "The Economics of the Steady State." *American Economic Review* 64, no. 2 (1974): 15–21.

Daly, Herman E., and Clifford W. Cobb. *For the Common Good.* Boston: Beacon, 1989.

Darwin, Charles. *On the Origin of Species by Means of Natural Selection.* 1859. Reprint, London: Watts & Co., 1950.

——. *The Descent of Man and Selection in Relation to Sex.* 1871. Reprint, London: Gibson Square Books, 2003.

Dawkins, Richard. *River out of Eden: A Darwinian View of Life.* New York: Basic Books, 1994.

Debo, Angie. *Oklahoma: Foot-Loose and Fancy-Free.* Norman: University of Oklahoma Press, 1949.

Duesenberry, James S. *Income, Saving, and the Theory of Consumer Behavior.* Cambridge: Harvard University Press, 1949.

Easterlin, Richard A. "Does Money Buy Happiness?" *The Public Interest* 30 (winter 1973): 1–10.

Edgell, Stephen, and Rick Tilman. "Veblen's Intellectual Antecedents." *Journal of Economic Issues* 23, no. 2 (1989): 1003–1027.

——. "John Rae and Thorstein Veblen on Conspicuous Consumption: A Neglected Intellectual Relationship." *History of Political Economy* 23, no. 4 (1991): 731–744.

Foley, Caroline A. "Fashion." *The Economic Review* 5 (1893): 458–474.

Frank, Robert H. *Choosing the Right Pond: Human Behavior and the Quest for Status.* New York: Oxford University Press, 1985.

——. *Luxury Fever: Why Money Fails to Satisfy in an Era of Excess.* New York: Free Press, 1999.

Fullbrook, Edward. "Caroline Foley and the Theory of Intersubjective Demand." *Journal of Economic Issues* 32 (1998): 709–731.

Gans, C. "Efficiency, Effectiveness, Perfection, Optimization: Their Use in Understanding Vertebrate Evolution." In *Efficiency and Economy in Animal Physiology,* edited by Robert W. Blake. Cambridge: Cambridge University Press, 1991.

Ghiselin, Michael. *The Economy of Nature and the Evolution of Sex.* Berkeley: University of California Press, 1974.

Gilman, Nils. "Thorstein Veblen's Neglected Feminism." *Journal of Economic Issues* 33 (1999): 689–711.

Hamilton, David. "What Has Evolutionary Economics to Contribute to Consumption Theory?" *Journal of Economic Issues* 7 (1973): 197–207.

——. "Veblen as the First Professor of Marketing Science." *Journal of Economic Issues* 23 (1989): 1097–1103.

Hamsun, Knut. *Segen der Erde (Markens grøde).* 1917. Reprint, München: Deutscher Taschenbuch Verlag/List, 1978.

Hobson, John Atkinson. *Wealth and Life: A Study in Values.* London: Macmillan, 1929.

Hodgson, Geoffrey M. "Veblen's Theory of the Leisure Class and the Genesis of Evolutionary Economics." In *The Founding of Institutional Economics: The Leisure Class and Sovereignty,* edited by Warren J. Samuels. London: Routledge, 1998.

——. "Darwin, Veblen, and the Problem of Causality in Economics." *History and Philosophy of the Life Sciences* 23 (2001): 385–423.

Hrdy, Sarah Blaffer. *Mother Nature: A History of Mothers, Infants, and Natural Selection.* New York: Pantheon, 1999.

Jackson, Tim. "Evolutionary Psychology in Ecological Economics: Consilience, Consumption, and Contentment." *Ecological Economics* 41 (2002): 289–303.

Jackson, Tim, and N. Marks. "Consumption, Sustainable Welfare and Human Needs—With Reference to UK Expenditure Patterns 1954–94." *Ecological Economics* 28 (1999): 421–442.

Jevons, William Stanley. *The Coal Question.* 1865. Reprint, New York: Augustus M. Kelley, 1965.

Joplin, Janis. "Lord, Won't You Buy Me a Mercedes Benz?" Pearl, 1970.

Keynes, John Maynard. "Economic Possibilities for Our Grandchildren." In *Collected Writings, Vol. IX, Essays in Persuasion.* London: St. Martin's Press, 1971–73. Originally published in 1930.

Leibenstein, Harvey. "Bandwagon, Snob, and Veblen Effects in the Theory of Consumers' Demand." *Quarterly Journal of Economics* 64 (1950): 183–207.

Leiss, William. *The Limits to Satisfaction: An Essay on the Problem of Needs and Commodities.* Toronto: University of Toronto Press, 1976.

Low, Bobbi S., and Joel T. Heinen. "Population, Resources, and Environment: Implications of Human Behavioral Ecology for Conservation." *Population and Environment* 15, no. 1 (1993): 7–42.

McAdams, Richard H. "Relative Preferences." *The Yale Law Journal* 102, no. 1 (1992): 1–104.

McCracken, Grant. *Culture and Consumption.* Bloomington: University of Indiana Press, 1988.

Marshall, Alfred. *Principles of Economics.* 1890. Reprint, London: Macmillan, 1916.

Miller, Geoffrey. *The Mating Mind: How Sexual Choice Shaped the Evolution of Human Nature.* New York: Doubleday, 2000.

Mixter, Charles W. "Böhm-Bawerk on Rae." *Quarterly Journal of Economics* 16 (1902): 385–412.

——. *The Sociological Theory of Capital: Being a Complete Reprint of the New Principles of Political Economy, 1834, by John Rae,* M:A. New York & London: Macmillan, 1905.

Morrison, Reg. *The Spirit in the Gene.* Ithaca, N.Y.: Cornell University Press, 1999.

Olson, Paulette. "My Dam Is Bigger than Yours: Emulation in Global Capitalism." In *Thorstein Veblen in the Twenty-first Century,* edited by Doug Brown. Cheltenham, U.K.: Elgar, 1998.

Orr, David W. "The Ecology of Giving and Consuming." In *Consuming Desires: Consumption, Culture, and the Pursuit of Happiness,* edited by Roger Rosenblatt. Washington: Island, 1999.

Rae, John. *Statement of Some New Principles on the Subject of Political Economy: Exposing the Fallacies of the System of Free Trade, and of Some Other Doctrines Maintained in the "Wealth of Nations."* 1834. Reprint, New York: Augustus M. Kelley, 1964.

Sanne, Christer. "Willing Consumers—or Locked In? Policies for a Sustainable Consumption." *Ecological Economics* 42 (2002): 273–287.

Santayana, George. *The Sense of Beauty.* 1896. Reprint, Cambridge: MIT Press, 1988.

Schor, Juliet. *The Overworked American: The Unexpected Decline of Leisure.* New York: Basic Books, 1992.

Schumacher, Ernst Friedrich. *Small Is Beautiful.* Point Roberts, Wash.: Hartley & Marks, 1999.

Scitovsky, Tibor. *The Joyless Economy.* New York: Oxford University Press, 1976.

Spengler, Joseph J. "John Rae on Economic Development: A Note." *Quarterly Journal of Economics* 73 (1959): 393–406.

Tilman, Rick. "The Utopian Vision of Bellamy and Veblen." *Journal of Economic Issues* 19, no. 2 (1985): 879–898.

Trivers, Robert. *Social Evolution.* Menlo Park, Calif.: Benjamin/Cummings, 1985.

Veblen, Thorstein. "The Economic Theory of Woman's Dress." In *Culture, Social Norms and Economics,* Vol. I, edited by Mark Casson. Cheltenham, U.K.: Elgar, 1997. Originally published in 1894.

——. *The Theory of the Leisure Class.* 1899. Reprint, Amherst, N.Y.: Prometheus Books, 1998.

——. *The Instinct of Workmanship and the State of the Industrial Arts.* 1914. Reprint, New York: Augustus M. Kelley, 1964.

——. *Absentee Ownership and Business Enterprise in Recent Times: The Case of America.* 1923. Reprint, New York: Augustus M. Kelley, 1964.

Wilson, Edward O. *Sociobiology: The New Synthesis.* Cambridge: Harvard University Press, 1975.

Zahavi, Amotz, and Ashivag Zahavi. *The Handicap Principle: A Missing Piece of Darwin's Puzzle.* Oxford: Oxford University Press, 1997.

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Ecological Economics 54 (2005) 9–21

ECOLOGICAL ECONOMICS

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SURVEYS

Jevons' paradox

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Received 21 July 2004; received in revised form 11 February 2005; accepted 2 March 2005

Abstract

In *The Coal Question* William Stanley Jevons [Jevons, W.S., 1865/1965. The Coal Question: an Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-mines. 3rd edition 1905, Ed. A.W. Flux. Augustus M. Kelley, New York.] maintained that technological efficiency gains—specifically the more "economical" use of coal in engines doing mechanical work—actually increased the overall consumption of coal, iron, and other resources, rather than "saving" them, as many claimed. Twentieth-century economic growth theory also sees technological change as the main cause of increased production and consumption. In contrast, some ecologically-oriented economists and practically all governments, green political parties and NGOs believe that efficiency gains lower consumption and negative environmental impact. Others doubt this 'efficiency strategy' towards sustainability, holding that efficiency gains 'rebound' or even 'backfire' in pursuing this goal, causing higher production and consumption. Because many environmental problems demand rapid and clear policy recommendations, this issue deserves high priority in ecological economics. If Jevons is right, efficiency policies are counter-productive, and business-as-usual efficiency gains must be compensated for with physical caps like quotas or rationing.

Keywords: Technological efficiency; Rebound; Impact; Consumption; Growth; Jevons

1. Introduction

The paper briefly presents today's 'rebound' debate and refers to the relevant literature (Section 2). It then goes into Jevons' (1865) theoretical arguments (Section 3), his analogy with the employment effects of increased labor efficiency (Section 4), and his empirical arguments (Section 5). Open questions in today's debate are how to reconcile the environmental efficiency strategy with growth theory, whether empirical or theoretical work is more urgent, how to integrate consumer behavior into a formal rebound theory, and why the matter is 'paradoxical' (Section 6). The conclusion (Section 7) is that since greater efficiency, ceteris paribus and given latent demand, must raise, not lower, environmental impact, efficiency policies are wrong.

Throughout 'efficiency' denotes the ratio of physical inputs to physical outputs—rather than to

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doi:10.1016/j.ecolecon.2005.03.020

'services', 'units of consumption', 'economic activity', or monetary gross product.[1] Furthermore, it means technological changes rather than institutional or organizational ones which lower other kinds of input like time and human effort per unit of output.[2] 'Consumption' means the *using up* rather than the 'use' of resources (Boulding, 1949; Princen, 1999, p. 355) and covers pollution as well as resource destruction.[3] A further assumption is that consumption is proportional to environmental impact as understood in the $I=PAT$ equation (impact a function of population, affluence, and technology). No mention is made of the capital and junking costs of efficiency improvements themselves, and the problem of comparing outputs over time (paper letters to e-mail, or horse to plane) is ignored.

2. The current rebound debate

Although previous writers like Hotelling (1931, p. 64) and Domar (1962, p. 605) noted that efficiency, sales, and resource use rise hand in hand, the present debate was re-opened by Brookes (1979) and Khazzoom (1980) and continued by Lovins (1988), Saunders (1992, 2000), Schipper and Meyers (1992), Howarth (1997), Wirl (1997), Schipper and Grubb (2000), Brookes (2000), and Binswanger (2001). Regarding household appliances and explicitly assuming positive price elasticity of demand,[4] Khazzoom's insight was that "...changes in appliance efficiency have a price content.... [W]ith increased productivity comes a decline in the effective price of commodities, and that in the face of lower effective prices, demand does not remain stagnant...but tends to increase" (Khazzoom, 1980, pp. 22, 23). For example, a more fuel-efficient car enables one to drive more.[5] This universally acknowledged phenomenon is called 'rebound' (or feedback, take-back, snap back, or respending). A distinction is made between the somewhat measurable 'direct', 'micro', or 'own' rebound effect for goods and services produced more efficiently and the elusive 'indirect', 'secondary', 'economy-wide' or 'equilibrium' rebound effects concerning all other goods and services, present and future, using the same inputs.

To define it one needs the notion of *engineering savings*. This is the difference between two ratios, the first stating energy/material input per unit of product or service *before*, the second *after*, a technologically achieved lowering of input per unit output. Multiplying pre-change demand times this percentage difference yields a physical quantity: when car kilometers and tons of steel can be had for 20% less energy input than before, then 0.20 times the amount previously consumed yields the real amount of energy that *could* be saved. Such gains immediately lower consumption of inputs of material and energy for these outputs; but by both doing more and becoming cheaper, demand for them in turn increases, and output or consumption rise again. If this demand rise is large enough more people consume more; no 'savings' really occur, and we have a paradox. The environmental efficiency strategy—lowering the 'T' factor in the $I=PAT$ equation in hopes of thereby lowering 'I'—must come to terms with this paradox, first identified as such by Jevons.

Rebound analysis thus shows that holding demand constant is gratuitous. The 'savings' is theoretical only, because lower costs heighten demand. 'Rebound' is nevertheless defined as the ratio between the engineering savings in percent and new and old quantities of units consumed, corrected for the efficiency change. If the ratio of post-change demand

[1] I believe embodied energy, recycling, and product durability are subsumable under either technological or 'consumer' efficiency, and that both the sufficiency strategy of doing without some affluence and the 'decoupling' of services from input are logically separate issues.

[2] For example, economies of scale, trade, education, legal security, property rights, low transaction costs, Taylorite factory-floor measures, management hierarchies, etc. One writer indeed defines rebound as "...the overall effects of technical, organisational, and social progress which increase the efficiency of the economy and give room for more consumption" (Sanne, 2000, p. 494; also Moezzi, 2000).

[3] The debatable suggestion here is sink problems are reducible to source problems: Bad water, air, soil, food, and space would be simply good water, air, soil, food, and space used up. Even greenhouse gases would use up the 'good' of a life-supporting climate. Pollution, degradation, assimilation, degeneration, and 'waste' could be parsimoniously defined in terms of consumption.

[4] In the debate, price elasticity of supply is universally ignored (Schipper and Grubb, 2000, p. 369).

[5] One concise version is that after efficiency gains "...the amount of product or service usually does not stay the same. Because the equipment becomes more energy efficient, the cost per unit of product or service...falls which, in turn, increases the demand for the product or service" (Binswanger, 2001, p. 120; also Howarth, 1997, p. 2).

times the post-change input–output ratio to pre-change demand times the pre-change input–output ratio is greater than 1, one speaks of 'backfire' or 'boomerang' (Khazzoom, 1980, p. 23; Wirl, 1997, pp. 28–29; Saunders, 2000, pp. 439–40). In judging rebound's size some bank on empirical study while others focus on theory.[6] Both sides abandon pure empiricism, however, by claiming that after a rise in efficiency absolute consumption is higher than, or lower than, *it would have been otherwise*, i.e. without the efficiency change (Khazzoom, 1980, pp. 22, 31; Brookes, 2000, p. 356; Howarth, 1997, p. 3; Schipper and Grubb, 2000, p. 370; Moezzi, 2000, pp. 525–26[7]).

[6] Empirically measured rebounds range from less than 1% to several hundred percent, but never zero or less than zero (Khazzoom, 1989, p. 158; Greene, 1992, pp. 136–137; Wirl, 1997, p. 46; Greene et al., 1999, p. 27; Greening et al., 2000, p. 392; Berkout et al., 2000, p. 431). Some call them insignificant (Lovins, 1988; Schipper and Grubb, 2000; Howarth, 1997; Greening et al., 2000), others significant (Khazzoom, 1987, 1989; Brookes, 1979, 1990, 2000; Greenhalgh, 1990; Greene, 1992; Saunders, 1992, 2000; Sanne, 2000, 2002). Others ignore rebound while asserting or implying that efficiency is environmentally advisable (Stern et al., 1985; Schmidheiny, 1992, pp. 35–36, 40–41; Goodland, 1992, p. 10; Mikesell, 1992, p. 87; Holdren, 1992, p. 42; von Weizsäcker et al., 1997; Vincent and Panayotou, 1997).

[7] Schipper and Grubb's formal presentation: 'We define "energy savings" as the product of a future activity level and the difference between the energy intensity at that time compared to the present level. If E is the energy use for a particular activity, then: $E = A \times I$, (1) where A is the level of activity and I the corresponding intensity. After energy saving is implemented, A changes to A' and I to I', and the new energy use is $E' = A' \times I'$. (2) If I' is less than I, energy saved is $A' \times (I - I')$. [$A \times (I - I')$ would be my 'engineering savings'.] But E' might be larger than E because over the time that I fell to I', A grew by a greater relative amount to A'. Now, the decline in I itself could cause an increase in A' to A'', so that $E'' = I'' \times A''$. We shall look for a rise in A' relative to incomes or output if I falls as a sign of an important feedback effect or structural change "caused" by lower energy intensities or costs' (p. 369). In this formulation the term 'energy saved' *assumes* either that A' is less than A or that if it is greater than A, it is nevertheless not high enough to boost E' above E. Furthermore, if I correctly understand 'A grew by a greater relative amount', their own position is that the 'decline in I itself' causes A to *fall* 'by a greater relative amount to' A''', yielding an E''' smaller than E. They accurately portray the 'backfire' position thus: ' If saving energy is to lead to greater, not less energy use than otherwise, then either... the activities and output for which the savings were made must increase by more than the savings decreased energy use of the overall mix of output must evolve in a two way towards greater, not lower uses than otherwise'(Schipper and Grubb, 2000, p. 383).

3. Jevons' theoretical view

The first chapter of Jevons' much-cited book (1865, to which all page citations hereafter refer) bears the title "The Opinions of Previous Writers." Taking this to heart, what exactly did Jevons say? His 460-page argument is unequivocally for backfire. His concern not only for England's material and intellectual prosperity, but also for posterity, prompts his question of the coal supply's duration. Since coal is progress, and it will eventually run out, his answer is pessimistically bittersweet (pp. 11–13, 136, 156, 200–201, 274, 460). His theoretical argument that coal-efficiency heightens coal consumption relies on the concepts of *profitability* (Chs. VII, VI, IX), *new inventions and uses* (Chs. VI, VII), and *consumer behavior* (Introduction, Chs. IX, X). He also briefly offers the analogy that labor efficiency causes higher levels of employment (p. 140). His detailed but necessarily indecisive empirical argument correlates efficiency increases and consumption increases (pp. 145–154, 386–391, Chs. XI and XII).

3.1. Almighty coal

His Frontispiece is from Adam Smith: "The progressive state is in reality the cheerful and the hearty state to all the different orders of society; the stationary is dull; the declining melancholy." He embraced the progressive state for its civilization, amelioration of society, international power, and material wealth (pp. 33, 232, 454–460; Ch. VI) and knew it depended on coal (pp. 1–3, 9, 37, 274–76). Without coal fuel "we are thrown back into the laborious poverty of early times;" to not use the fuel "lavishly and boldly" means "safe smallness, . . .dullness and degeneration," a stationary period "devoid of intellectual nobility" (pp. 2, 459, 456–457). The Lord Chancellor ought to sit no longer on a bag of wool, but rather a bag of coal (p. 126). Thus it was with "anxiety" that geologists, coal miners, statesmen, and economists were asking the "solemn question" as to the "duration" of coal supplies (pp. 3–6, 412, 454, Ch. XII). Today we ask the oil and pollution questions out of the same anxiety. On the way to his answer Jevons presaged today's themes of limits to growth (pp. 196–200, 419, 427, 454–55), duty to posterity (pp. 4, 373, 455), renewable and non-renewable resources (p. 201), liv-

ing off capital instead of income (pp. 412, 455), the energy costs of getting energy (pp. 7, 49, 62–63, 72, 77, 196, 198, 200), entropy (p. 412), the sad loss of forests (pp. 37, 183, 249–250, 286, 369–80), and sustainability (p. 454).

Jevons' detailed discussion of British and foreign coal-field geology, mining technology, transportation, and prices leads him to take other researchers to task for overestimating coal's duration—whether 365, 610, 1727, or many thousands of years (Ch. II, pp. 273–75, 280–84[8]). Their "compendious statements" were well-founded except that they overlooked the fact of rising annual demand, or consumption! (p. 19). Two exceptions were John Holland and Edward Hull, Jevons' main source, who nevertheless reassured ". . .the public at large. . .that for a long period to come British commerce is not likely to languish, or British household fires to smoulder, for want of that prime necessary of British life—COAL" (Hull, 1905, p. 281; Ch. XXXIII; Hull, 1861, pp. 1–6, 236–37, 241–45; Jevons, pp. 23–31, 195–200, 267–274). Jevons insisted that ". . .the quantity of coal existing is a less important point in this question than the rate at which our consumption increases, and the natural laws which govern that consumption" (pp. 25, 34–36).

What determines this all-important rate of consumption's increase? Always based on assumptions about coal quality, mine depth, and mining costs (pp. 88–89, 132, 156, 230–32, 274, Ch. IV), three factors were population growth (pp. vi, 9–10, 194–200, 275, 457), newly found or invented applications (pp. 141–142, 152–53, 176, 196, 457–458, Ch. VI), and our wish to consume (p. 25, Ch. IX). But "discovery" was constantly rendering coal "a more and more efficient agent. . ." (p. 8; also 136, 387–88). The bone of contention was whether this raises, or lowers, total consumption.

3.2. Chapter VII: "*of the economy of fuel*"

"And we ought not at least to delay dispersing a set of plausible fallacies about the economy of fuel. . .which at present obscure the critical nature of the question, and are eagerly passed about among those who like to believe that we have an indefinite period of prosperity before us" (p. 4). In the dark shadow of future coal shortage many saw the efficient use or "economy" of fuel as a chance to "save" it and postpone the day of reckoning. Thinking of Percy (p. 36), Waterston (p. 22), and Hull (pp. 29–30; Hull, 1861, pp. 238–240) Jevons wrote, "It is very commonly urged, that the failing supply of coal will be met by new modes of using it efficiently and economically. The amount of useful work got out of coal may be made to increase manifold, while the amount of coal consumed is stationary or diminishing. We have thus, it is supposed, the means of completely neutralising the evils of scarce and costly fuel" (p. 137). Countless efficiency strategists today join in with Percy, Waterston, Hull, and Mundella (1878).

After granting the question the status of a "paradox" (also Wirl, 1997, pp. 29, 36, 112; Giampietro and Mayumi, 1998, p. 24), Jevons' dissenting opinion was that "It is the very economy of its use which leads to its extensive consumption" (p. 141). Due to *invention* and *improvement* ". . .the economy of coal in manufactures" advanced constantly (pp. 8, 152), but "*It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth*. . .[E]very. . .improvement of the engine, when effected, does but accelerate anew the consumption of coal" (pp. 140, 152–53). Lowering the input/output ratio causes neither less input for the same output, nor the same input for more output, but more input for more output.[9]

[8] While even Jevons' projections ran in the order of many centuries, British politics today seems comfortable with the fact that North Sea oil and gas will last another decade or two. On energy alternatives to coal, Jevons, to his posthumous misfortune, acknowledged but underestimated petroleum (pp. 184–185), while Hull bet on electricity (Hull, 1905, pp. 387–393, 434–435).

[9] According to Greenberg, a similar position had been held a generation before Jevons by Richard Jones, namely that 'energy efficiency—whether biological or technological—constituted the true determinant of wealth' (Greenberg, 1990, p. 713). Also presaging some of Jevons' ideas were Lauderdale (1804, pp. 161–165, 184–185); Say (1820, pp. 137, 143, 151) and John Rae (1834), who influenced Jevons through William Edward Hearn (1864) and who posthumously enjoyed Schumpeter's highest praises (Schumpeter, 1911, pp. 12–13) (pp. 19, 23, 292, 258–59 (rebound); 86–87, 115–117, 261–62, 365 (new uses); 164–65, 263 (profit and new capital); 226–229 metallurgy; 242 (pre-efficiency invention); 245–248 (coal and steam); 245, 258–59, 323 (Jevons' social growth); 259 (baking); 310, 321–22 (institutional efficiency)).

The argument is saturated with examples of invention in the "arts" of mining, metallurgy, and engines over some 300 years, as coal and iron out-competed wood, water, wind, human, and horse power (also Cipolla, 1962, pp. 40–52; Clapp, 1994, pp. 161–71; Sieferle, 2001, pp. 61–67, 103, 115–27). The key case was Savery's steam engine of 1698. Intended to pump water out of (coal) mines, the machine however still "wasted" too much heat; without an intervening piston "it was so uneconomical that, in spite of the cheapness of coals, it could not come into common use" (pp. 114–119).[10] That is, the coal-burning steam engine would have to become *more efficient* before it could consume coal. Once improved, this engine "as it were in an instant, put every coal-field, which was considered lost, within the grasp of its owners. Collieries were opened in every district…" (p. 120). Other materials like iron also saw efficiency gains, as with the "substitution…of [lighter] wrought-iron for cast-iron…[which] effected a general economy and advance in the employment of machine power" (pp. 129–130, 372). But what is this vague "general economy" which causes rebound greater than unity in the consumption of iron as well as coal?

3.3. The paradox solved

"Nor is it difficult to see how this paradox arises" (p. 141).[11] The key to his argument is efficiency's effects on *profitability*, *price*, and *demand*: "Economy multiplies the value and efficiency of our chief material…[and] renders the employment of coal more profitable, and thus the present demand for coal is increased…. [If] the quantity of coal used in a blast-furnace, for instance, be diminished in comparison with the yield, the profits of the trade will increase, new capital will be attracted, the price of pig iron will fall, but the demand for it increases and eventually the greater number of furnaces will more than make up for the diminished consumption of each" (pp. 156, 8, 141; also Jevons, 1871, pp. 254–57). Any given blast furnace gives way to an improved one, and the number of furnaces and the amount of steel rise absolutely. Jevons thus makes rebound theoretically plausible, but he has not yet proven that the amount of coal consumed must "more than" make up for engineering savings.

The solution for Jevons lies somewhere in this step from efficiency to *profitability*, a term both broadly synonymous with productivity and more narrowly covering producers' margins. He notes that "it is a maxim of trade, that a low rate of profits, with the multiplied business it begets, is more profitable than a small business a high rate of profit" (p. 141). The costs of pig iron and even coal fall, upping sales; otherwise no new capital (no new production capacity) is attracted to these sectors, which, however, it manifestly is. This brief argument stays inconclusive, and he immediately adds that the greater demand stems as well from "new activity in most other branches" (pp. 141–42; see below).

One contemporary rendering of this 'profitability' argument states that "An improvement of energy efficiency of capital implies that [the producer] can (a) shift the production factor mix in the long run, and (b) reduce the unit production costs, creating a margin for price setting…. [A] lower sales price may generate additional demand' (Berkout et al., 2000, p. 426). A fuller version states that "…efficiency gains and current incentives often work directly and indirectly *against* resource conservation. Many factors contribute to this counter-intuitive [paradoxical] result, including the price and income effects of technological savings. Improved energy or material efficiency may enable firms to raise wages, increase dividends or lower prices, which leads to increased net consumption by workers, shareholders or consumers respectively" (Wackernagel and Rees, 1996, pp. 127–28).[12]

3.4. New uses, other consumption

Jevons sensed his argument's incompleteness: Profitability causes new demand that is claimed to

[10] When even endosomatic energy input (Cipolla, 1962, p. 39) is too inefficient, the possibility is that consumption ceases.

[11] Lucky Jevons. Today it is a "theoretical riddle" (Wirl, 1997, p. 29) commanding with good reason special journal issues (*Energy Policy* 28, vols. 6–7; *Energy and Environment* 11, vol. 5). Rebound is like the "Loch Ness monster" sighted by Schipper and Grubb (2000), or rather not sighted.

[12] Joseph Schumpeter, using Lauderdale's example of the loom, also described how efficiency and/or new combinations are conditions for profitability (Schumpeter, 1911, pp. 42–47, 100, 191–92, 208–15).

"more than make up for" lower input intensity, but "...such is not always the result within a single branch...[and therefore] it must be remembered that the progress of any branch of manufacture excites new activity in most other branches, and leads indirectly, if not directly, to increased inroads upon our seams of coal" (pp. 141–142). Khazzoom similarly first acknowledges that "improved efficiency may...result in some reduction in energy consumption," but adds that "An improvement in the efficiency of one appliance influences not only the demand for own end-use, but also the demand for other end-uses. This follows from the fact that end-uses compete for the same overall budget..." (Khazzoom, 1980, pp. 23, 35). Again, current literature distinguishes between micro and indirect or macro rebounds, the latter being an income effect leaving a "consumer surplus" which we use not only to upgrade quality; "the associated increase in the real income allows [us] to raise all kinds of demands including the demand for the service in question" (Wirl, 1997, pp. 41, 20, 26–27, 31, 197; also Wackernagel and Rees, 1996, pp. 128–29; Schipper and Grubb, 2000, pp. 367, 386; Saunders, 2000, pp. 445–48). It is because inputs are thus freed for new uses that single-sector studies are seriously inconclusive.

"Again, the quantity consumed by each individual is a composite quantity, increased either by multiplying the scale of former applications, or finding wholly new applications;" any given "enterprise" has limits, "*But the new applications of coal are of an unlimited character*' (pp. 196–197). "Old applications of coal have been extended, and yet admit of great extension, while new ones are continually being added" (p. 199). Inventions in iron production, like hot-blast smelting, or in metallurgy, like relatively light-weight wrought iron, yield "cheap iron" (pp. 125, 129–30, 405). This "...materially lowered the cost of iron, and, therefore, has led to its employment for many purposes...previously unknown" (p.154; also 152–56, 245, 368–78). Cheap iron in turn raised the demand for coal (p. 372). He quotes Williams that "Whatever, however, conduces to increase the efficiency of coal, and to diminish the cost of its use, directly tends to augment the value of the steam-engine, and to enlarge the field of its operations" (p. 144). Although some new technologies are "of purely organic origin, ...many of the more important substitutions are due to coal.... With fuel and fire, then, almost anything is easy" (pp. 134–136). One opinion in today's debate holds that although backfire can happen in "the iron/coal example of Jevons...[such examples] appear to be rare exceptions" (Schipper and Grubb, 2000, p. 385).

One neo-classical model today holds that technologically "augmented" labor and capital mean "...more consumption per worker" (Saunders, 1992, pp. 136–37; 2000, pp. 440, 445, 448). For instance, one study of the replacement of kerosene with solar power for lighting (an efficiency gain even after deducting embodied energy costs) found that this leads both to lighting for more hours, to using the "saved" kerosene for cooking, and indeed to a "...whole range of behavioral responses of the end-users that follow any technical efficiency improvement all of which may, however, not be traced empirically" (Roy, 2000, p. 433). Jevons' perhaps hyperbolic conclusion is that "modes of economy which, in reducing the cost of a most valuable material, lead to an indefinite demand" (p. 390).

Jevons' detailed history of technology covers metallurgy, pumps, plows, coal-cutters, cotton factories, engines, roads and canals, railroads, bridges, water pipes, photography, ice machines, screw steam-vessels, smelting, refining, and forging (pp. 382–386; also Sieferle, 2001, pp. 115–124). He looks as well at "substitutions" and "interdependence" between types of energy and material (p. 385). From this emerges a question about the definition of efficiency. We substitute "a cheaper for a dearer [in the same process], a new for an old process" (p. 136). The former are straightforward efficiency gains, as when coal is lighter and more heat-efficient than wood, or coke bears more ore weight in the furnace than charcoal. But some new processes and products perhaps do not themselves represent efficiency gains, but rather add new denominators, rather like moving targets for calculations of efficiency ratios. He accordingly first posits something new, and then calls efficiency gains "subsequent steps in...improvement" (p. 119). His example is an invention for "determining the longitude of a ship at sea" (p. 113). It is not an improvement in a preceding instrument, although it does improve the efficiency of *shipping*. Railroads were new and open to subsequent gains, but the

denominator of 'transport'—is old.[13] Tying the ideas of profit and new uses together, Jevons repeats, "But no one must suppose that coal thus saved is spared—it is only saved from one use to be employed in others, and the profits gained soon lead to extended employment in many new forms" (p. 155). If efficiency indirectly enables new things, his thesis gains plausibility.

3.5. The consumer

But *why* are new applications of material resources "*of an unlimited character*" (p. 197)? Why are price elasticities of demand positive, why is demand not saturated? These stupid questions arise because till now, the discussion has concerned production. Jevons has shown only that greater economy *enables* higher consumption; real rising consumption also requires consumers. His short chapter "Of the Natural Law of Social Growth" fills this gap by examining the tendencies of population and consumer desires to increase and includes his opinion that "We are getting to the gist of the subject" (p. 194). He first notes that "coal itself is limited in quantity" (p. 198), that a "vague but inevitable limit. . .will stop our progress" (p. 200), and that "We cannot, indeed, always be doubling the length of our railways, the magnitude of our ships, and bridges, and factories" (p. 196). Whether this last opinion would survive a visit to the USA or western Europe today is debatable, but "our *environment*" or " the powers and capabilities of. . .inorganic nature" have "elastic" yet "inexorable" limits, subject moreover to diminishing returns (pp. 194–98).

These limits contrast, however, with organic nature, including humans. Invoking Malthus and Spencer, his claim is that population and consumption "*tend* to increase. . .[in] *geometrical ratio*" (p. 193; also 245–247; Malthus, 1798, pp. 20–26, 30, 56, 71). His seminal version of the $I=PAT$ formula is that society's consumption consists of "the number of people, and the average quantity consumed by each" (p. 196). His argument is that "*If* children do as their fathers did. . ." then "*multiplication*" and average consumption both rise; "If our parents doubled their income, or doubled the use of iron, or doubled the agricultural produce of the country, then so ought we, unless we are changed either in character or circumstances" (pp. 193–94, 232, 275). The "purposes" and "needs" driving invention (p. 113) come from our reservoir of unmet demand whenever costs go down. These are, then, the "natural laws which govern. . .consumption" (p. 25) and a "natural law of growth, or multiplication in social affairs" (p. 275). Not only our numbers, but also our "social advance" tend to grow "ad infinitum" (pp. 194, 195; also Hearn, 1864, pp. 68, 100–102, 123–133, 178–185; Wackernagel and Rees, 1996, p. 127). We choose more output over less input and more free time. With cheap coal and "skill in its employment, . . .[the English] are growing rich and numerous. . ." (pp. 199–200).

Given widespread poverty, population growth, new products, and competitive consumption,[14] sizeable latent demand need not be belabored. As an assumption, though, or factor in a consumption function, it should be made explicit. Brookes, for instance, writes that ". . .it has been claimed since the time of Jevons that. . .for a resource to find itself in a world of more efficient use is for it to enjoy a reduction in its implicit price with the obvious implications for demand" (2000, pp. 356–57). Obvious or not, a *proof* of backfire is impossible without this demand. Both previous consumers and marginal consumers (Wirl, 1997, pp. 19–20, 29–32; Brookes, 2000, pp. 360, 362) must be invoked—or denied, as in one argument against significant rebound that explicitly assumes saturation (Grubb, 1990, pp. 39–43, 187, 242). Were we only seeking to lower the costs in our cost/benefit ratios, efficiency would save resources; when we seek as well to raise benefits, rebound is positive and maybe >1.

3.6. The clincher?

Jevons' strongest theoretical point arises from his musings over Savery's failed and Newcomen's somewhat more efficient but still voracious and noncom-

[13] Jevons' full-blown theory of new discoveries has three "conditions of invention": first a "purpose" or "need", then a "principle" of knowledge, and thirdly "the material, power, and skill for embodying this principle in a. . .construction." A steam-engine is such a construction—the thing with a price, input costs, and profitability (pp. 112–19, 148–49; Hearn, 1864, pp. 168, 187).

[14] Thorstein Veblen's analysis of efficiency, emulation, and status consumption offers a psychological explanation for Jevons' position (Veblen, 1899, pp. 25, 32,73, 99, 110–11, 156–63, 208, 227, 241, 342; also Alcott, 2004).

petitive engine. Because the water-wheel had "been carried near its mathematical maximum of efficiency," coal-burners had a hard time (p.177). Brindley's opinion of the Newcomen engine was that "...unless the consumption of coal could be reduced, the extended use of this steam-engine was not practicable, by reason of its dearness, as compared with the power of horses, wind, or air" (p. 143). (Note that replacement of labor by capital, of endosomatic by exosomatic input, also continues at today's higher technological levels.) With the Savery engine, though, "...as he allowed the steam to act straight upon the water, without the intervention of a piston, the loss of heat was tremendous. Practically, the cost of working kept it from coming into use; *it consumed no coal, because its rate of consumption was too high*' (pp. 143, 118). That is, had efficiency not led to lower and lower "rates of consumption", we would consume no coal!

Jevons is asking his 'economy' adversaries what would have happened to population and consumption had the steam engine not progressed from Newcomen to Watts and further. Is 1865's level of production then even conceivable (pp. 152–54, 265–79)? The same question today is: If we assume a fuel technology frozen at Watt's thermal efficiency of about 4%—even imagining any number of institutional and factory-floor efficiency gains—is it plausible that 6 billion people would be living at today's affluence (Brookes, 2000, p. 359)? Or, remember that supporters and opponents of Jevons both compare a scenario *with* and *without* technological efficiency gains, opponents claiming that absolute consumption is higher in the scenario *without* them. But if in this scenario we assume the *same* increase in population and affluence that has really obtained, then at Watt's level of material/energy intensity charcoal, coal, oil, and gas would all be long gone. But positing that not only T but also $P \times A$ remain the same begs too many questions. Both sides must explain the real rise in population-times-affluence. For this Jevons can invoke technological efficiency gains; his opponents cannot. Only if today's $P \times A$ is remotely possible at 'Watt' technology is the low rebound position plausible. Jevons insisted that "...it cannot be supposed we shall do without coal more than a fraction of what we do with it" (p. 9; Brookes, 2000, p. 359).

A corollary is that if "economy" lowers total consumption, diseconomy or efficiency *losses* should raise it. Take an efficiency *decrease* and compute engineering *losses* by keeping demand constant and multiplying by the higher input–output ratio. Input prices rise, lowering demand again in a sort of reverse rebound. The anti-Jevons position (Schipper and Grubb, 2000) would then say yes, consumption did go down, but less than it would have ("otherwise") *without* the efficiency decrease. Curiously, though, no one would deny that straightforward price increases lower consumption. Thus, for Waterston et al. to believe that economy "spares" fuel, they must also believe that as inputs become more *costly*, we consume more of them.

4. Analogy: the economy of labor

Jevons' brief argument from *analogy* concerns time or labor efficiency. "As a rule, new modes of economy will lead to an increase in consumption according to a principle recognised in many parallel instances. The economy of labor effected by the introduction of new machinery throws labourers out of employment for the moment. But such is the increased demand for the cheapened products, that eventually the sphere of employment is greatly widened" (p.140; also Petty, 1675, pp. 249–250; Cipolla, 1962, pp. 65, 105; Khazzoom, 1980, p. 23; Clapp, 1994). Seamstresses for instance have higher wages due to the sewing machine (p. 140). In agriculture of course "Labour saved is rendered superfluous...because the area of land is limited and already fully occupied" but other economic sectors then absorb this labor (pp. 243–244). In coal mining or the iron trade, he notes that although "hand labour is still further replaced by mechanical labour" (p. 153), population and employment in towns and around collieries rose greatly (pp. 130–131, 213–218, 277–278).

Khazzoom also offers this analogy, substituting "labor made redundant" for "energy saved" (both temporarily) (Khazzoom, 1987, p. 87; Khazzoom, 1980, p. 23). Greenberg relates the calculations of Owenite John Brooks in 1836 that the mechanical and chemical power of Great Britain and Ireland was doing the work of 600,000,000 people; it in no way follows, though, that even a thousandth of a percent of this number was therefore "out of work" (Greenberg, 1990, p. 711). Her study of early 19th-century atti-

tudes toward "technological unemployment" concludes that ever more productive machines were seen to supplement, rather than supplant, human power (pp. 699–703, 712). In light of the huge population increase over the last two centuries, it seems that neither human beings nor fossil fuels, in spite of huge productivity increases, remained unemployed.[15] Again, regarding time/labor input, the anti-Jevons 'savings' position must claim that *without* labor efficiency gains rises in work and population would have been *even greater*!

One reason that the case of labor efficiency was "recognised" was perhaps Say's well-known proof in his fourth Letter to Malthus (1820). He endorses Malthus' argument that technological improvement lowers cost and that both consumption and employment in the newly more efficient or "quickly producing" industries rise above previous levels, e.g. in textiles and printing (pp. 127–129). He criticizes Sismondi, whose logic failed to appreciate that efficiency raises purchasing power, scathingly predicting that his diagnosis of unemployment would earn him the ridicule of posterity (pp. 138–144). He then adds to Malthus' argument: Even if demand is saturated for the more efficiently produced product, what is today called an income effect "costlessly" augments consumption (pp. 129–130, 135, 151). He quantifies the example of efficient, mechanical flour milling, whereby the laid-off grain-grinders must and will *do something else* (pp. 133–134, 140).

Thus foreshadowing Jevons' argument from new applications, he says that people will make and buy *new products* as efficiency improvement enables "progress" to spread to other industries (pp. 137, 143, 151). Say's observation is that after any sort of efficiency gains, at least the same amount of flour, workers, energy, ability, and tools remain (pp. 137, 140). Paralleling Jevons' 'profitability' argument, he notes that capital gets formed only if greater production ensues—and capital formation is a fact (pp. 146–150; also Schumpeter, 1911, pp. 208–215). By taking the long view (pp. 132–133, 142–144), surpassing single-sector analysis, and taking the marginal consumer seriously, Say demonstrates *growth* effects of the *perfectionnement d'les arts*. He even hints that the matter is paradoxical: the augmentation of "employment and population" is *survenue* (p. 142).

5. Jevons' empirical argument

The duration of coal sources depends for Jevons' not only on how much there is and at what depth, but also on consumer behavior; this derives in turn from our numbers, our wanting to consume at least as our ancestors did, and how economically we used these sources. Tables throughout the book show that "In round numbers, the population has about quadrupled since the beginning of the nineteenth century, but the consumption of coal has increased sixteenfold, and more. *The consumption per head of the population has therefore increased fourfold*' (pp. 196, vi, 457). Covering all sectors of the British economy, his figures show large rises in both pig iron and coal consumption (pp. 246, 262–265, 280). He then establishes a *correlation* between this and rises in efficiencies. In terms of pounds of coal per horse power per hour, he traces the more than tenfold increase in steam engine efficiency from Newcomen and Watt to Woolf and Elder (pp. 145, 261–271; also Greenberg, 1990, pp. 703–705). Or in smelting: The foregoing decrease in coal use per ton of pig iron "*to less than one-third of its former amount, was followed, in Scotland, by a tenfold total consumption*, between 1830 and 1863 in Scotland. . ." (pp. 154, 387–388). Efficiency and total consumption had risen together, moreover, the latter more than the former. His opponents today reply that this proves nothing: Other factors cause the growth, and but for the greater economy, even more would have been used up.

While efficiency gains were attested by all, Mundella was one who disputed their effects in raising consumption, claiming that although from 1869 to 1876 efficiency and pig iron production both went up, consumption of coal "used in its Manufacture" went down (1878, pp. 90, 112). He identified efficiency gains through better furnace construction, use of waste heat, and in general hotter and better blasts (Bessemer and Siemens), concluding that "There is no evidence showing that the economy of fuel in the making of pig iron, and the consequent reduction in price, has led to the manufacture of more iron, by which more coal would have been consumed, as Mr.

[15] Another analogy is with agricultural input and output per square meter: Do efficiency gains mean we take land out of cultivation?

Jevons [in his "remarkably able work"] argues" (pp. 112, 89). In his reply to Mr. Mundella's "fairest" treatment of the subject, Jevons stuck to his guns. But the only numbers he crunched concerned whether coal consumption rises 2.5% or 4% every year, reiterating his point that at neither rate could the increase go on forever (Mundella, pp. 118–119).

Mundella's argument raises three questions still haunting the debate. 1) The time period considered: While his text looks at 1869–1876 only, and its 5% fall in coal consumption "in the manufacture of pig iron" (p. 90), his supporting Table F covers 1840–1876, showing a fourfold hike (p. 112); he believed that the trend had recently reversed. 2) He was only looking at coal's consumption "in [pig iron] Manufacture"! Actually, the Table's caption records "Coal used in its Manufacture" whereas the Table itself leaves out the word "its" (p. 112). His Tables B, C, and D showed, in fact, large overall use increases from 1660 to 1876 (pp. 109–111). But whatever the numbers, his single-sector study is ignoring new uses and thus today's income, substitution, or general equilibrium effects. 3) He restricts himself to Britain (while Jevons at least devotes Chs. XIII–XVI to the international scene).[16]

Since correlation does not prove causality, both sides need theory. Note that Mundella does concede the link between "economy" and "the consequent reduction in price," but not the rebound step to raised demand (p. 112). Jevons' reply to Mundella also reemphasized Cairne's thesis "that the cost of production was not the cause, but the effect of the efficiency of production" (1878, p. 118). In sum, Jevons establishes growth of population, agricultural and manufactured goods, and coal consumption alongside higher "economy" or productivity. Today as well nobody doubts such worldwide increases over, say, 250 years. One treatment for instance both attests to these statistics and warns of the complexity of the concept of "global energy intensity" (Smil, 2003, pp. 6–7, 49, 65–81). But to establish the causal arrow, I think Jevons is asking in his chapter on "social growth" why we seek efficiency in the first place. Surely to consume more easily and cheaply, but also to consume more.

6. Discussion

Jevons' view is compatible with later production functions and theories of economic growth[17] that attribute much to technological change as opposed to mere changes in labor productivity or population size (itself in need of explanation). One version sees "two obvious candidates" to explain growth, namely "technological progress and increasing returns to scale…. I reckon that technological progress must be the more important of the two in real economies…. The natural rate of growth [in the model] is now the sum of the rate of population increase and the rate of technological progress" (Solow, 1970, pp. 33–35, 38; also Schumpeter (1911); Schurr (1982, 1985). One list of terms for this strong factor ranges from "output per unit of input" through "efficiency index", and "total factor productivity" to "measure of our ignorance" and "the Residual" (Domar, 1961, p. 709). Anticipating the rebound concept, the same author states that a "rapid growth of [Kendrick's technological progress] Index in any industry reduces the prices of its output, and thus stimulates sales" (Domar, 1962, p. 605). Notwithstanding the difficulty of deriving an absolute quantity (consumption) from a ratio (efficiency), the theoretical question is whether the view that rebound is lower than 1 is also compatible with this consensus.

Recall that today's debate compares paths of total consumption with, and without, technological efficiency change—far more explicitly than in Jevons' treatment (Saunders, 1992, p. 135; Schipper and Grubb, 2000, p. 370). In the anti-Jevons position, both paths posit growth, even the one with frozen technology. But what, then, is to cause this posited growth (Brookes, 2000, p. 359)? Population? Institutional efficiency gains of all sorts? Schipper et al. (1996) indeed name exactly these three effects—population,

[16] My father's belief that 'figures can't lie, but liars sure can figure,' is assumed to apply to neither side. Domar (1962, p. 602) wrote, "Like politics, empirical work is the art of the possible".

[17] More accurately: explanations of the exact size or scale of the economy, whether growing or shrinking.

structure, and intensity—conceding that although the intensity effect lowers the costs of "energy services", growth is mainly due to "structural" effects (1996, pp. 192, 174). Another analysis (of US data from 1929 to 1970) concludes with the calculation that the "Khazzoom–Brookes hypothesis. . .must assert that improvements in energy efficiency were responsible for a full 29% of the increase" in GNP during a particular span of 41 years, but that "Claims of this sort, however, seem palpably implausible" (Howarth, 1997, pp. 2–4). But the author offers us neither a criterion of 'plausibility' nor a clear identification of the factors that do account for GNP growth. Note that whatever they are, these factors must be extremely strong: they must not only do without technical progress, but must also *compensate for* it. Thus, while growth proponents and neutral analysts universally know that both technological and institutional efficiency must figure in the recipe,[18] some who do not welcome the environmental impact of growth claim that efficiency will, ceteris paribus, reduce the size of the material economy.

Regarding empiricism, Jevons early on tells us that he "must also draw attention to principles governing this subject, which have rather the certainty of natural laws than the fickleness of statistical numbers" (pp. 6, 198–99). Of course the book then delivers pages of fickle numbers, but they do not suffer any worse from methodological problems than today's: 1) limitation to certain time periods; 2) limitation to certain sectors; and 3) limitation to certain countries or groups of (usually OECD) countries. Following Jevons quite strictly, most researchers lament these acknowledged inadequacies while continuing to conduct micro studies (Grubb, 1990, pp. 195, 235; Howarth, 1997, p. 4; Greene et al., 1999, p. 28; Brookes, 2000, pp. 358, 365; Greening et al., 2000, p. 392; Binswanger, 2001, p. 124). Short of studies of two non-trading economies alike in every respect except technological change, the debate still seems heavily dependent on theory.

Another open question concerns how, exactly, to integrate into a formal theory the consumer's high price elasticities of demand—be these "natural" or somehow more contingent. Marginal consumers must at any rate be added. And finally, what is so paradoxical about this matter? Perhaps that if an efficiency gain causes a drop in the price of an input of 10%, and this input makes up 10% of product cost, then costs are down a mere 1%. Many (single-sector) studies indeed compute rebounds of 15% to 50%. Or perhaps that individually, if I replace my open fireplace with a ceramic stove, I simply cut less firewood back of my house, 'saving' time and wood. The macro result remains thus 'counter-intuitive'.

7. Conclusions

Jevons writes with the same uneasiness we feel today about overburdening the planet and exhausting its resources. Is greater material or energy efficiency a remedy, as many optimists and some environmentalists believe? "This is a question of that almost religious importance which needs the separate study and determination of every intelligent person" (p. 14). He reluctantly answered with 'No.' Today ecological economics must give advice on this surely not unanswerable question—the more so if Impact is growing rapidly—but a firm consensus is lacking. Certainly, theoretical work must see whether the environmental 'efficiency strategy' is reconcilable with standard growth theory. One certain conclusion, though, is that if Jevons is right, then efficiency policies are simply counter-productive. Even taxes on fuel or CO_2 will be compensated by efficiency increases, and moreover they face the problem that tax revenue also gets spent on material and energy (Wackernagel and Rees, 1996, p. 20).

By enabling population and affluence to rise, both business-as-usual and policy-induced efficiency gains are partial causes of environmental stress. Indeed, efficiency, sufficiency, and population strategies all face the problem that the $I=PAT$ equation is transitive: all right-side factors influence each other, leaving impact the same or higher. This enhances the attractiveness of directly lowering impact through rationing and quotas, whether of resources or emissions (as in the 'Kyoto' agreement) (Daly, 1973, pp. 337ff., 1996, p. 15; Wackernagel and Rees, 1996, p. 129; Brookes, 2000, pp. 363–64; Rudin, 2000). Politically unfashionable though they may be—Jevons himself denied

[18] For instance, the mainstream in Switzerland today does not doubt that the country's bilateral agreements with the EU will put it back on the path of 2% annual growth.

that "the consumption of coal can be kept down in our free system of industry…" (p. 136)—ecological economics should once again take resource rationing seriously.

References

Alcott, Blake, 2004. John Rae and Thorstein Veblen. Journal of Economic Issues 38 (3), 765–786.

Berkout, Peter H.G., Muskens, Jos. C., Velthuijsen, Jan W., 2000. Defining the rebound effect. Energy Policy 28 (6/7), 425–432.

Binswanger, Mathias, 2001. Technological progress and sustainable development: what about the rebound effect? Ecological Economics 36 (1), 119–132.

Boulding, Kenneth, 1949-50. Income or welfare. The Review of Economic Studies, Volume XVII: 77-86.

Brookes, Leonard, 1979. A low energy strategy for the UK. Atom 269, 73–78 (March).

Brookes, Leonard, 1990. The greenhouse effect: The fallacies in the energy efficiency solution. Energy Policy 18 (2), 199–201.

Brookes, Leonard, 2000. Energy efficiency fallacies revisited. Energy Policy 28 (6/7), 355–366.

Cipolla, Carlo M., 1962/1966. The Economic History of World Population. Penguin, Harmondsworth, U.K.

Clapp, Brian William, 1994. An Environmental History of Britain Since the Industrial Revolution. Longman, London.

Daly, Herman E., 1973/1980. Economics, Ecology, Ethics. W.H. Freeman, San Francisco.

Daly, Herman E., 1996. Beyond Growth. Beacon, Boston.

Domar, Evsey D., 1961. On the measurement of technological change. The Economic Journal 71 (4), 709–729.

Domar, Evsey D., 1962. On total productivity and all that. Journal of Political Economy 70 (5), 597–608.

Giampietro, Mario, Mayumi, Kozo, 1998. Another view of development, ecological degradation, and North–South trade. Review of Social Economy 56 (1), 20–36.

Goodland, Robert, 1992. The Case That the World has Reached its Limits. In: Goodland, Robert, Daly, Herman, El Serafy, Salah (Eds.), Population, Technology, and Lifestyle: The Transition to Sustainability. Island, Washington, DC.

Greenberg, Dolores, 1990. Energy, power, and perceptions of social change. American Historical Review 95 (3), 693–714.

Greene, David L., 1992. Vehicle use and fuel economy: how big is the rebound effect? Energy Journal 13 (1), 117–143.

Greene, David L., Kahn, James R., Gibson, Robert C., 1999. Fuel economy rebound effect for U.S. household vehicles. Energy Journal 20 (3), 1–32.

Greenhalgh, Geoffrey, 1990. Energy conservation policies. Energy Policy 18 (4), 293–299.

Geening, Lorna A., Greene, David L., Difiglio, Carmen, 2000. Energy efficiency and consumption—the rebound effect—a survey. Energy Policy 28 (6/7), 389–401.

Grubb, Michael, 1990. Energy Policies and the Greenhouse Effect, vol. 1. Dartmouth Publishing Co., Aldershot, U.K.

Hearn, William Edward, 1864. Plutology: Or the Theory of the Efforts to Satisfy Human Wants. Macmillan, London and George Robertson, Melbourne.

Holdren, John P., 1992. Prologue to Lee Schipper & Stephen Meyers, 1992. Energy Efficiency and Human Activity: Past Trends, Future Prospects. Cambridge U. Press, Cambridge.

Hotelling, Harold, 1931. The economics of exhaustible resources. Journal of Political Economy 39 (2), 137–175;
In: Darnell, Adrian C. (Ed.), The Collected Economic Articles of Harold Hotelling. Springer-Verlag, New York.

Howarth, Richard B., 1997. Energy efficiency and economic growth. Contemporary Economic Policy XV (4), 1–9.

Hull, Edward, 1861. The Coal-Fields of Great Britain: Their History, Structure, and Resources, 2nd ed. Edward Stanford, London.

Hull, Edward, 1905. The Coal-Fields of Great Britain: Their History, Structure, and Resources, 5th ed. Hugh Rees, London.

Jevons, William Stanley, 1865/1965. In: Flux, A.W. (Ed.), The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-mines, 3rd edition 1905. Augustus M. Kelley, New York.

Jevons, William Stanley, 1871/1879/1888/1911. The Theory of Political Economy, 5th edition 1957. Augustus M. Kelley, New York.

Khazzoom, J. Daniel, 1980. Economic implications of mandated efficiency in standards or household appliances. Energy Journal 1 (4), 21–40.

Khazzoom, J. Daniel, 1987. Energy saving resulting from the adoption of more efficient appliances. Energy Journal 8, 85–89.

Khazzoom, J. Daniel, 1989. Energy saving resulting from the adoption of more efficient appliances: a rejoinder. Energy Journal 10 (1), 157–166.

Lauderdale, Earl of, 1804. An Inquiry Into the Nature and Origin of Public Wealth and Into the Means and Causes of its Increase. Arch. Constable & Co, Edinburgh.

Lovins, Amory B., 1988. Energy saving from more efficient appliances: another view. Energy Journal 9, 155–162.

Malthus, Thomas Robert, 1798/1976. An Essay on the Principle of Population. W.W. Norton, New York.

Mikesell, Raymond, 1992. Project evaluation and sustainable development. In: Goodland, Robert, Daly, Herman E., El Serafy, Salah (Eds.), Population, Technology, and Lifestyle: The Transition to Sustainability. Island, Washington, DC.

Moezzi, Mithra, 2000. Decoupling energy efficiency from energy conservation. Energy and Environment 11 (5), 521–537.

Mundella, Anthony J., 1878. What are the conditions on which the commercial and manufacturing supremacy of Great Britain depend, and is there any reason to think they have been, or may be, endangered. Journal of the Statistical Society of London, 87–126 (March).

Petty, William, 1675/1899. Political arithmetik. In: Hull, Charles Henry (Ed.), The Economic Writings of Sir William Petty. Cambridge U. Press, Cambridge, pp. 213–233.

Princen, Thomas, 1999. Consumption and environment: Some conceptual issues. Ecological Economics 31, 347–363.

Rae, John, 1834. Statement of Some New Principles on the Subject of Political Economy, Exposing the Fallacies of the System of Free Trade, and of Some Other Doctrines Maintained in the

"Wealth of Nations". Hilliard, Gray, and Co., Boston. Reprint (facsimile) 1964, Augustus M. Kelley, New York.
Roy, Joyashree, 2000. The rebound effect: some empirical evidence from India. Energy Policy 28 (6/7), 433–438.
Rudin, Andrew, 2000. Let's stop wasting energy on efficiency programs—energy conservation as a noble goal. Energy and Environment 11 (5), 539–551.
Sanne, Christer, 2000. Dealing with environmental savings in a dynamical economy—how to stop chasing your tail in the pursuit of sustainability. Energy Policy 28 (6/7), 487–495.
Sanne, Christer, 2002. Willing consumers-or locked in? Policies for a sustainable consumption. Ecological Economics 42, 273–287.
Saunders, Harry D., 1992. The Khazzoom–Brookes postulate and neoclassical growth. Energy Journal 13 (4), 131–148.
Saunders, Harry D., 2000. A view from the macro side: rebound, backfire and Khazzoom–Brookes. Energy Policy 28 (6/7), 439–449.
Say, Jean-Baptiste, 1820. Lettres a M. Malthus Sur Différens Sujets d'Économie Politique. Chez Bossange, Paris.
Schipper, Lee, Meyers, Stephen, 1992. Energy Efficiency and Human Activity: Past Trends, Future Prospects. Cambridge U. Press, Cambridge.
Schipper, Lee, Haas, R., Sheinbaum, C., 1996. Recent trends in residential energy use in OECD countries and their impact on carbon dioxide emissions: a comparative analysis of the period 1973–1992. Mitigation and Adaptation Strategies for Global Change 1 (2), 167–196.
Schipper, Lee, Grubb, Michael, 2000. On the rebound? Feedbacks between energy intensities and energy uses in IEA countries. Energy Policy 28 (6/7), 367–388.
Schmidheiny, Stephen, 1992. Changing Course: A Global Business Perspective on Development and the Environment. MIT Press, Cambridge, Mass.
Schumpeter, Joseph A., 1911. Theorie der Wirtschaftlichen Entwicklung, 2. Auflage 1926. Duncker and Humblot, München.
Schurr, Sam H., 1982. Energy efficiency and productive efficiency: some thoughts based on American experience. Energy Journal 3 (3), 3–14.
Schurr, Sam, 1985. Energy conservation and productivity growth: can we have both. Energy Policy 13 (2), 126–132.
Sieferle, Rolf Peter, 2001. The Subterranean Forest. White Horse Press, Cambridge.
Smil, Vaclav, 2003. Energy at the Crossroads: Global Perspectives and Uncertainties. MIT Press, Cambridge, Massachusetts.
Solow, Robert M., 1970. Growth Theory: An Exposition. Clarenden Press, Oxford.
Stern, Paul C., Berry, Linda G., Hurst, Eric, 1985. Residential conservation incentives. Energy Policy 13 (2), 133–142.
Thorstein, Veblen, 1899/1998. The Theory of the Leisure Class. Prometheus Books, Amherst, N.Y.
Vincent, Jeffrey R., Panayotou, Theodore, 1997. Consumption: distraction to sustainable development. Science 276, 53–57.
Von Weizsäcker, Ernst, Lovins, Amory B., Lovins, L. Hunter, 1997. Factor Four: Doubling Wealth—Halving Resource Use. Earthscan, London.
Wackernagel, Mathis, Rees, William, 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. New Society Publishers, Gabriola Island, BC, Canada.
Wirl, Franz, 1997. The Economics of Conservation Programs. Kluwer Academic, Boston.

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ANALYSIS

The sufficiency strategy: Would rich-world frugality lower environmental impact?

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ARTICLE INFO

Article history:
Received 22 April 2006
Received in revised form
26 February 2007
Accepted 30 April 2007
Available online 12 June 2007

Keywords:
I=*PAT*
Resource consumption
Sufficiency rebound
Efficiency
Ethics
Quotas

ABSTRACT

One alleged weapon against unsustainable environmental impact is for the wealthy to consume less. This *sufficiency strategy* is to complement the *efficiency strategy* of lowering ratios of resource inputs to economic outputs; the former would reduce the affluence factor in *I*=*PAT*, the latter the technology factor. That the latter strategy suffers from a consumption *rebound* is widely recognized. This paper identifies a similar rebound when the affluence factor is autonomously lowered: The lower initial demand lowers prices, which in turn stimulates new demand *by others*. The strategy moreover addresses only the rich, raising questions of its theoretical maximum efficacy. Its proponents usually conflate frugality with the North–South dichotomy and *intra*generational with *inter*generational equity. Moreover, there are difficulties with the supporting arguments that frugality is good for one's own sake as well as for the environment, and that the rich should 'lead the way' to living more lightly. Personal behaviour change is furthermore not a substitute for international political efforts. Finally, since all changes in right-side factors of the *I*=*PAT* equation change other right-side factors, such indirect attacks on impact should be abandoned in favor of supply and emissions quotas.

1. Introduction

> "The institutions [of a steady-state economy]…seek to induce…a change toward resource-saving technology and patterns of living, and to a greater reliance on solar energy and renewable resources." — Herman Daly (1974, p.18)

In the *I*=*PAT* equation the causes of environmental *impact* are *population*, *affluence*, and *technology*. "Environmental strategies" here denotes groups of policies to lower resource consumption and emissions,[1] and are classified under these three headings. While population strategies are seldom discussed, much attention shines on the *T* factor, specifically the technological *efficiency strategy* meant to raise the ratio of affluence to the environmental goods used up in the economic process — through technology *per se* as well as measures such as environmental bookkeeping, life cycle analysis, mandated capital efficiency, renewable resources, recycling, legal standards, taxes, and 'consumption efficiency'. More broadly, the *T* factor is an ornery variable including

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[1] I define consumption as 'using up' (German *Verbrauch*) rather than 'use' (*Gebrauch*) – i.e. as 'taking with' or destruction – following Boulding (1949–50; 1992, 117, 129; also Princen, 1999, 355) – and conjecture that pollution is reducible to consumption of goods such as clean air or water.

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doi:10.1016/j.ecolecon.2007.04.015

production-process efficiency, input/emissions ratios, degrees of emissions toxicity, risk, and institutions.

Affluence is consumption (depletion) or emissions (pollution) *per person*; the *sufficiency strategy* attacks this affluence (*A*) factor, seeking to lower *per capita* resource consumption in hopes of thereby lowering total – or aggregate – consumption or impact (*I*). Of course, humanism demands restricting this strategy to those who are consuming at least enough for their health, reproduction, longevity and education. Lowering the affluence of the poor would after all mean more sickness, death, and armed conflict. The strategy thus envisions cuts in material and energy consumption within the 'affluent' target group that are large enough to reduce total impact even if (hopefully) the poor consume more. In this it is thus distinct from the strategy to lower MIPS (Material Input Per unit of Service) (Hinterberger et al., 1996). MIPS computations assume that the denominator (whether expressed as monetary GDP, services, utility, or material consumption) remains constant or rises while the numerators of resource inputs are minimised, whereas sufficiency intends a lower output, a smaller denominator, lower global demand. The 'factor four' blueprint – doubling affluence while halving impact – similarly foresees no *doing without* (Von Weizsäcker et al., 1997; Schmidt-Bleeck, 1994; Grubb, 1990).[2]

One analysis illustrating the application of *I*=*PAT* and setting the stage for the sufficiency strategy is that of Ekins, which computes how much technological improvement is needed if 1) sustainability requires halving impact, and 2) population will double and affluence quadruple by 2040 – *T* would have to decrease 93% (1991, 250; Goodland and Daly, 1992, 131). The obvious difficulty of this leads Ekins to place hope in frugality: "The environmental crisis, the crisis of unsustainability, must be laid squarely at the door of northern industrial consumer lifestyles and their imitations now in nearly all the countries of the Third World." (249; [see my] Section 4.1) Rather than appeal to ethical duty he envisions the double benefit of less impact as well as, since money doesn't buy happiness, a better family life and better health without "stress and pollution". (253; Section 4.3)

In Section 2 I define and describe the strategy. Section 3 shows that like the efficiency strategy it triggers a consumption *rebound*: Whereas input–output efficiency constitutes an income effect and can lower prices of material-energy inputs, 'lighter lifestyles' of the wealthy constitute an autonomous demand reduction that lowers prices. In both cases new demand emerges, in the case of sufficiency that of new or marginal consumers who take up the 'slack' left by the previous consumers' environmentally motivated frugality. This rebound is plausible if there is latent demand and if supply functions are relatively price inelastic. Section 4 identifies four questionable strands in arguments for the strategy: the North–South dichotomy, *intra*generational ethics, selfish reasons for sufficiency, and emphasis on personal rather than political behaviour. Section 5 discusses 1) some concepts necessary for quantification of strategy goals and possibilities; 2) the costliness of co-ordinating changes in the independent variables on the right side of *I*=*PAT*; and 3) quotas as opposed to taxes.

2. The sufficiency strategy

Although the plan to lower impact by consuming less consists mainly of exhortation, and seldom of legal restrictions on consumption,[3] I nevertheless call this body of thought a 'strategy', both because a sizeable advocacy literature exists and because, however weak the means of achieving it presently are, the goal of humanity's living materially more modestly is a clear and, for many, appealing *vision*. First I define the strategy, then describe it in the form of a literature survey.

2.1. *Definition*

Starting with what it is *not*, the strategy is distinct from the correction of policies or institutions that make us consume more than we would like: e.g., settlement and zoning policies and poor public transportation bless us with unwanted hours behind the steering wheel (Røpke, 1999; Sanne, 2002). It is also not the correction of externalities and market failures that favour consumption by rendering natural resources 'too cheap'; i.e., it has nothing to do with welfare economics' *optimality*. Finally, it is not the same as *consumption efficiency*, by which is meant behaviour that achieves a given level of utility with less (energy) input: e.g., boiling *only* the amount of water needed for the cup of coffee, switching off unneeded lights, or carpooling. (Hannon, 1975; Etzioni, 1998, 630; Prettenthaler and Steininger, 1999; Princen et al., 2002, 67; Nørgard, 2006, 96) Sufficiency, in contrast, means doing without the cup of coffee, getting by with dimmer lighting, and not taking the car. That is, assuming that 'environmental concern' is left out of the utility function, sufficiency implies lower utility or welfare. (Section 4.3)

Two concepts are needed to define sufficiency behaviour. First, it presupposes *purchasing power*: Those who are to alter their behaviour towards less consumption must be *able to* consume. Their purchasing power either remains unused or is itself reduced through working and earning less. The second concept is *environmental motivation*: We all limit consumption at some point, for many reasons. I am however confining the definition to the costs of non-consumption that are voluntarily traded for the benefits of believing one is relieving human pressure on planetary resources and thus benefiting other (present or future) humans or other species.

2.2. *Literature survey*

Using the method of ostensive definition, several quotations from the literature advocating sufficiency follow. One paradigmatic statement is, "The North should stabilize its rate of

[2] It is thus incorrect to conflate the efficiency and sufficiency strategies, as when the MIPS strategy is called "a nature–human model of doing without" or when "factor four" or "factor ten" strategies are characterised as "being maximally sufficient at the existence minimum" (quoted by Luks, 2000, 61).

[3] Even the neglected population strategy often goes beyond education and propaganda to subsidise sterilisations, birth control technology, and abortions, or proscribe one-child families. During wars many societies ration (Simms, 2005), but today we are merely 'encouraged' to live more lightly.

resource consumption to free resources for the South and to free up ecological space… [by] reducing Northern throughput growth and decreasing Northern consumerism"; we must both "adjust… consumption patterns and reduce the environmental impact of each unit of consumption…" (Goodland and Daly, 1992, 131, 142; Section 4.1) This argument is partly from *intra*generational equity: "Less consumerism… in the North could be invested in much-needed poverty alleviation and growth in the South" (133; Section 4.2). As an argument from environmental quality it is moreover implicitly *inter*generational: If the rich North would at least "stabilize" its resource consumption, global resource destruction and waste will fall. The call is for "remolding consumers' preferences and steering wants in the direction of environmentally benign activities" and for less consumption by "rich countries,… whose material well-being can sustain halting or even reversing throughput growth…" (Goodland et al., 1992, xii, xv).

Elsewhere the same authors observe that "OECD overconsumers" cause both *intra*generational inequality and our global "hurtling away from environmental sustainability", attesting "the wasteful and destructive practices being pursued by Northern consumption and pollution patterns" and noting in support of the sufficient lifestyle that "affluence and overconsumption do not increase welfare" (1996, 1005, 1015, 1009; Section 4). "Sufficiency" is thus a concept "which needs dissemination" and which they define as "doing more with less"[4] and "emphasizing quality and non-material satisfactions."'' (1009) Their question is: "[C]an humans lower their per capita impact (mainly in OECD countries) at a rate sufficiently high to counterbalance their explosive increases in population (mainly in low-income countries)?" (1011) Daily and Ehrlich similarly advocate the "…de-development of the overdeveloped countries,… that is, controlling runaway consumption in order to reduce the physical throughput of their economies" (1996, 1000).

In $I=PAT$ terms, Princen holds that "Consumption or, more precisely, overconsumption, ranks with population and technology as a major driver of global environmental change" (1999, 348). After decades of research into "…production, overall human or economic activity, equity, technology, or population", he urges a "comprehensive research agenda on consumption and environment…" (349, 352). He envisions "… peoples' choices *not* to purchase or to seek less consumptive, less material-intensive means of satisfying a need", and where needs cannot be met non-materially, this can be done less impact-intensively (354). He relies on a conventional concept of "normal" or "background" consumption and goes on to identify harmful ways of "material provisioning", variously termed "excessive or maladaptive consumption", "problematic consumption", or the "overconsumption" harmful to our *species* and the "misconsumption" harmful to the *individual*. He diagnoses the "inability of individuals to meet their needs in a given social context" (356–358) and pleas for lower consumption by "us Northerners and Southern elites" who can indeed change to embrace "thrift, frugality, and self-reliance" (360, 361).

Røpke's starting point is likewise that "…growing consumption in the North contributes substantially to environmental problems, and considerations about the need to change lifestyles are popping up in official publications" (1999, 401). Consumption patterns must change, through mainfold concrete measures (417–418), toward less environmental intensity. However, this move towards "labour-intensive goods and services: theatre and music performances, courses in new skills, lectures on interesting topics, art objects, high quality clothes and houses made as handicrafts, child care, and massage treatments — is not likely to take place…", and therefore there is no way around consumption *reduction* (401–402). However, this environmentally and distributionally motivated desire to "halt the forces behind… ever growing consumption" is hard to fulfill due to causes lying in the domains of economics, socio-economic institutions, socio-psychology, history, and socio-technology (402, 416). Like others including Schor (1992, 1999a, 1999b; Veblen, 1899, 111) she attests the *prima facie* reasonableness of gaining free time through consuming and working less (403), concluding that while "voluntary curtailment of consumption in the rich countries is… first of all an ethical issue," we should avoid "too much moralizing" (416–417).

Building on both Røpke and Agenda 21, Sanne identifies "reduc[ing] consumption in rich countries" as a "condition for sustainable development. This turns the searchlight on the consumer as the principal lever of change" (2002, 273; Section 4.4). "Household consumption in industrial societies like the UK must decline" and the fact that "consumption comes in packages… calls for an analysis of activities and aggregate consumption as it is realized in lifestyles" (274). "The predicament of overconsumption can only be overcome if the values behind present lifestyles change; …the green claim in this spirit is that we should combine the trend towards higher *efficiency* with a sense of *sufficiency*" — the "'ethical question of 'living lightly'" (275). Not just as consumers, but also as "citizens in the political process" (275), we are subject to "economic…, cultural, and social…structural forces driving consumption" (276, 284). He then advocates several institutional and lifestyle measures to further sustainable consumption and liberate consuming agents "locked-in by… circumstances" (282–286). A similar analysis by Spangenberg and Lorek sees "households making a difference" and uses the concept of "consumption clusters" to compute "low-impact affluence" in the interests of "eco-sufficiency" (2002, 134, 139).

Further recent works zeroing in on consumption's negative environmental[5] impact are Rosenblatt (1999) and Princen et al. (2002). Earlier, Jevons endorsed the sufficiency strategy to save coal (1865, 138), and Scitovsky's analysis of addictive "status consumption" in our "joyless economy" touched on environmental problems (1976, 144, 283–284), as did that of Leiss (1976, 98–99, 139). But the ecological critique of consumption began in earnest with Meadows et al. (1972), Schumacher (1973) and Daly (1973) and has been continued by Johnson (1985), Durning

[4] In contrast, I classify this within the efficiency strategy.

[5] Other literature on the social, ethical, aesthetic, and psychological, rather than environmental, costs of consumption includes Rae (1834), Mackenzie (1892), Smart (1892), Veblen (1899), Galbraith (1958a), Baudrillard (1970), Linder (1970), Hirsch (1976), Douglas and Isherwood (1979/96), Mason (1981), Frank (1985, 1999), McCracken (1988), Schor (1992), Fine and Leopold (1993), Cross (1993, 2000), Ramstad (1998), Waller and Robertson (1998), Kasser (2002), and Brekke et al. (2003).

(1992), Hinchliffe (1995), Lintott (1998), Duchin (1998), and Jackson and Marks (1999). Ways of manipulating people into consuming less are dealt with by Cook and Berrenberg (1981), Ornstein and Ehrlich (1989), Meadows et al. (1992), Gardner and Stern (1996), Siebenhüner (2000), Brown and Cameron (2000), and Ekins (2004).

However, there is no better statement of both the efficiency and the sufficiency questions than the early one of Galbraith (1958b). In the days when environmental protection was called 'conservation', he wrote that our

> …gargantuan and growing appetite has become the point of departure for all discussions of the resource problem…. [W]e have been busily assessing reserves of various resources and measuring the rate of depletion against the rate of discovery. We have become concerned with the efficiency of methods of recovery…. [T]he high rate of resource use has stirred interest in the technology of resource use and substitution…. [I]nzvestment in…innovation may well substitute, at more or less constant rates, for investment in orthodox discovery and recovery. This means, in less formidable language, that if a country puts enough of its resources into researching new materials or new sources of materials, it may never be short of the old ones. (90–91)

He was one of the first to move beyond efficiency to sufficiency:

> If we are concerned about our great appetite for materials, it is plausible to seek to increase the supply, to decrease waste, to make better use of the stocks that are available, and to develop substitutes. But what of the appetite itself? Surely this is the ultimate source of the problem. If it continues its geometric course, will it not one day have to be restrained? Yet in the literature of the resource problem this is the forbidden question. (92)

Presaging present challenges to consumer behavior and moves away from exclusively working on production efficiency, he notes that for instance the President's Materials Policy Commission began its report

> by stating its conviction that economic growth was important and, in degree, sacrosanct. "First, we share the belief of the American people in the principle of Growth." (It is instructive to note the commission's use of a capital G. A certain divinity is associated with the word.) *Growth* in this context means an increasing output of consumers' goods and an increase in the plant by which they are supplied. Having started with this renunciation, the commission was scarcely in a position to look critically at consumption in relation to the resource problem, and it did not (93).

His pioneering critique of high consumption's low correlation with satisfaction concludes that "if conservation is an issue, then we have no honest and logical course but to measure the means for restraining use against the means for insuring a continuing sufficiency of supply and taking the appropriate action. There is no justification for ruling consumption levels out of the calculation" (98).

3. The sufficiency rebound

This section seeks to render plausible the most important weakness of the sufficiency strategy, namely that its effectiveness is reduced by a *rebound effect*. To explain the *sufficiency* rebound stemming from autonomous frugal behaviour, it is necessary to describe the rebound concept in terms of its original domain, namely (energy) *efficiency*. This detour is justified moreover because the sufficiency literature often welcomes greater technological energy efficiency (*T*) but regards it as *insufficient* to lower impact, thus giving rise, in the first place, to the complementary sufficiency strategy (*A*). Using basic economic concepts familiar from the efficiency rebound literature, the assertion is that due to ensuing price drops, frugal behavior causes new consumption by others.

3.1. *The efficiency rebound*

While sufficiency means lowering *A* on the right side of $I = PAT$, efficiency would lower *T*, not in point of toxics or risk, but rather of material and energy inputs per unit of production. This technological ratio measures for instance the amount of energy put into a lumen, a ton–kilometre, a heated cubic metre of air, or tonne of steel, as well to *material* inputs like metals, stone, glass, and plastics (all with their own energy costs), and lower ratios constitute *technological efficiency increases*.[6] The belief that these relieve environmental pressure is too widespread to need documentation.

However, the efficiency strategy has an Achilles heel first elaborated by Jevons (1865, Chs. VII–XII) and known as the *backfire* problem or simply as 'Jevons' Paradox' (Giampietro and Mayumi, 1998, 24–25; Alcott, 2005). Khazzoom's modern formulation of the problem assumed positive price elasticity of demand and observed that "…changes in [household] appliance efficiency have a price content…[;] with increased productivity comes a decline in the effective price of commodities, and… in the face of lower effective prices, demand does not remain stagnant… but tends to increase" (1980, 22, 23; Brookes, 1978). Holding the *number* of consumed units constant then multiplying by the lower input–output ratio achieved by new technology *per unit* yields the theoretical quantity *engineering savings* (Binswanger, 2001, 122). Rebound is then the percentage of this 'savings' *not* realized due to income and price effects. If for example more efficient motors mean that a given number of driven kilometers is newly possible at less expense, this is the same as increased income or purchasing power — which can then be spent on further energy inputs even with no lowering of energy's relative price.

New demand for energy can also stem from the relative fall in energy's price when demand drops initially following the input-efficiency increase. In terms of production functions, if a unit of energy can produce more, energy's new relative power

[6] *T* also includes 1) organizational efficiencies like economies of scale, Taylorite factory-floor rationality and transportation infrastructures; 2) institutional ones like property rules, honesty, security, and trade; and 3) further cultural ones (Swaney, 1991; Durham, 1992). No one claims that increasing *these* efficiencies lowers resource consumption; indeed, they are seen to contribute unequivocally to economic growth.

or attractiveness results in substitution effects (Brookes, 1990; Saunders, 1992). Binswanger sums up the effects of efficiency gains: "Because the equipment becomes more energy efficient, the cost per unit of product or service that is produced with this equipment falls which, in turn, increases the demand for the product or the service" (2001, 120; Howarth, 1997; Birol and Keppler, 2000).[7]

The demand-stimulating effects of the more efficient use of any kind of input was identified by many classical economists including Say, who attributed greater overall wealth to the more productive use of "power" (energy):

> But whence is derived this…larger supply of wealth, that nobody pays for? From the increased command acquired by human intelligence over the productive powers and agents presented gratuitously by nature.… A power… before known and available is directed with superior skill and effect, as in the case of every improvement in mechanism, whereby human or animal power is assisted or expanded. (1803, 101; 295; Malthus, 1820, 49, 53–56; Rae, 1834, 29, 166, 171, 261–262; Mill, 1848, 133–134, 751)

In terms of costs of production rather than income effects, Domar similarly noted that "[A] rapid growth of [Kendrick's] Index [Total Factor Productivity] in any industry reduces the prices of its output, and thus stimulates sales…" (1962, 605; Hotelling, 1931, 137).

Estimates of the size of efficiency rebound vary wildly from nearly zero (Lovins, 1988) to insignificant (Grubb, 1990; Von Weizsäcker et al., 1997; Howarth, 1997; Greening et al., 2000; Schipper and Grubb, 2000; 4CMR, 2006) to greater than 100%, when it is called 'backfire' (Brookes, 1990, 2000; Greenhalgh, 1990; Giampietro and Mayumi, 2000; Rudin, 2000; Dahmus and Gutowski, 2005; Hanley et al., 2006; Herring, 2006). As rebound approaches 100%, both the effectiveness and cost-effectiveness of the strategy sink; if backfire pertains, the efficiency strategy is even environmentally *counterproductive*.[8] Analogously, heated 19th-century debates concerning *labour* efficiency eventually led to a consensus that backfire indeed obtains: So-called 'productivity' increases do *not* in the long run cause unemployment. (Say, 1820; Malthus, 1820, 281, 287; Mill, 1848, 756–757; Jevons, 1865, 140; Sraffa, 1951, lvii–lx; Greenberg, 1990; Alcott, 2005, 16–17) A further, similar rebound or 'feedback' effect is identified by Kaufmann, in what is perhaps a fatal challenge to the entire concept of the 'material intensity' of a good, service, or expenditure: When labour or capital are substituted for energy, these also have energy costs, which "offsets some fraction of the direct energy savings and reduces the amount of energy saved by price-induced microeconomic substitution." (1992, 49) Wages, for instance, are used to demand material and energy.

3.2. *"Efficiency is not enough"*

Sanne bolsters his argument that consumption per capita among the affluent must be lowered by agreeing with Jevons:

> Higher efficiency due to technological improvement may… create a rebound effect: saving energy or natural resources per unit of production results in lower costs which encourage increased consumption. In the end, a growing volume of activity will offset the initial gain, like futile attempts to catch one's own tail." (2002, 275)

It follows that if the environmental *efficiency* strategy is thus only weakly effective, or even counter-effective, the sufficiency strategy recommends itself all the more (assuming it is to some degree effective). Yet even many who attest the efficiency strategy's effectiveness regard it as *insufficient* for lowering impact to a sustainable level. In Ekins' view, for instance, "The energy performance of technology can be affected by regulation or, for example, minimum standards, but it is not clear that this will be sufficient to achieve the large cuts in carbon emissions that are necessary without complementing changes in personal behavior in both market and non-market choices" (2004, 1897). Smil likewise, echoing Galbraith (1958b), advocates going "beyond higher efficiency" to include changing "attitudes regarding the material consumption and the stewardship of the biosphere" (2003, 332, 368). For Princen "A productive efficiency is an undeniably, unassailably good thing", but we have too long focused on that agenda to the neglect of the consumption problem (1999, 360–361).[9]

Schor's (2005, 310–312) disaffection with the efficiency strategy includes the observation that technological solutions are popular because they promise a "free lunch" and because they are "apolitical… [Section 5.2]; intelligent design and technological innovation" shall bring us (in the curt formula of Factor Four) double the prosperity for half the resources. Her main problem with technological approaches, though, is that "…they fail to address increases in the scale of production and consumption, sometimes even arguing that such increases are not unsustainable, if enough natural-capital-saving technical change occurs;…[but] increases in scale have outpaced technological improvements." Note that Jevons' backfire theory *predicts* this scale increase; technology can save 'natural capital' only *per unit* of output, not overall.[10]

Schor goes on to adopt the Veblenian position that "in addition to the impact of rising income…competitive consumption" or "luxury fever (Frank, 1999)" increases consumption

[7] Also special issues of *Energy Policy* (28 (6/7) 2000) and *Energy & Environment* (11 (5) 2000).

[8] See further Cipolla, 1962, 49, 99; Pimentel et al. 1973, 1994; Schurr, 1982, 5; Rosenberg, 1982, 75 and 1994, 166–167; Saunders, 1992, 2000; Clapp, 1994, 161–171; Giampietro and Mayumi, 1998, 20–24; Wirl, 1997, 19–32, 41, 112, 197; Berkout et al., 2000, 426; Roy, 2000, 433; Moezzi, 2000, 524, 528; Sieferle, 2001; Smil, 2003, 68–81; Luks, 2005, 50–52.

[9] Also Sachs, 1988; Lovins, 1988, 158; Schmidt-Bleeck, 1994, 189; Daly, 1996, 219–222; Goodland and Daly, 1996, 1009; Gardner and Stern, 1996, 253; Bogun, 1997, 212; Von Weizsäcker et al., 1997, xvi, 244, 258, 292–295; Carley and Spapens, 1998, 51, 108; Røpke, 1999, 416–417; Sanne, 2000, 2002, 275; Siebenhüner, 2000, 19; Princen et al., 2002; Robinson, 2004, 379; Jackson, 2005, 20.

[10] The 'technical progress' of neo-classical growth theory is in large part greater efficiency in the use of material/energy as well as labour inputs. (Solow, 1957; 1970, 33–38) However, since this school of thought defines growth in monetary or utility terms, rather than biophysical ones, it does not necessarily support Jevons' position.

(2005, 310). However, if consumption indeed ends up higher than it would have been *without* energy efficiency increases, the conclusion is mistaken that "technological change is a necessary, but not sufficient condition for achieving sustainability" (310). A correct conclusion is that the less efficate the efficiency strategy proves to be – and especially if technological efficiency is part of the problem due to rebounds greater than unity – the more necessary are the further strategies of sufficiency, consumption efficiency, population limits, energy taxes, or quotas.

Further writers warn of backfire. Røpke for instance writes:

> Obviously, the environmental benefits of a change in consumption practices in one area can easily be counterbalanced by increased consumption in other areas, if overall growth is not limited [Sections 4.2 and 4.3]. For instance, a successful policy to reduce private motoring would imply the saving not only of energy, but of money [the income effect], which could be converted into extended weekends by plane to interesting places entailing increased energy consumption…" (1999, 401)

Reijnders similarly attests that "improvements in technology may be counterbalanced by increases in affluence and/or population", but then contradictorily asks whether "improvement of technology is sufficient" to lower impact to a sustainable level (1998, 17).

3.3. *The sufficiency rebound*

The position that efficiency is 'not enough' for sustainability thus makes sense only if the efficiency rebound is less than 100%, i.e., only if efficiency does not contribute to physical macroeconomic growth. This subsection claims, however, that the sufficiency strategy likewise suffers in point of efficacy: In constituting a drop in demand, it initially lowers prices, and this in turn raises others' demand, so that in the end some of what was 'saved' through non-consumption is consumed after all — merely by others. Analogous to the *engineering savings* theoretically achievable through technical change, the environmentally motivated drop in consumption is here called *sufficiency savings* and is likewise only theoretical; *marginal consumers* (Inhaber, 1997, xii; Wirl, 1997, 32) take up the slack left by the newly frugal people who have left the market. The analysis in this subsection holds for consumption of raw materials (metals, energy); whether it applies equally well to other consumption items such as food, water, or clothing is an open question.

The description of the sufficiency rebound in terms of price and income changes is simpler than that of the efficiency rebound. The chain of economic events here under discussion starts with an autonomous reduction in demand for or consumption of natural resources. In economic terms it amounts to a change in consumers' 'tastes' wherein they exchange, on average, some materially-derived utility for the emotional or ethical utility of reducing their own pressure on the environment. Instead of thinking in terms of small increments, imagine an overnight behavioural change: Moved by the desire to ease up on the environment OECD consumers decide to buy, say, 20% less fossil fuel than before. This sufficiency *shift* initially leaves 20% of their purchasing power unused; because these ex-consumers, *ceteris paribus*, work less, at this point in the dynamic demand is destroyed. The sufficiency rebound then amounts to a passive, rather than intentional, *transfer* of purchasing power to marginal consumers. The mechanism at work is that of price reductions of goods, services, and energy inputs themselves.

Fig. 1 shows, in terms of classical economics' laws of supply and demand, the results of a leftward sufficiency shift in the OECD demand function from $D_{0\ \mathrm{OECD}}$ to $D_{1\ \mathrm{OECD}}$. The graph shows $Q_{0\ \mathrm{WORLD}}$ ($=Q_{0\ \mathrm{OECD}}+Q_{0\ \mathrm{OTHER}}$) and P_0 (World price) given by the intersection of S with $D_{0\ \mathrm{WORLD}}$ (itself the sum of $D_{0\ \mathrm{OECD}}$ and $D_{0\ \mathrm{OTHER}}$). Holding both World supply function and price constant, then the sufficiency lurch, entailing as it does a

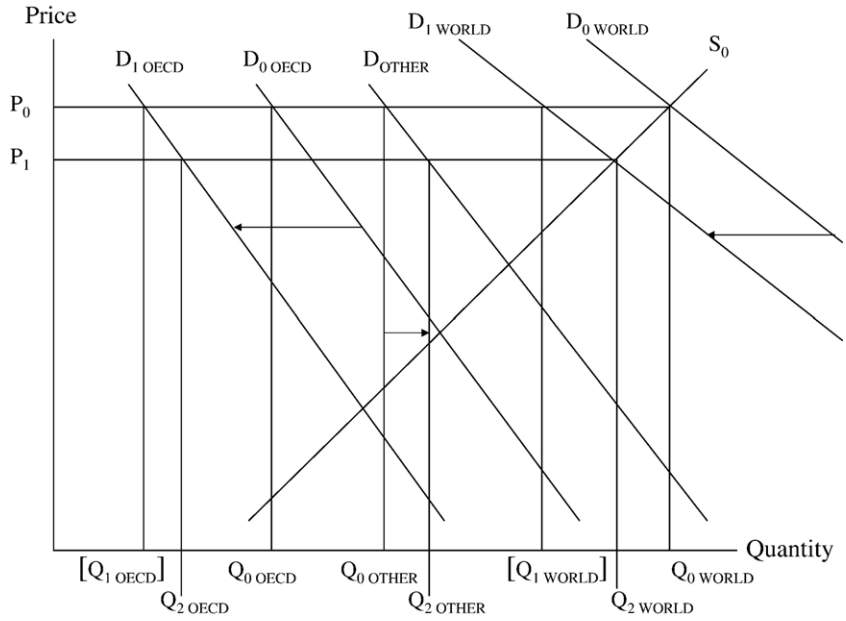

Fig. 1 – Fossil fuel demand OECD, non-OECD and World.

leftward shift from $D_{0\ WORLD}$ to $D_{1\ world}$, yields the theoretical quantities $Q_{1\ WORLD}$ and $Q_{1\ OECD}$, both of which are less than the original Q_0 quantities.

That is, the sufficiency shift in the OECD demand function is such that by definition ΔQ_{OECD}=a reduction or (theoretical) 'sufficiency savings' of 20% of $Q_{0\ OECD}$: Prices fall and non-OECD ('Other') demand rises; to what height depends on non-OECD price elasticities of demand; technology and S are held constant.

The imagined overnight demand reduction by OECD consumers shifts the world demand function of which it is a part from $D_{0\ WORLD}$ to $D_{1\ WORLD}$. The intersection of S and $D_{1\ WORLD}$ yields the new lower price P_1. For non-OECD countries (D_{OTHER}), the new, lower price (P_1) yields $Q_{2\ OTHER}$ which is *greater than* $Q_{0\ OTHER}$. Part of the resource savings realized by the OECD consumers is thus 'taken back' or wiped out by the classical economic behavior of others. At this price OECD countries consume $Q_{2\ OECD}$. (Note that there is no $Q_{1\ OTHER}$ because there was no shift in Other's demand function. Note further that at (the lower) price P_1, $D_{1\ OECD}$ would yield some increase in consumption, namely $Q_{2\ OECD}$ minus $Q_{1\ OECD}$; but we have assumed this away: regardless of price, OECD consumers consume 20% less than before.) Total consumption $Q_{2\ WORLD}$ (given by the intersection of $D_{1\ WORLD}$ and S) now results from the 20% reduction in consumption of the OECD countries plus the increase in consumption of other countries. The sufficiency *rebound* is $Q_{2\ OTHER}$ minus $Q_{0\ OTHER}$. The theoretical quantity 'sufficiency savings' ($Q_{0\ OECD}$ minus $Q_{1\ OECD}$) is exactly the same as the theoretical quantity $Q_{0\ WORLD}$ minus $Q_{1\ WORLD}$. The overall effect, or real savings ($Q_{0\ WORLD}$ minus $Q_{2\ WORLD}$), is smaller: Worldwide real savings *must* be lower than the savings initially achieved by a successful sufficiency strategy.

Wackernagel and Rees attest this same rebound in terms of *nations* as consumer units (and without mentioning price changes):

> Indeed the very integration of the global economy mitigates against any individual country adopting the ecological alternative: the marginal global benefits resulting from one nation's restraint would quickly be dissipated by non-cooperating countries, all of which have open access to the ecosphere (1997, 22).

In conclusion, insofar as the sufficiency strategy expects consumption to remain at the level reached by subtracting the OECD frugality alone ('sufficiency savings') it is unrealistic.

3.4. *Empirical measurement*

Whether any net worldwide real savings results – i.e. how close $Q_{2\ WORLD}$ is to $Q_{0\ WORLD}$ – depends on many things, but the necessary and sufficient conditions for the rebound itself are only 1) any amount of latent demand by marginal consumers and 2) any amount of supplier profit (any upward-sloping supply function). That is, price elasticities must merely be non-zero. When the utility curve of anyone is such that a purchase happens at the incrementally lower price, and the profit situation of any producer is such that supply continues at this price, the level of consumption cannot remain at the level computed by subtracting the foregone consumption of newly frugal people, but must rebound.

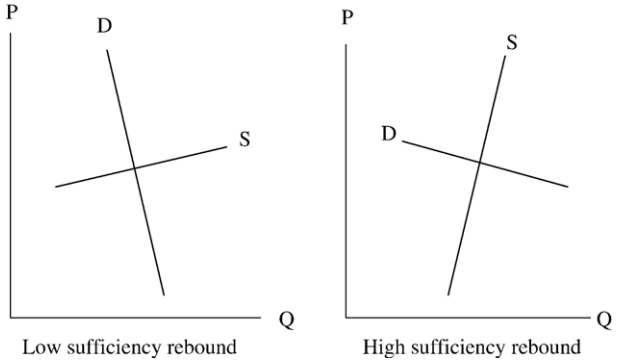

Fig. 2 – Possible new equilibrium.

But how could one measure sufficiency rebound? Assuming that the sufficiency behavior itself were measurable – the previous section simply assumed a 20% reduction in consumption [Section 5.1] – what would be the *magnitudes* of more demand and/or less supply of fossil fuels worldwide? Quantification would have to estimate the initial price fall and the slopes of the respective supply and demand functions, predicting the new equilibrium. Fig. 2 shows extreme cases of low and high sufficiency rebound, its size being some function of the ratio of the two elasticities (see also Larsen and Nesbakken, 1997). Keep in mind that the appropriate scope or scale of empirical studies must be the world economy, not any individual country or group of countries such as the OECD.[11]

First, how would producers react? Although estimates of the price elasticity of supply vary widely, much opinion holds that rents and profits in the fossil fuel sector are large enough to tolerate a considerable price fall (Katzner, 1987, 555; Wirl, 1991, 242; 1994, 79; Shim and Siegel, 1995, 322; Noreng, 2002, 9–10, 14; Salameh, 2003, 1090; Horn, 2004, 269, 271, 275; but see Kaufmann and Cleveland, 2001; Noreng, 2002, 8–9; Smil, 2003, 87) Second, is a historical worldwide demand curve feasible? Research is found for instance in Smil's analysis of total consumption of electricity and fossil fuels over long periods, showing rising quantities alongside (despite?) falling relative energy prices in terms of purchasing power (2003, 6–10, 82–84, 149–153; also Schurr and Netschert, 1960, 156; Cleveland et al., 1984, 896; Cleveland and Kaufmann, 2003, 486). Variability in elasticity estimates seems to depend on scale of study and economies studied. Also relevant is the cause of the price decline — in our case a sufficiency shift as opposed to technological efficiency increases, quantity of remaining reserves, or political (e.g. OPEC) decisions.[12]

[11] Market globalisation and the global nature of depletion and emissions damage lessen the usefulness of country studies. (Saint-Paul, 1995; Brown et al., 1998, 114; Cleveland and Ruth, 1998, 44–45; Dahlström and Ekins, 2006) In the efficiency-rebound literature this is often acknowledged (Grubb, 1990, 195, 235; Greenhalgh, 1990, 298; Hinchliffe, 1995, 94; Howarth, 1997, 4; Greene et al., 1999, 28; Roy, 2000, 433; Greening et al., 2000, 392; Saunders, 2000, 439; Binswanger, 2001, 124; Rhee and Chung, 2006).

[12] Also Harris, 1984, 40; Krautkraemer, 1998; Cleveland and Kaufmann, 2003. Most literature unfortunately starts with price *rises* like those of the mid-1970s.

3.5. *Backfire?*

Is a sufficiency rebound greater than unity possible? Some writers mention the possibility that, per unit of affluence at the margin, the consumption of the poor could be more environmentally damaging that of the rich. (Khazzoom, 1980, 26; Goodland and Daly, 1996, 1013; Schipper, 2000, 353; Binswanger, 2001, 126; Shi, 2003, 32, 38–39). A bus ride in Colombia might burn more fuel per kilometer than one in Switzerland, or – eschewing the North/South imagery – a museum visit might use up fewer resources than a hungrier person's eating a meal. In terms of Environmental Kuznets Curves,[13] the sufficiency shift might move the world economy to a position where consumption rises more steeply over against income.

Deciding whether the strategy is efficate or counter-productive thus entails testing for the theoretical conditions for a sufficiency backfire, using worldwide data. However, Section 3 has merely attempted to enrich the discussion with the concept of the sufficiency rebound, whose existence is a certainty. While *efficiency* rebound is conceptually established and increasingly corrected for (4CMR, 2006; Allan et al., 2006), post-frugality rebound is as yet unacknowledged. Discussions concern motivations for frugality, psychological and social barriers to it, how to sell the idea, and how to garner the same number of consumer satisfaction units in spite of it but now we should examine interdependencies within the affluence (A) factor itself — the necessary rise in the affluence of marginal consumers.

4. Weaknesses in argumentation

Section 3 showed that the strategy cannot be effective to the full extent of the original 'sufficiency savings'. Yet since it remains possible that the strategy is to some degree effective, i.e., that rebound is lower than 100% of sufficiency savings, the next four sections explore weaknesses either in the *arguments for* the strategy, or in estimates of the attainability of the initial, voluntary change in behaviour towards frugality.

4.1. *'North' and 'South'*

Most expositions of the sufficiency strategy conflate the categories of rich and poor with those of North and South or developed vs. developing countries. As Leiss paradigmatically wrote,

> The one-third of the human population in the industrially developed nations currently uses 90% of the available resources; it is the exponential increase of their demands, not those of the human population as a whole, which is the real and immediate cause of the emerging global crisis…. It is the unforgivable squandering of resources in the developed countries…that currently determines the general direction of the global 'political economy' and that constitutes the source of potential future disasters for the entire human population." (1976, 98, 99)

He quotes Paul Ehrlich: "The most serious population growth occurs among the affluent whites of the USA, and their analogues in Western Europe, the Soviet Union, and Japan. These people are the prime looters and polluters of our planet." (139)

'North' is here surrogate for 'rich', and since for ethical reasons the strategy aims only at the rich, the target becomes, as expressed by Sanne, "Northern consumption as overconsumption and unsustainable" or the "Western consumption pattern" (2002, 282, 274). Daly and Goodland similarly write that because rich countries consume more per capita, we must "look at consumption patterns in the North" (1996, 1015). Røpke, incidentally avoiding the mistake of arguing in *per capita* terms, writes that "the growing consumption of the North constitutes an important part of global environmental problems" (1999, 399, 401). The implicit syllogism is that the rich consume more than the poor; the rich are (predominantly) in the North; therefore Northern consumption must be lowered (also UNCED, 1993, Ch. 4; Hinterberger et al., 1996, 85; Homburg and Matthies, 1998, 121; Kasser, 2002, 92).

However, openness between economies means that sufficiency-induced lower prices are known everywhere. Goods, services, fossil fuels, and people cross borders increasingly unhindered. Marginal consumers taking up the slack are wherever there is purchasing power. Higher demand in recent years from 'developing' economies supports this view. Yet the relevant metric for environmental impact is only the total amount of depleted resources or ambient amounts of emissions: Nature does not 'care' which countries pollute, or what per capita pollution is. "Because of the universal nature of world trade, the concept of 'carrying capacity' is difficult to apply to a nation or region." (Bartlett, 1994, 26) We should thus follow Princen in adding "southern elites" and the "rich in developing countries" to the rough concept of 'Northern' (1999, 360), or Myers in writing neutrally of "affluent communities" (1997, 53; Spangenberg and Lorek, 2002, 127).

For the economics of global consumption and pollution the terms 'Western', 'Northern', and even 'developed' are largely gratuitous, as recognized by both Ayres (2000) and Opschoor (2000) in questioning the value of computing national or regional 'ecological footprints', and the simpler taxonomy of relatively rich and relatively poor is preferable. One strategy framed accordingly in worldwide terms is that of "contraction and convergence", whose premise is that the atmosphere is a limited global commons and that "Anything less than a global deal cannot solve climate change" (Simms, 2005, 167, 173); while rich people have a moral "ecological debt" – taking more than their *fair* share – there will always be "…the problem of uncontrollable greenhouse gas emissions from free-riding countries." (173) Poor free-riders can also ruin the deal, and it is not sufficient for the rich to consume less; rather, everybody must be democratically mutually coerced.

While emissions do not carry source labels, politics may require that rich nations reduce first. (Goodland and Daly,

[13] The vertical axis (dependent variable) of such curves must be in absolute rather than per capita units (Opschoor, 1995; De Bruyn and Opschoor, 1997; Luzzati and Orsini, in press).

1996, 1009) But this is not equivalent to the common claim that rich nations must morally "take the lead" towards sufficiency. (UNCED, 1992, Ch. 4) A country that involuntarily lives 'sufficiently' cannot be expected to adopt the role of a follower, just as it is unproven that the poor emulate the rich in 'overconsumption'. The paternalism and the donning of the hair shirt implicit in this concept of 'leadership' do not support the case for sufficiency.

4.2. *Sufficiency is morally good*

Yet not only could voluntary 'Northern' frugality under certain conditions result in a rich, overconsuming 'South'. Even when 'rich' is not equated with 'North', the common claim that the rich are responsible for negative impact is ambiguous, as when Spangenberg and Lorek write that "…there is a consensus that particular responsibility for the level, composition and impact of consumption" rests with this "class" of affluent consumers (2002, 128): 'Responsible' means both 'causally efficacious' and 'morally culpable'. (also Siebenhüner, 2001, 23) In the first, causal or non-normative sense that the rich are consuming the lion's share, the claim is tautological. The concepts of marginal consumers and sufficiency rebound in Section 3 imply furthermore that the affluent are easily replaced by the slightly less affluent, who would then in their turn assume this 'responsibility' *ad infinitum*.

In the *ethical* rather than biophysical sense, on the other hand, the claim that the rich *should* consume less is straightforward and arguable as a moral assertion (also Goodland and Daly, 1996, 1009). Both for traditionally ethical reasons of human equity and on the newer ethical grounds of environmental concern, Smil too writes that "…shaping the future energy use in the affluent world is primarily a moral issue…." (2003, 370), while Greenhalgh sardonically observes that "The fear of environmental damage… has introduced an ethical or moral dimension into the argument [over continued economic growth]. Excessive or wasteful consumption and associated pollution which it causes is sinful; frugality is a virtue" (1990, 293).

The exact bearing of the moral goodness of frugality on the fight to lower impact, however, is not clear. Let us distinguish three ethical goals: 1) *intra*generational equality or justice, especially alleviation of poverty; 2) *inter*generational justice; and 3) the preservation and health of non-human species and the biosphere in general. Let us further distinguish the ethical *motivation* for frugality from its consequences. Judged according to motivation, voluntary frugality is on all three counts 'good'. But unless eschewed consumption is accompanied by an explicit transfer of purchasing power either to present poorer people or in general to future people does the envisioned good consequence of greater *intra-* or *inter*generational equality actually happen. (Pearce, 1987) Without this explicit transfer, the beneficiary of the income effect could be an affluent neighbour who heats his swimming pool more often. As Robinson notes (albeit concerning efficiency rather than sufficiency), it is "…easy to imagine cases where the gains from such approaches are appropriated disproportionately by those who already are well-off…" (2004, 379) When combined with a gift to a poorer person conditions are at least fulfilled for *intra*generational ethical behavior. But a personal shift to frugality guarantees neither less impact, nor more present equality, nor more *inter*generational equality. Moreover, even explicit transfers fall short of sustainable impact to the extent that either higher population results, or the consumption patterns of the poorer recipients are somehow environmentally more detrimental than those of the previous consumers. (Siebenhüner, 2000, 19; Section 3.5). Brown and Cameron similarly make

> …an important conceptual distinction between prosocial values and proenvironmental values: Individuals may be prosocial (altruistic and cooperative) but not proenvironmental (value sustainability of environmental resources). It is possible, however, that a well-developed pro-environmental position must include prosocial values involving: (1) altruistic motivations to sacrifice personal gain by limiting resource consumption in order to promote environmental integrity; and (2) cooperative orientations to use only one's fair share of resources and to act in ways to ensure that others are allowed their fair share. In effect, prosocial values may be necessary, but not sufficient conditions for guaranteeing proenvironmental values.' (2000, 38–39)

One way of acting on proenvironmental values, that of frugal personal behavior, is in any case weakened by the sufficiency rebound.

The other two goals above – more equal distribution towards future humans and less impact on non-human nature – thus require further conditions. The view that "… justice implies sustainability" (Pearce, 1987, 13) is true only if "justice" is meant *inter*generationally. Put otherwise, a perfectly just present distribution of resources is consistent with crassly unsustainable consumption of resources as well as crass disregard for future people. *Intra*temporal equality, at a too-large scale of the economy, can amount to unjust *inter*temporal material standards of living. And again, the sufficiency rebound weakens any connection between avoided consumption on anybody's part and sustainability. Pearce is right, though, that leaving all future generations a quantity and quality of resources necessary for life is more or less the same as respecting biophysical constraints in the present.

Judged both by motivation and consequences, one type of ethically good transfer from rich to poor is the purchase of emissions certificates held by poorer countries in 'Kyoto' schemes. But since the latter can and do buy fossil fuels with the proceeds,[14] such transfers in the name of equity do not *ipso facto* reduce impact. Thus it is true that "Wasteful consumption in rich countries must be reduced to allow for needed growth in poor countries…", but it does not follow that "more equitable and efficient patterns of energy use… close the gap between rich and poor and reduce environmental damage compared with that which will result if current trends continue". (Ehrlich, 2000, 322) *Intra*generational equity and the

[14] Because the emissions of most poor countries are not capped, the Delhi version of the Kyoto agreement undoubtedly results in higher consumption in the remaining nations, a step for equality but not one for lowering impact.

level of impact are two separate things. Perhaps for such reasons Princen writes, "If the problem is one of inequity, no analytic advantage is gained by calling it consumption. Adding the environment and calling the problem consumption only muddles the longstanding debates of North and South, haves and have-nots, rich and poor, powerful and powerless, to include environmental inequities." (1999, 352) Or as Pearce says, "…the design of an economy such that it maximizes some measure of social (human) welfare but subject to biophysical constraints will assist in, but will not be sufficient for, attainment of the notion of extended justice." (1987, 10) In other words, a sustainable human economy could be presently unjust as well as indifferent to non-human nature.

For Goodland and Daly poverty reduction "will require considerable economic growth, as well as development, in developing countries. But global environmental constraints are real, and more growth for the South must be balanced by negative throughput growth [sic.] for the North if environmental sustainability is to be achieved." (1996, 1004). But since this "balancing" could leave impact unaffected, this conflates ethical goals with sustainability. Lower *A* and *T* among the rich is necessary but not sufficient for lower-impact-cum-justice, and even "large-scale transfers to the poorer countries" (1004) do not suffice because, again, "sustainability" and "intragenerational equity" (1005) are not the same. The sufficiency strategy does not suffice to solve conflicts between the humanist goal of present-day material equality and that of sustainable (eternally reproducible) impact.

4.3. *Two birds with one stone*

Many arguments for living lightly, downshifting and shrinking one's environmental footprint appeal not to ethics or environmentalism but to one's own good. Riding a bicycle is not only environmentally friendly but healthy; working and spending less, eating less, and in general possessing less leaves us with more free time, less noise, less stress, less body weight and less local pollution. In the early 1960s I eavesdropped on the discussions of business executives 'dropping out' of the 'rat-race'; in the late 1960s 'everybody' acquired this wisdom, captured by Etzioni's diagnostic term for the costs of a high-consumption lifestyle – "affluenza" (1998, 626). Insights from this line of thought, appealing to one's selfish interests, are mobilized in socially marketing the sufficiency strategy; two birds can be brought down with one stone.

The knowledge that material wealth doesn't buy happiness is as old as the hills (De Botton, 2000, 56–72, 97–99; Easterlin, 1973; Hirsch, 1976; Argyle, 1987; Diener et al., 1993; Kasser, 2002; but see Veenhoven, 1991) From Thoreau on, environmentally concerned writers have regarded this argument as an ally in pursuing environmental goals — recently Boulding (1949–50, 1966), Linder (1970), Scitovsky (1976), Schor (1992), Durning (1992), Goodland and Daly (1996), Orr (1999), Princen et al. (2002), Sanne (2002) and Jackson (2005). In bolstering an argument for rationing, one author argues:

> Research shows that people's happiness rises along with conventional wealth only up to the point that our needs for basics like adequate warmth, food, clothing, and shelter are met. After that our well-being depends on other things like friendships, opportunities for creativity and the quality of our family relationships. This means that with better awareness of what really gives us a sense of well-being, by ignoring the adverts, we could actually consume less and be happier. (Simms, 2005, 187)

Simms backs his case up with evidence from World War II Britain, where both legal and voluntary frugality left people fitter (155–164).

While pointing out the personal, selfish advantages of riding one's bike, or the aesthetic beauty of natural landscape, or the disadvantages of breathing dirty street air are useful parts of the story, there are some difficulties with this argument. First, the jury is still out concerning this hypothesis that, above a certain level, greater affluence does not mean greater happiness: Much 'luxury' consumption fulfills deep psychological desires, e.g. for prestige, thus contributing to 'happiness'. Second, even if the thesis is somehow true, evolutionary forces may interfere with our doing what we rationally see as our own good; the everyday examples of overeating and unrequited love suffice for illustration. Evolutionary forces seeking 'status' or 'display' or 'conspicuous' consumption may indeed be virtually ineradicable; and the bad consequence for the environmental sufficiency strategy is that since the purported benefits of such prestige consumption are *relative to* others' consumption, the sky is the limit (see Veblen, 1899; Ornstein and Ehrlich, 1989; Konrad, 1990; Low and Heinen, 1993; Morrison, 1999; Frank, 1999; Jackson, 2002; Alcott, 2004).

Third, the argument maintains that the great majority of human beings has for centuries or millenia acted to its own detriment — a strong claim based on no discernable theory that challenges evolutionary theory at its roots. On this view materialistic, 'overconsuming' behaviour is not selfish after all, but rather anti-selfish and pathological also. Again, from the vantage of human ethology, this claim that we systematically act in certain ways even though costs outweigh benefits bears the burden of proof. Alternatively, one must claim for instance that those with economic and political power force us, in *their* own interest and perhaps subtly through advertising, etc., to 'overconsume' (Galbraith, 1958a; Packard, 1959; 1960). Some authors recognise that they owe us an explanation of why, judged on these apparently simple, selfish criteria, we choose to live so stupidly (Schor, 1999a,b, 138; Frank, 1999, 7; Cross, 1993, 2000). Others offer selfish reasons for frugality apparently without this awareness (Mirrlees, 1991, 64; Ekins, 1991, 253, Princen, 1999, 357; Kasser, 2002). At the least, sufficiency strategists who enlist this argument for environmental ends must 1) offer a more careful rendering of the hoary concept of human welfare than hitherto, and 2) *explain* 'overconsumption'.

4.4. *The political vs. the personal*

The sufficiency strategy is most often conceived as a sum of individual behavioural changes. The view of Meadows et al. is representative: People who "care about other people" thereby contribute to staying within the limits; they advocate "fifty simple things you can do to save the planet" such as to "buy an energy-efficient car [and] recycle your bottles and cans"

perhaps at the cost of some speed, time and effort (1992, 218–19; Durning, 1992; Orr, 1999; Green Media, 2007; Union of Concerned Scientists, 2007). To the extent that the personal is local, the slogan 'Think globally, act locally' captures this philosophy. British politician Gordon Brown similarly asserts the necessity that

> …decisions made by national governments must be matched by individual actions. We all have a responsibility to do what we can to tackle environmental degradation. So I believe what we do as a community nationally and internationally must be matched by a new sense of personal responsibility.' (2006, 2)

This regards the personal and the political as equally valuable, but I hope to have shown that personal behavioural change is at most a necessary condition for sustainability and that it is thus questionable whether it adds significantly much to "decisions made by national governments."

The position of this paper, that personal responsibility resulting in changed consumption behaviour is not an *alternative* to collective measures, is seemingly shared by Sanne (2002). He clearly distinguishes between the consumer and the citizen and advocates collective, non-personal measures like "halting (or reducing) production volumes — as radical greens propose…" (285), just as we as *citizens* already force ourselves to pay taxes, go to school, and obey traffic lights and public smoking bans (275, 281 [but see 273]; Sagoff, 1988). Indeed, the income tax is a good example of such mutually agreed-upon mutual coercion: No one argues that we should *want* to pay them, but we politically agree to — i.e., provided everybody else must. Worldwide reduction of affluence, to be achieved by world citizens, thus requires a philosophy of 'Think globally, act globally.' Only prescribed caps leaving no room for free-riders or marginal consumers to take up slack are not subject to an affluence rebound (also Ornstein and Ehrlich, 1989; De Young, 1993; Stern et al., 1995; Milbraith, 1995; Gardner and Stern, 1996; Siebenhüner, 2000). In spite of these reservations, however, there is truth in the sufficiency strategy's insight that one can say of any person who newly lives lightly, 'One down, 6,499,999,999 to go.'

5. Discussion

Three further questions to be briefly discussed are: 1) What amount of depletion-and emission-reduction is possible and/or expected by those who urge greater frugality? 2) What can be said more generally about the advisability of strategies aiming *indirectly* at impact by altering population, affluence, and technological factors as opposed to strategies, like the Kyoto Protocol, that aim *directly* at impact? 3) Finally, how are consumption taxes to be classified?

5.1. *Quantification*

Sections 3.4 and 3.5 raised questions on measuring rebound; different ones arise concerning measurement of the theoretical sufficiency savings itself, of which rebound is a percentage. As established earlier, these are limited by the ethical criterion that only the rich shall cut consumption. But definitions of 'rich' and 'sufficient' are needed in order to quantify both the number of people targeted by the strategy as well as how much per person counts as 'over'-consumption. Indeed, without some criterion based on the traditional distinction between needs as opposed to mere wants, no consumption is less necessary or justified than any other, and the sufficiency appeal simply targets those who may feel altruistic. That is, the whole concept of sufficiency would lose meaning. To better define and measure this building block of the strategy design, a rich literature is available: In addition to the classical economists and the 19th-century socialist tradition of Owen and Ruskin, as well as Maslow (1943), Baudrillard (1970), and Kasser (2002), writers who have pursued this in the economics tradition are Hobson (1929), Max-Neef (1995), or Jackson and Marks (1999). For overviews see McAdams (1992) and Brekke et al. (2003, 30, 38).

Common ostensive definitions of dispensable or at least negotiable consumption include that of meat, cosmetics, air travel, large houses, and SUVs, and it is not difficult to calculate amounts of joule inputs, or emissions, per unit of these physical outputs. Alternatively, computations could be monetary, in terms of purchasing-power-parity; perhaps corrected by a material-intensity co-efficient. As is required of any global environmental strategy, this calculated amount of maximum possible sufficiency savings would then have to be measured against a level of impact deemed to be the maximum consistent with sustainability — e.g., perhaps 450 ppm for CO_2 (Wackernagel and Rees, 1997; Hinterberger et al., 1996, 84–88). It is beyond the limits of both my knowledge and this paper to cite any rigorous research quantifying sufficiency savings (before price changes and rebound). But at the least it seems mistaken to talk merely of curbing the demand of "humanity" (Wackernagel and Silverstein, 2000, 394).

Quantifications of sustainable consumption, yielding some maximum per capita affluence at a given population, could however challenge our humanistic belief that large numbers of people can live not only healthily but comfortably. Only such an honest comparison of quantified *sufficient* consumption with quantified *sustainable* consumption can help us to judge whether hopes for this win–win situation between ecology and economy are justified. Gordon Brown for instance claims:

> We can and should demonstrate that economic growth, social justice and environmental care can and must advance together. For years no international concensus has been possible that recognises how our global duty of stewardship to the environment can be discharged while delivering economic and social progress. (2006)

However, political acceptability aside, all environmental strategies must face the empirical possibility and emotional dilemma that some combination of population and affluence would have to be lowered to *intra*generationally unacceptable levels if justice toward future humans and other species is to be achieved.

5.2. *Right-side vs. left-side strategies*

The $I=PAT$ identity, implying as it does that changes in affluence or technology *directly* change impact, holds only aggregately —

as a static description of the environmental state of the world. However, any change in population, affluence, or technology changes the other two factors: Agricultural technology allows a larger population, higher affluence can lower (or raise) the birth rate, high consumption ($P \times A$) makes us use more efficient technologies, etc. Bartlett for instance writes,

> Reductions in the rates of consumption of resources and reductions in the rates of production or pollution can shift the carrying capacity in the direction of sustaining a larger population…. When resources are used more efficiently, the consequence often is that the 'saved' resources are not put aside for the use of future generations, but instead are used immediately to encourage and support larger populations.' (1994, 21, 23; Jevons, 1865, 9, 196, 200, 457, Ch. X; Cipolla, 1962, 49–53, 94–95, 105; Giampietro, 1994; Daly, 1996, 220; Smil, 2003, 55)

Due to these interdependencies we must therefore abandon $I=PAT$ and write $I=f(P,A,T)$. Moreover, Section 3.3 showed shifts of demand among consumer groups *within* the affluence term A. That is, the sufficiency rebound is described by $A_1=f(A_2)$: A value-induced reduction in the affluence of person 1 enables the affluence of person 2 to rise, and the 'sufficiency savings' does not necessarily ever 'get over to' the left side of the equation to lower impact.

'Direct' or 'left-side' strategies do exist, exemplified by the UNFCCC attempt to set *global* greenhouse-gas emissions caps within which country caps are politically allocated, leaving each political unit to decide on the most desirable and/or economically efficient mixture of population, affluence, and technological measures. Once the exo-market country caps have drawn the 'Plimsoll line' of each economy, then adjustments in the right-side factors follow with little further detailed regulation, perhaps through tradable rations. (Fawcett, 2004, 1077–1078; Ophuls, 1977; Pearce, 1987, 17; Daly, 1991, 42; Røpke, 1999, 401)

On the other hand, in the absence of overall caps on the system right-side strategies must depend on and integrate flanking or complementary strategies regarding the other right-side factors. Perhaps it is possible to compute a super-strategy of simultaneous and co-ordinated changes between and within all three factors, effectively lowering *I*. But as with all environmental strategies, the costs of design, administration, transaction and implementation must be scrutinized in order to measure *cost*-effectiveness.[15] The intuition here is that direct measures – by definition effective – are likely to show the better *cost*-effectiveness ratio than indirect ones, in line with Daly's suggestion that "…throughput [be] controlled at its input (depletion) rather than at the pollution end because physical control is easier at the point of lower entropy" (1974, 20).[16]

[15] The project of balancing life-cycle efficiency, renewable energy, green taxes, sufficiency, and population control has been criticized as tinkering and social engineering (Sachs, 1988; Rudin, 2000). But it does provide us with lessons of how to maximize welfare once limits are politically set.

[16] Analogously, within smaller political units, it is infrastructure limitation which most cost-effectively lowers impact: Road traffic can be controlled by laws limiting parking spaces and air traffic by airport runway capacity.

5.3. *Taxes*

Taxes, for instance on fossil fuels, in effect force us to increase technological and consumption efficiency as well as lower our personal sufficiency standards. In common with other right-side measures, however, these resource or depletion taxes only *contingently* lower impact. Again, when we react by making production more efficient or consumption more sufficient, prices (including the tax) fall and some of the effect is "taken back" (Pearce, 1987, 14). Eco-taxes would accordingly have to be periodically raised. Moreover, when the government refunds the revenue or spends it itself, a *tax rebound* results because demand is thereby generated for, among other things, the taxed fossil fuels. Hannon, therefore, while discussing the possible energy savings of large "consumption shifts", writes that "…the amount of net energy savings might be small because of the respending effect…. In any event, there is a limit to the savings that can be realized by such lifestyle changes which preserve the national income" (1975, 100). The concept of the sufficiency rebound shows that such limits to savings also exist when the changes do *not* preserve the national income.

Wackernagel and Rees accordingly maintain that the environment can "afford cost-saving energy efficiency…only if efficiency gains are taxed away or otherwise removed from further economic circulation" (1997, 20; Greene, 1992, 118; Binswanger, 2001, 131). The purchasing power newly in the hands of government, or restored to citizens through refunds or lowering other taxes, would somehow have to be destroyed or perhaps invested in renewable resources.[17] For these reasons Hannon prefers left-side measures: "Another method that would conserve energy, and that is more fundamental than taxation, would be energy rationing through the use of coupons" (1975, 101). This subsection merely suggests that such tax rebound problems be formally integrated not only into the 'double-dividend' debate but into environmental policy generally — to date seldom the case (e.g. Goodstein, 2003; Parry and Williams, 2004; Sterner and Isaksson, 2006).

6. Conclusions

The environmental sufficiency strategy of greater consumer frugality has become popular in ecological economics, its attractiveness increasing along with awareness that not much can be done to stem population growth and that energy-efficiency measures are either not enough or, due to backfire, part of the problem. Concerning the strategy's feasibility, effectiveness, and common rationale, several conclusions can be drawn.

- The consequences of the strategy's frugality demand shift – price reduction and the ensuing consumption rebound – are not yet part of mainstream discussion.
- Contrary to what is implied by the strategy's advocates, the frugality shift cannot achieve a one-to-one reduction in

[17] One reviewer made the neglected point that higher fossil fuel prices increase the pressure on biomass, e.g. forests.

world aggregate consumption or impact: Poorer marginal consumers increase their consumption.
- The size of the sufficiency rebound is an open question.
- The concepts of 'North' and 'South' are not relevant to the consumption discussion.
- Even if the voluntary material consumption cuts by the rich would effect some lowering of total world consumption, changing human behaviour through argument and exhortation is exceedingly difficult.
- While our moral concern for present others is stronger than that for future others, this *intra*generational equity is in no way incompatible with non-sustainable impact.
- Since savings effected by any one country or individual can be (more than) compensated by other countries and individuals, the relevant scale of any strategy is the world.
- No single strategy to change any given right-side factor in $I=f(P,A,T)$ guarantees any effect on *impact* whatsoever.
- Right-side strategies in combination are conceptually complicated and perhaps more costly than explicitly political left-side strategies directly lowering impact.
- Research emphasis should be shifted towards measures to directly lower impact both in terms of depletion and emissions.

Lower consumption may have advantages on the individual, community, or regional level. There is for instance some truth in the view of Diogenes that happiness and quantity of consumption do not necessarily rise proportionally. Living lightly can offer not only less stress and more free time but also the personal boon of a better sense of integrity, fulfilling the Kantian criterion that one's acts should be possible universally (worldwide). Locally it could mean cleaner air, less acid rain, less noise, less garbage, and more free space. And in the form of explicit, guaranteed shifts of purchasing power to poorer people it would enable others to eat better or to buy goods such as petrol and cars.

However, given global markets and marginal consumers, one person's doing without *enables* another to 'do with': In the near run the former consumption of a newly sufficient person can get fully replaced. And given the extent of poverty and the temptations of luxury and prestige consumption, this near run is likely to be longer than the time horizon required for a relevant strategy to stem climate change and the loss of vital species and natural resources.

Efficiency and sufficiency strategies both offer relatively painless solutions to non-sustainability.[18] The former is praised by 'negawatt' advocates not only as a free lunch, but one you are paid to eat. The latter appears to many of its addressees tolerable — switching off a few lights, riding a bike, or eating less meat, and here, too, a lunch you are paid to eat comes in the form of various health and happiness benefits. Supply-side or other impact-side strategies, on the other hand, are hard. They confront us with the neglected question of the carrying capacity of the planet. But strictly following sustainability logic by capping extraction and/or emissions – 'cost' what it may – collides with our hopes and humanism. Efficiency deals with the 'how', the material and social technology, of our wealth-making; sufficiency speaks to us at the border between our needs and our (mere) wants, and to our inborn desire for justice. Neither addresses the taboo of population size. Both strategies distract us from the insight that nature limits us.

[18] The business community welcomes efficiency (but not sufficiency) research.

Acknowledgments

I thank Barbara Brändli, Len Brookes, Bas Girod, Tim Jackson, John Lintott, Cecilia Roa, Steve Stretton and the anonymous reviewers.

REFERENCES

Alcott, Blake, 2004. John Rae and Thorstein Veblen. Journal of Economic Issues 38 (3), 765–786.
Alcott, Blake, 2005. Jevons' paradox. Ecological Economics 54 (1), 9–21.
Allan, Grant, Nick, Hanley, Peter, G., McGregor, J., Kim, Swayles, Karen, Turner, 2006. The macroeconomic rebound effect and the UK economy. Final Report to Defra. www.defra.gov.uk/environment/energy/research.
Argyle, Michael, 1987. The Psychology of Happiness. Routledge, London.
Ayres, Robert U., 2000. Commentary on the utility of the ecological footprint concept. Ecological Economics 32, 347–349.
Bartlett, Albert A., 1994. Reflections on sustainability, population growth, and the environment. Population and Environment 16 (1), 5–35.
Baudrillard, Jean, 1970 (1988). La Société de Consommation (The Consumption Society: Myths and Structures). Gallimard, Paris (Sage, London).
Berkout, Peter H.G., Muskens, Jos.C., Velthuijsen, Jan W., 2000. Defining the rebound effect. Energy Policy 28 (6/7), 425–432.
Binswanger, Mathias, 2001. Technological progress and sustainable development: what about the rebound effect? Ecological Economics 36 (1), 119–132.
Birol, Fatih, Keppler, Jan Horst, 2000. Prices, technological development and the rebound effect. Energy Policy 28 (6/7), 457–469.
Bogun, Roland, 1977. Lebensstilforschung und Umweltschutz. In: Karl-Werner, Brand (Ed.), Nachhaltige Entwicklung. Vs Verlag für Sozialwissenschaften. Wiesbaden.
Boulding, Kenneth, 1949–50. Income or welfare. The Review of Economic Studies, vol. XVII, pp. 77–86.
Boulding, Kenneth, 1966/1973. The economics of the coming spaceship earth. In: Daly, Herman E. (Ed.), Toward a Steady-State Economy. W.H. Freeman, San Francisco.
Boulding, Kenneth, 1992. Towards a New Economics. Elgar, Aldershot, U.K.
Brekke, Kjell Arne, Howarth, Richard B., Nyborg, Karine, 2003. Status-seeking and material affluence: evaluating the Hirsch hypothesis. Ecological Economics 45, 29–39.
Brookes, Leonard, 1978. Energy policy, the energy price fallacy and the role of nuclear energy in the UK. Energy Policy 6 (1), 94–106.
Brookes, Leonard, 1990. The greenhouse effect: the fallacies in the energy efficiency solution. Energy Policy 18 (2), 199–201.
Brookes, Leonard, 2000. Energy efficiency fallacies revisited. Energy Policy 28 (6/7), 355–366.
Brown, Gordon, 2006. The Independent Nr 6,087. London. 20 April.
Brown, Lester et al., 1998. State of the World. Worldwatch/Earthscan, London.
Brown, Paul M., Cameron, Linda D., 2000. What can be done to reduce overconsumption? Ecological Economics 32, 27–41.
Carley, Michael, Spapens, Philippe, 1998. Sharing the World: Sustainable Living and Global Equity in the 21st Century. Earthscan, London.

Cipolla, Carlo M., 1962/1966. The Economic History of World Population. Penguin, Harmondsworth, U.K.
Clapp, Brian William, 1994. An Environmental History of Britain Since the Industrial Revolution. Longman, London.
Cleveland, Cutler J., Costanza, Robert, Hall, Charles A.S., Kaufmann, Robert, 1984. Energy and the U.S. economy: a biophysical perspective. Science 225, 890–897.
Cleveland, Cutler, Kaufmann, Robert, 2003. Oil supply and oil politics: déjà vu all over again. Energy Policy 31 (6), 485–489.
Cleveland, Cutler, Ruth, Matthias, 1998. Indicators of dematerialization and the materials intensity of use. Journal of Industrial Ecology 2 (3), 15–50.
Cook, Stuart W., Berrenberg, Joy L., 1981. Approaches to encouraging conservation behavior: a review and conceptual framework. Journal of Social Issues 37 (2), 73–107.
Cross, Gary, 1993. The Making of Consumer Culture. Routledge, London.
Cross, Gary, 2000. An All-Consuming Century. Columbia U. Press, New York.
Dahlström, Kristina, Ekins, Paul, 2006. Combining economic and environmental dimensions: value chain analysis of UK iron and steel flows, vol. 58 (3), pp. 507–519.
Dahmus, Jeffrey B., Gutowski, Timothy G., 2005. Efficiency and production: historical trends for seven industrial sectors. Working Paper U.S. Society for Ecological Economics Conference, July 2005, Tacoma, Washington. jdahmus@mit.edu and gutowski@mit.edu.
Daily, Gretchen, Ehrlich, Paul, 1996. Socioeconomic equity, sustainability, and earth's carrying capacity. Ecological Applications 6 (4), 991–1001.
Daly, Herman E., 1973. The steady-state economy: toward a political economy of biophysical equilibrium and moral growth. In: Daly, Herman E. (Ed.), Toward a Steady-State Economy. W.H. Freeman, San Francisco.
Daly, Herman E., 1974. The economics of the steady state. American Economic Review 64 (2), 15–21.
Daly, Herman E., 1991. Elements of environmental macroeconomics. In: Costanza, Robert (Ed.), Ecological Economics: The Science and Management of Sustainability. Columbia U. Press, New York.
Daly, Herman E., 1996. Beyond Growth. Beacon, Boston.
De Botton, Alain, 2000. The Consolations of Philosophy. Penguin, Harmondsworth, U.K.
De Bruyn, Sander, Opschoor, John B., 1997. Developments in the 1throughput–income relationship: theoretical and empirical observations. Ecological Economics 20 (3), 255–268.
De Young, R., 1993. Changing behavior and making it stick: the conceptualization and management of conservation behavior. Environmental Behavior 25, 851–864.
Diener, Ed., Sandvik, Ed., Seidlitz, Larry, Diener, Marissa, 1993. The relationship between income and subjective well-being: relative or absolute? Social Indicators Research 28, 195–223.
Domar, Evsey, 1962. On total productivity and all that. Journal of Political Economy 70, 597–608 (Dec.).
Douglas, Mary, Isherwood, Baron, 1979/96. The World of Goods: Toward an Anthropology of Consumption. Routledge, London.
Duchin, Faye (Ed.), 1998. Structural Economics: Measuring Change in Technology, Lifestyles, and the Environment. Island, Washington, D.C.
Durham, D.F., 1992. Cultural carrying capacity: *I=PACT*. Focus 2 (3), 5–8.
Durning, Alan Thein, 1992. How Much Is Enough? Earthscan, London.
Easterlin, Richard A., 1973. Does money buy happiness? The Public Interest, vol. 30, pp. 1–10. Winter.
Ehrlich, Paul, 2000. Human Natures: Genes, Cultures, and the Human Prospect. Island, Washington.
Ekins, Paul, 1991. The sustainable consumer society: a contradiction in terms? International Environmental Affairs 3, 243–257.
Ekins, Paul, 2004. Step changes for decarbonising the energy system: research needs for renewables, energy efficiency and nuclear power. Energy Policy 32 (17), 1891–1904.
Etzioni, Amitai, 1998. Voluntary simplicity: characterization, select psychological implications, and societal consequences. Journal of Economic Psychology 19, 619–643.
Fawcett, Tina, 2004. Carbon rationing and personal energy use. Energy and the Environment 15 (6), 1067–1083.
Fine, Ben, Leopold, Ellen, 1993. The World of Consumption. Routledge, London.
Frank, Robert H., 1985. Choosing the Right Pond: Human Behavior and the Quest for Status. Oxford U. Press, New York.
Frank, Robert H., 1999. Luxury Fever: Why Money Fails to Satisfy in and Era of Excess. Free Press, New York.
Galbraith, John Kenneth, 1958a. The Affluent Society. Houghton Mifflin, New York.
Galbraith, John Kenneth, 1958b. How much should a country consume? In: Henry, Jarrett (Ed.), Perspectives on Conservation. Resources for the Future/Johns Hopkins, Baltimore, USA.
Gardner, Gerald T., Stern, Paul C., 1996. Environmental Problems and Human Behavior. Allyn and Bacon, Boston.
Giampietro, Mario, 1994. Sustainability and technological development in agriculture. Bio-Sciences 44 (19), 677–689.
Giampietro, Mario, Mayumi, Kozo, 1998. Another view of development, ecological degradation, and North–South trade. Review of Social Economy 56 (1), 20–36.
Giampietro, Mario, Mayumi, Kozo, 2000. Multiple-scale integrated assessments of social metabolism: integrating biophysical and economic representations across scales. Population and Environment 22 (2), 155–210.
Goodland, Robert, Daly, Herman E., Serafy, Salah El (Eds.), 1992. Population, Technology, and Lifestyle: The Transition to Sustainability. Island, Washington, D.C.
Goodland, Robert, Daly, Herman E., 1992. Ten reasons why Northern income growth is not the solution to Southern poverty. In: Goodland, Robert, Daly, Herman E., Serafy, Salah El (Eds.), Population, Technology, and Lifestyle: The Transition to Sustainability. Island, Washington, D.C.
Goodland, Robert, Daly, Herman E., 1996. Environmental sustainability: universal and non-negotiable. Ecological Applications 6 (4), 1002–1017.
Goodstein, Eban, 2003. The death of the Pigovian tax? Policy implications from the double-dividend debate. Land Economics 79 (3), 402–414.
Green Media, 2007. www.greenconsumerguide.com.
Greenberg, Dolores, 1990. Energy, power, and perceptions of social change. American Historical Review 95 (3), 693–714.
Greene, David L., Kahn, James, Gibson, Robert C., 1999. Fuel economy rebound effect for U.S. household vehicles. Energy Journal 20 (3), 1–32.
Greenhalgh, Geoffrey, 1990. Energy conservation policies. Energy Policy 18 (4), 293–299.
Greening, Lorna A., Greene, David L., Difiglio, Carmen, 2000. Energy efficiency and consumption – the rebound effect – a survey. Energy Policy 28 (6/7), 389–401.
Grubb, Michael, 1990. Energy Policies and the Greenhouse Effect, vol. 1. Dartmouth Publishing Co., Aldershot U.K.
Hanley, Nick P.G., McGregor, J.K. Swales, Turner, K.R., 2006. The impact of a stimulus to energy efficiency on the economy and the environment: a regional computable general equilibrium analysis. Renewable Energy 31, 161–171.
Hannon, Bruce, 1975. Energy conservation and the consumer. Science 189.
Harris, Deverle P., 1984. Mineral Resources Appraisal: Mineral Endowment, Resources, and Potential Supply: Concepts, Methods, and Cases. Clarendon Press, Oxford.
Herring, Horace., 2006. Energy efficiency — a critical view. Energy 31, 10–20.

Hinchliffe, S., 1995. Missing culture: energy efficiency and lost causes. Energy Policy 23 (1), 93–95.
Hinterberger, Friedrich, Luks, Fred, Stewen, Marcus, 1996. Ökologische Wirtschaftspolitik: Zwischen Ökodiktatur und Umweltkatastrophe. Birkhäuser Verlag, Berlin, Basel, Boston.
Hirsch, Fred, 1976. Social Limits to Growth. Harvard U. Press, Cambridge, Mass.
Hobson, John Atkinson., 1929. Wealth and Life: A Study in Values. Macmillan, London.
Homburg, Andreas, Matthies, Ellen, 1998. Umweltpsychologie: Umweltkrise, Gesellschaft und Individuum. Juventa, Weinheim.
Horn, Manfred, 2004. OPEC's optimal crude oil price. Energy Policy 32 (2), 269–280.
Hotelling, Harold, 1931. The economics of exhaustible resources. Journal of Political Economy 39 (2), 137–175.
Howarth, Richard B., 1997. Energy efficiency and economic growth. Contemporary Economic Policy XV (4), 1–9.
Inhaber, Herbert, 1997. Why Conservation Fails. Quorum, Westport, Connecticut, USA.
Jackson, Tim, 2002. Evolutionary psychology in ecological economics: consilience, consumption, and contentment. Ecological Economics 41, 289–303.
Jackson, Tim, 2005. Live better by consuming less? Is there a 'double dividend' in sustainable consumption? Journal of Industrial Ecology 9 (1–2), 19–36.
Jackson, Tim, Marks, N., 1999. Consumption, sustainable welfare and human needs — with reference to UK expenditure patterns 1954–94. Ecological Economics 28, 421–42.
Jevons, William Stanley, 1865/1965. The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-mines. 3rd edition 1905, Ed. A.W. Flux. Augustus M. Kelley, New York.
Johnson, Warren, 1985. The Future Is Not What It Used to Be. Dodd, Mead, New York.
Kasser, Tim, 2002. The High Price of Materialism. Bradford/MIT, Cambridge, Mass.
Katzner, Donald W., 1987. Supply functions. In: Eatwell, John, Milgate, Murray, Newman, Peter (Eds.), The New Palgrave: A Dictionary of Economics. Macmillan, London.
Kaufmann, Robert, 1992. A biophysical analysis of the energy/real GDP ratio: implications for substitution and technical change. Ecological Economics 6, 35–56.
Kaufmann, Robert, Cleveland, Cutler, 2001. Oil production in the lower 48 states: economic, geological, and institutional determinants. Energy Journal 22, 27–49.
Khazzoom, J. Daniel, 1980. Economic implications of mandated efficiency in standards for household appliances. Energy Journal 1 (4), 21–40.
Konrad, Kai, 1990. Statuspräferenzen: Soziobiologische Ursachen, Statuswettrüsten und seine Besteuerung. Kyklos 43, 249.
Krautkraemer, Jeffrey A., 1998. Nonrenewable resource scarcity. Journal of Economic Literature 36 (4), 065–2107.
Larsen, Bodil Merethe, Nesbakken, Runa, 1997. Norwegian emissions of CO_2 1987–1994: a study of some effects of the CO_2 tax. Environmental & Resource Economics 9, 275–290.
Leiss, William, 1976. The Limits to Satisfaction: An Essay on the Problems of Needs and Commodities. U. of Toronto Press, Toronto.
Linder, Stefan B., 1970. The Harried Consumer. Columbia U. Press, New York.
Lintott, John, 1998. Beyond the economics of more: the place of consumption in ecological economics. Ecological Economics 25, 239–248.
Lovins, Amory B., 1988. Energy saving from more efficient appliances: another view. Energy Journal 9 (2), 155–162.
Low, Bobbi S., Heinen, Joel T., 1993. Population, resources, and environment: implications of human behavioral ecology for conservation. Population and Environment 15 (1), 7–42.
Luks, Fred, 2000. Postmoderne Umweltpolitik? Sustainable Development, Steady-State und die Entmachtung der Ökonomik. Metropolis Verlag, Marburg.
Luks, Fred, 2005. Innovation und Nachhaltigkeit. Jahrbuch Ökologische Ökonomie Band 4. Metropolis Verlag, Marburg.
Luzzati, Tomasso, and Marco Orsini, forthcoming.
McAdams, Richard H., 1992. Relative preferences. The Yale Law Journal 102 (1), 1–104.
McCracken, Grant, 1988. Culture and Consumption. U. of Indiana Press, Bloomington.
Mackenzie, J.S., 1892. The relation of ethics to economics. Report to the British Association for the Advancement of Science, Paper read on Saturday, August 6, pp. 837–838.
Malthus, Robert Thomas, [1820]/1836. Principles of Political Economy, 2nd Ed. Eds. Wrigley and Souden 1986, Pickering, London.
Maslow, Abraham, 1943. A theory of human motivation. Psychological Review 50, 370–396.
Mason, Roger S., 1981. Conspicuous Consumption: A Study of Exceptional Consumer Behavior. St. Martin's, New York.
Max-Neef, Manfred, 1995. Economic growth and quality of life — a threshold hypothesis. Ecological Economics 15, 115–118.
Meadows, Donella H., Meadows, Dennis L., Randers, Jørgen, Behrens III, William W., 1972. The Limits to Growth. Earth Island, London.
Meadows, Donella H., Meadows, Dennis L., Randers, Jørgen, 1992. Beyond the Limits. Earthscan, London.
Milbraith, L.W., 1995. Psychological, cultural, and informational barriers to sustainability. Journal of Social Issues 51, 101–120.
Mill, John Stuart, 1848/1965. Principles of Political Economy. Ed. J.M. Robson, U. of Toronto Press and Routledge, Kegan Paul, London.
Mirrlees, James A., 1991. The economic uses of Utilitarianism. In: Sen, Amartya, Williams, B. (Eds.), Utilitarianism and Beyond. Cambridge U. Press, Cambridge.
Moezzi, Mithra, 2000. Decoupling energy efficiency from energy conservation. Energy and the Environment 11 (5), 521–537.
Morrison, Reg, 1999. The Spirit in the Gene. Cornell U. Press, Ithica, N.Y.
Myers, Norman, 1997. Consumption: challenge to sustainable development? Science 276, 53–57.
Noreng, Øystein, 2002. Crude Power: Politics and the Oil Market. I.B. Tauris, London.
Nørgard, Jørgen S., 2006. Consumer efficiency in conflict with economic growth. Ecological Economics 57 (1), 15–29.
Ophuls, William, 1977. Ecology and the Politics of Scarcity: Prologue to a Political Theory of the Steady State. W.H. Freeman, San Francisco.
Opschoor, Hans, 1995. Ecospace and the fall and rise of throughput intensity. Ecological Economics 15 (2), 137–140.
Opschoor, Hans, 2000. The ecological footprint: measuring rod or metaphor? Ecological Economics 32, 363–365.
Ornstein, Robert, Ehrlich, Paul, 1989. New World New Mind. Doubleday, New York.
Orr, David W., 1999. The ecology of giving and consuming. In: Rosenblatt, Roger (Ed.), Consuming Desires: Consumption, Culture, and the Pursuit of Happiness. Island, Washington.
Packard, Vance, 1959/60. The Status Seekers. Longmans, London.
Packard, Vance, 1960. The Waste Makers. David McKay, New York.
Parry, Ian, Williams, Roberton, 2004. The death of the Pigovian tax: Comment. Land Economics 80 (4), 575–581.
Pearce, David, 1987. Foundations of an ecological economics. Ecological Modelling 38, 9–18.
Prettenthaler, Franz E., Steininger, Karl W., 1999. From ownership to service use lifestyle: the potential of car sharing. Ecological Economics 28, 443–453.
Princen, Thomas, 1999. Consumption and environment: some conceptual issues. Ecological Economics 31, 347–363.

Princen, Thomas, Maniates, Michael, Conca, Ken, 2002. Confronting Consumption. MIT Press, Cambridge, Mass.
Rae, John, 1834. Statement of Some New Principles on the Subject of Political Economy, Exposing the Fallacies of the System of Free Trade, and of Some Other Doctrines Maintained in the "Wealth of Nations". Hilliard, Gray, and Co., Boston. Reprint (facsimile) 1964, Augustus M. Kelley, New York.
Ramstad, Yngve, 1998. Veblen's propensity for emulation: is it passé? In: Brown, Doug (Ed.), Thorstein Veblen in the Twenty-First Century: A Commemoration of *The Theory of the Leisure Class* (1899–1999). Edward Elgar, Cheltenham, U.K.
Reijnders, Lucas, 1998. The factor X debate: setting targets for eco-efficiency. Journal of Industrial Ecology 2 (1), 13–22.
Rhee, Hae-Chun, Chung, Hyun-Sik, 2006. Change in CO_2 emission and its transmissions between Korea and Japan using international input–output analysis. Ecological Economics 58 (4), 788–800.
Robinson, John, 2004. Squaring the circle? Some thoughts on the idea of sustainable development. Ecological Economics 48 (4), 369–384.
Røpke, Inge, 1999. The dynamics of willingness to consume. Ecological Economics 28 (3), 99–420.
Rosenberg, Nathan, 1982. Inside the Black Box: Technology and Economics. Cambridge U. Press, Cambridge.
Rosenberg, Nathan, 1994. Exploring the Black Box: Technology, Economics, and History. Cambridge U. Press, Cambridge.
Rosenblatt, Roger (Ed.), 1999. Introduction to Consuming Desires: Consumption, Culture, and the Pursuit of Happiness. Island, Washington, D.C.
Roy, Joyashree, 2000. The rebound effect: some empirical evidence from India. Energy Policy 28 (6/7), 433–438.
Rudin, Andrew, 2000. Let's stop wasting energy on efficiency programs — energy conservation as a noble goal. Energy and the Environment 11 (5), 539–551.
Sachs, Wolfgang, 1988. The gospel of global efficiency. ifda (International Foundation for Development Alternatives) dossier 68, 33–39.
Sagoff, Mark, 1988. The Economy of the Earth. Cambridge U. Press, Cambridge.
Saint-Paul, Gilles, 1995. Discussion. In: Golding, Ian, Winters, L. Alan (Eds.), The Economics of Sustainable Development. Cambridge U. Press, Cambridge.
Salameh, Mamdouh, 2003. Quest for Middle East oil: the U.S. versus the Asia-Pacific region. Energy Policy 31 (11), 1085–1091.
Sanne, Christer, 2000. Dealing with environmental savings in a dynamical economy — how to stop chasing your tail in the pursuit of sustainability. Energy Policy 28 (6/7), 487–495.
Sanne, Christer, 2002. Willing consumers — or locked in? Policies for a sustainable consumption. Ecological Economics 42, 273–287.
Saunders, Harry D., 1992. The Khazzoom–Brookes postulate and neoclassical growth. Energy Journal 13 (4), 131–148.
Saunders, Harry D., 2000. A view from the macro side: rebound, backfire and Khazzoom–Brookes. Energy Policy 28 (6/7), 439–449.
Say, Jean-Baptiste, [1803]/1836. A Treatise on Political Economy. Intro by Munir Quddus and Salim Rashid. Transaction, New Brunswick, New Jersey and London.
Say, Jean-Baptiste, 1820. Lettres a M. Malthus Sur Différns Sujets d'Économie Politique. Chez Bossange. Paris.
Schipper, Lee, 2000. On the rebound: the interaction of energy efficiency, energy use and economic activity (Editorial). Energy Policy 28 (6/7), 351–353.
Schipper, Lee, Grubb, Michael, 2000. On the rebound? Feedbacks between energy intensities and energy uses in IEA countries. Energy Policy 28 (6/7), 367–388.
Schmidt-Bleeck, Friedrich., 1994. Wieviel Umwelt braucht der Mensch? MIPS – Das Mass für ökologisches Wirtschaften. Birkhäuser, Berlin.
Schor, Juliet, 1992. The Overworked American: The Unexpected Decline of Leisure. Basic Books, New York.
Schor, Juliet, 1999a. The Overspent American: Upscaling, Downshifting, and the New Consumer. Basic Books, New York.
Schor, Juliet, 1999b. What's wrong with consumer society? Competitive spending and the 'New Consumerism. In: Rosenblatt, Roger (Ed.), Consuming Desires: Consumption, Culture, and the Pursuit of Happiness. Island, Washington.
Schor, Juliet, 2005. Prices and quantities: unsustainable consumption and the global economy. Ecological Economics 55 (3), 309–320.
Schumacher, Ernst Friedrich, 1973/1999. Small Is Beautiful. Hartley and Marks, Point Roberts, Washington, U.S.A.
Schurr, Sam H., 1982. Energy efficiency and productive efficiency: some thoughts based on American experience. Energy Journal 3 (3), 3–14.
Schurr, Sam., Netschert, Bruce C., 1960. Energy and the American Economy 1850–1975. Johns Hopkins, Baltimore.
Scitovsky, Tibor, 1976. The Joyless Economy. Oxford U. Press, New York.
Shi, Anqing, 2003. The impact of population pressure on global carbon dioxide emissions, 1975–1996: evidence from pooled cross-country data. Ecological Economics 44, 29–42.
Shim, Jae K., Siegel, Joel G., 1995. Dictionary of Economics. John Wiley, New York.
Siebenhüner, Bernd, 2000. Homo sustinens — towards a new conception of humans for the science of sustainability. Ecological Economics 32, 15–25.
Sieferle, Rolf Peter, 2001. The Subterranean Forest. White Horse Press, Cambridge.
Simms, Andrew, 2005. Ecological Debt: The Health of the Planet and the Wealth of Nations. Pluto, London.
Smart, William, 1892. The effects of consumption of wealth on distribution. Report of the British Association for the Advancement of Science, pp. 840–841. Paper read on Saturday, August 6.
Smil, Vaclav, 2003. Energy at the Crossroads: Global Perspectives and Uncertainties. MIT Press, Cambridge, Mass.
Solow, Robert A., 1957. Technological change and the aggregate production function. Review of Economics and Statistics 39, 312–320.
Solow, Robert M., 1970. Growth Theory: An Exposition. Clarenden Press, Oxford.
Spangenberg, Joachim, Lorek, Sylvia, 2002. Environmentally sustainable household consumption: from aggregate environmental pressures to priority fields of action. Ecological Economics 43, 127–140.
Sraffa, Piero, 1951. Introduction to David Ricardo, [1817]/1820, On the Principles of Political Economy and Taxation. Cambridge U. Press, Cambridge.
Stern, Paul C., Dietz, Thomas, Guagnano, G.A., 1995. The new ecological paradigm in social psychological context. Environmental Behavior 27, 441–461.
Sterner, Thomas, Isaksson, Lena Höglund, 2006. Refunded emission payments theory, distribution of costs, and Swedish experience of NO_x abatement. Ecological Economics 57 (1), 93–106.
Swaney, James A., 1991. Julian Simon vs. the Ehrlichs. Journal of Economic Issues 25, 499–509.
UNCED, 1992. Framework convention on climate change. HeinOnline–31 International Legal Materials, pp. 849–873. http://unfccc.int.
UNCED, 1993. Changing Consumption Patterns/Agenda 21. UN Department of Public Information.
Union of Concerned Scientists, 2007. www.ucsusa.org/publications/greentips.
Veblen, Thorstein, 1899/1998. The Theory of the Leisure Class. Prometheus Books, Amherst, N.Y.
Veenhoven, Ruut, 1991. Is happiness relative? Social Indicators Research 24, 1–34.

Von Weizsäcker, Ernst, Lovins, Amory B., Lovins, L. Hunter, 1997. Factor Four: Doubling Wealth — Halving Resource Use. Earthscan, London.
Wackernagel, Mathis, Rees, William, 1997. Perpetual and structural barriers to investing in natural capital: economics from an ecological footprint perspective. Ecological Economics 20 (3), 3–24.
Wackernagel, Mathis, Silverstein, Judith, 2000. Big things first: focusing on the scale imperative with the ecological footprint. Ecological Economics 32, 391–394.
Waller, William, Robertson, Linda, 1998. The politics of consumption and desire. In: Brown, Doug (Ed.), Thorstein Veblen in the Twenty-first Century. Elgar, Cheltenham, U.K.
Wirl, Franz, 1991. Energy demand and consumption price expectations. Resources and Energy 13, 241–262.
Wirl, Franz, 1997. The Economics of Conservation Programs. Kluwer Academic, Boston.
4CMR (Cambridge Centre for Climate Change Mitigation Research), 2006. The macro-economic rebound effect and the UK economy. Final Report to Defra, vol. 18. May, www.defra.gov.uk/environment/energy/research.

Energy 34 (2009) 370–376

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Energy rebound and economic growth: A review of the main issues and research needs ☆

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ARTICLE INFO

Article history:
Received 21 February 2008
Available online 18 December 2008

Keywords:
Energy efficiency
Rebound
Backfire
Economic growth

ABSTRACT

Contrary to conventional wisdom, more efficient use of energy may actually through rebound effects lead to greater instead of less total consumption of energy—or at least to no diminution of energy consumption. If so, energy efficiency strategies may serve goals of raising economic growth and affluence, but as an environmental or energy policy strategy could backfire, leading to more resource use in absolute terms rather than less. This, in turn, could in the long run hamper economic growth, for instance if resource scarcity crowds out technical change. The hypothesis that rebound is greater than unity ('backfire') predicts the observed real-world correlation between rising energy consumption and rising efficiency of energy services, however difficult it may be to define a precise holistic metric for the latter. The opposing hypothesis, i.e. that rebound is less than unity and that energy efficiency increases therefore result in less energy consumption than before, requires on the other hand strong forces that do account for the empirically observed economic growth. This paper summarises some of the discussions around the rebound effect, puts it into perspective to economic growth, and provides some insights at the end that can guide future empirical research on the rebound topic.

1. The economic consequences of energy efficiency change

In order to slow down the depletion of non-renewable energy sources and to reduce emissions from the combustion of fossil fuels, policies are often propagated that aim at increasing the energy efficiency of production processes. The claim that energy efficiency increases necessarily lead to reduced energy consumption has been questioned, as has the notion that such increases will always have a positive impact on economic growth. Obviously, the discussion presented here for the case of energy could easily be extended to other resources that are the target of conservation policies (e.g. water).

This paper investigates the relationship between changes in energy efficiency and total energy consumption of an individual entity (firm, household) and a collective economic entity (economic sector, national or world economy). Is there a causal connection? While some rebound effect is universally agreed to follow efficiency increases, is the size of this *total rebound* large enough to speak against efficiency as a resource-saving strategy?

Note that our dependent variable—the amount or quantity of energy used—is often taken as the explanatory or independent variable, correlated with growth of GDP, to address an entirely different question, viz. to explain growth [1–3]. Here, we are interested in the role of technical change and the substitutability between goods and services in shaping the relationships between energy consumption and energy efficiency (or rebound), energy efficiency (or rebound) and economic growth, and economic growth and energy consumption, respectively. Fig. 1 depicts the three dimensions considered in our rebound discussion, all of which are affected in important and often ambiguous ways by technical change and the substitutability of input factors of production.

One argument combining efficiency, energy consumption and GDP growth is for instance that increased efficiency in the use of energy inputs contributes to economic growth and since this, in turn, implies greater energy consumption, then efficiency itself implies some increase of energy consumption [4]. Yet if 'dematerialisation' obtains, then some net decrease of energy consumption could occur.

1.1. Some definitions

Before entering the discussion any further it is useful to define some of the terms used. *Engineering savings* is a theoretical

☆ This paper is a revised version of the paper presented at the 5th International Biennial Workshop "Advances in Energy Studies: Perspectives into Energy Future" held in Porto Venere, Italy, 12–17 September 2006.

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doi:10.1016/j.energy.2008.10.011

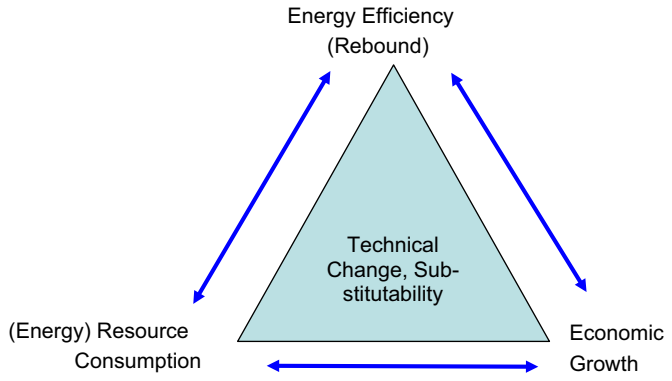

Fig. 1. Dimensions considered for the discussion of energy rebound and economic growth.

quantity of energy that could be saved after a certain increase in energy efficiency, if the quantity of goods and services demanded or consumed were held constant. As light bulbs, cars and steel-making machinery use less and less energy input per output (e.g. lumens/m^2, tonne-kilometres or tonnes of steel), respectively, we could—from a conservationist's perspective—deliberately opt to produce and consume no more of these outputs, or indeed other outputs, yielding real 'calculated' savings in energy in any given time period.

Rebound is the additional energy consumption enabled by energy efficiency increases, i.e. after energy input per unit of output has gone down, and provided the efficiency increase implicitly led to a reduction in the price of producing the output. We can afford to buy more energy-using outputs if costs per unit of output have fallen, resulting in an *income effect*: after enjoying our usual quantities of light, car travel and steel our budget is not used up; the quantities to consume have become cheaper per unit, and we can buy more of the same products, or other products, which also require energy inputs for their production and consumption. Because the *relative* prices of lighting, car- (actually tonne-) kilometres and steel have fallen there is also a *substitution effect:* all other things being equal, we will consume more of those goods and services that are now produced in a more energy-efficient way. Finally, if the initially lowered demand for energy inputs—holding production and consumption quantities constant—leads to a fall in the unit price of energy, a general *price effect* leads to the substitution of energy for other factors of production. In other words, the energy efficiency increase can also be regarded as an outward shift in the production possibilities frontier (i.e. a higher output can be achieved with the same input or, conversely, less input is needed for the same output level). The energy 'freed' from producing the previous level of output of goods and services is available, at no higher cost, for some additional production.

A few points are worth noting here. First, consumer preferences may also change due to improvements in energy efficiency, such that demand shifts to higher levels of comfort, or other quality attributes. Second, we may decide to substitute energy for time (using faster means of transport, eating more fast food, etc.). Third, changes in the capital costs of energy-related services have an important influence on the size of the rebound effect, and capital grants paid by government may actually inflate the rebound effect, as consumers do not have to bear the full cost of the purchase decision [cf. 13, pp. 6–7]. Fourth, we are only concerned here with technical change that affects energy efficiency, i.e. with energy rebound.

Rebound is commonly measured as a percentage of engineering savings; if it is greater than 100% this is usually referred to as *backfire*, so named because the modern discussion of rebound

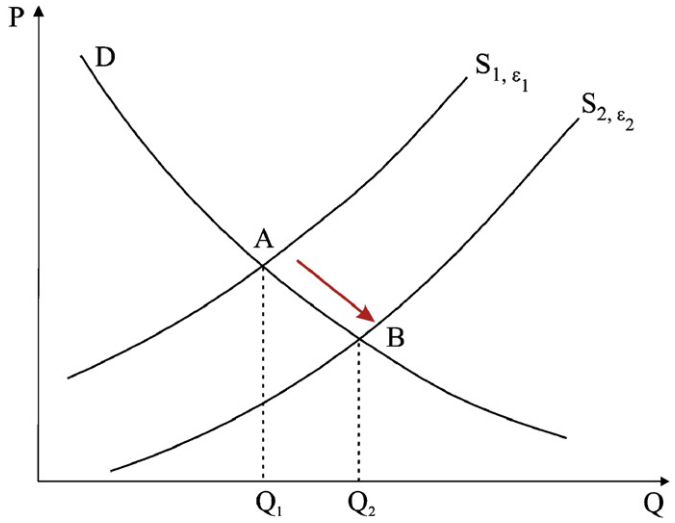

Fig. 2. Lower input factor costs due to an efficiency increase by $\Delta\varepsilon$ enable an outward shift in the supply function. *Source*: [7], modified.

begun by Brookes [5,6] and Khazzoom [7] asked whether newly enacted government policies to save energy through efficiency caused real energy savings, or—because of rebound greater than unity—might actually 'backfire'. If backfire exists, this would result in more energy consumption than before the (policy-induced) increase in energy efficiency. The 19th-century discussion of this paradox started and also ended with William Stanley Jevons' book *The Coal Question*, which expounded the backfire position [8,9]. This 'Jevons' paradox' is of course not to be confused with the 'energy paradox', the latter of which is related to the high implicit discount rates found empirically for many energy efficiency investments, and which attests the fact that economic actors often do not invest in energy efficiency measures or technologies, even though it appears to be in their economic interest to do so (seemingly irrational behaviour).

1.2. Shift of the supply curve

Khazzoom [7] described the increase in output offered at a given price level that is caused by efficiency-induced cost reductions (shift of the supply curve *S* to the right, due to an increase in efficiency from ε_1 to ε_2). This results, *ceteris paribus*, in greater demand Q_2 at the new equilibrium point B for the more efficiently-produced goods and services than before at demand Q_1 (in equilibrium A; see Fig. 2).

Since of course energy input *per unit* of economic output has fallen, demand for energy inputs does not necessarily rise above its previous level (backfire), but Khazzoom's point was that real savings *must* be lower than engineering savings. In his opinion calculations that are based on the engineering facts alone "… overlook the fact that changes in [e.g.] appliance efficiency have a price content." [7, pp. 21–22]. For further rigorous statements and definitions of rebound see, e.g., Wirl [10, p. 31], Birol and Keppler [11, pp. 460–463], Schipper and Grubb [12, pp. 369–370], Binswanger [13, p. 120], Sorrel and Dimitropoulos [14], and the synopsis provided in Herring [15] and Herring and Roy [16].

1.3. Taxonomy

When consuming the previous quantity of output after a cost-neutral energy efficiency increase, some unused purchasing power thus remains, i.e. is freed for additional consumption.

This is an *economy-wide rebound effect*, already attested by Jean-Baptiste Say more than 200 years ago:

> But whence is derived this [...] larger supply of wealth, that nobody pays for? From the increased command acquired by human intelligence over the productive powers and agents presented gratuitously by nature [...]. A power [...] before known and available is directed with superior skill and effect, as in the case of every improvement in mechanism, whereby human or animal power is assisted or expanded [17, p. 101].

We have counted some 28 different terms for rebound effects in the literature. While we accept the basic classification into *income*, *substitution and price effects*, we further categorise the new 'rebound' demand as follows:

1. by the same consumer for the same product or service;
2. by the same consumer for a different product or service;
3. by a different consumer for the same product or service;
4. by a different consumer for a different product or service.

A fifth category is the case of consumers' choosing leisure instead of additional consumption, reducing their purchasing power (e.g. by working less) to a degree proportional to engineering energy savings. Here rebound would be zero (if macroeconomic effects of leisure can indeed be neglected), and the efficiency increases have enabled real resource savings with no loss of affluence.

The literature separates this demand into 'direct' (roughly, categories 1 and 3) and 'indirect' rebound (categories 2 and 4), together constituting 'economy-wide' or simply 'total' rebound (e.g. [16, p. 196]). A special problem is presented by *new products or services* or whole new industries, e.g. railroads in the 19th century or lasers in the 20th century, that are partially enabled by efficiency increases in extant products and industries [8,18,19], but for simplicity we ignore these here. Note that category five is always possible, i.e. were all humans to 'reap' energy efficiency benefits in the form of less work and less purchasing power, rather than greater consumption, this would lead to a 100% realisation of the potential (or theoretical quantity) engineering savings. A zero price elasticity of demand would describe this situation. Human history, psychology and poverty indicate that this is very unlikely. Given any positive value of the elasticity, rebound must thus be greater than zero.

2. Various approaches

How can one go about answering the question of whether total energy consumption ends up less, greater, or the same due to energy efficiency increases? We identify four different approaches here that can be used.

2.1. Economic/technological history

Jevons [8] rendered it at least plausible that without the efficiency increases in steam engines and metal smelting the demand for coal could never have reached mid-19th-century levels. That is, if we assume that energy technology had remained at efficiency levels of, say, the year 1800, how much (increase in) annual energy consumption is imaginable now, 200 years later? Rosenberg sums up this argument for the plausibility of backfire as follows:

> The Bessemer process was one of the most fuel-saving innovations in the history of metallurgy. However, the innovation made it possible to employ steel in a wide variety of uses that were not feasible before Bessemer, bringing with it large increases in the demand for steel. As a result, although the Bessemer process sharply reduced fuel requirements per unit of output [a *ratio*], its ultimate effect [seen from an economic, not just an engineering, perspective] was to increase, not to reduce, demand for fuel [18, p. 166; additions in square brackets by the authors].

Neither should one neglect the perhaps special case of the history of efficiency improvements in obtaining energy, known as the *energy return on* (*energy*) *investment*, or shortly EROI. [1] Without these increases, some law of diminishing returns—deeper mines and drill-holes, for instance—would have rendered energy more and more expensive rather than ever-cheaper, as has been the case. Related to the gradual improvement of technology over time are the two phenomena 'lock-in' and 'path-dependency' [20,21], respectively, both of which explain part of the more general issue of drag or inertia imposed on the turnover of the capital stock. Note, however, that the replacement rate of old against new capital stock as well as EROI are usually not part of the discussion about the size of rebound effects, since the two relevant measures for the assessment are (1) changes in the technical efficiency with which particular goods and/or services are provided and (2) total consumption levels.

2.2. Microeconomic aspects

Applying the microeconomic approach analysing prices, substitution and income effects, numerous empirical studies have investigated *direct rebound* (additional demand for a good or service that can be more efficiently produced with the new technology). For instance, after buying an energy-efficient Toyota Prius automobile, do people then either buy or keep additional cars, and does the weight of the household's entire car fleet perhaps increase [22]? One could also ask whether a more energy-efficient car is driven more than the previous one [23]. Studies in the UK attest, for instance, that after a house is insulated or obtains a more efficient space-heating system, people do tend to heat more (i.e. higher temperatures or additional, previously unheated rooms) [24]. A useful survey of such direct rebound studies can be found in [25], from where it can be learned that direct rebound effects identified were in the order of 10–30% (0–50%) for residential space heating (cooling), <10–40% for residential water heating, 5–12% for lighting, 0% for residential appliances, and 10–30% for automobiles, 0–2% for firm's lighting, and 0–20% for firm's process uses. It is worth mentioning that a reduction in the cost of any good or service due to energy efficiency increases also has an important bearing on marginal consumers, i.e. those that could not previously afford the energy service concerned.

Microeconomics illustrates why this topic is still a paradox: if driving a kilometre in a car with a more energy-efficient engine leaves unused budget, perhaps we buy more 'driven kilometres'. But since petrol inputs are only part of the costs of driving a kilometre, and since each kilometre is driven more efficiently, the new demand *for petrol* would seem to necessarily be lower than that saved in driving the customary number of kilometres [26]. However, a construct or measure such as a 'driven kilometre' is rather artificial, and we must also examine the induced substitution and price effects, as well as take the embedded energy and capital costs of the change to greater efficiency of the capital stock into account (note that we abstract from changes in labour input and quality or comfort here, and only consider energy and capital inputs). In microeconomic terms, the size of rebound depends upon the *efficiency elasticity of demand* for energy [27], a

compound which can be broken down into the efficiency elasticity of energy price times the price elasticity of energy demand.

The viability of this approach would be enhanced by fulfilling two conditions: First, the system boundaries of empirical studies must be expanded to world scale; since many energy markets and emissions are international, and since embedded energy and material are increasingly traded globally, country or OECD studies alone are insufficient for a complete picture [28–30]. Second, the goal must be to measure *total rebound*, i.e. indirect as well as direct effects: the increased 'purchasing power' of the budget can be used to purchase any products whatsoever, and can be shared by people who were previously not in the market at all. The rebound from more efficient automobile motors can just as well be additional demand for air travel. Tracing indirect effects with the tools of microeconomics, however, proves to be extremely difficult [26,31]. Moreover, estimates of total rebound vary wildly. For instance, while for the UK 4CMR [32] arrives at a figure of 26% and Allan et al. [33] closer to 40%, for others it is clear that backfire might be the case [8,34,35]. On whether rebound is greater or less than unity, the jury is still out.

2.3. Macroeconomic aspects

With statistical methods one could test the hypothesis that, in aggregate and over time, technological efficiency increase is a net contributor to the size of energy consumption and its growth. The long-term increase of energy consumption needs no documentation. On the other hand, although few doubt it, are we so sure that energy efficiency has increased also if measured with physical metrics? How, indeed, can we measure changes in energy efficiency in the aggregate non-monetarily [36]?

Jevons [8] was the first writer to show that large and obvious energy efficiency increases were accompanied by energy consumption increases; he traced efficiency increases in steam engines and steel (or pig-iron) production, then compiled statistics on coal consumption. Greenhalgh [28] shows engineering efficiency gains of over 20% for household appliances in Denmark between 1977 and 1986, alongside rising electricity consumption. Rudin [37] does the same for US energy use in commercial buildings (8% more efficient from 1979 to 1995) and cars (30% from 1967 to 1997). Smil [38], likewise, analysed changes in energy efficiency with changes in energy consumption (also [39]). Recently, Herring [15] maintains a (positive) causal relationship between lighting efficiency and electricity consumption. In aggregate terms for the US economy during the entire 20th century [4, pp. 340 and 351] show a strong correlation between technical efficiency increase and exergy consumption.

However, correlation is not causality, and for testing the hypothesis rigorously it would be ideal to have a metric for energy efficiency levels that is valid in different time periods and in different countries (or at different scales). But again, given the global nature of many environmental problems (e.g. climate change) and the global nature of the market for fossil fuels, for a more comprehensive assessment and understanding of rebound effects we need to study world statistics as well. Second-best would be metrics for well-defined products, industries or sectors, whose efficiency change could be measured in percentages, and then some average for the whole world economy calculated. Recent work by Ayres and associates [4,40,45] makes important strides in measuring efficiency changes in terms of exergy and work at point of use, yet it remains difficult to measure aggregate global output as physical work, heating, endothermic change, lighting and produced electricity.

To measure both 'economic growth' and 'output' as the numerator in input–output efficiency (or as denominator for energy 'intensity'), one must decide between financial, utility or welfare, and physical metrics. Taking GDP as the metric—i.e. economic output in monetary terms divided by energy input—has many disadvantages. It is well known that GDP fails to measure many economic activities, ranging from unpaid work to bartered goods, and also resource depletion and loss of environmental services [41] where the true costs are not reflected in the price. Moreover, the prices of the goods that GDP counts are also influenced by factors not pertaining to changes in efficiency and costs of production, but rather consumer tastes, quality changes, and even politics [38,42,43].

Taking human utility—or welfare, or services—as the quantity against which energy inputs are measured also has problems. For instance, if a second person rides in a car, utility is virtually doubled while energy input stays virtually the same. But this is not a *technological* efficiency change, although it is often regarded as a measure of something like economy-wide energy efficiency or productivity. Welfare, too, is subject to many influences. The energy efficiency policies we wish to scrutinise, however, typically involve energy inputs compared with some *physical*, environmentally relevant output, like lumens per m^2, tonne-kilometres or tonnes of steel.

To find a physical metric has proven difficult. Even on the input side, is it rigorous enough to measure inputs of *energy* in tonnes or Joules of different kinds of oil or petrol, of coal, or of natural gas? Or should we measure instead *exergy* inputs [44]? Ayres and Warr [45], for instance, refer to an exergy/energy ratio, i.e. the conversion of useful energy to useful work. But since work is understood in terms of energy, how do we distinguish between an input and an output Joule of exergy? And since exergy is energy of higher quality, or greater availability to do work, what are the inputs into the 'transformation' process increasing this quality, or is it simply meant to describe, for instance, low-entropy petrol as opposed to high-entropy crude oil?

On the output side, can the weight (or mass) of consumable and durable goods, including the (energy-using) stock of capital goods actually doing the work, serve as an aggregate metric? Radetzki and Tilton [46] consider this, but because of qualitative differences in products find it necessary to 'weight' these weights. Among others, Dahlström and Ekins [29] attempt to weight physical characteristics—e.g. chemical elements, weight, waste, shape, and recycled tonnage—by economic value, attempting to integrate traditional material flow analysis with value chain analysis. But here the danger of conflating physical and subjective economic characteristics is very great (see also [47,48]). The quest for an all-encompassing, purely physical measure of efficiency is a precondition for rigorous statistical analysis, but seems still far off in current research.

A further element largely ignored in discussions on the size of energy rebound effects is time. In many situations it has economic value if goods or services can be provided in less time. As an example, if we extract from the same amount of energy the same amount of useful work in a shorter time span, we create some additional value. With some exceptions (e.g. [13]), most rebound assessments, however, remain silent about this time value of energy (work over time equals power), and only address work over energy. Since, however, the time freed by the *energy* efficiency increase is available for further production and consumption, thus of course increasing economic growth, the entailed additional energy consumption must be booked under rebound. (The same argument can be put forward for exergy considerations.)

2.4. Economic growth theory

Early economic growth models incorporating technical change as an exogenous factor attempt to explain the role of technical

change for sustained growth by "manna from heaven" [49]. Growth models including energy and material alongside capital and labour reduced the statistical residual significantly [1,50].

Newer research has accounted for this very large 'technical change' residual in the earlier studies by means of a KLEC production function (capital, labour, energy and creativity). By including both amounts of energy and our creativity in using energy more efficiently, not only is product ion output much more fully explained but it is also shown that energy's contribution to product ion output far exceeds that of its share in the monetary value of inputs as represented in the national accounts [51].

Energy efficiency, as part of the technical progress in neo-classical growth theory, is conventionally seen as a driver of economic growth. A commonly found argument in standard growth theory literature is that technical change and factor substitution can effectively de-couple economic growth from the demand for resources and environmental services, i.e. raise 'efficiency' measured against the monetary quantity GDP [52]. Depletion of finite energy and other resources and environmental degradation is not seen as a significant barrier to economic growth, since there will always be more abundant substitutes (either natural resources or human-made capital).

In the 1990s, however, endogenous growth theorists have started to formally include concerns about environmental and resource factors limiting growth in standard growth models (e.g. [53,54]). Doing so, endogenous growth theory enables new insights about the relationships between resource scarcity, technical change, and economic growth, and hence constitutes a great leap forward compared with standard neo-classical growth theory. A further development of endogenous growth models to also account for rebound effects renders hope that in the future the relationship between economic growth, technical change and resource use (and eventually the size of various rebound effects on the macroeconomic level) can be better modelled and understood.

There are diminishing returns to the ability of technology to reduce the amount of human-made and natural capital that is required to extract resources. Technical change can offset diminishing returns, either by a shift to more productive or less resource-dependent technologies, or by employing technologies that use new or more abundant resources. Resource scarcity or depletion often increases the use of human-made capital to extract a unit of natural resource, so that additional costs occur that have to be included. Microeconomic analysis typically ignores macroeconomic and global effects of substitution, thus underestimating thermodynamic limits, complementarity, irreversibility, waste, and scale (impact of trade) [55]. Technical change may thus alleviate scarcity limits, but on the other hand can be crowded out by resource scarcity. Such technical change enables greater rates of extraction than at the previous, lower level of efficiency in obtaining the mineral or fuel resources.

3. Insights concerning rebound studies and research needs

The following 12 observations are claimed to be insights that can guide further research into the empirical analysis of rebound effects. Not all of them follow directly from the foregoing, and for reasons of space we explain them only briefly.

1. Evaluations of government energy efficiency programmes are flawed because they usually take *only engineering quantities* into account, i.e. they implicitly and untenably assume that rebound equals zero, and *lack a global perspective*. The chapter on energy efficiency policies in a recent UK report, for instance, does not mention the rebound effect at all [56]. This practice should be abandoned forthwith and efforts redoubled to provide more evidence about the size of indirect rebound, and to settle the question of backfire. Another recent UK study has made significant strides toward this goal [27].
2. The models of energy consumption in such assessment studies should also avoid treating GDP and population as fully exogenous, because this begs the question of whether (and to what extent) energy efficiency contributes to economic and population growth. It should also be kept in mind that energy consumption may rise as well due to other kinds of growth-enhancing efficiency gains (organisational, institutional), but this should not be booked under energy rebound (lack of a technical change component).
3. Two concepts are crucial for rebound studies: that of engineering energy savings, of which rebound is a percentage, and that of the purchasing power increase (income effect), which must result from efficiency increases. How efficiency affects the price of energy is, on the other hand, more difficult to determine. Perhaps price remains constant while at the new equilibrium demand is greater [57]. Ultimately, what consumers want are energy services, not energy *per se*, the costs of which may be reduced by energy efficiency improvements.
4. The common concept in the rebound literature of 'energy services' should be reconsidered, because *every* good and service requires energy inputs—just as, perhaps, they require capital, labour and non-energy material inputs as in an ordinary production function $Q = f(K,L,E,M)$. The concept furthermore can lead to the conflation of physical and utility criteria.
5. Tractable though it may be, measuring *direct rebound* compared with engineering savings calculations is insufficient as a basis for policy advice. The ultimate goal must be the measurement of *total rebound*, i.e. direct and indirect rebound—demand for goods or services other than the newly more efficiently supplied one, demand by additional consumers who enter the market at the new, lower prices, and demand for totally new products or services which (at least partly) result from energy efficiency increases.
6. Any rebound analysis must apply both to business-as-usual or 'autonomous' energy efficiency increases [58] as well as policy-induced ones.
7. For statistical analysis, some physical metric or metrics enabling a rigorous definition and measurement of macro-level energy efficiency change (e.g. at the national or global level) must be found.
8. Energy efficiency increase *enables* (but does not always implicate) greater energy consumption; hence our analyses must include 'the consumer'. That is, *saturation* or any deliberate decision to abstain from additional consumption (sufficiency strategy) does lower rebound, rendering large rebound effects, and the more so backfire, by no means an unavoidable consequence.
9. Further concerning 'the consumer', increases in energy efficiency are no panacea for either energy conservation or economic growth and welfare; demand saturation and substitutability of input factors matter a great deal, and both of them change over time, as do our needs and wants. An interesting topic in this respect is *status signalling*, i.e. situations where an individual communicates (honest or bogus) information about his/her status to other individuals that the others do not have [59,60]. Often it is the (perceived) relative consumption levels among consumers that determine needs and wants, and that impact the (perceived) status of an individual. As an example, someone may own a bigger car or house than the neighbours in order to signal to others a higher

economic or social status. Unfortunately, many status goods today are resource-intensive, making saturation or even a decline in total material or energy consumption less likely.

10. Perhaps we can learn from the history of increased *labour* efficiency. A consensus reigns that 'labour-saving' innovations did not save labour at all, but enabled, indeed, ever-increasing population and employment. If we discover the mechanisms responsible for this, can they shed light on the economic processes following *energy* efficiency increases [61–63]? Moreover, greater *time* efficiency in production, even holding the amount of useful work gained per unit of energy input, can free time for further production and consumption [13].
11. For policies to save energy resources it is important to determine, and to take into account, the approximate magnitude of total rebound. As rebound increases, energy efficiency policy becomes ever more ineffective as well as cost-ineffective, reaching counter-productivity beyond a level of 100%. The difficult debate over the paradoxical backfire issue, while of great theoretical interest, is thus not strictly pertinent to judging the effects of political measures mandating or encouraging greater efficiency.
12. Future research should begin with a broader and more accurate concept of efficiency itself. Efficiency is *both* less input for the same output or more output for the same input. While the latter case seems to well describe human history, where natural resources freed from one task are committed either to other tasks or to population growth, the former obtains only if people choose leisure and reproduce at no more than replacement rates. Embracing both types of efficiency change means studying economics as well as engineering, and raises the likelihood of policy-relevant new insights that actually help to curb energy consumption.

Not only is there at present no viable methodology for measuring indirect or economy-wide rebound, but these two concepts are themselves poorly defined. Microeconomic tools can describe the elasticities to be discovered, but data at aggregate levels to estimate such elasticities are lacking. We know that technological efficiency increases expand the production possibilities frontier—we are enabled to consume both more end product and more inputs, whether of energy, materials or labour. We know that over the last 200 or more years energy consumption has risen and real energy prices have fallen; and it is safe to assume that technological efficiency has also risen. But whether this correlation reflects causality is undetermined. In deciding whether to prescribe or subsidise energy efficiency improvements beyond those that take place as business-as-usual, it is of crucial importance to know the size of the economy-wide (global) rebound. Otherwise, energy efficiency policies become ineffective, or even counterproductive, as rebound rises, with important implications for policy design and the achievability of, say, energy supply security or greenhouse gas mitigation targets.

Acknowledgements

The authors gratefully acknowledge comments received from Leonard Brookes, Tim Foxon, Steve Sorrell, three anonymous referees, as well as from Mario Giampietro, Kozo Mayumi and several other participants of the 5th International Biennial Workshop "Advances in Energy Studies" held in Porto Venere, Italy, 12–17 September 2006. Needless to say that only the authors should be held responsible for any misconceptions or remaining errors.

References

[1] Cleveland C, Costanza R, Hall CAS, Kaufmann R. Energy and the US economy: a biophysical perspective. Science 1984;225:890–7.
[2] Kraft J, Kraft A. On the relationship between energy and GNP. J Energy Dev 1978;4:401–3.
[3] Soytas U, Sari R. Energy consumption and GDP: causality relationship in G-7 countries and emerging markets. Energy Econ 2003;25(1):33–7.
[4] Warr B, Ayres R. REXS: a forecasting model for assessing the impact of natural resource consumption and technological change on economic growth. Struct Change Econ Dyn 2006;17(3):329–78.
[5] Brookes L. Energy policy, the energy price fallacy and the role of nuclear energy in the UK. Energy Policy 1978;6(1):94–106.
[6] Brookes L. Energy efficiency fallacies revisited. Energy Policy 2000; 28(6–7):355–66.
[7] Khazzoom JD. Economic implications of mandated efficiency in standards for household appliances. Energy J 1980;1(4):21–40.
[8] Jevons WS. In: Flux AW, editor. The coal question: an inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines, 3rd ed., A.M. Kelley, New York, 1906.
[9] Alcott B. Jevons' paradox. Ecol Econ 2005;54(1):9–21.
[10] Wirl F. The economics of conservation programs, vol. 21. Boston: Kluwer Academic Publishers; 1997.
[11] Birol F, Keppler JH. Prices technological development and the rebound effect. Energy Policy 2000;28(6–7):460–3.
[12] Schipper L, Grubb M. On the rebound? Feedbacks between energy intensities and energy uses in IEA countries. Energy Policy 2000;28(6–7):367–88.
[13] Binswanger M. Technological progress and sustainable development: what about the rebound effect? Ecol Econ 2001;36(1):119–32.
[14] Sorrell S, Dimitropoulos J. The rebound effect: microeconomic definitions, limitations and extensions. Ecol Econ 2008;65(3):636–49.
[15] Herring H. Energy efficiency: a critical review. Energy 2006;31(1):10–20.
[16] Herring H, Roy R. Technological innovation, energy efficient design and the rebound effect. Technovation 2007;27(4):194–203.
[17] Say J-P. A treatise on political economy. Introduction by Munir Quddus and Salim Rashid. New Brunswick, NJ/London: Transaction Publishers; 1836 [first published 1803, in French].
[18] Rosenberg N. Inside the black box: technology and economics. Cambridge: Cambridge University Press; 1982.
[19] Rosenberg N. Exploring the black box: technology, economics, and history. Cambridge: Cambridge University Press; 1994.
[20] David PA. Clio and the economics of QWERTY. Am Econ Rev 1986;75(2): 332–7.
[21] Arthur AB. Competing technologies, increasing returns and lock-in by historical events. Econ J 1989;99(394):116–31.
[22] de Haan P, Mueller MG, Peters A. Does the hybrid Toyota Prius lead to rebound effects? Analysis of size and number of cars previously owned by Swiss Prius buyers. Ecol Econ 2006;58(3):592–605.
[23] Greene DL. Vehicle use and fuel economy: how big is the rebound effect? Energy J 1992;13(1):117–43.
[24] Defra (UK Department of the Environment, Food and Rural Affairs), Energy efficiency commitment, April 2002 〈http://www.defra.gov.uk/environment/climatechange/uk/household/eec〉.
[25] Greening LA, Greene DL, Difiglio C. Energy efficiency and consumption—the rebound effect—a survey. Energy Policy 2000;28(6–7):389–401.
[26] Howarth RB. Energy efficiency and economic growth. Contemp Econ Policy 1997;15(4):1–9.
[27] Sorrell S. The rebound effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. UK Energy Research Centre; 2007 (November).
[28] Greenhalgh G. Energy conservation policies. Energy Policy 1990;18(4):293–9.
[29] Dahlström K, Ekins P. Combining economic and environmental dimensions: value chain analysis of UK iron and steel flows. Ecol Econ 2006;58(3):507–19.
[30] Rhee H-C, Chung H-S. Change in CO_2 emission and its transmissions between Korea and Japan using international input–output analysis. Ecol Econ 2006;58(4):788–800.
[31] Roy J. The rebound effect: Some empirical evidence from India. Energy Policy 2000;28(6–7):433–8.
[32] 4 CMR (Cambridge Centre for Climate Change Mitigation Research). The macro- economic rebound effect and the UK economy. Final Report to Defra, May 2006 〈www.defra.gov.uk/environment/energy/research〉.
[33] Allan G, Hanley N, McGregor PG, Swales JK, Turner K. The macroeconomic rebound effect and the UK economy. Final report to Defra, May 2006 〈http://www.defra.gov.uk/environment/climatechange/uk/energy/research/〉.
[34] Giampietro M, Mayumi K. Another view of development, ecological degradation, and North–South trade. Rev Social Econ 1998;56(1):20–36.
[35] Brookes L. Energy efficiency fallacies revisited. Energy Policy 2000; 28(6–7):355–66.
[36] Reijnders L. The factor X debate: setting targets for eco-efficiency. J Ind Ecol 1998;2(1):13–22.
[37] Rudin A. Let's stop wasting energy on efficiency programs—energy conservation as a noble goal. Energy Environ 2000;11(5):539–51.
[38] Smil V. Energy at the crossroads: global perspectives and uncertainties. Cambridge, MA: MIT Press; 2003.
[39] Clapp BW. An environmental history of Britain. London: Longman; 1994.

[40] Warr B, Schandl W, Ayres R. Long term trends in resource exergy consumption and useful work supplies in the UK, 1900–2000. Ecol Econ 2008;68(1–2):126–40.
[41] Arrow K, Bolin B, Costanza R, Dasgupta P, Folke C, Holling CS, et al. Economic growth, carrying capacity, and the environment. Ecol Econ 1995;15(2):91–5.
[42] Schipper L, Meyers S. Energy efficiency and human activity. New York: Cambridge University Press; 1992.
[43] Saunders HD. A view from the macro side: rebound, backfire and Khazzoom–Brookes. Energy Policy 2000;28(6–7):439–49.
[44] Ayres RU. Resources, environment, and economics: applications of the materials/energy balance principle. New York: Wiley; 1978.
[45] Ayres RU, Warr B. Accounting for growth: the role of physical work. Struct Change Econ Dyn 2005;16(2):181–209.
[46] Radetzki M, Tilton JE. Conceptual and methodological issues. In: John E Tilton, editor. World metal demand: trends and prospects. Baltimore: Johns Hopkins for Resources for the Future; 1990.
[47] Van den Bergh, J, editor. Handbook of environmental and resource economics. Cheltenham, UK and Northampton, MA, USA: Edward Elgar;1999.
[48] Weisz H, Krausmann F, Amann C, Eisenmenger N, Erb K-H, Hubacek K, et al. The physical economy of the European Union: cross-country comparison and determinants of material consumption. Ecol Econ 2006;58(4):676–98.
[49] Solow R. A contribution to the theory of economic growth. Q J Econ 1956;70(1):65–94.
[50] Kümmel R. Energy as a factor of production and entropy as a pollution indicator in macroeconomic modelling. Ecol Econ 1989;1(2):161–80.
[51] Kümmel R, Henn J, Lindenberger D. Capital, labor, energy and creativity: modeling innovation diffusion. Struct Change Econ Dyn 2002;13(4):415–33.
[52] Cleveland CJ. Biophysical constraints to economic growth. In: Al Gobaisi D, editor. Encyclopedia of life support systems. Oxford, UK: EOLSS Publishers; 2003.
[53] André FJ, Smulders S. Energy use, endogenous technical change and economic growth [unpublished mimeo, version as of 13 January 2006].
[54] Smulders S, de Nooij M. The impact of energy conservation on technology and economic growth. Resource Energy Econ 2003;25(1):59–79.
[55] Stern DI, Cleveland CJ. Energy and economic growth. Rensselaer working paper in economics no. 0410, March 2004.
[56] DTI (UK Department of Trade and Industry). The energy challenge: energy review report, July 2006 〈www.berr.gov.uk/files/file31890.pdf〉.
[57] Saunders H. The Khazzoom–Brookes postulate and neoclassical growth. Energy J 1992;13(4):131–48.
[58] Manne AS, Richels RG. CO_2 emission limits: an economic cost analysis for the USA. Energy J 1990;11(2):51–74.
[59] Frank RH. Choosing the right pond: human behavior and the quest for status. New York: Oxford University Press; 1985.
[60] Jackson T. Evolutionary psychology in ecological economics: consilience, consumption and contentment. Ecol Econ 2002;41(2):289–303.
[61] Say J-B. Lettres a M. Malthus Sur Différens Sujets d'Économie Politique. Paris: Chez Bossange; 1820.
[62] Greenberg D. Energy, power, and perceptions of social change. Am Histor Rev 1990;95(3):693–714.
[63] Alcott B. Historical overview of the Jevons paradox in the literature. In: Polimeni John, Mario Giampietro, Kozo Mayumi, Blake Alcott, editors. The Jevons paradox and the myth of resource efficiency improvements. London: Earthscan; 2008.

Historical Overview of the Jevons Paradox in the Literature

by Blake Alcott

This is Chapter 2 in the book edited by myself, John M. Polimeni, Kozo Mayumi & Mario Giampietro: *The Jevons Paradox and the Myth of Resource Efficiency Improvements,* 2008, Earthscan, London, ISBN 978-1-84407-813-4, issued in paperback in 2009 retitled *The Myth of Resource Efficiency: The Jevons Paradox.* I've made a few minor changes to the 2009 text now in August 2012.

Epigraph

> [In] a stationary condition of capital and population… the industrial arts might be as earnestly and successfully cultivated, with this sole difference, that instead of serving no purpose but the increase of wealth, industrial improvements would produce their legitimate effect, that of abridging labour. Hitherto it is questionable if all the mechanical inventions yet made have lightened the day's toil of any human being. They have enabled a greater population to live the same life of drudgery and imprisonment, and an increased number of manufacturers and others to make fortunes.
>
> – John Stuart Mill (1848), *Principles of Political Economy*, pp756-757

Introduction

For William Stanley Jevons's immediate predecessor Mill, according to the above epigraph, the legitimate effect of 'industrial improvements' such as efficiency increases would be less work per capita. This is, after all, *enabled by* labour-efficiency increases at the same level of affluence. In the same manner, today's environmental strategy of technological efficiency holds that the legitimate effect of *energy*-efficiency improvements is less energy consumption at the same or an even higher level of affluence. Jevons asked, and to his satisfaction answered, the question of whether energy efficiency by itself leads to this hoped-for result or whether it leads to the same or even a higher rate of energy-resource consumption. He titled the seventh chapter of his 1865 book *The Coal Question* 'Of the Economy of Fuel', which confronts us with the 'paradox' that less fuel consumption per unit of equipment causes greater total consumption (p141). Fuel can be 'saved' per unit while not at all being 'spared' for posterity's use (p155).

The fuel in question was the coal to which Britain owed its affluence, power and civilization; the worry was that supplies, especially easily-mined ones, were dwindling fast. Some experts advised not to worry because coal's use in steam-

engines, smelting and so forth was becoming more and more efficient, a view to which Jevons objected by means of his 460-page argument that 'it is the very economy of its use which leads to its extensive consumption' (p141). And while today's fuel worries concern pollution somewhat more than depletion, the paradox remains. Why otherwise would virtually all governmental bodies, green lobby groups and the greater part of public opinion favour efficiency increases to reduce our rate of overall consumption?
Yet many academics take Jevons's part in doubting this.

To his brief statement of his thesis Jevons cheekily added,

> Nor is it difficult to see how this paradox arises… It needs but little reflection to see that the whole of our present vast industrial system, and its consequent consumption of coal, has chiefly arisen from successive measures of economy. (pp141-142)

Today however the *solution* of the paradox is requiring a great deal of reflection, of which the present book is a part. The revival of Jevons's argument by Leonard Brookes (1978 and 1979) and Daniel Khazzoom (1980), both of whom doubted the environmental efficacy of the efficiency standards for cars, refrigerators, houses and light bulbs that were being enacted in the decade that saw the Club of Rome report[1] and OPEC fuel price hikes, opened a heated debate. In Khazzoom's words,

> changes in appliance efficiency have a price content… [W]ith increased productivity comes a decline in the effective price of commodities, and… demand does not remain constant… but tends to increase. (1980, pp22-23)

While this new/old insight that efficiency increases trigger *some* additional input consumption – known by the cute technical term *rebound* – was readily acknowledged by all, a school of thought emerged regarding it as 'insignificant' (Lovins, 1988, pp156-157) or 'small' (Schipper & Grubb, 2000, pp367-368, 394-386), meaning that greater efficiency would indeed bring net resource savings. Empirical attempts to measure economy-wide rebound have failed, and theorists have indecisively argued the pros and cons of Jevons's extreme and very important thesis that rebound is not only significant but in truth greater than the savings theoretically possible when equipment becomes more efficient and demand stays constant.

[1] Meadows et al., 1972.

This rebound of more than 100 per cent of theoretical 'engineering savings' is called *backfire* because in this case environmentally motivated efficiency measures are counterproductive. As we will see Jevons's economist predecessors made Khazzoom's point of rebound's necessity in countless passages in their treatises on the principles of political economy. Concerning Jevons's backfire thesis, however, they were largely silent: the question had not yet arisen. Nevertheless, some of their time-tested insights can aid today's search for a definitive answer to how much energy consumption results from greater energy efficiency – an assistance sorely needed in a debate plagued by rudimentary difficulties of definition, taxonomy and methodology (Sorrell and Dimitropolous, 2006)

Some of the open questions are as follows:

- What is energy efficiency? While energy inputs are perhaps easily defined and measured, with what outputs are they to be compared? Are these in physical, monetary or welfare units?
- What is the strict definition of rebound? Of what, exactly, is it a percentage?
- What would a proof of backfire even look like? What, for that matter, would a proof that greater efficiency begets real savings look like?
- Do we even need the concepts of theoretically possible savings, rebound and backfire, or can we, for example, describe a production function then note that if a factor such as energy becomes relatively more productive, demand for it goes up, perhaps more than it would have otherwise?
- Can one fully trace consumers' reactions to their increased purchasing power (income effect) resulting from lower prices?
- Can we, for instance, measure efficiency elasticities of price and then price elasticities of demand for both the goods and services and the primary energy inputs themselves?
- Many approximations exist for *direct* rebound, in other words the energy-consumption increase entailed by increased consumption of goods and services produced more energy-efficiently. But of what use is this in measuring *indirect* rebound and then the environmentally relevant quantity *total* rebound?
- Is macroeconomic empirical work – regression analysis with energy consumption as the dependent and energy efficiency as an independent variable – even possible? (see Polimeni, this volume)
- At what scale is such work fruitful? Are studies limited to sectors, countries or groups of countries (usually OECD) helpful?

- Can standard models of energy consumption continue treating population size and GDP as wholly exogenous, or are they themselves partly a function of energy efficiency?
- Can we assume that human beings will continue to multiply and consume rather than take 'efficiency dividends' in the form of less reproduction, work and production?
- What is the experience of the last three centuries with increasing *labour-input* efficiency? Have these caused less population and employment, in other words was rebound less than 100 per cent?[2]

Discouraged by this state of affairs in rebound research, I took inspiration from the title of Jevons's first chapter, 'The opinions of previous writers', and turned to the classical political economists. To be sure, the writers Jevons surveyed by name were not the 'old-timers' of political economy but rather geologists, politicians and mining engineers. Nevertheless, it seems clear that it was the economics texts of the 19th century that gave Jevons much confidence in his thesis and that discouraged challenges by later economists.[3] By *The Coal Question*'s posthumous third edition of 1906, petroleum had certainly taken the pressure off coal just as coal had taken the pressure off wood (Jevons, pp183-185; Hearn, 1864, pp194-195), but how could succeeding economists resist the chance to wrestle with a paradox unless the consensus saw the question as settled?[4] For Thorstein Veblen, for instance, it was sure knowledge that latent demand would lap up every efficiency gain (1899, pp32, 110, 241), and Harold Hotelling wrote that the goal of resource conservation, traditionally, was pursued by either proscribing production or prescribing inefficiency (1931, p137).

[2] In our epigraph Mill is stating that labour-'saving' production processes have led to greater demand for labour: with α as an efficiency coefficient, $\alpha L\uparrow\uparrow\rightarrow L\Uparrow$. With this passage from Mill Karl Marx opened his chapter 'Machinery and Modern Industry' (p323) and Thorstein Veblen broke for the only time his rule of not quoting or citing anybody (1899, ppx, 111). Jevons's claim, taking E for fuel and β as its efficiency coefficient, is that E = f(βE), namely $\beta E\uparrow \rightarrow E\uparrow$.

[3] The only challenge known to me is that of Mundella (1878).

[4] After granting the physiocrats a germ of truth concerning the priority of land-product surplus, Smith allows himself a joke at their expense (and perhaps that of the present elucidators of Jevons' paradox): '[A]s men are fond of paradoxes, and of appearing to understand what surpasses the comprehension of ordinary people, the paradox which it maintains, concerning the unproductive nature of manufacturing labour, has not perhaps contributed a little to increase the number of its admirers.' (1776, IV.ix.37-38)

With due respect for the efficiency conundrum – how can per-unit efficiency be outweighed by the the sheer number of consumed units? – but with the reassurance that a paradox is only an *apparent* contradiction, let us examine the main works of William Petty (1675), Richard Cantillon (1755), Adam Smith (1776), Jean-Baptiste Say (1803), Lord Lauderdale (1804), David Ricardo (1817), Jean Simonde de Sismondi (1819), Thomas Robert Malthus (1820), John McCulloch (1825), Richard Jones (1831), Charles Babbage (1832), John Rae (1834), John Stuart Mill (1848), William Hearn (1864) and Karl Marx (1887).[5] Jevons mentions, and extremely favourably, only Babbage, Mill and Hearn, but all dealt explicitly with efficiency and named it as a cause in their explanations of the increases in population and wealth so palpable in Europe and North America. Efficiencies of varied provenance were increasing: of the individual labourer, of the organization of production, of the institutions of society, and of the technology of using tools, mills, machines, energy and materials, the last constituting Jevons's and our realm of interest. Although for them the increase in demand for labour, land, coal and metals was no less palpable, on our question of whether this increase in wealth entailed an increase in consumption of these *inputs* to wealth, they shed only indirect light. Yet because their and Jevons's analyses contain all the concepts in today's debate, they offer a chance to clear up our thinking. To be sure, today's bone of contention – whether greater consumption of inputs is *due to* (Brookes, 2000, p356; Moezzi, 2000, pp525-526) or *despite* (Howarth, 1997, p3; Schipper & Grubb, 2000, p370) efficiency increases – was not buried for us until Jevons's book of 1865.

Our 'previous writers' did, however, close in on the gist of our subject in their lengthy debate over *labour* as opposed to *energy* efficiency. Alongside energy, space and materials, no production can do without the input of working hours, and it was indeed in terms of labour productivity that 'progress' in the 'arts' of agriculture and manufacture was defined, as when Jevons refers to the labour-

[5] The named years of publication are those of first editions, cited here except for Say (4th edition 1819), Ricardo (3rd edition 1821), Sismondi (2nd edition 1827), Malthus (2nd edition 1836) and Jevons (3rd edition 1906). *These dates are understood and omitted in all references.* If other writings by these authors are cited, the date is given in the parentheses, for example (Malthus, 1798) or (Say, 1820).

saving invention of gunpowder (p105). Their examples of the making of pins, books, stockings, metal and flour were expressed in terms of output per worker or per man-hour, and analogous to energy inputs one could and did argue that such 'progress' meant unemployment. In his curt rejection of this argument (p140), Jevons was standing on an explicit controversy involving not only Luddites, Owenites and industrialists but also Say against Sismondi and, with more ambiguity, Malthus and McCulloch against Ricardo (and also, later, Marx, Part IV, Ch. XV). Note that in terms of today's debate the position taken by Sismondi that work efficiency causes less total work is analogous to today's position that energy efficiency effects a rebound of less than unity: unemployment, that is, of either labour or fossil fuels. If labour inputs are really saved, *ceteris paribus,* by increasing the efficiency of their use, then any growth in work-hours (including population) must be due to other factors. The contrary position, taken by Say, holds that those immediately and distressingly laid off will find work, albeit usually not in their former occupation. Employment increase can even 'backfire': saving work per unit creates more work overall – our paradox.

This chapter is not organized chronologically but according to concepts and arguments used in today's debate. Statements by the 'old-timers' are enriched with references to similar contemporary ones. The categories are:

- What is output/input efficiency?
- How is the output numerator defined?
- Do efficiency increases cause wealth increases?
- How does efficiency change affect prices and profitability?
- Do efficiency increases amount to a societal free lunch?
- Is rebound proven?
- Do consumers choose further consumption or indolence?
- Is backfire proven?
- How do we deal with population growth?
- Is there technological unemployment?
- What would resource and labour consumption be if technological efficiency had not increased?

Jevons' own conslusions and arguments have been analzyed previously (Alcott, 2005) and are here spread throughout the text.

Please keep these methodological points in mind:

- We are asking whether lower energy or labour inputs per unit of 'product' *cause* lower input consumption economy-wide; our independent variable is thus a ratio. Our dependent variable, on the other hand, is a total or absolute amount, namely of resource depletion or emissions – the values of interest to the environmental problem since, metaphorically speaking, the environment does not 'care about' *ratios* of outputs and inputs or of consumption or pollution per person or per unit of GDP or per rich or poor nation.[6] The formal problem confronting all rebound measurement is that it is impossible to derive an absolute number from a ratio or change in a ratio; without further factual information, an 'extensive' number cannot be deduced from an 'intensive' one. (Giampietro & Mayumi, 2000, pp183-187, 191, and this volume)

- Must we seek *necessary* connections? In our case this would involve assumptions regarding human nature and the particularities of human societies, mainly whether or not consumers, including marginal ones, are satiated. Absolute saturation regarding all goods and services would mean rebound of zero; the income effect would disappear because people would choose to earn and spend less and theoretical 'engineering' savings would equal real savings. But with any positive price elasticity of demand we have some additional consumption. Thus we must always compute or judge the probability that consumers will keep doing more-or-less like their parents did (Jevons, pp192-196).[7]

- A long-time world-wide regression analysis would have to include data on energy efficiency, energy consumption and energy prices. The latter two can be traced with some certainty,[8] but, as we shall see, efficiency presents severe data and definitional difficulties. Since products and activities come and go, over time the 'output' part of our ratio is a moving target (Rosenberg, 1982, 1994; Giampietro & Mayumi, this volume) Must we resort to that workhorse GDP, or can we find *physical* output metrics like 'useful work' or 'exergy' or tons or volumes, perhaps unaggregated? We would also have to control for other factors like non-technological

[6] Most Environmental Kuznets Curve (EKC) studies suffer the fatal flaw of showing ratios on the vertical axis; for critiques see Jänicke et al., 1989; Opschoor, 1995; De Bruyn & Opschoor, 1997; Alcott, 2006, Section 3.5; Luzzati & Orsini, 2007; Giampietro & Mayumi, this volume.
[7] This belongs to our *ceteris paribus* just as did Malthus' two 'postulata' for his principle of population, namely that we need food and that there is passion between the sexes. (1798, p19) And it was Malthus who insisted that following a labour-efficiency increase we could always choose 'indolence' (p258).
[8] See for example Jevons, pp85, 91, 256; Schurr & Netschert, 1960; Cleveland et al., 1984; Schurr, 1985; Smil, 2003, pp6-14, 22-34, 82-88.

efficiency increases[9] and partially-exogenous population and wealth.[10] Nevertheless, few would deny that technological efficiency has increased, and regression analysis offers undisputed insights (Polimeni, this volume).

- *Direct* rebound is a pet subject of study, but in and of itself is not relevant for environmental policy, which needs to know total, or 'economy-wide', rebound adjusted for trade of embodied energy. If nevertheless computed, researchers owe us a demonstration of *how* to use it in calculating *total* rebound. At the minimum, the ambiguity in much literature as to which rebound is being discussed must be eliminated (Greening et al., 2000, pp390-392; Berkout et al., 2000, pp425-431).

Please recall the urgency of this policy question. Depletion and pollution concerns are both inexorable and ethically binding. Among Jevons's many emotional passages are those where he attests the 'religious importance' of the coal question, where he laments living off 'a capital which yields no annual interest' or where he quotes Drayton concerning the fuel voracity of the iron industry: 'These iron times breed none that mind posterity' (pp14, 412, 373, 136). Moreover, Jevons advocated using coal-given prosperity for posterity and for a sort of soft landing at coal's limits (ppxlvi-xlvii, 4, 37, 156, 184, 195, 200, 232, 274-275, 455; Boulding, 1966). Running out of fossil fuels can, however, be spread over a long time horizon or ameliorated by using them as embodied energy in renewable energy installations. But two other sets of concerns stand no postponement: first, and obviously, our present and intensifying planetary greenhouse with its welfare consequences; second, and today often ignored, the side-effects of the machines and infrastructure that enable and embody energy efficiency: noise, accidents, public ugliness, local air pollution, overuse of freshwater, monotonous work, and so on. The community of ecological and environmental economists should waste no more time in delivering a decisive, policy-useful *judgment* on this question: is efficiency part of the solution or part of the problem?

[9] For example stemming from education, training, increased effort, Taylorite factor-floor organization, free trade, scientific norms, private property and further cutters of transaction costs.

[10] For empirical *sectoral* correlations see Jevons (pp193-194, 232, 275, 154, 387-388); Greenhalgh, 1990; Rudin, 2000; Dahmus & Gutowski, 2005; Pearson & Fouquet, 2005; and Herring, 2006.

What is efficiency?

Like all cost-cutting efficiency increases, energy efficiency until recently exclusively served the goals of higher profits and greater average affluence. Insofar as the costs of the efficiency introduction itself could be amortized, they are the business-as-usual maximization of material well-being. This fact is today often downplayed or ignored when energy efficiency increases are singled out to serve the contrasting *environmental* goal of lowering the yearly rate of energy consumption and/or pollution. In whichever way they are perceived, though, they are the starting point and logical centre of our investigation. As such they warrant careful definition and taxonomy.

Throughout the following examination of our authors' definitions of efficiency it is axiomatic that efficiency denotes a *ratio.* The numerator is output and the denominator is (energy) input. 'Efficacy', 'effectiveness' or more ambiguously 'power' denote in contrast the causation of a given amount of output regardless of cost or input. Ontologically, the thing that is more or less efficient is the input. In classical parlance, *power* resided in the inputs labour and nature, measurable in terms of what a certain amount of these could *produce*; the classical production function was $Q = f(\beta M, M, \alpha L, L)$, where M was material/energy, L was labour and the Greek letters were productivity co-efficients.[11] The ubiquitous classical concept of 'productive power' thus implies, like the Latin-based term efficiency, both a 'making' and an 'out of something'. The inverse of efficiency is *intensity* as in the 'material intensity of production' common in today's environmental-efficiency discussion (Schmidt-Bleeck, 1994; Hinterberger et al., 1997; von Weizsäcker et al., 1997). The ratio describes, moreover, the amount of input *per unit* of output. Finally, we are not investigating *consumption* efficiency – for example boiling only the amount of

[11] The *causes* of efficiency however lie perhaps ontologically in capital or organization: the piston, the hot blast and the factory system changed, not coal or iron ore or human beings. Yet classically capital was usually reduced to labour and land, as insisted upon also by Schumpeter (1911, pp20-21, 29, 37, 210-219); this historical topic is the subject of work in progress. See for example Smith, II.iii.25ii, 33-34; Say, p293; Rae, pp91, 256, 258; Mill, pp100, 154, 182.

water needed for the cup of coffee or driving in low gears (Hannon, 1975, p96; Etzioni, 1998, p630; Prettenthaler & Steiniger, 1999; Norgard, 2006)[12]

Of a certain area of land William Petty asked, 'How many Men will it feed?', implying an output/input ratio of food over square metres and holding food per Man constant; he offered data on the agricultural productivity of 'improved Acres' (1675, pp286-288). Cantillon likewise employed this agricultural paradigm either as rice/m^2 or as yield/seed (1755, pp26, 128). Departing from the spatial metric, Petty also attested differences in transport efficiency for 'bulkey Commodities' between 'Water Carriage' and 'Land Carriage', a given output of bulk-times-distance achieved by less (water) or more (land) input of time and endo- or exosomatic energy (pp255, 293-294). Using the examples of flour grinding and printing, his 'Arithmetick' showed, for instance, that a mill, after deducting the labour embodied in its construction, 'will do as much Labor, as Four Men for Five Years together' – an efficiency increase of 20 times; with printing a factor of 100 results; the wagon means that 'one Horse can carry upon Wheels, as much as Five upon their backs' (pp249, 256).

Petty's endeavour is to explain why different European nations of similar size and population have different levels of wealth. Like Malthus (1824, p265), Mill (p100) and Solow (1957), his *explicans* turns out to be not such absolute quantities of land or people but their productivity ratios: England was more efficient and therefore richer than France or Holland. Would that we could today use the method of Petty and Solow for our *explicandum* of energy inputs,[13] a path open to us only if GDP is a good proxy for output; however, both the 'dematerialization' of GDP* and the difficulty of identifying what it is that GDP measures weaken the GDP metric. A godsend would be a time series of two non-trading countries similar in all respects except level of technological efficiency.

[12] *Sufficient* or frugal consumer behaviour, like consumer and production efficiency, also suffers from rebound (Alcott, 2007).
[13] Saunders in passing quotes Solow that 'it's hard to break the habit,... "factor-augmenting" does *not* mean "factor saving"' (1992, p131).

Presaging today's computations of theoretical 'engineering' savings, Petty even reckons the monetary savings from innovations (pp255-257). If costs of production fall then society, left with at least the same amount of flour, printed matter and transport as before, has purchasing power left over.[14] Petty explicitly attests huge labour savings (pp306-308), but his only remark bearing on labour rebound is that as a result of 'improvement' of 'Art' many millions *could* work, but aren't 'disposed or necessitated to labour' (pp249, 307). This hints at a normative issue that confused the discussion between Say, Sismondi, McCulloch, Mill and Marx: given that work is basically a painful, irksome cost, 'unemployment' would be a good thing, and like today regarding energy inputs, we should hope for low or no rebound.[15] But in the absence of political means to spread work equitably, by bestowing purchasing power work becomes a good thing.

As his title and Introduction reveal, Smith's *explicandum* was wealth or 'produce', usually defined materially (I.v, I.viii.21, IV.ix.38, V.ii.e.10).[16] His favourite explanatory variable was the intensive one of 'productive Powers [of Labour]', itself mainly explained by a number of variables, including division of labour, dexterity, work organization and machines, themselves explained by the 'propensity in human nature… to truck, barter, and exchange one thing for another' (I.i, I.ii.1). The only other factor raising 'produce' is an increase in labour's *quantity* (I.intro.3-4, II.iii.32, IV.ix.34-36). Productive *power* is 'the quantity of work [*produce* such as nails], which… the same number of people are capable of performing' and its increase is 'improvement' (I.i.5, I.i.6). Surrounded by increasing population and production, it is not surprising that Smith does not define efficiency the other way around as a constant output with less input: the fact was that *number of pins* rises (by a factor somewhere between 240, 4800), not that society spends fewer hours making pins (I.i.3). Smith also framed productivity in other terms, attesting, for example, the greater

[14] As shown later, this income effect for consumers, if expressed monetarily, could be balanced by a 'loss effect' for producers.
[15] Say spoke for all economists before and since in attesting the disutility of work: 'labour… implies trouble (*une peine*)' (p85; also Smith, 1776, I.v.4, I vi.2; Mill, p25). Veblen made fun of our seeming love of 'irksome' labour (1899, ppix, 18-19, 110).
[16] Also Say, pp61-62; Rae, pp1, 15, 21.

efficiency of water over land transport, his ratio being that of tons 'carried'/man, and, as with his pins, the waters between London and Leith are plied more often (I.iii.3, I.xi.b.5). Jevons later showed that canals lowered coal prices, a case of greater *transport* efficiency raising *coal* consumption (pp121-122, 166).

Smith's denominator was sometimes space (land, soil), with output as food or wool (I.xi.b.2-6, 15, IV.ix.5-6; see also Say, p295), and sometimes mines (thinkable in m^3) of varying 'fertility' (I.v.7, I.xi.c.10-11). The productivitiy of the soils and mines in turn partially determine the efficiency of labour*. Again, output quantity is a function of both the productivity and quantity of the material and labour inputs, capital bein able to increase both productivities. In Say the material factor is the *agens naturels* or *services productifs*, with 'agency' denoting the 'power' and the power's strength determining the agent's 'fertility' or 'fecundity' – here with no reference to labour inputs (pp40, 63-77, 101, 127, 301, 395). Jevons similarly asserted that 'power' was 'in' coal – and that it was power that had through 'increased… efficiency' become *cheap*' (pp145-146, 186). In contrast to later neo-classical neglect of material as a productive factor, he held that 'in our successes hitherto it is to nature we owe at least as much as to our own energies' (p318). Similarly, coal and oil, as well as coal mines and oil 'fields', have varying *inherent* fertility in both chemical terms and terms of ease of access. Ricardo confirmed this ambiguity in the concept of material efficiency by noting that 'improvements in agriculture are of two kinds: those which increase the productive powers of the land, and those which enable us, by improving our machinery, to obtain its produce with less labour' (p80; see also Smith, I.xi.d.1; Mill, pp724-725).

As the pin and nail examples show, Smith by no means neglected manufacturing, for example the 'woollen manufacture', where the ‘working up’ of a 'quantity of materials' was facilitated by 'a variety of new machines' (I.xi.o.12, II.intro.3). His usual denominator was labour input (I.ix.34-35, I.xi.p.4): for land of *given* fertility, then, greater produce results only from the greater 'efficacy of human industry [= *labour*, not manufacture], in increasing the quantity of wool or raw hides' (I.xi.m.14). Note especially that often 'improvement' was expressed

as *less* labour input for 'any particular piece of work' (I.xi.o.1); this formulation holds output constant and is the version of the ratio found in Ricardo, for whom 'economy in the use of labour' or labour's 'abridgement' – by means for instance of engines – meant lower or at least not higher 'charges of production' (pp25, 26, 41, 69, 397). But more often Smith's ratio change held input constant over against a 'great increase of the quantity of work [= *produce*, not labour]' (I.i.5); with good farm capital and the 'best machinery', the same amount and quality of labour made a 'much greater quantity of work' (II.ii.7; I.viii.3, I.xi.o.12).[17] Malthus's rendering of efficiency change likewise described 'a machine in manufactures…, which will produce more finished work with less expenditure than before' (p145).

As with the question of whether a glass is half full or half empty, it matters whether we define efficiency increase as 'less input per unit of output' or 'more output per unit of input'. Although technically equivalent, the former biases our thinking by holding output constant and looking at what could be saved while the latter biases it by highlighting increased output with perhaps no saving. A simple example is replacing an open fireplace with a ceramic stove: one can heat the same amount of space to the same temperature, thus really saving firewood, or use the same amount to heat more rooms warmer.[18] Starting one's chain of thought with the resources still available (lying fallow) for more economic activity after such an efficiency increase is conducive to perceiving large rebound; in Hearn's words, greater efficiency 'sets free a quantity of commodities…or…materials' (p271).

Say's denominators were both labour and materials like land, water, mines, wind and other *agens naturels*. In some cases 'tools and machines… enlarged the limited powers of our hands and fingers'; in China tools for 'drilling, in lieu of the broad-cast, method [of sowing] raises the productivity of land' (pp86, 394). In other cases 'useful machinery' is 'strengthening and aiding the productive

[17] Occasionally Smith explicitly inserted 'capital' as input, thus adding K and γK to the production function, with some given amount yielding 'greater produce' (IV.ix.6; see also Mill, pp100, 154).
[18] This example reveals further outcomes complicating rebound research: 1) the 'saved' firewood can be used for building and is thus not saved; 2) the time 'saved' cutting and stacking wood can be spent for other earning and consumption.

powers of nature', the category within which today's energy efficiency efforts fall (p357). He insisted on the equivalence of ratios with higher numerators (output) and those with lower denominators (input):

> Every saving in the cost [*les frais*] of production implies the procurement, either of an equal product by the exertion of a smaller amount of productive agency [Q_{same}/$expense_{less}$], or of a larger product by the exertion of equal agency [Q_{more}/$agency_{same}$], which are both the same thing. (p301; see also pp86, 88, 201, 204, 395)

However, while he sometimes thus underlines the 'saving of productive agency' (p395), Say's excitement is aroused by the opposite case, namely 'to obtain a larger produce from the same quantity of human labour.—And this is the grand object and acme [*le comble*] of industry' (p86).

Note that one of his examples describes an increase of labour efficiency (αL↑) whereby one man mills as much as ten men previously when a windmill by means of sails (capital or K) is substituted for a tread-mill (pp74-75)[19] While this is clearly an increase in labour efficiency, a case of 'capital enlarging productiveness' (p77), it is *not* an increase in *wind* efficiency (βM↑) – unless starting from zero. Similarly, the first internal combustion engine did not increase the economy of fuel but only the economy of transport in terms of time and labour. Therefore, innovation seems not always subsumable under efficiency. Say does hint at a distinction between an invention – effecting the first-time use of a natural resource – and a new 'process' to 'produce… an old [product] with greater economy', for example a new 'method of reducing the friction of bodies' (pp329, 433).[20] Another, endearing example was the use of sulphuric acid to destroy the 'mucilaginous articles of vegetable oils', which could then be substituted for expensive fish oil, an efficiency increase, in the broadest sense, that 'placed the use of those lamps… within the reach of almost every class' (p116). Here the production of lumens became more efficient, but not that of vegetable oils in producing lumens, because these were not before used. Brindley, on the other hand, observed that the Newcomen engine wasn't efficient enough for coal to replace 'the power of horses, wind, or air' (Jevons, p143). This seems to be a case of increased efficiency in the use of an

[19] Also Jevons, p177.
[20] Also Jevons, pp119, 159, 389.

exosomatic energy source, already stutteringly in use, substituting for others whose efficiency potential had been exhausted.

In discussing rebound we should take this distinction between innovation and technological efficiency seriously: When cutting-tools change from steel to ceramics to carbide (diamonds) these raise cutting efficiency but are not more efficient uses of a given material (Rosenberg, 1982, pp3-4, 65). Malthus's more abstract formulation distinguishes between the invention of machines and the more efficient or 'best' machines' replacing less efficient ones (pp145, 170, 229). With Rae the distinction is straightforward – between 'new arts' and 'improvement in the arts already practiced' (p15; see also pp224, 253). His examples include the plough itself as opposed to better ploughs, macadamized as opposed to stone roads, and better steel tools (pp87, 114, 226-228, 259). He moreover traces the steam engine's invention, improvement and connection with coal mining in terms almost the same as Jevons's (Rae, pp245-248; Jevons, pp142-153.[21] Hearn wrote that

> By [improvement] I mean not the discovery of natural agents previously unknown or unused; but the knowledge of new combinations of agents already known… Those improvements which increase the efficiency of the actual agent [coal] are… distinct from those inventions the utility of which consists in the abridgment of human labour, and the substitutions for it of physical forces. (pp99-100)[22]

First, for instance, India rubber was used to do new things, then became more efficient through vulcanization and sulphur treatment; coal likewise was first found and substituted for charcoal, then made more efficient through the hot-blast in smelting (pp100-102).

The point is that greater resource consumption caused in the first place by inventions should not be booked under rebound. That said, Malthus has a point that inventions sometimes 'are the natural *consequence* of improvement and civilization' (p281). In other words, efficiency increase can cause inventions and

[21] Rae then offers a full-blown analysis in terms of the varying 'capacities' and speed of returns of tools and machines, a function of their cost of production, their durability, and their efficiency (pp87-110), closely resembling that of Malthus (pp71-73). See the analysis of Spengler (1959).
[22] Also Jevons, p188; Schumpeter, 1911, pp297-306. Jevons likewise gives many examples of the enlistment of new agents, as opposed to 'subsequent steps in…improvement' (pp119; 113-134, 147-148)

new uses.[23] At any rate, once more, identifying which efficiency changes to measure is vexed both by new products and by better-'quality' products that may even constitute efficiency decreases*. Rae lamented that while of course 'wealth' had vastly increased since Henry VII, there had been 'not only an increase, but a change' (pp18-19; Giampietro & Mayumi, this volume)

For 'efficiency' Malthus uses not only 'productiveness' and 'fertility' but also the 'facility' or 'difficulty' of producing or obtaining output, again almost always in terms of labour input. At times he emphasizes 'saving of labour' or 'relief from labour' in producing 'a given effect' (pp128, 152, 170), at times a greater produce (pp63; 1824, pp281-283), and once simultaneously greater 'finished work' with 'less expenditure' (p145). Referring to Say, who had written that 'a landed estate may be considered as a vast machine for the production of grain, which is refitted and kept in repair by cultivation; or a flock of sheep as a machine for the raising of mutton or wool' (Say, p86 note, p318 note), Malthus writes:

> The Earth has been sometimes compared to a vast machine, presented by nature to man for the production of food and raw materials; but, to make the resemblance more just, as far as they admit of comparison, we should consider the soil as a present to man of a great number of machines, all susceptible of continued improvement by the application of capital to them, but yet of very different original qualities and powers. (pp144-145; see also pp66, 111, 115, 168; McCulloch, p278)

Say also repeatedly talked of the 'spontaneous gifts of nature' like air, water, light, fire, gravity, pressure and steel (pp63, 71, 75, 86, 286, 362), all susceptible to improvements through 'industry' which must 'awaken, assist, or complete the operations of nature' (pp63-64; 74, 86; Smith, II.iii.3).

Undoubtedly impressed both by Say and what he observed in rural Canada, Rae likewise repeatedly described the material factors of production and their 'productive powers' (pp10-12); he saw 'fire and water transformed into our obedient drudges' (p14); our 'instruments… draw forth stores' of materials, and 'improvement in their construction… put additional stores within reach of the nation' (pp19, 68); a 'North American Indian' improves a 'wild plumb tree' or

[23] Jevons, pp125-130, 141-144, 152-156, 196-199, 245, 368-378, 405; Sieferle, 2001, pp115-124.

dams 'a very scanty brook' (p83). The doctrine perceives an efficiency ratio in that

> the knowledge of the civilized man, compared with that of the savage or barbarian, gives him the power of constructing a much greater number of instruments out of the same materials… (p99)

Just as Petty and Smith had distinguished between the quantity of labour and its productivity,[24] Rae's analysis of 'the action of matter upon matter' separated the 'amount of materials' from 'the efficiency of these materials' (pp112-113), but he is additionally discussing the effect of our 'instruments' on matter's efficiency rather than their greater or lesser *inherent* natural power (pp87-110). 'Instruments' roughly mean capital, in other words anything man-made for the purpose of future production, including fields and even food (in classical terms 'circulating capital').[25]

More than our other authors, Rae thus analyzes material rather than labour inputs (p99). He also conceptualizes the *costs* of efficiency, once even defining efficiency as the total production of an instrument (until its 'exhaustion') divided by the cost of making it measured in units of labour; this is 'the ratio of the capacity… to cost' (pp259, 173, 354-355).[26] Smith had already made the pertinent point that the

> expence which is properly laid out upon a fixed capital of any kind, is always repaid with great profit, and increases the annual produce by a much greater value than that of the support [depreciation] which such improvements require. (II.ii.7)

With an example of more durable pots and pans taken from Smith, Rae shows that in spite of (because of?) their 'becoming more expensive articles', they 'augment… national capital… with advantage to society' and are 'preferred by good economists' (p21). The relevance of the (energy) costs of energy efficiency to rebound is disputed. One solution is simply to deduct these from the savings theoretically possible during the *operation* of the more efficient

[24] 'When we want to double the produce of a field we cannot get it by simply doubling the number of labourers' (Jevons, p195; also Smith, I.intro.1 & 5, I.viii.57, II.intro.4, II.iii.32, IV.ix.34; Say, pp70-71, 303; Mill, pp154, 413-414).

[25] Like McCulloch (pp92-95) Rae took this idea to what he admitted to be an extreme, defining his key concept of 'instruments' to include almost everything having social ontology (resulting from man), including not only tools as conventionally understood but also fields, horses and even food as means of maintaining human capital (pp86-88, 115). Although Mill adopted this broad definition for capital he, like Rae, knew it was too broad for 'general acceptance' (Mill, pp153, 10).

[26] Petty's comparable example had been that 'a Mill made by one Man in half a Year will do as much Labor, as Four Men for Five Years together' (p256).

instrument – thus lowering the quantity of which rebound is a percentage (Jevons, p446).[27]

Rae also distinguishes between 'efficiently' and 'effectually' (in the sense of merely getting a job done well), as when the threshing machine not only saves labour but separates grain *better than* the flail method (p20). This again raises the question of the changing quality of the output in our numerator. Otherwise Rae's treatment closely follows Say's, for example in emphasizing the equivalence of ratios with lower inputs and those with higher outputs (pp66, 92, 131, 259). If anything, his bias is toward the latter: adding to manufacturing capital will

> effect an increase in the productive powers of the community; that is, they give those powers the capability of producing the same quantity of an article at less expense, which certainly must be allowed to be an increase of them. (p70)

This language comes close to a description of an outward shift of a community's *production possibilities frontier*. This is the key assertion of and proof of rebound, if not backfire: we are *enabled* to produce and consume more without more effort, time or material. Whether backfire obtains depends then on consumer behaviour or, in fancier language, the efficiency elasticity of demand.

Rae and Malthus, whose *Principles'* last edition appeared two years after Rae's treatise, were describing the phenomenon that is the starting-point of our investigation: the human ability to get more out of the same amount of nature. Rae's fellow Scotsman McCulloch had a few years earlier written, in the usual terms, that division of labour 'saves labour', but also that 'the invention and improvement of tools and engines' caused a rise in our variable – 'the quantity of raw materials which the same number of people can work up…' (pp96, 99). His term for output* is here materially expressed, moreover in terms of raw material rather than material objects. McCulloch also introduced the method of assuming an overnight economy-wide increase of efficiency then deriving the consequences (pp166-167; Mill, pp723-725). But whereas today researchers at

[27] 'Life cycle' aspects as well as recycling are thus reducible to our output-input efficiency, as demonstrated by Rae in showing that a more expensive but more durable hat saves labour input for the wearer over time (pp200-201). He also gives examples of thick sturdy walls for buildings and good steel for tools, which *both* increase heating or cutting efficiency and last longer (pp109, 114).

Strathclyde, Scotland, similarly assume an 'efficiency shock' of five percent (Allan et al., 2006, pp5, 36), McCulloch's was by a *factor* of ten![28] Say later got rhetorical mileage out of assuming 'that machinery should be brought to supercede human labour altogether' – a labour-efficiency 'shock' of 100 per cent (p88).

Finally, Mill's characterization of efficiency reminds one of *economic* or 'Pareto' efficiency. His causal chain is from an 'extension of the market' (here exogenous) to more 'division of labour' to 'a more effective distribution of the productive forces of society' (pp87-88, 281). In a passage quoted by Hearn (p68) the doctrine presented to Jevons was that 'any improved application of the objects or powers of nature to industrial uses, enables the same quantity and intensity of labour to raise a greater produce' (Mill, p106).[29] However, greater consumption is merely enabled: equally enabled is a real saving of labour and material inputs. We choose between them.

Mill's numerous descriptions of productiveness epitomize the classical analysis (pp93, 99, 106, 118, 129, 153-154, 710, 724).[30] Yet notwithstanding his famous defense of the stationary state (pp752-757), one discerns his preference for the growing economy in his remark that the 'increased effectiveness [efficiency] of labour… always implies a greater produce from the same labour, and not *merely* the same produce from less labour' (p133, emphasis added). He also claimed that 'no one would make or use ploughs for any other reason than… the increased returns, thereby obtained from the ground' (which could pay the plough-maker) (p31). That society as a whole – macroeconomically – could choose the version 'same output less input' is impossible. This reflects the normative position persisting to the present day of the unassailability of

[28] Of course while McCulloch was asking after the effects on quantity of output (Q), believing 'the power of production… a thousand or million times increased' (p167), the Strathclyde group was asking after the effects on the quantity of consumed *input* once it is used five percent more efficiently.
[29] Also Malthus, 1824, p303; McCulloch, p99; Sanne, 2000, p487.
[30] Mill added precision to Ricardo's (p80) two types of agricultural improvements, naming some that 'have not the power of increasing the produce', but only diminishing labour (Mill, p180); these *cannot* raise total output of the farm – here the ratio is output/farm – just as some factory-floor efficiencies might increase not the productivity of the factory unit but only of the labour units.

economic growth, epitomized by Smith's sentiment that Jevons chose for his frontispiece:

> The progressive state is in reality the chearful and the hearty state to all the different orders of society. The stationary is dull; the declining, melancholy. (I.viii.43)

As shown later, Malthus stood alone in objecting that we could indeed choose 'indolence' (pp258, 267-268, 283, 284, 320, 337).

More neutrally, Mill presents his parsimonious theory of production:

> We may say, then, without a greater stretch of language than under the necessary explanation is permissible, that the requisites of production are Labour, Capital, and Land. The increase of production, therefore, depends on the properties of these elements. It is a result of the increase either of the elements themselves, or of their productiveness. The law of the increase of production must be a consequence of the laws of these elements… (p154)

These laws enable both extremes: less work and less resource consumption to the full extent of the 'engineering savings' (Alcott, 2005, p10); or an increase of production and consumption so great that in the end even more work and material resources are *put into* the economic process. Other laws, of human nature and of desires, consumption and reproduction rather than production, determine exactly where, between these extremes, we end up (Jevons, pp25, 191-201; Princen, 1999; Sanne, 2002; Alcott, 2004)

What is output?

Energy economics literature offers many terms for our numerator: GDP, units of 'service', goods and services, various physical aggregates, 'product' and, vaguest of all, 'economic activity'. In measuring 'eco-efficiency' Reijnders names five metrics for efficiency: 'a product (such as the automobile), a service (e.g., transport over a certain distance at a specified speed), an area of need (e.g., clothing), a sector of the economy (e.g., energy supply and demand), or the economy as a whole' (1998, p14). Let us distinguish three broad categories – money (GDP), utility and matter.

- GDP's well-known weaknesses include both ignoring large parts of the economy and valuing some losses as gains (Daly & Cobb, 1989, pp401-455). Specific problems* in energy models are elaborated by Rosenberg (1982, pp23, 55), Jänicke et al. (1989, pp14, 391), Schipper & Meyers (1992, p54), Kaufmann (1992, p54) and Cleveland & Ruth (1998, p35);

Smil 'deconstructs' the concept of energy intensity in monetary terms. (2003, pp66, 71-78, 81).[31] This contemporary monetary metric of choice was not available to Jevons and his predecessors.

- The utility or services concept dominating the rebound literature posits an 'energy service' such as a 'passenger-kilometre'. However, as soon as two people ride in a car, efficiency would then have doubled with no technological change whatsoever, and when a heavy car replaces a lighter car efficiency would stay the same in spite of a technological change especially relevant to environmental impact. Utility moreover ignores *waste*, an anthropocentric concept referring to tons of gases and materials; at best, integrating them is a complicated exercise in computing and deducting 'externalities'. Should these be excluded from our numerator, or not? For an incisive account of this concept's difficulties see Ayres (1978, pp50-67). Furthermore the common concept of 'energy services' is invalid: since *every* service (and good) involves embodied and/or operational energy input, any distinction over against 'non-energy services' must be arbitrary.[32]

- A physical metric (including waste) could be in tons, volume, chemical elements, heat, exergy, work defined in terms of force and direction, or non-aggregated lists of products. Jevons used the metric 'useful work' per pound of coal, expressed in 'foot-pounds', and defines thermodynamic efficiency (pp137-138, 148, 186).[33] A manageable literature has taken up this challenge, usually with the hope of aggregation[34] and sometimes attempting to integrate physical and utility/monetary metrics.[35] Also, probably all of the technological efficiency changes striven for in efficiency policies are susceptible to physical definition: instead of a 'passenger-kilometre' a ton-kilometre, instead of 'heating comfort' a certain temperature rise in a given volume of space over a given time and instead of a kilowatt hour the amount of primary energy involved. A remaining problem is that, due to the first law of thermodynamics, output always equals input, leaving us without a ratio! Perhaps only a list of consumer and capital goods (and their utilization rates) remains, and an *aggregated* physical metric is impossible.

After ironically speaking of 'the mass of solid goods and useful services', Joan Robinson sought a non-monetary metric for technical progress, choosing the

[31] Also Robinson, 1954, p18; Radetzki & Tilton, 1990, p21; Manne & Richels, 1992; Saunders, 2000a, p442; Alcott, 2006, Ch6.
[32] See Howarth, 1997, p3; Wirl, 1997, p14; Berkout et al., 2000, p427; Saunders, 2000b; Binswanger, 2001, pp120-121; Sorrell & Dimitropoulos, 2006, p3.
[33] Sorrell & Dimitropoulos, 2006, pp3-9.
[34] For example Ayres, 1978, pp53-66; Birol & Keppler, 2000, p461; Ayres & van den Bergh, 2005, pp102-103; but see Weisz et al., 2006, p681.
[35] For example Cleveland & Ruth, 1998, p35; van den Bergh, 1999, pp551, 559; Dahlström & Ekins, 2006, pp509, 515-518.

capital/labour ratio with capital physically measured as the 'value of a stock of goods in terms of commodities' or 'equipment, work-in-progress [and] materials' and labour measured in terms of time (1956, pp19, 122, 65). She concluded, however, that 'index-number ambiguities' are insoluble (pp64-65, 115) and that 'economics is the scientific study of wealth, and yet we cannot measure wealth' (p24).[36] The classical economists similarly suffered in defining wealth. Its *genus* was material objects or 'produce' for Smith (I.viii.3-9, 21 & 23, IV.ix.38, V.ii.e.10), Malthus (pp20-28, 294) and Mill (pp48-49, 55). Ricardo also regarded 'riches' in terms of the ubiquitous physical concept of 'necessities, conveniences and enjoyments' (sometimes 'luxuries' or 'amusements') which had nothing to do with exchange values in terms either of money or other objects (pp275-276). Rae criticized Smith's various definitions* and tended to treat wealth and capital synonymously and as physical commodities and instruments (pp387-388, 14, 18, 21, 171). But all acknowledged some *differentia* specifying their (use or exchange) *value* to us. In Lauderdale's typical phrase wealth was 'the abundance of the objects of man's desire… [including] lands, houses, shipping, gold and silver coin, wares, merchandise, plate, furniture, etc.' (pp146, 42; see also Malthus, p29; 1824, pp258-259). In avoiding Lauderdale's criticism (p152) of Smith's emphasis on durable objects, Mill chose with questionable ontology 'permanent utilities… embodied in human beings, or in any other animate or inanimate objects' (p48).

If the definition of output* must include some quality or value element, let us ponder Say's reaction to his insight[37] that was to become the first law of thermodynamics. He said that we confront a

> mass of matter [not]… capable of increase or diminution. All that man can do is, to re-produce existing materials under another form, which may give them a utility they did not before possess, or merely enlarge one they may have before presented. So that, in fact, there is a creation not of matter, but of utility; and this I call *production of wealth*…. [Production is] creation, not of substance, but of utility, so by consumption is meant the destruction of utility, and not of substance, or matter. (pp62, 387)[38]

Moreover 'creating matter… is more than nature itself can do' (p65). More than the others, Say thus emphasized utility rather than goods themselves and

[36] Also Solow, 1957, pp316-317; Rosenberg, 1982, pp23, 55; Victor, 1991, pp204-206.
[37] And Cantillon's (p2).
[38] Also McCulloch, pp61-63; Rae, pp15, 81-83; Mill, pp25, 27, 46.

posited such a thing as 'immaterial product' (pp62, 119-124). But he also held that 'the ratio of the national revenue, in the aggregate, is determined by the amount of the product, and not by its value' and never denied that some material was necessary for utility to adhere to: the services of musicians and lawyers, for instance, required their food and education as well as wear and tear on their capital (pp295, 122, 124; see also Malthus, 1824, pp258-259; Costanza, 1980).

If we include usefulness in our definition, how do we deal with unwanted objects and waste, both of which affect the environment? While Mill's idea of waste was physical, including 'diving-bells sunk in the sea' and the use of too many horses and men to plough a field (pp8, 51-52), and Hearn gave the example of close parallel mine-shafts (p208), Rae's chapter 'Of Waste' deals with the *economic* inefficiencies of fraud, trade restrictions, transaction costs and so forth – making the point in a very different way that less efficiency means less production and consumption* (pp313-319). Among the classical economists there was moreover some debate as to whether only anthropogenic objects counted as wealth, or also 'air, water, and light' (Say, p63; Mill, pp8, 153), opening up the water/diamonds discussion over use value as opposed to exchange value and scarcity. Jevons, incidentally, counted waste-reduction as an increase of 'economy' (pp30, 271-272).

A large contemporary literature thus discusses various metrics for 'environmental' (or energy) efficiency in terms of *desirable* output.[39] The attempt is to abandon purely quantitative measures and introduce the 'quality' of energy, as when 'exergy' is taken to measure input (Ayres & Warr, 2005). Similiarly, following a general exposition of energy and its transformations, Jevons offered this definition of efficiency:

> Now it will be easily seen that the resources of nature are almost unbounded, but that economy consists in discovering and picking out those almost infinitesimal portions which best serve our purpose. (p163; see also p170)

He elsewhere uses the ratio of 'useful work' to 'power' (pp186-187), thus risking conflation of physical and utility criteria just as Ayres & van den Bergh do when

[39] Also Ayres, 1978, pp39-66; van den Bergh, 1999; Birol & Keppler, 2000, p461; Schipper & Grubb, 2000, p369.

insisting on counting high-entropy 'process waste', the difference between 'work done by the economic system [and] the exergy of all inputs'* (2005, p103). For if exergy is already defined anthropocentrically as useful or available energy and can, unlike energy, be destroyed (Ayres, 1978, p52), it itself becomes a (desirable) output. Even taking mass instead of energy in both numerator and denominator, where the output is mass 'embodied in the physical output (finished products)' (Ayres & van den Bergh, 2005, p103) does not escape the fact that to identify 'finished products' we need some anthropocentric criterion.[40]

McCulloch, after acknowledging the law of the conservation of matter, laid down the principle:

> And hence we are not to measure consumption by the magnitude, the weight, or the number of the products consumed, but exclusively *by their value*. Large consumption is the destruction of large value, however small the bulk in which that value may happen to be compressed. (p 390; also p61)

But can environmental studies ignore what is produced but has *no value*?[41] All oxidized molecules, unless they are recycled by means of further energy inputs, as with CO_2 sequestration, must count as 'final' output. Space heating can be defined by the time needed for the space to return to (lower) ambient temperature from that desired, but the higher-entropy energy is nevertheless part of output. Lumens rather than 'lighting services' can be measured, but light pollution and heat as a 'by-product' are also output. Steel cannot be made without producing 'scrap'. While a 'first-law' ratio must be one to one, 'efficiency' must be variable, perhaps leaving no way around some concept of utility: We must measure inputs only over against the output we *like*. While GDP thus aggregates unsatisfactorily, physical or combined physical/utility metrics have not yet been found.

[40] The terms for mass and measure in German are very close (*Masse, Mass*); 'pound' in English is both weight and money, as is *peso* in Spanish (Smith, I.iv.10).

[41] Mill distinguishes between the 'absolute waste' of 'unproductive labour' lacking even the utility of 'pleasurable sensation', and the relative waste of 'productive labour' when for instance 'a farmer persists in ploughing with three horses and two men… when two horses and one man are sufficient' (pp50-51; also p28; Say, pp42-43, 121, 404; Alcott, 2004, pp770-776).

Correlation of efficiency and output increase

Whatever 'output' turns out to be, Jevons's immediate predecessor Mill captured the classical conclusion that, formally, productiveness is equivalently lower land/labour inputs and 'increased produce', what everyday observation showed was a 'greater absolute produce' or a 'long succession of contrivances for economizing labour and increasing its produce' (pp180, 189, 706; Smith, I.xi.g.20, II.iii.33).[42] By 1865 Jevons could write:

> When we turn from agriculture to our mechanical and newer arts, the contrast is indeed strong, both as regards the numbers employed and the amounts of their products. But the subject is a trite one; every newspaper, book, and parliamentary return is full of it: factories and works, crowded docks and laden waggons are the material proofs of our progress. (p244; see also pp187-188)

But as Rae lamented, 'all we see is the sum produced by [change], the fact of the increase being more easily ascertained than the manner of it' (p19). Thus, while in dozens of passages all writers previous to Jevons tied increased efficiency to increased product, they seldom formally declared necessary connection. Mill for instance claimed,

> It will be seen, that the quantity of capital which will, or even which can, be accumulated in any country, and the amount of gross produce which will, or even which can, be raised, bear a proportion to the state of the arts of production there existing; and that every improvement, even if for the time it diminish the circulating capital and the gross produce, ultimately makes room for a larger amount of both, than could possibly have existed otherwise. (p98)

'Room is made', production *possibilities* increase, but there is no claim of universal causality.

Jevons praised Hearn's *Plutology* as 'both in soundness and originality the most advanced treatise on political economy which has appeared' (p168 note). Hearn, himself explicitly building on Rae (see, for example, Ray, p260) and Justus von Liebig (1851), described the shift in the production possibilities frontier as follows:

> It is self-evident, as Mr. Mill has observed, that the productiveness of the labour of a people is limited by their knowledge of the arts of life; and that any progress in those arts, any improved application of the objects or powers of nature to industrial uses, *enables* the same quantity and intensity of labour to raise a greater produce. (p68, emphasis added; see also p184)

[42] Mill implies a broader array of formal expressions for efficiency when talking of greater produce 'without an equivalent increase of labour' (p180): the term 'equivalent' implies elasticities, in other words efficiency also increases, for example, in the extreme case where both input and output go down, but the former percentage-wise more than the latter.

Jevons then contributed two new thoughts: for 'labour' he substituted 'coal'; and he asked the further question, not of the effects of efficiency on produce, but on input consumption. The doctrine is on the one hand curiously conditional but on the other insistent that growth is impossible without improvement in the 'arts' – a conclusion reached by later growth theorists by statistical means. (see, for example, Solow, 1957 and 1970)

Remember that the classical concept of efficiency included individual, organizational and institutional as well as material or technological types, often attested in one and the same passage.[43] Seminal statements of 'economic' efficiency also appear explicitly, wherein what the society does produce is compared to what it could produce given a certain natural fertility and a certain technology (Smith, I.ix.15; Say, pp166, 380; Malthus, pp266, 304). And although not to my knowledge discussed in classical economics, remember that land and labour inputs are mutually dependent; that is, all terms on the right side of $Q = f(\beta M, M, \alpha L, L)$ influence each other, rendering reduced-form expressions inadequate.

Petty already gave a version of classical 'growth theory' in seeing 'greater consumptions' not only of food but of 'Coaches, Equipage, and Household Furniture' due to 'improved Acres' and population density – and even a growth of postage due to transport efficiency (pp287-305; Smith, I.xi.c.7). Cantillon presaged Malthus's principle of population and the concept of carrying capacity using as examples both people and mice: population followed sustenance, itself a function of land and mine fertility as well as the energy and labour of the population (pp43-44, 46, 62, 128). He conceived labour in terms of both its quantity and efficiency r*, but in any case greater population and greater consumption entailed each other. As shown later, this idea that people are also produced – fully conceptualized by later writers – is crucial for the discussion of the Jevons paradox; models of (energy) consumption or of wealth in general

[43] For example Petty, pp256, 261-264, 300; Smith, I.xi.o.1, IV.ix.17 & 34-35; Say, pp127, 286, 432-438; Rae, pp29, 310, 327; Mill, pp87-88, 133-135, 184-189, 706, 723; see also McCulloch, pp73-143.

that treat population entirely exogenously necessarily significantly underestimate rebound.[44]

If wealth was 'necessaries, conveniences, and amusements' or the goods affording these (Smith, I.intro. 1-4, I.v.1 & 9; IV.i.17-18), no writer except Ricardo failed to both attest and laud their *growth*.[45] Rae for instance made the empirical claim that the wealth of Great Britain was ten times what is was under Henry VIII (pp14, 18). Smith saw the gradual spread of 'universal opulence' (I.i.10) or at least 'almost universal prosperity' (I.xi.g.20) and by mid-century for Mill economic growth was axiomatic:

> Production is not a fixed, but an increasing thing. When not kept back by bad institutions, or a low state of the arts of life [technology], the produce of industry [labour] has usually tended to increase; stimulated not only by the desire of the producers to augment their means of consumption, but by the increasing number of consumers [population]. Nothing in political economy can be of more importance than to ascertain the law of this increase of production. (p153)

Jevons reported many statistics on the increase of both per capita wealth and population since the 18th century (ppvi, 196-200, 457). He moreover both extolled and feared for Britain's prosperity and greatness: the 'Age of Coal' enabled

> [a] multiplying population, with a constant void for it to fill; a growing revenue, with lessened taxation; accumulating capital, with rising profits and interest. *This is a union of happy conditions which hardly any country before enjoyed, and which no country can long expect to enjoy…* It is the very happiness of civilisation… [Without coal] we must… sink down into poverty [and] *begin a retrograde career*. (see pp2, 11, 231, 201, 454-460; emphasis original)

He quotes Baron Liebig that civilisation 'is *the economy of power*' (p142; see also p156). And since for Jevons the greater economy of coal increased not only affluence but its quicker exhaustion, *'We have to make the momentous choice between brief but true greatness and longer continued mediocrity'* (p460). The discussion today likewise contains the political hope that energy efficiency is the key to both happy prosperity and sparing natural resources. Now, as then, we should not ignore our normative assumptions.

That the correlation between consumption and efficiency reflected causality was, to be sure, denied by no one. Clarity has reigned from Petty onward on the

[44] See Smith, I.viii.18, 23, 39, IV.ix.12; Malthus, pp61, 130, 180; Mill, p33; Jevons, p213; Giampietro, 1994.
[45] For example Smith, I.viii.21, IV.ii.9, IV.ix.38; McCulloch, p99; Rae, p7; Mill, p159.

point that *quantities* of land, labour or capital do not suffice to explain the size of the wealth of a nation.[46] The causal factor for greater wealth, produce, riches, returns and surpluses was higher productive powers of land and labour, often aided by invention and machines.[47] Mill even asserted that 'improvements,… by the very fact of their deserving that title, produce an increase of return' (p93) and elsewhere *equated* 'the magnitude of the produce' with 'the productive power of labour' (p413). Today also this seems self-evident.

Even for Malthus, despite his observation that we could always choose to really save through indolence or non-consumption, the doctrine was that 'the increased powers of labour would *naturally* produce an increased supply of commodities' (p63, emphasis added). Say said that although lower input and greater output are mathematically 'the same thing' both are 'sure to be followed by an enlargement of the product'; for both producers and consumers 'every thing saved is so much gain' (pp301, 357). It was Rae who, while concurring with the standard causal chain from increased capital through increased division of labour to increased wealth, shifted the emphasis from organizational to technological efficiency: it is 'the intention of the inventive faculty', which creates and improves instruments, to increase 'necessaries, conveniences, or superfluities' and make 'larger returns', 'supplies', 'absolute capital and stock', 'revenue' and 'supply for future wants' (pp67, 258-260; Brewer, 1991). For him the 'effective desire of accumulation' was necessary but not sufficient for the 'increase of stock and capital', which also required 'augmentation', that part of growth occuring 'through the operation of the principle of invention' (pp205-209, 264 and Chs. VI & VII; see also Malthus, p339). And since invention results in higher efficiency a causal arrow goes from efficiency to 'larger provision… made for the future wants of the whole society' (p165). Since instrument formation means cost and 'sacrifice' in the present, without 'some future greater good…

[46] For example Cantillon, pp19, 62-63; Smith, II.iii.32, IV.ix.34; Malthus, p252; Rae, pp12-13; Marx, p358; Solow, 1957.
[47] For example Smith, I.viii.3, III.i.1; Ricardo, pp273-274; Say, pp71, 86, 295; Malthus, p296; McCulloch, pp97-102, 166-167, 411; Jones, pp237-250; Rae, pp15, 99, 216, 253; Mill, pp88, 98.

the instrument… will not be formed', yet this results only from greater efficiency*. (pp19, 110-118, 171)[48]

If pressed, no classical economist would have claimed that he was describing mere correlation rather than causality. And since all wealth requires material inputs, in any description of the 19th-century economy rebound is certain and low rebound out of the question. Without efficiency increases and given only certain *quantities* of material resources and labour, not much more in the way of food or any other goods can come into existence; and unless we enjoy these (labour-)efficiency increases wholly and exclusively as the less work and more leisure that they enable, there is *some* consumption that wouldn't be there without the 'improvements'. And this consumption depends on labour and material inputs. Until Jevons, however, the doctrine did not attest backfire. Before surveying classical views on the magnitudes of this new consumption of goods and services, and their inputs, let us relate their descriptions more closely to today's debate by introducing the term *prices* and the *price falls* that result when a good is produced with lower input.

Price falls

In 1815, Ricardo wrote to James Mill, 'I know I shall soon be stopped by the word price, and then I must apply to you for advice and assistance' (Sraffa, 1951, pxiv). And no classical economist failed to warn of conflating money and wealth, with the term 'value' leading an ambiguous life between the two.[49] But being economists, our previous writers could not avoid monetary terminology altogether. While prices *can* be physically expressed as exchange value in terms of other commodities, the monetary metric is convenient. Thus all of them presaged the point made by Khazzoom in re-opening the debate over the Jevons paradox that efficiency increases have a 'price content' (1980, p22). In Smith's analysis for instance

[48] Also McCulloch, pp187-188; Mill, pp133-134.
[49] For example Smith, I.xi.c.7, II.ii.23; Say, pp240-248; Ricardo, pp274-275; Sismondi, vol. 1, pp373- 387; Malthus, pp97, 255; Mill, pp71-72, 410; also Robinson, 1956, pp18, 24, 65, 122; Binswanger, 2006.

> It is the natural effect of improvement… to diminish gradually the real price[50] of almost all manufactures… In consequence of better machinery, of greater dexterity, and of a more proper distribution of work… a much smaller quantity of labour becomes requisite for executing any particular piece of work; and though, in consequence of the flourishing circumstances of the society, the real price of labour should rise very considerably, yet the great diminution of the quantity will generally much more than compensate the greatest rise which can happen in the price. (I.xi.o.1; I.viii.57; Jones, p238; Marx, p379)

Although Smith here succumbs to the tendency to exogenize a vague 'flourishing circumstances of the society' (a rise in GDP), the point is well made that because improvement more than compensates rising input prices, output prices fall. He then considers rising and falling prices of 'rude material' and metal inputs together with a comparison of output prices over three centuries (I.xi.o.2-13; see also Barnett & Morse, 1963)

In Malthus's formulation, 'We all allow that when the cost of production diminishes, a fall of price is almost universally the consequence' (p60; see also pp87-88, 145).[51] Favourite empirical examples were cottons in general and stockings in particular.[52] Printed goods likewise had experienced a palpable, undeniable 'reduction in price' per copy (Say, pp302, 88). Rae liked the example of more efficiently produced, cheaper bread (p259; see also Mill, p181), while Mill liked Say's 'still stronger example' of playing cards (p123). Babbage's example of riveted tanks showed an extreme price fall (p100). Malthus even distinguishes between 'a fall of price necessary… to prevent a constant excess of supply contingent upon a diminution in the costs of production' and one following 'an increased supply of commodities'*, albeit itself due to 'the increased powers of labour' (pp56-57, 63).[53]

The necessity of this step from efficiency increase to price fall – and then on to consumption increase – lies in producer behaviour. '[C]ompetition of producers brings the price of the product gradually to a level with the charges of

[50] Roughly, 'real', 'inherent' or 'natural' prices were long-term and determined by costs of production, while 'market' prices were shorter-term results of supply and demand only; 'nominal' prices were in terms of money (gold and silver). See Mill's '*necessary* price, or value' (p471).
[51] Also Jevons, pp120, 140, 154, 156, & ch V.
[52] For example Say, pp300, 303; Ricardo, pp25, 52; Malthus, pp281-282; McCulloch, pp117, 176, 278.
[53] In such passages from Smith, Say, Ricardo and Malthus several questions are often discussed simultaneously: 1) why and how wealth increases, 2) how it is distributed between rent, wages and profits, and 3) how supply, demand and price interact in the short term.

production', wiping out temporarily high profits (Say, pp395, 93). Of course patents must first run out or secrets be divulged, but eventually 'The grinding of corn is probably not more profitable to the miller now than formerly; but it costs infinitely less to the consumer' (Say, p89). For Rae, still in monetary terms, each of

> the venders of a commodity wishes to sell as much as possible, and as he can do so most readily by underselling his neighbors, the price gradually falls under a free competition, until the dealers in it receive only the profits that the effective desire of accumulation, and the progress of improvement in the society measures out to them. (p307)[54]

Mill also pointed to producers' 'power of permanently underselling' which can 'only… be derived from an increased effectiveness of labour' (p133; see also p495). Jevons relied on this argument from profitability (pp8, 141, 156) and names the 'series of inventions' by Bessemer, Gilchrist and Thomas as 'modes of economy which, in reducing the cost of a most valuable material, lead to an indefinite demand' (p390).

Rae solves the profits 'paradox' thus: 'Now I apprehend that high profits springing from improvement, can never lessen the sale of goods either at home or abroad, for they do not occasion a rise in their price, but rather a fall in it' (p263). Domar's later version is that 'a rapid growth of [Kendrick's] Index [total factor productivity] in any industry reduces the prices of its output, and thus stimulates sales' (1962, p605).[55] Malthus once chastises Ricardo for ignoring this point and in effect assuming that profits stayed high – 'at *cent* per cent' (p291). Moreoever, whatever the profit-maximizing price policy of a monopolist is, even monopoly profits get spent because, in Say's terms, producers are also consumers (p89; see also Smith, I.xi.o.4; Ricardo, pp386-387, 392-394). This fact casts doubt on today's view that rebound is low in sectors where 'market failures' are high (Grubb, 1990b, pp783-785; 4CMR, 2006, pp5, 14).[56]

[54] Also Say, p300; Jevons, pp8, 140-142; Schumpeter, 1911, pp297-306.
[55] Also Mill, pp133-134; Hotelling, 1931, p137.
[56] Grubb cryptically adds that 'When energy price or availability constrains demand… the apparent savings from using more efficient technologies would be largely offset by the macroeconomic response – the tendency to use more energy services because they are made cheaper' (1990b, p783). That is, he attests rebound approaching 100 per cent in run-of-the-mill cases.

The classical axiom is that prices of output are the sum of the prices of inputs or charges of production (Ricardo, p397). Say talks of 'a real fall of price, or *in other words*, a reduction in the price paid to productive exertion' (p303, emphasis added).[57] Output and input prices are exactly proportional. Supply costs fall, prices fall, effective demand rises, number of units sold rises; these are today's 'price and income effects' of efficiency increase.[58] Rebound is then a function of this new quantity sold (Q) after deducting another quantity no longer sold (Q_s) of units, if any, *for which* the newly more efficiently produced item is substituted.

As for price elasticity of demand, Malthus writes that 'The increase in the whole value of cotton products, since the introduction of the improved machinery, is known to be prodigious', offering the empirical evidence of 'the greatly increased population of Manchester, Glasgow, and the other towns where the cotton manufactures have flourished' (p192; see also pp281-282; Rae, p292). Say observed the same for 'Amiens, Rheims, Beauvais,… Rouen and all Normandy', where there had first been 'loud remonstrances' over the annihilation of local industry, and gives further examples of 'prodigious' price falls (pp147-148, 300-304); he then can't resist imagining prices' falling to zero, which would at once be 'the very *acme* of wealth' and the death of political economy as a science (p304). Finally, Mill makes the empirical macroeconomic claim of falling prices over two centuries, 'accelerated by the mechanical inventions of the last seventy or eighty years' (p182). All these economists were describing, via price falls, a very high 'efficiency elasticity of demand' (Sorrell & Dimitropoulos, 2006, p7). But demand for what? For the newly cheaper good? For everything, as described in the next section? For our topic of interest, material and labour inputs?

[57] Say indeed calls *'prix'* a measure of *'valeur'* and *'valeur'* a measure of *'utilité'* (p62). But if prices reflect utility and utility is very different from costs of production, then prices confuse environmental analysis. Utility is not an environmentally relevant concept. If Mill is right, however, that prices in their long-run movement to 'natural price' reflect utility to perhaps 1 per cent and efficiency (or difficulty or cost of production) to 99 pre cent* (pp462-464), then this objection falls and prices are a satisfactory proxy for environmental impact.

[58] For example Wackernagel & Rees, 1996, pp127-128; Wirl, 1997, p41; Binswanger, 2001, p120.

But as long as we are thinking in monetary terms, what happens to the *total* amount of money paid for the goods now cheaper *per unit*? This is the new price per unit times the new quantity (P x Q) as opposed to the new quantity physically measured (Q) and was termed by Say *'le montant total'* or sum total (p450). He gives a descriptive example of (direct) backfire in the 'art of printing':

> By this expeditious method of multiplying the copies of a literary work, each copy costs but a twentieth part of what was before paid for manuscript; an equal intensity of total demand, would, therefore, take off only twenty times the number of copies; probably it is within the mark to say, that a hundred times as many are now consumed. So that, where there was formerly one copy only of the value of 12 dollars…, there are now a hundred copies, the aggregate value of which is 60 dollars, though that of each single copy be reduced to 1-20 [one twentieth]. (p302; see also Rae, pp216, 249-250)

Taking price and costs as equal and substituting 'labour time' or 'material amount' for 'dollars', we can estimate input consumption. Substituting 12 hours of labour for 12 dollars, if the price elasticity of demand is in a ratio of 20:100, in the end 60 hours of labour are demanded and labour input demanded is higher than it *would have been* without the efficiency increase. Say could analogously describe 'direct backfire' regarding energy efficiency today.

Still referring only to manufactured goods made cheaper, rather than the whole economy, Malthus writes that by means of

> the introduction of improved machinery, and a more judicious division of labour in manufactures… not only the quantity of manufactures is very greatly increased, but… the value [price, cost] of the whole mass [P x Q] is augmented, from the great extension of the demand for them both abroad and at home, occasioned by their cheapness… The reader will be fully aware that a great fall in the price of particular commodities… is perfectly compatible with a continued and great increase, not only in the exchangeable value of the whole produce of the country, but even in the exchangeable value of the whole produce of these particular articles themselves. (pp135, 314)[59]

While Khazzoom's demonstration of rebound assumed *any* positive price elasticity of demand (1980, p22), Malthus describes a very high elasticity. The point, in Say's words, is that 'every real reduction of price, instead of reducing the nominal value of produce raised [P x Q], in point of fact augments it' (p303). P x Q for product or sector X increases following productivity-induced price falls. Following Say that work is done by nature (for example fossil fuels) as well as human beings, in other words it commits 'productive exertion' (pp40, 63, 74-75, 90, 245 note; Rae, pp246, 256-258), we have, for any X, P_{Labour} and $P_{Material}$

[59] Also (Malthus), pp190-192, 296, 319-322, 339; Jones, pp237-239; Babbage, pp112, 232-233; Rosenberg, 1982, p106.

both as costs and prices. Q x $P_{Material}$ after an efficiency increase is compared with that before, but where Q rises by any amount, direct rebound is proved. The relative degrees of growth of Q and $P_{Material}$ determine the size of this direct rebound.

But what happens in sectors not affected by productivity increases? Or, how can the 'value of the whole mass' (economy-wide) increase unless *money supply* increases? If it doesn't, *less* demand would have to accrue to goods that did not enjoy a productivity increase.[60] And monetarily, the consumer's gain is perhaps equal to the producer's loss. Monetary analysis also entails identifying cases where substitution of the newly cheaper good for another good occurs then measuring both the price and the substitution elasticities. Should rebound research discard the veil of money and deal only with the ratio of Q to joules, with each unit q measured physically – rather than compare ratios of P x Q to joules before and after an efficiency shock, as with the concept of energy intensity of a unit of GDP?

Mill's heroic attempt to sort out the concepts of price, use value, exchange value and their application to particular goods as opposed to the whole mass (pp455-459) relegates 'price' to goods' relationship to money and 'exchange value' to an economic discourse dispensing with 'money', namely to 'the command which [a good's] possession gives over purchaseable commodities in general' (p457).[61] He also made the point that 'if inventions and improvements in production were made in all commodities, and all in the same degree, there would be no alteration in [relative exchange] values' (p710). But Say (pp303-305) and Malthus (p135), even when using the term 'exchange value', were talking not sectorally of the 'values' or prices of things relative to each other but of the 'whole mass', conceivably tradable for other things in other countries. Criticizing his predecessors in all but name, Mill concludes that 'All commodities may rise in their money price. But there cannot be a general rise of values' (p459).

[60] If the whole mass is X + Y where X is the newly more efficiently-produced good and Y is all else, then $\Delta P \times Q_x$ would equal $\Delta P \times Q_y$.
[61] Perhaps Mill's father James led Ricardo to the distinction between the 'net produce' or 'riches' – which always increase with efficiency – and the other 'value of that net produce' (P x Q), which 'may not… increase' (pp391-392, 16), leaving J.S. Mill the work of deciphering.

Mill has a point. If, as Malthus somewhat circularly said, 'exchangeable value is the relation of one object to some other or others in exchange' (p51), then the concept of exchange is of no use in analyzing the *growth* of wealth. And to the extent that prices are an abstract proxy for millions of exchange values, monetary concepts are likewise perhaps inapplicable. In Malthus's words,

> When it is said that the exchangeable value of a commodity is determined by its power of purchasing *other goods*, it may most reasonably be asked, *what goods?* It would be absolutely impossible to apply all goods as a measure. (p97 note)

This does not prevent Malthus elsewhere from talking of 'the increase in the exchangeable value of the whole produce estimated in labour' (p192) and even of the value of money expressed in labour (p144 note). And after listing shortcomings of *any* metric of value, which remind one of today's criticisms of GDP, he opines that we can't do without one, if only to compare the total products of different economies (pp247-248, 255-256). Such difficulties in integrating concepts of exchange and price with the 'value of the whole mass' arise in Rae's struggle with the paradox that a limited amount of exchange value in terms of prices coexists with greater wealth [deflation], and he concludes that the relevant magnitude was the *physical* increase in 'absolute capital and stock' (pp259-260).[62]

Whatever happens economy-wide, price falls and underselling of more energy-efficient goods raises their relative attractiveness. Jevons used the common classical phrase that coal 'commands' iron and steam (p2; see also Martinez-Alier, 1987, p161); whatever is more cheaply or powerfully commanded – products requiring iron and steam – enjoy higher demand. If I can commute to work by bicycle, bus, horse, car or on foot, more efficient motors give the car the edge. This implies high economy-wide or total rebound and even backfire even if economy-wide Q or P x Q does *not* increase* – a pure 'substitution' effect distinct from income effects and the derived categories of 'direct' and 'indirect' rebound.

[62] Efficiency and its consequences can be grasped physically. Smith resorts to this method in solving the paradox that 'improvements in… productive powers' are accompanied not only by price falls but 'in appearance' price rises of many things including labour (I.viii.4; also I.i; Malthus, p215).

The purely physical perspective shows us that the actual amount of coal or oil for a steam engine, car or light bulb over its 'lifetime' drops, enabling us to ask after the price or exchange-value effects on the *inputs themselves* rather than the outputs such as a pair of stockings: the initially lower demand at constant output lowers the price of the input, in turn raising demand for it relative to all else. Combining this aspect with the income effects discussed in the next two sections, Burniaux et al., for instance, write,

> There is a link between technical progress, output prices and real income… [T]he rise in energy productivity tends to lower the relative price of energy, thereby generating a substitution effect from non-energy towards energy goods. In the aggregate the increase in autonomous energy efficiency also generates a real income gain that leads to higher consumption of both energy and nonenergy goods. The net result is that emissions do not decrease in the same proportion as the AEE [autonomous energy efficiency] increase because the energy conservation effect is partly compensated by the relative price and income effects. (1995, p246; Hearn, p99)

The size of this input-price-determined rebound depends also on the price elasticity of supply, for example of petroleum. At any rate, empirical work must analyze energy prices as well as efficiency change and change in the consumption of 'outputs'.[63]

Societal income effect

Smith's 'invisible hand' is not all that invisible but a name for the mechanism starting with efficiency increase, in other words with dexterity, division of labour, trade and machines 'directing… industry in such a manner as its produce may be of the greatest value' – a 'greatest value' variously called 'wealth', the 'annual revenue of the society', its 'power of purchasing', or 'the exchangeable value of the whole annual produce of its industry'. (IV.ii.4, 9, I.iv.13, I.vi.17, II.ii.21) This revenue or purchasing power – concepts closer to consumption than to production – was divided between labour/wages, capital/profits and land/rents, raising the allocative question which for Ricardo was the defining *explicandum* of political economy (pp 5, 347).[64] While the others likewise devoted much effort

[63] Saunders shows that backfire is consistent with constant prices when the productivity of energy rises in the a production function with capital, labour, energy and material (1992).
[64] The term 'purchasing power' is explicitly found in, for example, Smith, I.v.3, I.xi.m.19-20, II.ii.21; Malthus, pp42, 49, 53, 80; McCulloch, pp171, 177; Mill, pp67, 458.

to this issue,[65] their main concern was the question of scale, or the size and growth of production and consumption (Daly, 1992). Malthus even castigates Ricardo by name, writing that 'to estimate rent and wages by the *proportion* which they bear to the whole produce, must, in an inquiry into the nature and causes of the wealth of nations, lead to perpetual confusion and error' (p164). More politely, Say remarks of landowners and capitalists, 'The world at large may be content to comprehend, without taking the trouble of measuring, their respective shares in the production of wealth' (p74 note).

Rae conceptualized this crucial distinction with the terms 'acquisition' and 'augmentation' (sometimes 'accumulation'); the former is a mere shift of wealth from one person, group or nation to another, the latter a rise of the total (or per capita average) amount of produce (pp11-12, 24, 260, 264, 307; Say, p85; Malthus, p35; Mill, p62). Following Say (Say, pp70, 117-118) he names this 'creating wealth', claiming that 'the ends which individuals and nations pursue, are different. The object of the one is to acquire, of the other to create' (Rae, p15). 'As individuals seem generally to grow rich by grasping a larger and larger portion of the wealth already in existence, nations do so by the production of wealth that did not previously exist' (p12). Not Smith's invisible hand, but the state or 'community' must promote and encourage 'progress of art', the 'discovery of new arts' and the 'discovery of improvements in the arts already practised in the country [efficiency]' (pp15, 12).

The clearest description of the augmentation of societal income is Say's:

> [T]he aggregate utility will be augmented; the quantum of products procurable for the same [total] price will be enlarged… But whence is derived this accession of enjoyment, this larger supply of wealth, that nobody pays for? From the increased command acquired by human intelligence over the productive powers and agents presented gratuitously by nature. A power has been rendered available for human purposes, that had before been not known, or not directed to any human object;… or one before known and available is directed with superior skill and effect, as in the case of every improvement in mechanism, whereby human or animal power is assisted or expanded. (p299)

He sharpened this concept of greater wealth that nobody pays for by expanding his system boundary to include the whole world, describing sales between nations as mere acquisitions in Rae's sense* and insisting that 'the general

[65] For example Smith, I.vi.6-18; Say, pp15, 77; Malthus, Book I, Chs. III, IV, & V; Mill, p235.

stock of wealth, existing in the world… can only be enlarged by the production of some *new* utility' (p305, emphasis added; see also p318). Malthus later described this shift of the societal supply curve caused by lower costs of production as a change in the 'conditions of supply… advantageous to the consumer' (1825, p303).[66] Mill as well identified this rise in 'general purchasing power', caused for instance by 'an invention… made in machinery, by which broadcloth could be woven at half the former cost'; for him, simply, 'all… improvements make the labourers better off with the same money wages…' (pp457-458, 751).

'Wealth, that nobody pays for'? Is there a free lunch after all? (Jones, pp288-289) Evidently yes, once inventors, research-and-development and embodied inputs are deducted as costs. The point is that the source of this lunch is efficiency. This productiveness inheres either in nature, as with increased dexterity or education of humans and the substitution of naturally better materials, or in our ways of organizing themselves and their materials by 'forming' or 'transforming' matter for utility (Cantillon, p2; Say, pp62, 65, 387; McCulloch, p61; Rae, pp81-83).[67] Virgin land, virgin mines and population growth can bring greater output for constant input per unit, but efficiency brings this result even when the limits of these things are reached, or closely approached.

Once Say had fingered this win-win process he defended it with sarcasm against Galiani and Forbonnais, whose idea that one's gain must be another's loss underpinned the 'systems of all the short-sighted merchants' (pp16, 31 note and 70). More didactically and again reflecting the struggle with the term 'value' he wrote,

> If different commodities have fallen in different ratios,… they must have varied in relative value to each other… There is this difference between a real and a relative variation of price [*valeur*]: that the former is a change of value, arising from an alteration of the charges of production; the latter, a change, arising from an

[66] Also Mill, pp477-487; Khazzoom, 1980, pp22-24.
[67] Ecological economics parts company with Say when he declares these 'spontaneous gifts of nature…, neither procurable by production, nor destructible by consumption' to lie outside the realm of political economy (pp63, 86). In the frequent classical emphasis on exchange, as in environmental economics' emphasis on allocation, one sees that new biophysical facts, and limits, necessitate a re-definition of political economy (Boulding, 1966; Daly, 1992).

> alteration of the ratio of value of one particular commodity to other commodities. Real variations are beneficial to buyers, without injury to sellers; and *vice versâ*; but in relative ones, what is gained by the seller is lost by the purchaser, and *vice versâ*. (p304; see also Mill, pp457-458)

His summary:

> In commercial, as well as manufacturing industry, the discovery of a more economical or more expeditious process, the more skilful employment of natural agents, the substitution, for instance, of a canal in place of a road, or the removal of a difficulty interposed by nature or by human institutions, reduces the cost of production, and procures a gain to the consumer, without any consequent loss to the producer, who can lower his price without prejudice to himself, because his own outlay and advance are likewise reduced. (p101; see also pp89, 301)

He later offers a numerical example expressing purchasing power in terms of 'the quantity of his own particular product' instead of money: once stockings are made cheaper, a sugar tradesman can get the same number of stockings as before for less sugar (p300). He then assumes simultaneous price falls of sugar and stockings, asking whether we are now

> authorized to infer, that this fall is a positive fall, and has no reference or relation to the prices of commodities to one another? that commodities in general may fall at one and the same time, some more, some less, and yet that the diminution of price may be no loss to any body? (pp300-301)

McCulloch also argued against the claim that consumers' gains might be balanced by producers' losses, and in his own jibe at Ricardo also saw win-win cases where 'profits… would have risen, without their rise having been occasioned by a fall of wages' (p372). Distribution is here not the issue.* Malthus also empirically attests rising profits and, moreover, lest anyone fear slacking demand, capitalists' rising expenditures 'in objects of luxury, enjoyment, and liberality' (p293). While arguing that labour efficiency causes unemployment, Sismondi had ignored this point that demand for labour originates from profits as well (Sismondi, vol 2, pp335, 322-324). Jevons later added that even when profits through competition fell to their minimum, there is a net gain to society (1871, p254).

This possibility that suppliers' profits as a total amount of purchasing power could fall seemed real. Charles Babbage 'strongly pressed upon the attention' of the manufacturer to very carefully 'ascertain how many additional customers he will acquire by a given reduction in the price of the article he makes' lest profits turn to losses, adding that falling prices would force firms to make further

efficiency gains (pp98-99; see also Say, p87).[68] Old goods produced more expensively, for instance, must be sold at a loss (albeit a gain for the consumer) (Say, pp305, 390; Ricardo, p274; Malthus, p282).[69] The profits of the producers of material inputs – for example of energy or mining companies – could also fall since they experience at least initially lower demand and must lower prices; however, the rebound caused by lower input prices in the longer term restores profits.

Smith was describing this economy-wide income effect of newly enabled, costless prosperity by writing for instance that 'all things would have become cheaper in reality'; 'improvements in mechanicks… are always regarded as advantageous to every society'; the surpluses of 'the country', division of labour and trade with 'the town' raise the revenue of *both* (I.viii.4, II.ii.7, III.i, IV.vii.c.88, IV.ix.51; IV.ix; Mill, pp119-122). For Rae 'all instruments at the period of their exhaustion return more than the cost of their formation' (p118) and 'good bread… produced… with half the labor and fuel… would not benefit the bakers exclusively, but would be felt equally over the whole society' (p259). Efficiency is like corn – one seed yields 100 seeds. Jevons likewise later wrote that profits falling to their minimum means that everything is cheaper, and that 'either the labourers themselves, or the public generally as consumers, gather all the *excess of advantage*' (1871, pp254, 257, emphasis added). Finally, Mill quoted Rae's description of the contrasting 'stationary state' society of China (Mill, pp168-169) and referred to the free increase of wealth caused by 'improvement' as an 'increased means of enjoyment' (p724).

If we now make the attempt to approach rebound while ignoring prices, as suggested in the last section, we can for instance assume that before an efficiency increase production is 10X, at 10 joules/X, equaling 100 joules of input. If afterwards there are 12X, at 9 joules/X, this equals 108 joules of input,

[68] Say also noted that efficiency is the *result* of a profusion of taxes (p473), a point likewise clear in today's debate wherein Pearce, for instance, notes that through efficiency some of the effect of eco-taxes is 'taken back' (1987, p14).
[69] A friend of mine who wholesaled slide rules once had to throw away several thousand slide rules with the advent of calculators – a process difficult to integrate into this gain/loss calculus and again raising the question of *undesired* output or waste.

in other words backfire. Our writers often claimed that this is the normal case: we can produce not only 10 per cent more X if efficiency increases 10 per cent, but 20 per cent. Is this something coming from nothing? It is easy to accept that 11X are produced, using 99 joules of input, in other words rebound of 100 per cent. But whence the twelfth X? Seen monetarily, the source can only lie with increased purchasing power due to X's price fall, with purchasing power seen as an income effect, or taken away from rival factors of production like labour, or due to a price fall *of the input joules* when the supply function for joules does not shift.

One argument for the possibility of backfire thus does not depend on the concepts of societal income effect or even growth of total output: if a given factor of production becomes more powerful, to use the classical term, demand for that factor will increase relative to rival factors of production whose productiveness remains the same (Marx, p354; Brookes, 1990, 2000; Saunders, 1992, 2000). Brookes writes,

> The market for more productive fuel is greater than for less productive fuel, or alternatively… for a resource to find itself in a world of more efficient use is for it to enjoy a reduction in its implicit price with the obvious implications for demand [for fuel]. (2000, p355)

Jevons similarly concluded his chapter 'Of the Economy of Fuel' by asserting necessary rises in both input and output consumption:

> And if economy [efficiency] in the past has been the main source of our progress and growing consumption of coal, the same effect will follow from the same cause in the future. Economy multiplies the value and efficiency of our chief material; it indefinitely increases our wealth and means of subsistence, and leads to an extension of our population, works, and commerce, which is gratifying in the present, but must lead to an earlier end. Economical inventions are what I should look forward to as likely to continue our rate of increasing consumption. (p156)[70]

Again, if we interpret the societal income effect monetarily we encounter the paradox that a consumer with a new park of efficient appliances pays less to the electricity supplier, lowering his income, purchasing power or consumption. Where a high price elasticity of demand is claimed (for example Say, p302, or Malthus, p192), we could encounter a bookkeeping quantity 'that nobody pays for': if before an efficiency event 36 units are sold at £2 each, P x Q = £72, and

[70] Brookes concurs with Jevons that, *ceteris paribus,* really saving such a material lowers affluence (1990, 2000).

where price elasticity of demand is 1, 7 x £1 also = £72. If price elasticity of demand is 2, then 144 units sold yields £144. Whence the additional £72? If withdrawn from sectors previously favoured we must deduct this from rebound. Again, it seems clearer to simply realize that *more output* is here at the same cost in physical inputs. If societal purchasing power is £1,000,000 and newly more efficiently produced things are now £1,000 cheaper, we have a monetary hole that gets filled up with material goods.

High rebound

One conclusion till now is that efficiency-induced consumption of output, entailing as it does *some* input, proves rebound. Before looking more closely at classical descriptions of high rebound, some taxonomy is useful.[71] Increased society-wide purchasing power results from the increased efficiency of producing an average unit of a good of type X, as opposed to Y, representing all other goods. At this moment, as Malthus said, 'there must be a considerable class of persons who have both the will and power to consume more material wealth than they produce…' (p319). This new demand can be

1. for additional X by consumer A, a previous consumer of X;
2. for some Y by consumer A;
3. for additional X by a new 'marginal' consumer B;
4. for some Y by consumer B, who after consuming some X retains some 'consumer surplus'; and
5. for leisure – in the extreme, all consumers choose to lower their purchasing power to the full extent of engineering savings.

Aside from these variations of the income effect, a more efficient production factor is substituted for another one – a 'substitution' effect.

The first and second cases are called 'direct rebound', today's workhorse example being that if my new car uses less petrol per kilometre, my existing purchasing power allows me to drive more kilometres; this is Khazzoom's 'own'

[71] See Sanne, 2000, pp488-489; Binswanger, 2001, p122 note.

price elasticity of demand (1980, p22). The total cost of the car including its use has dropped, freeing income.

The second case is in Malthus's words 'distinct from' the first and pertains when 'the commodity to which machinery is applied is not of such a nature that its consumption can extend with its cheapness' but 'there would be a portion of revenue set free for the purchase of fresh commodities' (pp282-283). Given higher purchasing power, when the price elasticity of demand for the newly cheaper good is low, *indirect rebound* results (even with high efficiency elasticity of price). In unfairly claiming that Malthus missed this point McCulloch offers a clear description of it:

> Suppose the price of cottons were reduced in the proportion of ten to one; if the demand for them could not be extended, it is certainly true, that nine-tenths of the capital and labourers engaged in the cotton manufacture would be thrown out of *that* employment: But it is equally certain, that there would be a proportional extension of the demand for the produce of *other* branches of industry. It must be remembered, that the means by which the purchasers of cottons formerly paid for those that were high-priced, could not be diminished by the facility of their production being increased and their price reduced. They would still have the *same capital* to employ, and the *same revenue* to expend. (pp177-178, 188)

The indirect rebound of the second a

nd fourth categories above is likewise in Say's remark that:

> A new machine supplants a portion of human labour, but does not diminish the amount of the product; if it did, it would be absurd to adopt it. When water-carriers are relieved in the supply of a city by any kind of hydraulic engine, the inhabitants are equally well supplied with water. The revenue [purchasing power] of the district is at least as great, but it takes a different direction… [I]nferior charges of its production [mean that] the revenue of the consumers is benefited. (pp86-87)

Say's translator Prinsep is explicit: Our revenues are enlarged by lower costs of production of X, and we are free 'to employ them upon some other object [types 2 & 4], or upon an enlarged production of the same object [types 1 & 3]' (p296 note). Ricardo likewise, quoting Smith's attestation of unlimited desires for all but food, brings the example where 'improved machinery, with the employment of the same quantity of labour' quadruples 'the quantity of stockings' [but] the demand for stockings were only doubled', leading to 'the production of some other commodity' (p387). In Malthus's version:

> … though the wills and means of the old purchasers might remain undiminished, yet as the commodity could be obtained without the expression of the same intensity of demand as before, this demand would of course not then show itself. (p55)

Based on this consumer surplus, demand could and would show itself elsewhere.

In the classification above good Y could also be a *new good*, i.e. one not existing at the time of the efficiency increase but whose supply and consumption depends on that efficiency increase. Examples are legion – railways following better steam engines and cheaper steel, or emails following the more efficient use of electricity in data transmission. Transportation, milling, printing, and glass-making all count for Rae as consumption areas opened up by efficiency (pp116-117, 245-250, 291-292) while Hearn presaged Jevons' emphasis on new uses and products in observing that:

> In many districts the price of coal has been reduced from thirty to forty per cent; and the purposes to which it has been applied have consequently been largely increased. (p274)

Jevons repeated this general point (pp141-142, 197) and named new uses of coal in metallurgy and transportation (see footnote 23). Martinez-Alier points out that instead of substituting for coal, electricity increased demand for it (1987, p88; also Jevons, p181) Sanne draws the exact parallel with new applications of electricity as it becomes cheaper due to increased efficiency of coal-fired plants (2000, p489).

Jevons called this new consumption 'the reaction and mutual dependence of the arts' as when Darby's powerful-blast smelting oven required the substitution of coal for water (pp372, 385). And the fundamental phenomenon of productivity's opening up *new* markets had been sketched early on by Smith (I.xi.c.36) and filled out somewhat by Say (pp89-90) and Rae (pp245, 247, 253). But granted that 'many of the more important substitutions are due to coal' (Jevons, p134), what are the net effects? Coal's efficiency meant that fewer horses and oats were consumed due to railroads, just as today efficiencies of electricity production and use mean perhaps that fewer paper letters are sent due to e-mail. Again, how much of this new consumption should be booked under rebound is hard or impossible to decide, and while today it is implicitly subsumed under 'economy-wide' rather than either direct or indirect rebound it is *ignored* by all rebound studies. Fresh study is warranted of Babbage, von

Liebig (1851), Cipolla (1962), Rosenberg (1982, 1994), Clapp (1994) and Sieferle (2001).

As for the direct rebound of the third case, where marginal consumer B purchases X, all writers observed that the efficiency-induced cheapening of X enables marginal consumers to buy it. Say writes,

> Suppose that… knit-waistcoats of woollen [cost] 2 dollars each;… those who should have but a dollar and a half left must… go without. If the same article could be produced at one dollar and a half, these latter also might all be provided and become customers; and the consumption would be still further extended, if they should be produced at one dollar only. In this manner, products formerly within the reach of the rich alone have been made accessible to almost every class of society, as in the case of stockings. (p288)

How much of this demand is truly new, in other words not shifted from Y, however, is an open question. Malthus echoes Say, talking of

> such an extension of the demand for the commodity, by its being brought within the power of a much greater number of purchasers, that the value of the whole mass of goods made by the new machinery greatly exceeds their former value'. (p281; see also p314)

In terms of I = PAT (that is, environmental Impact = Population x Affluence x Technology), $(P \times A)_{after} > (P \times A)_{before}$. Sismondi reminded these economists however that since the laid-off workers have no more purchasing power the market extension is inhibited (vol 2, pp316-317, 326-327, 251). We can moreover ask Say and Malthus what the marginal consumer had done with his one dollar and a half before the price of the waistcoat fell from 2 dollars. Whatever would have been consumed without the cheapening of the waistcoat is no longer consumed, constituting to some degree a win-lose situation after all.

Also part of 'indirect' rebound is the fourth category where a marginal consumer's demand for X evidences some consumer surplus, leaving some purchasing power for Y. Taken together the four categories equal total rebound or the societal income effect. Today all rebound researchers acknowledge the difficulty of tracing these effects from direct rebound through indirect rebound to what really matters, namely total or economy-wide rebound. Wirl notes that excluding 'marginal consumers' gets around the 'conservation [or] energy paradox' but yields an underestimation of rebound (1997, pp19-32, 36, 112). Roy believes that there is 'a whole range of behavioral responses of the end-

users that follow any technical efficiency improvement all of which may, however, not be traced empirically' (2000, p433).[72] What then are we to make of Allan et al.'s assertion that 'rebound is an empirical issue… It is simply not possible to determine the degree of rebound and backfire from theoretical considerations alone…' (2006, pp21-22; see also pp3, 10)?

Malthus already saw this. Assuming, he said, that latent demand in the affected sector was low:

> To what extent the spare capital and labour thrown out of employment in one district would have enriched others, it is impossible to say; and on this subject any assertion may be made, as we cannot be set right by an appeal to facts. (p286)[73]

It is likewise doubtful whether we today have the data necessary for demonstrating that a given increase in one sector constitutes indirect rebound from efficiency in another sector. Direct rebound is apparently more easily estimated. Some sectoral studies calculate high direct or even total rebound (Dahmus & Gutowski, 2005; Allan et al., 2005; Herring, 2006; Fouquet & Pearson, 2006) while some, implicitly or explicitly offering support to the environmental efficiency strategy, show total rebound as low as 26% and thus real energy savings (4CMR, 2006, pp6, 9, 66).[74] Other studies attest low rebound while however limiting themselves to direct rebound and moreover equivocating between direct and total rebound (Greening et al., 2000; Berkout et al., 2000).

The fifth category, wherein leisure is chosen, is crucial: rebound *can* be zero if price elasticity of demand is vertical. As shown in the next section, only Malthus gave weight to this possible reaction, the others agreeing with Rae that 'improvement [is] absorbed by vanity' (pp289-290) or with Jevons that children will continue doing as their elders did (p199). That is, humankind finds itself in a condition far from satiation. To attest rebound is merely to assert that, short of total consumer satiation, theoretical input savings are never fully realized, whereas backfire depends upon a strong low-satiation premise. The sixth

[72] Also Khazzoom, 1980, p32; Grubb 1990a, pp235, 195; Rosenberg, 1994, pp165, 166; Schipper & Grubb, 2000, pp368, 383, 387; Sorrell & Dimitropoulos, 2006, p3.
[73] Say at times also eschewed empirical study (p102 note), a view shared less categorically by Ricardo (1820-1822, pp362-363).
[74] Also Howarth, 1997, pp4, 7; Schipper & Grubb, 2000, p384.

category of 'substitution' effects, which includes the effects of a fall in the *input* price relative to other prices, received little explicit attention in Jevons and the classical literature.

The classical input metric was not always of labour, land area and mines, but of materials as well. Mill once observes that 'the tendency of improvements in production is always to economize, never to increase, the expenditure of seed or material for a given produce' (p99). And renewable energy resources concern him in his analysis of the invention of – *nomen est omen* – windmills and watermills (p28). Rae was more explicit:

> Every society possesses a certain amount of materials capable of being converted into instruments. The surface of its territory, the various minerals lying below the surface, its natural forests, its waters, [etc.]… are all to be regarded as materials, which, through the agency of the labor of its members, may be converted into instruments. The extent of the power, which the inhabitants of any state may possess, to convert into instruments… is however variable; and increases… as their knowledge of the properties of these materials and of the events [products], which in consequence of them, they are capable of bringing to pass, increases. [K]nowledge… gives… the power of constructing a much greater number of instruments out of the same materials. (p99)

This leads to Rae's long chapter on invention, which always serves efficiency either by changing 'materials' or applying given 'materials' to new arts (pp258-259, 224-229, 242-249). In Smith (I.xi.o.12), Say (pp89-90) and Rae (pp242-244) the insight is that without inventions, water and wind are not used at all, but that once the right equipment is available, the energy is used more and more. The bridge from invention to efficiency is established by Jevons's closely related, ironic observation on the difference between Savery's coal-burning steam engine and those of Newcomen and Watt: Savery's '*consumed no coal, because its rate of consumption was too high*' (p143). Once invention has occurred, the consumption of an input is positively proportional to the efficiency of its use – yielding rebound for sure but not necessarily backfire.

Surplus and indolence

Malthus threw a monkey wrench into the mechanism of output growth described by Smith, Say, Ricardo and himself:

> It has been supposed that, if a certain number of farmers and a certain number of manufacturers had been exchanging their surplus food and clothing with each

> other, and their powers of production were suddenly so increased that both parties could, with the same labour, produce luxuries in addition to what they had before obtained, there could be no sort of difficulty with regard to demand… But in this intercourse of mutual gratifications, two things are taken for granted, which are the very points in dispute. It is taken for granted that luxuries are always preferred to indolence, and that an adequate proportion of the profits of each party is consumed as revenue. The effect of a preference of indolence to luxuries would evidently be to occasion a want of demand for the returns of the increased powers of production supposed, and to throw labourers out of employment. (p258; see also p9)

Greater consumption following increased efficiency is not necessary but only what 'almost always happens' (p170). What if, he asks, 'after the necessaries of life were obtained, the workman should consider indolence as a greater luxury than those which he was likely to procure by further labour…' (p268)? 'The peasant, who might be induced to labour an additional number of hours for tea or tobacco, might prefer indolence to a new coat' (p283). In richer societies, likewise, it could be that the 'habits and tastes of the society prevent… an… increased consumption' and 'the demand for material luxuries and conveniences would very soon abate' (pp288, 191; see also Mill, p105) – the vision of today's sufficiency strategy (Alcott, 2007).[75] Even for poorer societies like that of North American Indians, whose 'proverbial indolence' he attests, the rule is that 'to civilize a savage, he must be inspired with new wants and desires' (Malthus, pp103-104).

Malthus's population essay already notes these limits to demand for produced goods (1798, pp95, 120). However, he knows that the 'laws of nature have provided for the leisure or personal services of a certain portion of society', and that the tastes and habits of this leisure class (Veblen, 1899), perhaps due to exposure to items of foreign trade, can sustain a good deal of luxury consumption (pp317, 284). The issue here is not 'Say's Law' – that overproduction is only temporary – but human psychology. Jevons explicitly maintained that we cannot count on consumption or reproduction desires subsiding, and even claims this to be 'the gist of the subject' (p194). He knew that his argument that fuel's very economy was part of the problem needed assumptions about desires, saturation and demand elasticities: the 'natural laws ['of growth'] which govern… consumption' (pp25, 275) must be firmly assumed in our models of energy use. To be sure, he frames the classical view both of

[75] His claim is also empirical: 'experience amply shows' this (pp284, 268).

population increase and the desire for greater and greater material wealth in the conditional:

> If our parents doubled their income, or doubled the use of iron, or doubled the agricultural produce of the country, then so ought we, unless we are changed either in character or circumstances. (pp193-194; see also pp232, 275)

But nothing else is to be *expected* (p199). Similarly, many later writers have conjectured that *if* consumer saturation were a fact, or *if* we would value the leisure dividend of efficiency increases more, problematic overconsumption and high natural-resource rebound would be mitigated (Schor, 1992, 1999; Grubb, 1990a; Sanne, 2000, pp489-490, 494-495).

Although Say once for some reason writes cautiously that 'the productive agency thus released *may* be directed [*peuvent être employés*] to the increase of production' (p295, emphasis added), aside from Malthus only took this possibility of non-consumption seriously:

> If the labourer's command over the necessaries and comforts of life were suddenly raised to ten times its present amount, his consumption as well as his savings would doubtless be very greatly increased; but it is not at all likely that he would continue to exert his full powers. In such a state of society workmen would not be engaged twelve or fourteen hours a day in hard labour, nor would children be immured from their tenderest years in a cotton-mill. The labourer would then be able, without endangering his means of subsistence, to devote a greater portion of his time to amusement, and to the cultivation of his mind. (pp167-168)

Our epigraph shows the mainstream view that indolence is seldom chosen. To be sure, Mill attributes this 'less leisure' only partly to unlimited desires; rising population and diminishing agricultural returns to labour also figure (p12). And indeed if Malthus's own principle of population is taken seriously, and 'multiplication…may be regarded as infinite', demand for more efficiently produced food and clothing is likely to dominate over the 'power to consume… in idleness' what has already been produced (Mill, pp154, 34). Smith's view also ran contrary to Malthus's: while the stomach is limited, our further willingness to purchase is not (I.xi.c.7), and in the end himself seconded this without reservation (pp167-178; see also Petty, p307). The doctrine thus stood that 'the limit of wealth is never a deficiency of consumers, but of producers and productive power' (Mill, p68).

For Rae, likewise, 'All instruments exist solely to supply wants' (p166). As proof he offers a psychological theory *why* indolence loses out to accumulation: 'The

increased facility of production has… in a great measure also been absorbed by vanity' (p289). While he takes leisure and indolence seriously, and regards labour as a cost (pp98, 118, 141, 209), display consumption wins out (p271); indeed his chapter 'Of Luxury' recounts in detail the human tendency towards display, competitive, or prestige consumption (pp265-292), presaging Veblen's famous 'conspicuous consumption' (1899, pp32, 110, 241; Sismondi, vol 2, p318). This relative consumption is by definition limitless (Alcott, 2004, pp776-778).

Unlike Veblen, Rae quotes extensively from other authors like Pliny, Smith, Heinrich Friedrich von Storch and Say's similar but less systematic analysis in his chapter 'Of Individual Consumption – Its Motives and Effects' (Say, pp 401-411). In a nascent appeal for sustainability Rae praises care for 'futurity', 'frugality' and saving in the interests of the 'social affections' (pp60, 265, 275), strongly seconded by Jevons in his worry for posterity over coal's depletion (pp3-6, 373, 412, 454-455). But these succumb in great degree to vanity:

> At length, in some quarter or another, an improvement began to be perceived. What do we find to have been the most prominent accompaniment of this change? Is it a diminished expenditure – and increased parsimony – a frugality before unknown? I believe not.' (p23)

Mill even built this power of consumption over investment and indolence into his very definition of political economy, which 'makes an entire abstraction of every other human passion and motive; except those which may be regarded as perpetually antagonizing principles to the desire of wealth, namely, aversion to labour, and desire of the present enjoyment of costly indulgences' (quoted by Bladen in Mill, pxxix). Our fifth (no-)rebound category stands as an extreme: at absolute consumer saturation every efficiency increase would bestow upon us free time and upon posterity relatively more resources.

Backfire

Malthus was the economist most worried about market glut or an insufficient 'extension of the market' (pp285, 288).[76] But he too in the end attested high rebound and even, with regard to labour inputs, *direct backfire* – for instance in the case of cotton goods where 'notwithstanding the saving of labour, more hands, instead of fewer, are required in the manufacture' (p281). He accordingly defended himself against being 'classed with M. Sismondi as an enemy to machinery' (p282 note). Between the first and posthumous second edition of his *Principles*, 1820 and 1836, many writers had banned thoughts of consumer satiation, if they occurred at all, to the realm of theory. recaps the story thus:

> Accumulation [of capital] and division [of labour] act and react on each other. The quantity of raw materials which the same number of people can work up increases in a great proportion, as labour comes to be more and more subdivided; and according as the operations of each workman are reduced to a greater degree of identity and simplicity, he has… a greater chance of discovering machines and processes for facilitating and abridging his labour. The quantity of industry [labour], therefore, not only increases in every country with the increase of the stock or capital which sets it in motion; but, in consequence of this increase, the division of labour becomes extended, new and more powerful implements and machines are invented, and the same quantity of labour is thus made to produce an infinitely greater quantity of commodities. (p96; see also Jones, pp237-244)

Three points of note in this passage are as follows: seems to be considering material rather than labour inputs. Next, circulating as well as fixed 'capital' is endogenized (see also pp94-95 and Mill, p63). Third, if material output ('commodities') really grows as much as he says, then backfire is very likely. Babbage likewise discusses efficiency in material/energy as well as time terms, and regards the growing economy as too obvious to mention (pp100, 112, 222, 273; see also Mill, p106). Rae concurs with McCulloch in almost the same words (pp67-68).

If McCulloch were to visit us today, would he regard his term 'infinite' as an exaggeration? He would in any case see the understatement in his view that the 'admirable machinery invented by Hargreaves, Arkwright, and others [enables] us to spin an hundred or a thousand times as great a quantity of yarn as could be spun by means of a common spindle' (p99). As Rae imagined, were 'some

[76] Mill also asked who would buy the 48,000 pins now produced every day in Smith's factory, going on to name some conditions for a large market including population and transportation infrastructure (pp129-130).

one of the men of olden time, waked from the slumber of the tomb and raised up to us', to witness even a tenfold yield, 'he might well demand how the power had been acquired that had wrought so great a change' (p14).

Let us take McCulloch literally: Without the efficiency granted us by the machines, we would make *much less* yarn requiring much less cotton. In Jevons's version 'economy renders the employment of coal more profitable, and thus the present demand for coal is increased… [I]t cannot be supposed that we shall do without coal more than a fraction of what we do with it' (pp8, 9, 141, 190). This thought is radical. Today's environmental efficiency strategy claims that an input's more efficient use lowers its rate of consumption. The inverse/corollary of this is that were processes to become *less* efficient, we* would consume the input at a *higher* rate. Or had technological efficiency increase remained unchanged – stopped, say, around 1781 with 'the introduction of Watt's engine, the pit-coal iron furnace, and the cotton factory' (Jevons, p270) – we would according to the strategy's assumptions today consume an hundred or a thousand times as much – or infinitely more – labour or cotton or fuel than we do today after over two centuries of efficiency increase. To maintain that rebound is less than 100 per cent one must defend this conclusion.

Jevons asks, 'Could we desire that Savery, Newcomen,…Darby,… Brindley… and Watt' had not increased our industrial efficiency (p457)? Say envisions the case of frozen technology in imagining that a given road exists still as just a path with much less transport efficiency. He says that we can't measure the 'gain' to consumers of the road because with no road 'the transport would never take place at all' (p443 note). Malthus similarly wrote, 'If the roads and canals of England were suddenly broken up and destroyed… there would be immediately a most alarming diminution both of value and wealth' (p243) – and implicitly of input consumption. As seen above, Jevons's comparable example was that Savery's steam engine '*consumed no coal, because its rate of consumption was too high*'… It was so uneconomical, that, in spite of the cheapness of coals, it could not come into common use' (pp143, 118; Rae, pp247-248). Marx would

later conclude that without machines for example '£2000 capital would in the old state of things, have employed 1200 instead of 400 men' (p393).** More drily, Mill takes division of labour as the proxy for improvement in efficiency and notes, 'Without some separation of employments, very few things would be produced at all' (p118).

Say played further with this mental exercise. In connection with his example of printed pages as a case of direct backfire he writes of efficiency-induced price falls that

> sooner or later… cheapness will *run away with* the consumption and demand [and] in all the instances I have been able to meet with, the increase of demand has invariably *outrun* the increasing powers of an improved production (pp87, 302; emphasis added)

That is, imagine the 'relative intensity of supply and demand', which determines price (Say, p290), as showing flat demand curves and steep supply curves. Now, he said,

> suppose… the charges of production are at length reduced to nothing;… Every object of human want would stand in the same predicament as the air or the water, which are consumed without the necessity of being either produced or purchased. In like manner as every one is rich enough to provide himself with air, so would he be to provide himself with every other imaginable product. (pp303-304)

Would total, overall, absolute consumption of resources be lower, or higher, in this state of infinite efficiency, where both commodities and their inputs are free and limitless?

Smith casts some doubt on this, writing that if a 'capital… was produced spontaneously, it would be of no value in exchange, and could add nothing to the wealth of society' (II.v.5); but this is only exchange value, and ‘wealth’ seen monetarily. In contrast Say takes the exercise in the opposite direction:

> By the rule of contraries, as a real advance of price must always proceed from a deficiency in the product raised by equal productive means, it is attended by a diminution in the general stock of wealth. (p302; Smith, I.xi.o.6)

That is, is greater wealth even conceivable under conditions of *decreasing* efficiency? If we take time, material, energy and space inputs and assume all historically known efficiencies away, we most likely arrive at the population and per capita production of hunter-gatherer societies living sustainably.

Sarcasm also distinguished an anonymous 1826 article on the 'machinery question' of technological unemployment:

> If the use of machinery is calculated to diminish the fund out of which labourers are supported, then by giving up the use of the plough and the harrow and returning to the pastoral state, or by scratching the earth with our nails, the produce of the soil would be adequate to the maintenance of a much greater number of labourers. There are many labourers now in England, and the gradations of ingenuity and skill in machinery are numerous; but as the number of labourers and the funds for their support would be gradually increased in proportion as we fell back upon the less perfect machinery, so, at last, when we deprived ourselves entirely of its assistance, the produce and hence the population of England would be increased beyond what has ever been exhibited in any country upon the surface of the globe.... (Anon., 1826, p102; see also Brookes, 2000, p359)[77]

The writer is criticizing Mr. Wakefield and Dr. Chalmers, but also chides Ricardo for his change of heart on this question – of which more in the final section.

Say twice frames his description of consumption growth in terms of inputs. Demand 'outruns' efficiency in a

> production, operating upon the same productive means; so that every enlargement of the power of the productive agency has created a demand *for more of that agency*, in the preparation of the product cheapened by the improvement… When the demand for any product whatever, is very lively, the productive agency, through whose means alone it is obtainable, is likewise in brisk demand, which necessarily raises its ratio of value: this is true generally, of every kind of productive agency. (pp302, 324, emphasis added; see also Brookes, 1990 and 2000, and Saunders, 1992 and 2000)

If the phrase 'ratio of value' refers to amounts of the input before, and after, the improvement, perhaps times their price per unit, Say is presaging Jevons's position exactly. Similarly, depending upon one's interpretation of Smith's term 'fund', he too could be attesting rebound greater than unity when he claims that 'Every saving… must increase the fund which puts industry into motion and consequently the annual produce of land and labour' (II.ii.25).

As shown earlier Rae frequently frames his analysis in terms of materials rather than labour, but he seems usually to denote only the materials *embodied in* tools, machinery, and instruments, as when he speaks of 'the efficiency of… materials when formed into instruments' (p112). However, since fields and foods are also 'instruments' we can infer that efficiency in some cases implies increased inputs of things other than knowledge (pp112-113): 'Every society possesses a certain amount of materials capable of being converted into

[77] Attributed to William Ellis by Mill (p736).

instruments' (pp99; see also p187). For Rae greater efficiency of an instrument means it yields 'quickened' returns (p164) and in general

> the effect of improvement, to carry instruments into orders of quicker return…, a greater range of materials is brought within the reach of [the accumulative] principle, and it consequently forms an additional amount of instruments… All [improvements], therefore, place a greater range of materials within compass of the accumulative principle, and occasion the construction of a larger amount of instruments. (pp261, 131, 365)[78]

Furthermore, 'A multiplication of instruments is of no avail, unless something additional be given on which they may operate', and our 'instruments… draw forth stores' of materials; 'improvement in their construction… put additional stores within reach of the nation' (pp29, 19, 68). In addition 'The various agricultural improvements… with which invention enriched that art in Britain…, occasioned a great amount of material to be wrought up, which before lay dormant' (p261).

Finally, with a rebound example familiar from today's debate, he notes of the macadamization of roads that 'the facility it gives to transport occasions an increase of transport…' (p114). Hearn similarly writes of invention that it 'enables the labourer to work materials which… were previously beyond his reach' (pp181-183). Taken together these observations are arguably a description of backfire: ultimately, efficiency leads to higher rates of *material-input consumption.* Since each instrument – a field, a steam engine – implies not only embodied but operating materials, we can infer little saving of material inputs from Rae's analysis. He continues by noting that improved instruments increased the amount of land under cultivation and that 'rocks were quarried; forests were thinned; lime was burned; the metal left the mine…' (pp261-262). A rise in Q entails rebound for sure and most likely backfire.

A summary by Mill contains almost all of the concepts introduced till now. Recall that 'circulating capital' covers all the food, fuel and other materials fed into production. Just before considering the 'stationary state' and 'to what goal… economical progress' should be aimed (p752) he writes:

> It already appears from these considerations, that the conversion of circulating capital into fixed, whether by railways, or manufactories, or ships, or machinery, or

[78] Also Mill, pp725-726; Price, 1988; Wirl, 1997, pp51-56, 81-87.

> canals, or mines, or works of drainage and irrigation, is not likely, in any rich country, to diminish the gross produce or the amount of employment for labour. How much then is the case strengthened, when we consider that these transformations of capital are of the nature of improvements in production, which, instead of ultimately diminishing circulating capital, are the necessary conditions of its increase, since they alone enable a country to possess a constantly augmenting capital without reducing profits to the rate which would cause accumulation to stop. There is hardly any increase of fixed capital which does not enable the country to contain eventually a larger circulating capital, than it otherwise could possess and employ within its own limits; for there is hardly any creation of fixed capital which, when it proves successful, does not cheapen the articles on which wages are habitually expended. All capital sunk in the permanent improvement of land, lessens the cost of food and materials; almost all improvements in machinery cheapen the labourer's clothing or lodging, or the tools with which these are made; improvements in locomotion, such as railways, cheapen to the consumer all things which are brought from a distance. (pp750-751; see also p344)

A few pages later our epigraph appears wherein Mill doubts that any labour had been saved by labour-saving devices. This fruit of classical thought fell to Jevons.

The principle of population

Since the classical era population size seems to have declined in importance as a dependent variable; yet the ten-fold increase of population in the last two centuries is surely an *explicandum* of the first order. No classical economist challenged productivity's causal role. Today by contrast this is for instance denied by Schipper & Grubb who, although they 'normalise… observations of absolute quantities to either population or GDP' see none of this 'significant' population growth as 'stimulated by the increases in energy efficiency' (2000, p368). Perhaps the OECD perspective of almost all studies, abetted by shyness in the face of the fact that people do die from lack of sustenance, has prevented the adoption of both agricultural and manufacturing efficiency as an independent variable. Yet if population rise is at least *enabled* by efficiency increase then the wholly exogenous treatment of population in energy-consumption models is wrong (for example Schipper et al., 1996, p174; Howarth, 1997, p4; Lantz & Feng, 2006, p235). It also means underestimation of rebound.

Presaging I = PAT, Jevons made the point that the 'quantity of coal consumed is really a quantity of two dimensions, the number of people and the average

quantity consumed by each' (p196). Malthus in both his major works endogenized 'number of people', his metaphorical phrase being that 'the necessaries of life, when properly distributed, [create] their own demand [by] raising up a number of demanders…' (pp113; see also pp114, 130, 181, 223, 251). He then points out that if increased 'powers of production' were not necessary for increased population 'the Earth would probably before this period [mid-19th century] have contained, at the very least, ten times as many inhabitants as are supported on its surface at present' (pp288, 251). In explaining wealth, '[to] suppose a great and continued increase of population is to beg the question. We may as well suppose at once an increase of wealth…' (p252). (Ironically, countless modellers of rebound do exactly this, exogenize GDP, 'economic activity' or total output![79]) As shown earlier, classical economics almost fully endogenized growth, attributing the size of the annual produce of land and labour partly to 'improvement' – as Mill's statement quoted above shows. Progress raises sustenance (in spite of diminishing returns in agriculture), increasing the extent of the market, which in turn allows more division of labour and larger, more expensive machinery, in turn enabling larger population (Mill, pp33, 129-131, 190, 712-714).

Perhaps building on Petty (p255), Smith states simply, 'The number of workmen increases with the increasing quantity of food, or with the growing improvement and cultivation of the lands…' (Ixi.c.7). Building on Say (pp71, 292-295), McCulloch writes that 'there does not seem to be any good reason why man himself should not… be considered as forming a part of the national capital. Man is as much the produce of labour as any of the machines constructed by his agency…' (p115; see also Mill, pp40-41). Malthus talked of the 'cost of producing a poacher' compared to that of a 'common labourer or… coal-heaver' (p180; see also Jones, p196). Rae abstractly but explicitly named 'invention' as 'the true generator of states and people' (pp31, 323). Sustenance includes not only food but warmth, housing and general health (Say, pp301 note, 373, 378; Mill, pp 154-159). The quantity of labour (and people) is a function of the quantity and quality ('human capital') of labour.

[79] For example Manne & Richels, 1990, p51; Schipper & Meyers, 1992, pp58-60; Howarth, 1997, p2; Saunders, 2000a, p442; Schipper & Grubb, 2000, pp368, 370.

Starting with Petty's question as to how many Men the Land would feed, all of the old-timers embraced the principle of population, expressed by Malthus in terms of 'tendencies', sustenance, and the effect of prosperity on decisions to marry and have children (1798, pp20-26, 33-34, 41, 52, 70, 74-75).[80] Jevons of course tied it empirically to coal: '[With] cheap supplies of coal, and our skill in its employment…[w]e are growing rich and numerous' (pp199-200). In terms of the I = PAT production function, we should write I = f(P,A,T), A = f(T) showing our becoming rich and P = f(T) showing our becoming numerous. That population is not *sui generis* is also shown and recognized by recent investigators (for example Giampietro, 1994, pp680-681; Hannon, 1998, p215).[81] Schmookler was one who consciously treated it both exogenously and endogenously (1966, pp104-106; also Rosenberg, 1982, p141). If moreover population and the scale of the economy are partially endogenous, the ubiquitous picture in the literature of a 'race' between a 'growth effect' and efficiency is incorrect (Levett, 2004, p1015).[82] The question of backfire is begged when growth and efficiency are assumed to be rivals, but the race metaphor again shows the *paradox*: Do efficiency increases compensate for growth or cause it?

Another population-related problem with most rebound analyses is the concept of the energy intensity of a given good, service or expenditure whereby 'energy costs are typically a… component of the total cost of owning and operating energy-using equipment' (Howarth, 1997, p2). '[T]otal energy costs are generally a few percent of GDP' and the size of any rebound or 're-spending effect [where] purchasing power is released for other energy-containing services' is proportional to this percentage (Grubb, 1990b, p784; see also Greening et al., 2000, p391).[83] Or, in analyzing indirect rebound one compares

[80] Also Cantillon, pp43-44; Smith I.viii. 21-39, I.xi.b.1 & c.7, IV.ix.36; Ricardo, p16; Say, pp189, 322, 371-381, 450; McCulloch, p278; Rae, pp28-31, 96, 160, 324; Mill, pp153-159, 187-190; Jevons, pp222-225, 420.
[81] Also Cipolla, 1962, pp49-53, 94-95, 105; Martinez-Alier, 1987, pp99-116; Abernethy, 1993; Pimentel, 1994; Bartlett, 1994; Clapp, 1994; Johnson, 2000; Giampietro & Mayumi, 2000.
[82] Also Besiot & Noorman, 1999, pp375-377; Binswanger, 2001, p120; SwissEnergy, 2004, pp3, 4.
[83] Rebound should however be defined as a percentage of engineering savings, not of GDP.

the energy intensity of the old and the new expenditure to help measure the change in energy consumption. As in Malthus's defence of the concept of natural price, this energy share and the other intensities, for example of labour or capital, add up to 100 per cent. (Malthus, pp66-67).

However, as shown above in discussing Say's 'immaterial objects', buying labour also implies expenditures by the labourers on material and energy, in the older terms of 'reproducing' themselves. Kaufmann's rendering of this 'feedback' effect for capital as well as labour is that when these are substituted for energy, these also have energy costs, which 'offsets some fraction of the direct energy savings and reduces the amount of energy saved by price-induced microeconomic substitution' (1992, p49). Mill's detailed analysis of a loaf of bread for instance names bakers, ploughmen, plough-makers, carpenters, bricklayers, hedgers, ditchers, miners and smelters who share the price (costs) of the loaf (p31). Labour and capital, the more so when seen in the classical sense as previous embodied labour, entail energy consumption and are not energy-neutral (Costanza, 1980). Mill also incidentally rejected the implication of perfect substitutability in these analyses:

> When two conditions are equally necessary for producing an effect at all, it is unmeaning to say that so much of it is produced by one and so much by the other; it is like attempting to decide which half of a pair of scissors has most to do in the act of cutting; or which of the factors, five and six, contributes most to the production of thirty. (pp 28-29)

In any event, the notion that 'non-energy' costs have no effect on energy consumption must be rejected: once the creation and support of population is included, attending a concert is not the environmentally friendly act it is alleged to be. The idea of decreasing marginal energy intensity as income rises – also due to the societal income effect – must be doubted.

Global population, along with technologically achieved levels of affluence, entailing as they do human usurpation of the living space of plant and other animal species, engenders interest in possible rebounds in the use of a further productive input, namely space, or land regarded merely as m^2 ($\lambda m^2\uparrow \rightarrow m^2\uparrow$ where λ is an efficiency co-efficient). Not only agricultural efficiencies, but also transport and architectural ones, can be expressed in terms of amount of land

use, raising the question of whether for instance more efficient farming reduces the pressure on forests. (Jevons, p200; Pascual, 2002, p497) Whenever classical literature raises this question, the answer is that following agricultural improvement we do *not* take land out of cultivation.[84]

The employment paradox

Because they directly raise population, labour and energy efficiency increases thus indirectly raise the number of work-hours or employment, but given the limited length of the work day is this true when we hold population constant? Labour rebound would be smaller, but as Mill said most likely work-hours don't decrease. Recall that before Jevons economists, except at times Say and Rae, conceptualized all sorts of efficiency changes – not just technological ones – but asked explicitly only after the fate of labour inputs, not of material inputs. Their specific debate concerned whether machines caused long-term unemployment, that is, whether labour-efficiency rebound was less than 100 per cent. Jevons of course saw that with 'every… improvement of the engine… hand labour is further replaced by mechanical labour' and that in *agriculture* 'Labour saved is rendered superfluous' (pp152-153, 243); also institutional efficiency, through free trade, 'raises the economy of labour to its highest pitch' (p413). But he asserted that it was obvious that demand for labour thereby grew:

> As a rule, new modes of economy will lead to an increase in consumption according to a principle recognized in many parallel instances. The economy of labour effected by the introduction of new machinery throws labourers out of employment for the moment. But such is the increased demand for the cheapened products, that eventually the sphere of employment is greatly widened. (p140)

He offers empirical proof with the examples of seamstresses, coal miners and iron workers (pp140, 130-131, 153, 213-218, 277-278) as his predecessors had with the examples of flour-milling, printing and cottons. As we shall see this result was not at all obvious for Marx (pp354-392), writing at the same time as Jevons, as it had not been for Ricardo and Sismondi.

[84] Smith, I.xi.b.2-6, IV.ix.5-6; Say, p295; Malthus, pp139-140; Jones, pp196, 242; Rae, pp116, 259, 261; Mill, pp173-185, 724-729.

The issue is the same as that concerning primary energy: Does an input-saving production system permanently lower, or raise, consumption of that input? We could even call this 'Say's Paradox', for after demonstrating that cheapened products create additional employment he writes:

> Paradoxical as it may appear, it is nevertheless true, that the labouring class is of all others the most interested in promoting the economy of human labour; for that is the class which benefits the most by the general cheapness, and suffers most from the general dearness of commodities. (p89 note)

The result that, out of 20 men at a flour mill, the 19 'unfortunate' ones laid off would find other work, was for him admittedly '*survenue*' (1820, p63).[85] But he claimed that in printing, even if machines had thrown 199 out of 200 copyists out of work, probably 20,000 people were working in the printing trade (p88).

While many energy-efficiency increases cause labour-efficiency increases as a side effect – if only in the mining and distribution of the energy per unit of product – labour-saving changes like new machines, household gadgets or the factory system usually *lower* energy-efficiency per unit of output – say a cup of coffee –, if only due to the substitution effect. Such feedbacks between βM and αL – the efficiencies of use of matter and labour, respectively – have yet to be systematically investigated in complete models of either labour or energy consumption (Rae, p20; Marx, pp386-387; Binswanger, 2001, pp127-128). Again with the example of the ceramic stove's replacing the open hearth: heating requires less time cutting and stacking wood as well as less wood (also Jones, pp249-250; Mill, pp106-107; Martinez-Alier, 1987, p3). Hearn's generalized insight was *both* that 'labour and... time are free to be applied to other industrial purposes' and that 'the introduction… of natural forces in lieu of or in addition to human powers sets free a quantity of commodities' (pp183-185, 271). But the Jevons Paradox concerns only M = f(βM), not M = f(αL) as well.

By arguments from price falls, profitability and the income effect, a near-consensus reigned concerning output growth and labour-input growth – epitomized by Mill's quip in our epigraph. Some years before the outbreak of the controversy over machines vs. men Smith claimed that:

[85] Curiously, this term is left out of Laski's English translation (p63).

> the accumulation of stock must… be previous to the division of labour… As the division of labour advances,… in order to give constant employment to an equal number of workmen, an equal stock of provisions, and a greater stock of materials and tools than what would have been necessary in a ruder state of things, must be accumulated beforehand. But the number of workmen in every branch of business generally increases with the division of labour in that branch… The increase in the quantity of useful labour actually employed within any society, must depend altogether upon the increase of the capital which employs it… (II.intro.3, IV.ix.36)

Remembering that 'capital' is both fixed and circulating (in this case wages in the form of food and provisions during the period of production), and that fixed capital always entails heightened efficiency (Jevons, pp150, 155), Smith's view is that technological efficiency ('tools') and organizational efficiency ('division of labour') are the conditions for growth in the number of jobs. There is no hint that machines throw people out of work.

However, the intuition that makes the economy of labour just as paradoxical as the economy of fuel, and the fact that visibly and locally machines *do* replace workers, had by 1820 spawned the theoretical positions of Say, Robert Owen, Ricardo, Sismondi and Malthus. Say first discussed the displacement of workers in his first edition in 1803 (ch IX), making important changes but keeping his conclusions in later editions as well as in the fourth of his *Letters to Malthus* (1820). Lauderdale also explicitly discussed machines that 'supplant labour', first agreeing with Smith that lower labour costs in textile manufacture had lowered prices and that machines generally increase wealth; but he at the same time attests a net loss for the supplanted 'unlettered manufacturers themselves' and sees good reason for the 'riots that have taken place on the introduction of various pieces of machinery' (pp168-171, 184, 189-192, 206).

Reminiscent of much microeconomic work on rebound today, most participants traced the fate of the money amounts of capital or revenue saved by efficiency increase. Employment was gained by making and maintaining the machines, but lost when production processes needed fewer hands; it was gained when employers spent their higher profits on luxuries or servants, but lost if demand for other products failed. The monetary examples are found in Ricardo (pp16, 388-391), Sismondi (vol 2, pp324-326), Say (1820, pp60-61, 65-67), Malthus (pp192-194, 282-283), McCulloch (pp179-182), and Marx (pp392-393). The parameters to observe are: 1) percentage labour-efficiency increase compared

to percentage price fall (usually seen as equal); 2) total fixed capital; 3) total circulating capital shifted between workers in different branches and between workers and capitalists; 4) the income effect of demand for further products; 5) labour demanded for making and tending the machinery; 6) duration of the machine; 7) demand for 'unproductive labour' or 'menial servants' whom these writers do not (usually) count as ‘labourers’; 8) foreign demand; and 9) the short-run deplacement of labour.

Most of these appear in Ricardo's contradictory discussion. In the third edition of 1821, without explicitly answering Say, he acknowledges a change of mind. Earlier he had believed that an increase of 'net income' (rents and profits) always entailed an increase of 'gross income' (including wages and implicitly jobs), arguing in Parliament against Owen's opposite view (Sraffa, 1951, plviii). But in 1821 in his new chapter 'On Machinery' he is thinks out loud: because the employer has less 'circulating capital*… his means of employing labour, would be reduced' (p389); but with increased profits after the introduction of the machine the 'power of purchasing commodities [of the 'net produce'] may be greatly increased' (pp389-390). In asserting that 'there will necessarily be a diminution in demand for labour [and] population will become redundant', however, his system boundary remains at the single factory or sector, in other words he forgets indirect rebound (p390); yet due to the necessary 'reduction in the price of commodities consequent on the introduction of machinery… there would not necessarily be any redundancy of people' (p390; see also p392).

He then seems to forget price reductions, doubting the demand for instance for a greatly increased supply of cloth (p391). In the simple example of replacing men with horses he sees a case of 'gross revenue' falling while 'net revenue' rises (p394); yet even here, the income of the farm employer could be so great, or 'the produce of the land [so] increased, that all of the unemployed find jobs 'in manufactures, or as a menial servant' (pp394-395). On the one hand he states,

> All I wish to prove, is, that the discovery and use of machinery may be attended with a diminution of gross produce… injurious to the labouring class, as some of their number will be thrown out of employment… [A]n increase of the net produce of a country is compatible with a diminution of the gross produce… By investing part of a capital in improved machinery, there will be a diminution in the progressive demand for labour… (pp390, 392, 397)

On the other hand, he believes that 'the employment of machinery should never be safely discouraged in a State [and] that machinery should… be encouraged' – both because its introduction is slow and because otherwise, even jobs in the machinery industry would move overseas (pp396, 395). In the terms of today's debate, Ricardo is arguing that rebound is never greater than 100 per cent and tends to be quite a bit less.

Say directly attacks the issue both in his *Treatise* (pp86-90) and in the fourth of the *Letters to Malthus* (1820). In the latter he explicitly bases his case first on large price falls and high price elasticity of demand (pp56-57), second on latent demand for other commodities that is satisfied by the income effect (which he unjustly accuses Sismondi of neglecting) (pp60-62), third on the fact that the machines can simply *do more work* than men (pp58-59) and fourth on the fact that after all is said and done, the factory produces the same amount of product available for consumption, and the laid-off workers, with this sustenance, will do something else (pp61-63). Mill echoed this last point in making the softer claim that 'if there are human beings capable of work, and food to feed them, they *may* always be employed in producing something' (p66; emphasis added). It seems also to be the case today that as well as labour, also natural resources not used for one purpose get used for another.

Say goes on to convincingly show that Sismondi's monetary example contains some unrealistic assumptions, but himself makes two numerical errors (pp60-61). He then appeals both empirically to the high and increasing employment all around him (p63) and to a historical overview: his 'model' predicts – accurately – that:

> if the arts still improve,… they will produce more at less expence [and] fresh millions of men in the course of a few ages will produce objects, which would excite in our minds, could we see them, a surprise equal to that which the great Archimedes and Pliny would experience could they revisit us. (p64)[86]

Two ambiguities mar the comparison of labour and material/energy inputs as well as the classical debate over the former. First, saving material is unmitigatedly good whereas saving labour, because people as opposed to

[86] He praises the relief from toil offered by machinery (p64).

materials must eat, is not. Holding population constant and raising work efficiency, the same or greater employment than otherwise (rebound 100 per cent or backfire) guarantees livelihoods. Somewhat contrary to the view that labour is painful and irksome, rebound greater than unity is therefore good. On the contrary, while resource consumption is obviously good for affluence, its 'over-consumption' and hence backfire is bad due to scarcity and pollution problems.

Secondly, precisely the bookkeeping offered by the debate's participants shows that the social or livelihood or full-employment problem is soluble: The amount of output does not decrease! Or as Ricardo concedes from the point of view of income rather than production, if employers lay off five of ten men, they nevertheless retain the purchasing power to employ all ten (1820-22, p355). If the fully realized production possibilities of the society supported everybody before, it can therefore support them after all the great and small productivity increases taking place daily. Seeing this, even those who held that efficiency savings were in fact realized – that is, that unemployment resulted – placed blame on the 'factory' or 'capitalist' set of institutions which included neither shorter work hours nor guaranteed employment. Many such as Owen (see Sraffa, 1951, pplvii-lx; Berg, 1980; Greenberg, 1990, pp710-712) and Sismondi (vol 2, pp312-313, 317) thus mixed ethical or socialist arguments with economic ones. Even Marx maintained that not only in the short run 'in the hands of capital' labour-saving productiveness increase meant 'lengthening the working day', and wrote that:

> workpeople [should] distinguish between machinery and its employment by capital, and to direct their attacks, not against the material instruments of production, but against the mode in which they are used. (p351; also 356, 374)

In contradiction to this, though, his final doctrine is that machinery and men are in competition; although new capital can employ many of the newly unemployed and although indeed as much or more 'of the necessaries of life' are still produced, a sufficient rise of demand is uncertain (pp374, 384-386).

The consensus that emerged, though, was that if the remaining work and/or the same or increased output is distributed equally, the problem of computing the

total-employment effects of employment efficiency would lose its social aspect. Again, all agreed with Say's point that even if a wind-driven flour mill does the work of eighteen persons, these 'eighteen extra [redundant] persons are [theoretically] just as well provided with subsistence' (p90; see also Rae, p259). The parallel to energy inputs is that after a machine 'does the work' of one out of two tons of coal, both the coal and the means to employ it remain. And Say, Malthus, McCulloch and Mill, although convinced that even more labour ensued (backfire), recognized that some measures to lessen the hardship of displaced workers are justified. Mill even imagines a 'benevolent government' assuring a just distribution of work, in other words of income (p67). Whatever the final level of employment, one must regard full employment as a social, not an economic, problem, as expounded by Edward Bellamy in his *Looking Backward* (1887).

The result is that if produce stays at least the same, 100 per cent rebound in terms of work-hours – that is, full employment – is likely at no additional cost. As Malthus claimed, the 'net produce' could always employ 'unproductive labourers' such as 'menial servants, soldiers, and sailors' (p191). But the opposite is possible. In a difficult passage which earned him a reputation as an advocate of labour rebound less than unity, he says that even with increasing 'exchangeable value of the whole produce' stable or sinking employment *could* result, namely when the production of 'luxuries and superior conveniences' rose at the expense of necessaries; but his more fundamental claim is to deny *any* proportional connection between either fixed and circulating capital, and thus efficiency, and demand for labour: consistent with his *Essay on the Principle of Population*, this depends only on 'the means of commanding the food, clothing, lodging, and firing of the labouring classes of society' (pp190-191).

If production is higher, some combination of raised affluence and raised population results. If, however, we assume that before the efficiency increase every worker was working his maximum number of hours, then without population increase labour *backfire* is logically impossible (Malthus, pp62-63). (Analogous energy-rebound limits perhaps exist due to scarcity or thermodynamic limits.) Malthus in fact concludes that if the 'introduction of fixed

capital' is gradual and 'the funds destined for the maintenance of labour' somehow keep pace, the result is a 'great demand for labour and a great addition to the population [and] there is no occasion therefore to fear that the introduction of fixed capital… will diminish the effective demand for labour' (p193; see also pp281-289). By the early 1830s he accordingly defends himself against being 'classed [by McCulloch] with M. Sismondi as an enemy to machinery' (p282 note), also rejecting the doubts of Ricardo and the opinions of 'M. Sismondi and Mr Owen' that labour-saving machines are 'a great misfortune' (p295 note).

McCulloch was indeed just as convinced as Say that the 'extension and improvement of machinery is always advantageous to the labourer' (p165), but not only because more work hours result. His first original point is that if machinery would lower demand for labour by raising labour's productivity, then so would any 'improvement of the science, dexterity, skill, and industry of the labourer'; therefore 'M. Sismondi could not… hesitate about condemning such an improvement as a very great evil' (pp165-166). As seen above McCulloch's macroeconomic assumption of a tenfold efficiency increase would also allow more leisure (pp166-168; Mill, pp105-106). His result entails considerable rebound in material/energy consumption; there is no backfire in labour consumption but rather a real savings of labour inputs; and the imagined cornucopia would enable society to politically assure full employment.[87] But he assumes no population growth. If population and/or work-hours increase, L-backfire could ensue.

Microeconomically McCulloch argues explicitly with the standard price falls, large price elasticities of demand and indirect rebound (pp176-180). In apparent contradiction to his vision of shorter working hours for all he then relies on both theory and observation to show that the machines of 'Hargreaves, Arkwright, and Watt' created employment for 'thousands and thousands of workmen' (p117). This raises our paradox again: According to Dolores Greenberg, Owenite John Brooks in 1836 calculated that machines in Great Britain and

[87] See Bellamy, 1887.

Ireland were doing the work of no less than 600,000,000 people (1990, p711; Jevons, p411). Can we infer from this that therefore 600,000,000 people were out of work – perhaps even in the sense that they had starved or not been born? If the machines were doing the work of only 300,000,000 people, would employment be twice as high?

Some of Jevons' statistics on population and substitution hint at these questions.

> In round numbers, the population has about quadrupled since the beginning of the 19th century, but the consumption of coal has increased sixteenfold, and more. The consumption per head of the population has therefore increased fourfold. (p196)

Pertinent to today's 'renewables' discussion he computes, for instance, that since an 'ordinary windmill has the power of about thirty-four men, or at most, seven horses… the great Dowlais Ironworks… would require no less than 1,000 large windmills!' (pp164-165; 203-205) And when he writes that 'it cannot be supposed that we shall do without coal more than a fraction of what we do with it', we may ask both how many are in this 'we' (p9) and how well-off we would be, since 'with coal almost any feat is possible or easy; without it we are thrown back into the laborious poverty of early times' (p2).[88]

Say, Malthus and McCulloch do not show labour backfire with *certainty.* They show us not that more work hours must result, but that less work hours must not result. Even Sismondi saw cases when for instance workers were not 'rendered superfluous' due to the stocking-machine – but only because of the three exogenous factors 1) changes of taste, 2) increased population and 3) increased wealth (vol 2, pp316-317, 330-331).[89] But in the normal case and contrary to Say's claims in ridiculing him (1820, pp 61-62) Sismondi does say that the stockings are cheaper and that demand can therefore rise due to the income effect in sectors having nothing to do with the one affected by the efficiency increase (here, stockings); but he treats the total purchasing power as no greater than that spent on the more expensive spats previously or even as

[88] That agricultural productivity increases raise population is clear; manufacturing and fuel-using efficiency increases do this less obviously through better housing and clothes, better medicine, better availability through transportation, etc. (Jevons, pp200, 205, 233, 243-245, 369).
[89] Just like the very similar independent variables of Schipper & Meyers (1992) and Schipper et al. (1996), Sismondi thus begs several questions.

less: 'new demand will never have the same proportion as that thereby lost by the laid-off workers' (vol 2, pp317, 323-324, 322; see also McCulloch, pp186-187) A further lack of certainty marks Say's empirical claims: perhaps backfire in cottons and printing is proven, given a demand function, but these are mere sectoral studies with no necessary economy-wide implications (p57).

One of Sismondi's arguments for low labour rebound is that while a machine may lower *labour* costs by 99 per cent, since the price of stockings consists of more than just labour costs, the price cannot fall in the ratio of the laid-off workers (vol 2, pp323-324). Similarly, many argue today that since energy costs are only a fraction of GDP the efficiency elasticity of price is low (Howarth, 1997, pp2, 3; Allan et al., 2006, pp18-19). Although this argument loses force if rebound is measured as a percentage not of total economic activity but only of potential engineering savings, its plausibility is a reason why Jevons' paradox is a paradox. If prices fall 50 per cent there is nevertheless more real purchasing power in the economy, whether the efficiency of a given input rises 51 per cent or 99 per cent; perhaps the concept of the efficiency elasticity of price, compares apples and pears.*

Mill, finally, confronts the problem we named earlier that the purchasing power drawn to the cheaper, more efficiently-produced goods is lacking for the older, previously purchased goods, thus lowering employment in those sectors. On the one hand he attests that:

> Every addition to capital gives to labour either additional employment or additional remuneration… If it finds additional hands to set to work, it increases aggregate produce: if only the same hands, it gives them a larger share of it; and perhaps even in this case, by stimulating them to greater exertion, augments the produce itself. (p68; also p87)

But he adds that the standard argument – greater employment through cheaper goods through more efficient production through applying fixed and circulating capital to this sector –

> does not… have the weight commonly ascribed to it…. [I]f this capital was drawn from other employments; if the funds which took the place of the capital sunk in costly machinery, were supplied not by any additional saving consequent on the improvements, but by drafts on the general capital of the community; what better were the labouring classes for the mere transfer? In what manner was the loss they sustained by the conversion of circulating capital into fixed capital made up to

> them by a mere shifting of part of the remainder of the circulating capital from its old employments to a new one? (p96)

Mill seems here to envision a zero-sum process, which indeed the economy is if measured monetarily with constant money supply. Perhaps his premise is wrong that the capital must be drawn from other, previous employments rather than from the real increased produce or 'returns' per unit of input. This is the answer Say would have given and that Rae gave (p118). Although Mill's subsequent attempt to counter his own argument is unsuccessful he then concludes with Say that employment is not threatened after all but in the end increased (pp133-134, 749-751, 119-120).

Today no one either hopes or fears that labour efficiency increases do not backfire. It is accepted that for over two centuries such 'improvements' have been accompanied by rising employment and population. A causal connection is even often explicit: More efficiency of all sorts, such as free trade, lower transactions costs, restructuring for synergies in industry as well as everyday streamlining of work processes, is known to further the economic growth upon which an expanding job market depends. But material/energy inputs are perceived differently, with different goals and hopes. Just as the older debate was fraught with the ambiguity of 'labour' seen negatively as a cost and 'labour' seen positively as a proxy for 'income', today's debate contradictorily lauds efficiency of any sort as a tool for lower environmental impact as well as for growth and affluence. If however energy rebound is close to or greater than unity, environmental ends are better served by direct means such as taxation or rationing (Hannon, 1975; Brookes, 2000, pp363-364; Sanne, 2000, pp488, 491-492; Fawcett, 2004; Simms, 2005).[90]

[90] Jevons however repeatedly notes that such solutions to the coal question are limited by Britain's 'system of free industry' (pp5, xlix, 13, 136, 442-447).

Conclusions

Jevons opened his seminal chapter on fuel 'economy' (his term for the efficiency ratio) by quoting Justus von Liebig, who wrote:

> Cultivation is the economy of force. Science teaches us the simplest means of obtaining the greatest effect [output] with the smallest expenditure of power [input], and with a given means to produce a maximum of force. The unprofitable exertion of power, the waste of force in agriculture, in other branches of industry, in science, or in social economy, is characteristic of the savage state, or of the want of true civilization. (1851, p462)[91]

Then, as now, force and therefore affluence and civilization lie in fossil fuel. But pollution and pending scarcity reveal the dark side of the prosperity that we so welcome. Roughly in the order of the sections presented above some conclusions can be drawn on whether more efficiency, *ceteris paribus,* achieves not only affluence and greater population but environmental relief.

Efficiency is an attribute of humans and other natural agents as well as capital and organization, but is always an output/input ratio. Seeing efficiency increase as larger output, as the classical economists usually did, biases us to find high rebound plausible; seeing it as smaller input biases us toward low rebound and real savings. The term 'rebound' itself is a metaphor describing a bouncing ball, but a bounce all the way into the backfire zone unfairly implies *perpetuum mobile* or more. Furthermore, an analysis of energy consumption is possible without computation of engineering savings derived when one holds consumption constant, and thus without the concepts of rebound and backfire.

In regression analysis, to explain increasing (rates of) energy consumption an independent variable 'technological efficiency' could be taken. But how is this measured for all sectors, all economies, over time and integrating new products? An adequate aggregate metric, whether in monetary, utility or physical terms, is hard to come by, but its absence makes empirical research difficult. The environmentally most relevant path of measuring output physically must seek a metric free of the anthropocentricity implied in terms such as

[91] Jevons here misquotes von Liebig as 'Civilisation is the economy of power' (pp142, 163). Jevons had just finished his chapter attributing Great Britain's greatness to coal and technology, whereas von Liebig was in the middle of an essay on agricultural productivity.

waste, usefulness, quality, service and value, for these conflate environmental with affluence criteria.[92] Rather unscientifically, though, we all assume that technological efficiency continually increases. The classical economists also attested this and correlated it not only with growing production of wealth but sometimes with growing labour and material input quantities. Jevons for instance offers the empirical evidence for backfire that alongside great rises in coal consumption, population and affluence there were increases in the economy of fuel, for example in pig iron production by a factor of about seven in 35 years (pp387-388, 145, 196, 261-271; see also Martinez-Alier, 1987, pp86).

Fruitful empirical research must be at a scale large enough to capture not only indirect rebound in all sectors but also an economy's consumption of imported embodied energy (Jevons, p317). This need to ultimately cover all sectors and economies has been acknowledged.[93] As McCulloch said we must investigate efficiency effects 'in a country surrounded by Bishop Berkeley's wall of brass' (p185), a good description of the whole globe. The more so since environmental problems are global, our studies should be both global and measure total rather than only direct rebound.

But in the absence of hard empirical results we must resort to theory, and indeed both sides in today's debate over the environmental effects of efficiency claim 'counterfactually' what energy consumption *would have been otherwise*, in other words without efficiency increases (Khazzoom, 1980, pp22, 31; Howarth, 1997, p3; Brookes, 2000, p356; Moezzi, 2000, pp525-526; Schipper & Grubb, 2000, p370). Which model, then, better predicts this correlation? That of Jevons can perhaps be quantified as containing a technological rebound factor of slightly over 100 per cent, or an efficiency coefficient in a model of energy consumption of, say, 1.01. Holding all other variables constant, this model predicts the increase in energy consumption better than models assuming rebound less than unity which yield a large gap between predicted and real

[92] A given CO_2 molecule, for instance, has no marker on it indicating its human value.
[93] For example Saint-Paul, 1995; Cleveland & Ruth, 1998, pp44-45; Giampietro & Mayumi, 2000, pp182, 185-186 & this volume; Weisz et al., 2006, p694; 4CMR, 2006, pp24, 52-53; Rhee & Chung, 2006; Polimeni, this volume.

consumption, a gap usually filled by exogenous GDP. Such models must moreover show what the causes of increased consumption then in fact are, if not efficiency increases.[94] And these causes must be strong enough to *overcome* the alleged consumption-reducing effect of greater efficiency.[95]

Efficiencies of all provenances have continually expanded the world economy's *production possibilities frontier* and thereby its consumption frontier. Grasping this physically – including the physical inputs into this consumption – can avoid some of the difficulties arising in microeconomic monetary analysis in terms of income effects and societal purchasing power. Yet while this immediately renders large rebound plausible, to directly infer backfire would beg our entire question; the Jevons *Paradox* must be taken seriously. In any case no answer can do without assumptions or empirical evidence concerning the (non-)satiation of material desires and greater production's affect on population size.

The policy situation is remarkable. The likelihood that theoretical and real input savings are identical is zero; some rebound is uncontested, and the lowest macroeconomic total-rebound estimates lie in the range of 25-40 per cent. It is therefore truly astonishing that with a handful of exceptions,[96] government agencies and policy assessment companies do *not* correct for it,[97] but rather, using a purely 'engineering' approach, set real savings equal to technologically possible savings. However, a rebound coefficient of 0.5, which is at the present state of knowledge justifiable, would significantly alter estimates both of efficiency's effectiveness and its cost-effectiveness.

Remarkably, Smith's 'human stomach' passage – written about 230 years ago – contains practically all the concepts needed to approach our question:

> But when by the improvement and cultivation of land the labour of one family can provide food for two, the labour of half the society becomes sufficient to provide food for the whole. The other half, therefore, or at least the greater part of them, can be employed in providing other things, or in satisfying the other wants and

[94] See Saunders, 2005.
[95] See Howarth, 1997, pp2-4, 7; Schipper & Grubb, 2000, p384; Solow, 1970, pp33-35, 38.
[96] Rebound coefficients crop up in Defra, 2002, p4; NRC, 2002, sections 4.1, 5.24-25; 4CMR, 2006, pp5, 12, 21, 35, 72-75.
[97] EEB, 2000, p32; INFRAS, 2002; CEPE, 2003, pp6, 32, 35, 44, 55; DTI 2006, pp36-60, 149; EnergieSchweiz, 2007.

> fancies of mankind. Cloathing and lodging, houshold furniture, and what is called Equipage, are the principal objects of the greater part of those wants and fancies. The rich man consumes no more food than his poor neighbour. In quality it may be very different, and to select and prepare it may require more labour and art; but in quantity it is very nearly the same. But compare the spacious palace and great wardrobe of the one, with the hovel and the few rags of the other, and you will be sensible that the difference between their cloathing, lodging and houshold furniture, is almost as great in quantity as it is in quality. The desire for food is limited in every man by the narrow capacity of the human stomach; but the desire for the conveniences and ornaments of building, dress, equipage, and houshold furniture, seems to have no limit of certain boundary. Those, therefore, who have the command of more food than they themselves can consume, are always willing to exchange the surplus, or, what is the same thing, the price of it, for gratifications of this other kind. What is over and above satisfying the limited desire, is given for the amusement of those desires which cannot be satisfied, but seem to be altogether endless. The poor, in order to obtain food, exert themselves to gratify those fancies of the rich, and to obtain it more certainly, they vie with one another in the cheapness and perfection of their work. The number of workmen increases with the increasing quantity of food, or with the growing improvement and cultivation of the lands: and as the nature of their business admits of the utmost subdivisions of labour, the quantity of materials which they can work up, increases in a much greater proportion than their numbers. Hence arises a demand for every sort of material which human invention can employ, either usefully or ornamentally, in building, dress, equipage, or houshold furniture; for the fossils and minerals contained in the bowels of the earth; the precious metals, and the precious stones. (I.xi.c.7)[98]

Here we find efficiency as 'improvement' and 'division of labour', greater output and an expanded production frontier as food surplus, greater population seen endogenously, the irrelevance of the energy proportion of a service, the reduction of quality to quantity, the limitlessness of latent demand, marginal consumers, the empirical fact of consumption's going hand in hand with efficiency and the derived large demand for material inputs including fossil fuel.

Greater technological efficiency enables us to squeeze more useful material out of a given amount of input, or more non-work time out of the 24 daily hours (Sanne, 2000, pp487, 494). This is Jevons' state of 'happy prosperity' (p276). But if it simultaneously increases demand for natural resource inputs, we face a trade-off between affluence and sustainability. With the evidence at hand today, and given a certain urgency in finding an answer, good judgement is called for. If asked by policy-makers today whether we can count on greater energy efficiency to lower energy consumption, how many economists can answer with a whole-hearted 'Yes'?

[98] Also Ricardo, p293; see Say on cheaper corn and ‘dress and household furniture’ (p301).

Acknowledgements

Thanks to Len Brookes, Marcel Hänggi, Ashleigh Hildebrand, Reinhard Madlener, Cecilia Roa, Christer Sanne, Irmi Seidl, Steve Sorrell, Steve Stretton, Peng Wang, Özlem Yazlik, and the staff of the Zentralbibliothek Zürich.

References:

4CMR (Cambridge Centre for Climate Change Mitigation Research) (2006) 'The macro-economic rebound effect and the UK economy', Final Report to Defra, 18 May. www.defra.gov.uk/environment/energy/research

Abernethy, Virginia (1993) 'Why the demographic transition got stuck', *Population and Environment*, vol 15, pp85-87

Alcott, Blake (2004) 'John Rae and Thorstein Veblen', *Journal of Economic Issues,* vol 38 (3), pp765-786

Alcott, Blake (2005) 'Jevons' Paradox', *Ecological Economics,* vol 54 (1), pp9-21

Alcott, Blake (2006) 'Assessing Energy Policy: Should Rebound Count?', Dissertation for the degree of Master in Philosophy in Land Economy, Cambridge University, UK, www.blakealcott.org

Alcott, Blake (2008) 'The Sufficiency Strategy: Would rich-world frugality lower environmental impact?, *Ecological Economics,* vol 64 (4), pp770-786

Allan, Grant, Hanley, Nick, McGregor, Peter G., Swales, J. Kim and Turner, Karen (2006) 'The macroeconomic rebound effect and the UK economy. Final Report to Defra', www.defra.gov.uk/environment/energy/research

Anonymous (1826) 'Effect of the Employment of Machinery &c. upon the Happiness of the Working Classes', *Westminster Review*, V (January 1826), pp101-130

Ayres, Robert U. (1978) Resources, Environment, and Economics: Applications of the Material/Energy Balance Principle, John Wiley & Sons, New York

Ayres, Robert U., and van den Bergh, Jeroen C.J.M. (2005) 'A theory of economic growth with material/energy resources and dematerialization: Interaction of three growth mechanisms', *Ecological Economics,* vol 55 (1), pp96-118

Ayres, Robert U., and Warr, Benjamin (2005) 'Accounting for growth: The role of physical work', *Structural Change and Economic Dynamics,* vol 16, pp181-20

Babbage, Charles (1832) *On the Economy of Machinery and Manufactures*, Knight, London

Barnett, Harold J., & Morse, Chandler (1963) *Scarcity and Growth: The Economics of Natural Resource Availability*, Resources for the Future/John Hopkins, Baltimore

Bartlett, Albert A. (1994) 'Reflections on sustainability, population growth, and the environment', *Population and Environment*, vol 16 (1), pp5-35

Bellamy, Edward (1887 [1917]) *Looking Backward:2000-1887,* Riverside Press, Cambridge, MA

Berkhout, Peter, Muskens, Jos, & Velthuijsen, Jan (2000) 'Defining the rebound effect', *Energy Policy*, vol 28 (6/7), pp425-432

Berg, Maxine (1980) *The Machinery Question and the Making of Political Economy,* CUP, Cambridge, UK

Besiot, W., & Noorman, K.J. (1999) 'Energy requirements of household consumption', *Ecological Economics*, vol 28, pp367-383
Binswanger, Hans Christof (2006) *Die Wachstumsspirale,* Metropolis, Marburg, Germany
Binswanger, Mathias (2001) 'Technological progress and sustainable development: What about the rebound effect?' *Ecological Economics*, vol 36 (1), pp119-132
Birol, Fatih and Keppler, Jan Horst (2000) 'Prices, technological development and the rebound effect', *Energy Policy,* vol 28 (6/7), pp457-469
Boulding, Kenneth E. (1966) 'The economics of the coming spaceship earth', in Henry Jarrett (ed) *Environmental Quality in a Growing Economy,* Johns Hopkins, Baltimore
Brewer, Anthony (1991) 'Economic growth and technical change: John Rae's critique of Adam Smith', *History of Political Economy,* vol 23 (1), pp1-11.
Brookes, Leonard (1978) 'Energy policy, the energy price fallacy and the role of nuclear energy in the UK', *Energy Policy,* vol 6 (1), pp94-106
Brookes, Leonard (1979) 'A low energy strategy for the UK', *Atom*, vol 269 (March), pp73-78
Brookes, Leonard (1990) 'The greenhouse effect: The fallacies in the energy efficiency solution', *Energy Policy,* vol 18 (2), pp199-201
Brookes, Leonard (2000) 'Energy efficiency fallacies revisited', *Energy Policy*, vol 28 (6/7), pp355-366
Burniaux, Jean-Marc, Martin, John P., Oliveira-Martins, Joaquim & van der Mensbrugghe, Dominique (1995) 'Carbon abatement, transfers and energy efficiency' in Ian Goldin and L. Alan Winters (eds.) *The Economics of Sustainable Development*, CUP, Cambridge, UK
Cantillon, Richard (1755 [1931]) *Abhandlung über die Natur des Handels im allgemeinen,* translation by Hella Hayek, introduction by Friedrich A. Hayek, Verlag von Gustav Fischer, Jena, Germany
CEPE (Centre for Energy Policy and Economics) (2003) *Begleitende Evaluation der Wirkungsanalyse 2002 von EnergySchweiz,* SwissEnergy, Bern, Switzerland
Cipolla, Carlo M. (1962 [1974]) *The Economic History of World Population,* 6th edition, Penguin, Harmondsworth, UK
Clapp, Brian William (1994) *An Environmental History of Britain since the Industrial Revolution,* Longman, London and New York
Cleveland, Cutler J., Costanza, Robert, Hall, Charles A.S., and Kaufmann, Robert (1984) 'Energy and the U.S. economy: A biophysical perspective', *Science*, vol 225, pp890-897
Cleveland, Cutler J., & Ruth, Matthias (1998) 'Indicators of dematerialization and the materials intensity of use', *Journal of Industrial Ecology*, vol 2 (3), pp15-50
Costanza, Robert (1980) 'Embodied energy and economic evaluation', *Science,* vol 210, pp1219-1224
Dahlström, Kristina & Ekins, Paul (2006) 'Combining economic and environmental dimensions: Value chain analysis of UK iron and steel flows', *Ecological Economics,* vol 58 (3), pp507-519
Dahmus, Jeffrey B, & Gutowski, Timothy G. (2005) 'Efficiency and production: Historical trends for seven industrial sectors', Working Paper, US Society for

Ecological Economics Conference, July 2005, Takoma, Washington. jdahmus@mit.edu and gutowski@mit.edu
Daly, Herman E. (1992) 'Allocation, distribution, and scale: Towards an economics that is efficient, just, and sustainable', *Ecological Economics,* vol 6, pp185-193
Daly, Herman E., & Cobb, Clifford W. (1989) *For the Common Good*, Beacon, Boston
De Bruyn, Sander, and Opschoor, John B. (1997) 'Developments in the throughput-income Relationship: Theoretical and empirical observations', *Ecological Economics*, vol 20 (3), pp255-268
Defra (UK Department of the Environment, Food, and Rural Affairs) (2002) Energy Efficiency Commitment, www.defra.gov.uk/environment
Domar, Evsey D. (1962) 'On total productivity and all that', *Journal of Political Economy*, vol 70 (5), pp597-608
DTI (UK Department of Trade and Industry) (2006) 'The energy challenge: Energy review report', July 2006, www.berr.gov.uk/files/file31890.pdf
EEB (European Environmental Bureau) (2000) Document 2000/021, Sarah Keay-Bright, www.eeb.org/publication/general.htm
EnergySchweiz (2007) 'Wirkungsanalyse', www.bfe.admin.ch/energie/00588/
Etzioni, Amitai (1998) 'Voluntary simplicity: Characterization, select psychological implications, and societal consequences', *Journal of Economic Psychology*, vol 19, pp619-643
Fawcett, Tina (2004) 'Carbon rationing and personal energy use', *Energy & Environment*, vol 15 (6), pp1067-1083
Fouquet, Roger, & Pearson, Peter J.G. (2006) 'Seven centuries of energy services', *Energy Journal*, vol 27 (1), pp139-177
Giampietro, Mario (1994) 'Sustainability and technological development in agriculture', *BioScience,* vol 44 (19), pp677-689
Giampietro, Mario, & Mayumi, Kozo (2000) 'Multiple-scale integrated assessments of social metabolism: Integrating biophysical and economic representations across scales', *Population and Environment*, vol 22 (2), pp155-210
Greenberg, Dolores (1990) 'Energy, power, and perceptions of social change', *American Historical Review,* vol 95 (3), pp693-714
Greenhalgh, Geoffrey (1990) 'Energy conservation policies', *Energy Policy,* vol 18 (4), pp293-299
Greening, Lorna A., Greene, David L., & Difiglio, Carmen (2000) 'Energy efficiency and consumption – the rebound effect – a survey', *Energy Policy*, vol 28 (6/7), pp389-401
Grubb, Michael J. (1990a) *Energy Policies and the Greenhouse Effect, Vol. 1*, Dartmouth Publishing Co., Aldershot, UK
Grubb, Michael J. (1990b) 'Communication: Energy efficiency and economic fallacies', *Energy Policy*, vol 18 (8), pp783-785
Hannon, Bruce (1975) 'Energy conservation and the consumer', *Science*, vol 189, pp95-102
Hannon, Bruce (1998) 'Letter to the Editor', *Ecological Economics,* vol 27 (2), pp215-216
Hearn, William Edward (1864) *Plutology: Or the Theory of the Efforts to Satisfy Human Wants,* Macmillan & George Robinson, London and Melbourne

Herring, Horace (2006) 'Energy efficiency – A critical view', *Energy,* vol 31, pp10-20
Hinterberger, Friedrich, Luks, Fred & Schmidt-Bleeck, Friedrich (1997) 'Material flows vs. "natural capital": What makes an economy sustainable?', *Ecological Economics*, vol 23 (1), pp1-14
Hotelling, Harold (1931) 'The economics of exhaustible resources', *Journal of Political Economy,* vol 39 (2), pp137-175
Howarth, Richard B. (1997) 'Energy efficiency and economic growth', *Contemporary Economic Policy* vol XV (4), pp1-9
INFRAS (2003) 'Begleitende Evaluation der Wirkungsanalyse 2002 von EnergieSchweiz', www.bfe.ch/energie
Jänicke, Martin, Mönch, Harald, Ranneberg, Thomas & Simonis, Udo E. (1989) 'Structural change and environmental impact', *Intereconomics*, vol 24 (Jan.-Feb.), pp24-35
Jevons, William Stanley (1865 [1965]) *The Coal Question*, 3rd edition, Augustus M. Kelley, New York
Jevons, William Stanley (1871 [1911]) *The Theory of Political Economy,* 5th edition, Augustus M. Kelley, New York
Jones, Richard (1831) *Essay on the Distribution of Wealth and the Sources of Taxation,* Murray, London
Kaufmann, Robert (1992) 'A biophysical analysis of the energy/real GDP ratio: Implications for substitution and technical change', *Ecological Economics,* vol 6, pp35-56
Khazzoom, J. Daniel (1980) 'Economic implications of mandated efficiency in standards for household appliances', *Energy Journal,* vol 1 (4), pp21-40
Lantz, V., & Feng, Q. (2006) 'Assessing income, population, and technology impacts on CO2 emissions in Canada: Where's the EKC?' *Ecological Economics*, vol 57 (2), pp229-238
Lauderdale, Earl of (1804) *An Inquiry into the Nature and Origin of Public Wealth and into the Means and Causes of Its Increase*, Arch. Constable & Co., Edinburgh
Levett, Roger (2004) 'Quality of life eco-efficiency', *Energy & Environment,* vol 15 (6), pp1015-1026
Lovins, Amory B. (1988) 'Energy saving from more efficient appliances: Another view', *Energy Journal*, vol 9, pp155-162
Luzzati, Tomasso, and Orsini, Marco (2007) 'Natural environment and economic growth: Looking for the Energy-EKC', in Sergio Ulgiati (ed), *Proceedings of the 5th Biennial Workshop in Advances in Energy Studies*, Porto Venere, Italy, 12-16 September 2006 or: (2009) 'Investigating the energy-environmental Kuznets curve', *Energy,* vol 34, pp291-300
Malthus, Thomas Robert (1798 [1976]) *An Essay on the Principle of Population,* Philip Appleman (ed), W.W. Norton, New York
Malthus, Thomas Robert (1820/1836 [1986]) *Principles of Political Economy*, 2nd edition, E.A. Wrigley & David Souden (eds), Pickering, London
Malthus, Thomas Robert (1824 [1986]) 'On political economy', in E.A. Wrigley & David Souden (eds) *Essays in Political Economy,* Pickering, London
Malthus, Thomas Robert (1825 [1986]) *Essays on Political Economy,* edited by E.A. Wrigley & David Souden. Pickering, London
Manne, A.S., & R.G. Richels (1990) 'CO2 emission limits: An economic cost analysis for the USA', *Energy Journal*, vol 11 (2), pp51-74

Martinez-Alier, Juan (1987) *Ecological Economics: Energy, Environment and Society*, Oxford, Blackwell
Marx, Karl (1887) *Capital: A Critical Analysis of Capitalist Production,* London/MEGA (Karl Marx Friedrich Engels Gesamtausgabe), Dietz Verlag, Berlin
McCulloch, John Ramsay (1825) *The Principles of Political Economy,* William and Charles Tait, Edinburgh and Longman & Co., London
Meadows, Donella H., Dennis L. Meadows, Jørgen Randers, & William W. Behrens III (1972) *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind,* Potomac Associates/Earth Island, London
Mill, John Stuart (1848 [1965]) *Principles of Political Economy, with Some of their Applications to Social Philosophy,* J.M. Robson (ed), University of Toronto and Routledge & Kegan Paul, Toronto and London [1848 edition published by John W. Parker, West Strand, London]
Moezzi, Mithra (2000) 'Decoupling energy efficiency from energy conservation', *Energy & Environment,* vol 11 (5), pp521-537
Mundella, Anthony J. (1878) 'What are the conditions on which the commercial and manufacturing supremacy of Great Britain depend, and is there any reason to think they have been, or may be, endangered?', *Journal of the Statistical Society of London,* March, pp87-126
NRC (National Research Council) (2002) *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards,* National Academies Press, Washington, D.C.
Norgard, J.S. (2006) 'Consumer efficiency in conflict with GDP growth', *Ecological Economics*, vol 57 (1), pp15-29
Opschoor, Hans (1995) 'Ecospace and the fall and rise of throughput intensity', *Ecological Economics,* vol 15 (2), pp137-140
Pascual, Unai (2002) 'Land use intensification potential in slash-and-burn farming through improvements in technical efficiency', *Ecological Economics*, vol 52 (4), pp497-511
Pearce, David (1987) 'Foundations of an ecological economics', *Ecological Modelling,* vol 38, pp9-18
Petty, William, (1675 [1899]) 'Political Arithmetick', in Charles Henry Hull (ed) *The Economic Writings of Sir William Petty*, CUP, Cambridge, UK
Prettenthaler, Franz E., and Steininger, Karl W. (1999) 'From ownership to service use lifestyle: The potential of car sharing', *Ecological Economics*, vol 28, pp443-453
Price, B.B. (1998) 'Rae's theory of the history of technological change', in Hamouda, O.F., Lee, C. and Mair, D. (eds) *The Economics of John Rae,* Routledge, London
Princen, Thomas (1999) 'Consumption and environment: Some conceptual issues', *Ecological Economics*, vol 31 (3), pp347-63
Radetzki, Marian & John E. Tilton (1990) 'Conceptual and methodological issues', in John E. Tilton (ed) *World Metal Demand: Trends and Prospects,* Johns Hopkins for Resources for the Future, Baltimore
Rae, John (1834 [1964]) *Statement of Some New Principles on the Subject of Political Economy, Exposing the Fallacies of the System of Free Trade, and of Some Other Doctrines Maintained in the 'Wealth of Nations',* Augustus M. Kelley, New York

Reijnders, Lucas (1998) 'The factor X debate: Setting targets for eco-efficiency', *Journal of Industrial Ecology*, vol 2 (1), pp13-22
Rhee, Hae-Chun, & Chung, Hyun-Sik (2006) 'Change in CO2 emission and its transmissions Between Korea and Japan using international input-output analysis', *Ecological Economics*, vol 58 (4), pp788-800
Ricardo, David (1817/1821 [1951]) *On the Principles of Political Economy and Taxation,* 3rd edition, Pierro Sraffa (ed), CUP, Cambridge, UK
Ricardo, David (1820-22) *Notes on Malthus' Principles of Political Economy,* Pierro Sraffa (ed), CUP, Cambridge, UK
Robinson, Joan (1956/1965) *The Accumulation of Capital*, 2nd edition, Macmillan, London
Rosenberg, Nathan (1982) *Inside the Black Box: Technology and Economics*, CUP, Cambridge, UK
Rosenberg, Nathan (1994) *Exploring the Black Box: Technology, Economics, and History*, CUP, Cambridge, UK
Roy, Joyashree (2000) 'The rebound effect: Some empirical evidence from India', *Energy Policy,* vol 28 (6/7), pp433-438
Rudin, Andrew (2000) 'Let's stop wasting energy on efficiency programs – energy conservation as a noble goal', *Energy & Environment,* vol 11 (5), pp539-551
Saint-Paul, Gilles (1995) 'Discussion', in Ian Goldin & L. Alan Winters (eds) *The Economics of Sustainable Development,* CUP, Cambridge, UK
Sanne, Christer (2000) 'Dealing with environmental savings in a dynamical economy – how to stop chasing your tail in the pursuit of sustainability', *Energy Policy,* vol 28 (6/7), pp487-495
Sanne, Christer (2002) 'Willing consumers – or locked in? Policies for a sustainable consumption', *Ecological Economics,* vol 42, pp273-287
Saunders, Harry D. (1992) 'The Khazzoom-Brookes postulate and neoclassical growth', *Energy Journal*, vol 13 (4), pp131-148
Saunders, Harry D. (2000a) 'A view from the macro side: Rebound, backfire and Khazzoom-Brookes', *Energy Policy*, vol 28 (6/7), pp439-449
Saunders, Harry D. (2000b) 'Does predicted rebound depend on distinguishing between energy and energy services?', *Energy Policy*, vol 28 (6/7) pp497-500
Saunders, Harry D. (2005) 'A calculator for energy consumption changes arising from new technologies', *Topics in Economic Analysis & Policy,* vol 5 (1), article 15
Say, Jean-Baptiste (1803/1836 [2001]) *A Treatise on Political Economy,* translation by Prinsep, introduction by Munir Quddus & Salim Rashid, Transaction, New Brunswick, New Jersey and London
Say, Jean-Baptiste (1820 [1936]) *Letters to Malthus,* translation Laski, Harold J., George Harding's Bookshop Ltd., London
Schipper, Lee, & Meyers, Stephen (1992) *Energy Efficiency and Human Activity,* CUP, New York
Schipper, Lee, Haas, R. & Sheinbaum, C. (1996) 'Recent trends in residential energy use in OECD countries and their impact on carbon dioxide emissions: A comparative analysis of the period 1973-1992', *Mitigation and Adaptation Strategies for Global Change*, vol 1 (2), pp167-196

Schipper, Lee, & Grubb, Michael (2000) 'On the rebound? Feedbacks between energy intensities and energy uses in IEA countries', *Energy Policy* vol 28 (6/7), pp367-388
Schmidt-Bleeck, Friedrich (1994) *Wieviel Umwelt braucht der Mensch? MIPS – Das Mass für ökologisches Wirtschaften*, Birkhäuser, Berlin
Schmookler, Jacob (1966) *Invention and Economic Growth*, Harvard U. Press, Cambridge, MA
Schor, Juliet (1992) *The Overworked American: The Unexpected Decline of Leisure*, Basic Books, New York
Schor, Juliet (1999) *The Overspent American: Upscaling, Downshifting, and the New Consumer,* Basic Books, New York
Schumpeter, Joseph A. (1911 [1926]) *Theorie der wirtschaftlichen Entwicklung*, 2nd edition, Duncker & Humblot, Leipzig, Germany
Schurr, Sam H. & Netschart, Bruce C. (1960) *Energy in the American Economy, 1850-1975*, Johns Hopkins, Baltimore
Schurr, Sam (1985) 'Energy conservation and productivity growth: Can we have both?' *Energy Policy,* vol 13 (2), pp126-132
Sieferle, Rolf Peter (2001) *The Subterranean Forest,* White Horse Press, Cambridge, UK
Simms, Andrew (2005) *Ecological Debt. The Health of the Planet and the Wealth of Nations,* Pluto, London
Sismondi, Jean Charles Léon Simonde de (1819 [1827]) *Nouveaux Principes d'Économie Politique ou de la Richesse dan ses Rapports avec la Population,* 2 vols, 2nd edition, Delaunay, Paris
Smil, Vaclav (2003) *Energy at the Crossroads: Global Perspectives and Uncertainties*, MIT Press, Cambridge, MA
Smith, Adam, (1776 [1976]) *An Inquiry into the Nature and Causes of the Wealth of Nations*, R.H. Campbell, A.S. Skinner & W.B. Todd (eds), Clarendon Press, Oxford
Solow, Robert (1957) 'Technological change and the aggregate production function', *Review of Economics and Statistics*, vol 39, pp312-20
Solow, Robert (1970) *Growth Theory: An Exposition,* Clarenden Press, Oxford
Sorrell, Steve, & Dimitropoulos, John (2006) 'The Rebound effect: Microeconomic definitions, extensions and limitations', Working Paper April 2006, London, UKERC/SPRU
Spengler, Joseph J. (1959) 'John Rae on economic development: A note', *Quarterly Journal of Economics,* vol 73, pp393-406
Sraffa, Pierro (1951) 'Introduction' (see Ricardo, 1817)
SwissEnergy (2004) 'Partner for the climate: Annual Report of SwissEnergy 2003/2004', Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation & Bundesamt für Energie, Bern
van den Bergh, Jeroen C.J.M. (1999) 'Materials, capital, direct/indirect substitution, and mass balance production functions', *Land Economics,* vol 4 (3), pp547-561
Veblen, Thorstein (1899 [1998]) *The Theory of the Leisure Class*. Prometheus, Amherst, NY
Victor, Peter A. (1991) 'Indicators of sustainable development: Some lessons from capital theory', *Ecological Economics*, vol 4 (3), pp191-213
von Liebig, Justus (1851) *Familiar Letters on Chemistry*, Taylor, Walton & Mabely, London

von Weizsäcker, Ernst, Lovins, Amory B., & Lovins, L. Hunter (1997) *Factor Four: Doubling Wealth – Halving Resource Use,* Earthscan, London
Wackernagel, Mathis, & Rees, William (1996) *Our Ecological Footprint: Reducing Human Impact on the Earth*, New Society, Gabriola Island, DC, Canada
Wackernagel, Mathis, & William Rees (1997) 'Perpetual and structural barriers to investing in natural capital: Economics from an ecological footprint perspective', *Ecological Economics*, vol 20 (3), pp3-24
Weisz, Helga, Krausmann, Fridolin, Amann, Christof, Eisenmenger, Nina, Erb, Karl-Heinz, Hubacek, Klaus & Fischer-Kowalski, Marina (2006) 'The physical economy of the European Union: Cross-country comparison and determinants of material consumption', *Ecological Economics*, vol 58 (4), pp676-698
Wirl, Franz (1997) *The Economics of Conservation Programs*, Kluwer Academic, Boston

Addendum to the Earthscan chapter for its submission for the PhD by Publication at NBS, UEA

This work on the history of ideas relevant to the rebound question certainly helped clarify and flesh out some of the concepts. It also brought into focus the following chain of reasoning in estimating high rebound:

1. technological efficiency increase itself, taken exogenously but including our reasons for doing it, entailing as it does certain costs;
2. the effect of technological efficiency increase on economic growth, i.e. growth in the amount of goods and services;
3. that this increase in society's production possibilities frontier was in some sense for free;
4. the effect on a natural resource's price when it is used more efficiently;
5. the result that such efficiency increase enabled population increase;
6. the central question of how efficiency in using resource X, through the medium of economic growth, affects the amounts of resource X consumed;
7. analogously, that labour inputs had been determined not to go 'unemployed' when used more efficiently;
8. and, mysteriously, that efficiency increases led to new products and thus perhaps to even more consumption of the input than before the efficiency increase.

Of course this study was no more conclusive than any of the dozens of attempts to measure direct rebound; but several sceptics found it convincing, perhaps due to the hoary reputations of the studied 'previous writers'.

Journal of Cleaner Production 18 (2010) 552–560

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Impact caps: why population, affluence and technology strategies should be abandoned

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ARTICLE INFO

Article history:
Received 20 January 2009
Received in revised form
24 July 2009
Accepted 1 August 2009
Available online 5 August 2009

Keywords:
Energy rationing
IPAT
Rebound
Efficiency
Sufficiency
Politics

ABSTRACT

This paper classifies strategies to reduce environmental impact according to the terms of the $I = PAT$ formula. Policies limiting resource depletion and pollution (*Impact*) – by heavily taxing resources or rationing them on a country basis – are thus called 'direct' or 'left-side' strategies. Other policies to achieve the environmental goal of lowering *Impact* strive to limit *Population* and *Affluence,* or to use *Technology* to lower the ratio of resource inputs to goods-and-services outputs. Next it is shown that lowering any of these 'right-side' factors causes or at least enables the other two to rise or 'rebound'. This has two consequences: 1) Since $I = PAT$ does not express these interdependencies on the right side, it is more accurately written $I = f(P,A,T)$; and 2) Success in lowering any of the right-side factors does not necessarily lower *Impact*. Rationing or Pigouvian taxation of resources or pollution, on the other hand, *necessarily* lower impact and are therefore preferable to population, consumption and technological environmental strategies. Finally, lifestyle and technology changes towards more sufficiency and efficiency would *follow* the caps as consumers and producers work to retain the greatest amount of welfare within the limits given.

1. Epigraph

> Quantitative limits are set with reference to ecological and ethical criteria, and the price system is then allowed, by auction and exchange, to allocate depletion quotas and birth quotas efficiently. The throughput is controlled at its input (depletion) rather than at the pollution end because physical control is easier at the point of lower entropy. (Herman Daly [1, p. 20])

2. Introduction

$I = PAT$, where unwanted environmental Impact depends on Population size, Affluence (consumption of goods and services per person) and Technology, suggests a distinction between left-side and right-side strategies for reaching a sustainable economic scale. 'Strategies' are simply sets of environmental policies, and the paper assumes conventional definitions of 'natural resource', 'pollution' and 'sustainability'. The left-side term, Impact, is both natural resource depletion and biosphere pollution – a non-aggregable term covering the loss of fuels, water, soil, space, ores, fish, biodiversity, favourable climate and other ecosystem amenities, etc. In this paper Impact more restrictively means *carbon-based energy resource* depletion with ensuing emissions.

Right-side terms and strategies include:

1) Population; policies achieving a lower number, *ceteris paribus*, could lower Impact.
2) Affluence (a ratio) is consumption of goods and services – desired *output* – per person; *ceteris paribus,* lowering affluence either voluntarily in the sense of sufficiency, frugality or 'living lightly', or through legal restrictions on what can enter the market, could lower total Impact computed as $P \times A$.
3) Technology is an admittedly ornery term covering *how* an economy produces and consumes: with what legal rules, type of organisation, chemicals and output–input efficiency. Consistent with the definition of Impact above, this paper singles out efficiency (another ratio) in using carbon-based energy resources as the T term; accordingly, *ceteris paribus*, policies achieving lower energy input *per unit* of output (goods and services) could lower Impact defined as the amount of energy inputs used up. Lower T means lower (energy) *intensity,* i.e. higher efficiency.

Consumer efficiency is another right-side strategy proposed within the current discussion of 'sustainable consumption'.[1] Taking the example of boiling water for a cup of coffee: more

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[1] While policy interventions in this area are loosely subsumed under the concept of 'sustainable consumption', there is in this research field no consensus on definitions and taxonomy. See [2, p. 1029–1032].

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doi:10.1016/j.jclepro.2009.08.001

energy-efficient kettles is physical (as opposed to institutional) technological change (*T*); doing without the odd cup of coffee, for environmental reasons, is living more 'sufficiently' (*A*); boiling *no more than* the amount of water needed for the cup of coffee, in contrast, is consumer efficiency, here also classed under *T*.[2] This paper places environmental restoration activities or traditional 'end-of-pipe' measures (for example carbon capture and storage) outside the $I = PAT$ framework because their pollution reduction is at the cost of some energy depletion.

Other strategies prominent in the sustainability discussion are here taxed as 'left-side' because they directly lower Impact with no reference to population, affluence and technology, namely:

1) Reduction of carbon-based energy resource *production*, i.e. a physically defined cap on harvesting and mining; from this 'upstream' measure are then deduced rations per country.
2) Limiting energy *consumption* per person (quotas, rations); one example of this 'downstream' measure is personal carbon budgets.
3) Reduction of *emissions* – targeting pollution rather than depletion – through physically defined caps; one example is the 'Kyoto' approach with derived country caps.
4) *Taxes* on depletion or emissions high enough to limit consumption of energy inputs to the level perceived to be sustainable (Pigouvian taxes).

These sets of policies do not attempt to influence number of people, number of goods and services per person or efficiency, but instead say: "These are the maximum allowed amounts. Each country, firm and person must find the combination of reductions in population, affluence and energy intensity that most suits them."

Section 1 describes the three right-side strategies intended to indirectly lower Impact, identifies their interdependencies (how each 'rebounds') and shows that they are 1) not *necessarily* effective and 2) taken all together, costly. Section 2 more fully describes left-side strategies directly lowering depletion and pollution through legal rules of resource use, whether through physically defined *caps* or taxes raising resource *prices*; these are *necessarily* effective and require only one policy. Section 3 shows this taxonomy's relation to well-known literature and applies it to a typical impact-reduction model containing both technical and lifestyle changes. Section 4 discusses policy simplicity and political acceptability.

3. Section 1: right-side environmental strategies

$I = PAT$ was introduced with policy in mind. As Faye Duchin writes,

> Ehrlich and Holdren (1974) identified the main factors responsible for environmental degradation as population increase, affluence, and technology, providing three potentially important 'handles' for operationalizing the concept of sustainable development. [3, p. 51]; [also 4] I have called each "handle" a 'strategy'[3]

IPAT is sometimes incorrectly called an "identity". As one of its first applications shows, it is however a *formula* with which to compute the amount of Impact, namely the amount of automotive lead in the air. Paul Ehrlich et al. set all IPAT values at 1 for 1946 then compared 1946 data with that of 1968 on population, number of driven auto kilometres per person and the amount of lead emitted per driven kilometre; impact increased 414% – i.e. a *worsening* from the environmental point of view [6, p. 206, 214]. The reason the formula is thus not an identity is that both the number of driven kilometres and technical efficiency increase or decrease exogenously to the model, whereby *T* is defined *per unit* of good or service and *A* as *total units* of goods and services. In general total units consumed does *not* stay constant after efficiency increases, but rather increases, constituting 'rebound' consumption of the newly more efficiently-used input. As illustrated by Fig. 1 [7], this partly or entirely wipes out the theoretical 'engineering' savings that would materialize had number of consumed units stayed the same.

This section argues that since each right-side strategy by itself is followed by rebounds, i.e. environmentally worsening of the other two factors, reduced Impact does not *necessarily* result. Given *any* latent demand for more goods and services, and/or greater population, it is thus *certain* that no right-side set of measures is *sufficient* for lowering Impact. Therefore either additional, complementary right-side measures are required, or resort must be taken to left-side measures. Equally certainly, the difficulties of enacting, enforcing and co-ordinating many simultaneous right-side measures lowers their *cost*-effectiveness.[4]

First, before showing seven interdependencies among the three right-side factors, some general observations on rebound (illustrated intuitively by Fig. 2). The literature is decisive that rebound itself is proven,[5] and a consensus has even emerged that rebounds are 'significant' or 'relevant' to environmental policy [19]. That is, these rebounds or system adjustments – more people, more goods and services, less efficient or more 'luxurious' technology – mean that environmental improvements on the right side *cannot* translate one-to-one into lower Impact: *some* potential input savings will be consumed.

What if *all of* the potential population, sufficiency or efficiency induced savings are consumed? In that case right-side strategies would, even if cleverly and simultaneously co-ordinated, have *no effect* on Impact. A third possibility is that efficiency policies would even environmentally 'backfire', the greater efficiency causing *more* energy to be consumed than if technology had stayed the same – a thesis known as Jevons Paradox [8,17,19] or the Khazzoom–Brookes Postulate [11,12], arguing that efficiency enables new products, fuels economic growth and thus increases Impact.

While assuming, to be sure, that rebounds are large or significant (say 50% worldwide and longer-run [20]), this paper is explicitly conceptual rather than empirical. It attempts only 1) to identify and classify the various types of rebound, or right-side interdependencies, and 2) show the major consequence for environmental policy *if* rebounds are 50 or 100% – namely, that right-side changes, while certainly fruitful in securing higher material living standards and, for some societies, energy independence, are either weak or futile in achieving the depletion and pollution reductions necessary for environmental sustainability.

The general interdependencies between the *P*, *A* and *T* factors are:

P) Lower population means lower impact *only if* affluence and factor productivity are held constant;

[2] Another example of consumer efficiency is carpooling, as opposed to more efficient cars (*T*) and cycling or staying at home (*A*).

[3] Waggoner & Ausubel [5] offer a less parsimonious ImPACT identity whose C, C_2, T and T_2 are the T of this paper and which offer four 'sustainability levers' for actors to behave more efficiently and sufficiently.

[4] Working Group III's Summary for Policy Makers (IPCC Fourth Assessment Report) lists no fewer than 25 right-side measures covering energy supply, transport, buildings, industry, agriculture, forestry and waste management, policies that would be rendered *superfluous* were caps in place.

[5] See Fig. 1 and references [7–18].

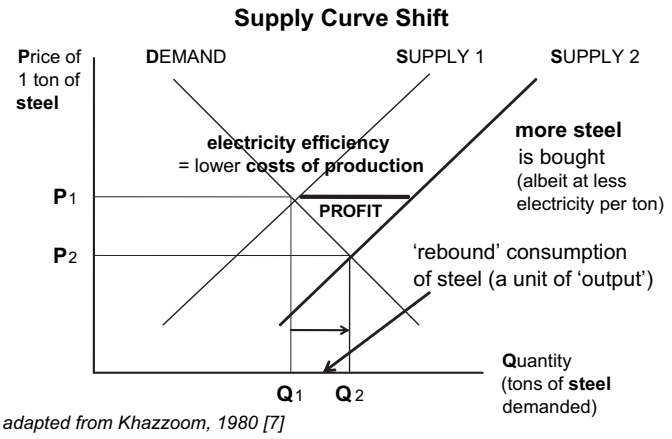


Fig. 1. Khazzoom's proof of rebound: Prices do not stay the same! Lower input use per unit of output means lower production costs, enabling suppliers to offer the same amount at a lower price or more at the same price: the supply curve shifts outward. For any demand curve sloping as depicted, i.e. with any positive price elasticity of demand, the lower price raises the quantity of good or service sold to a level above that previous to the production-cost-reducing technological efficiency increase. This 'rebound' consumption *of goods or services* entails 'rebound' consumption of *inputs* (e.g. energy) above the level it would have been had number of units consumed remained constant.

A) Only if population and efficiency are held constant does voluntary frugality lower impact;
and *T)* using resources more efficiently lowers impact *only if A* and *P* remain constant.

Put differently, impact is lowered only if there is complete 'demographic transition', full consumer satiation, and no decrease of technological efficiency[18, p. 884].

Hopefully, the following seven interdependencies establish the *plausibility* of system adjustments in any open economy.

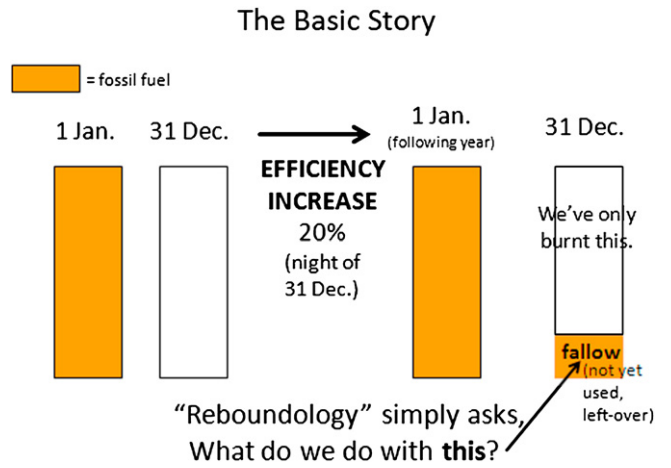


Fig. 2. Rebound visualized. During the post-efficiency-increase time period ("following year") an amount of energy equal to 20% of the previous time period's consumption is 'saved'. If the number of people and their consumption of goods and services stays the same (the *ceteris paribus* condition), the rate of consumption of energy inputs remains at 80% of the previous level and theoretical savings become real. If however population and/or affluence increase, the rate of consumption rises again – probably to the same level as before the efficiency increase. Society is free to use up the freed-up energy resources or not. The disciplines of history, economics, psychology, anthropology and political science must combine their efforts with a portion of wisdom to judge what society does.

3.1. Population change

3.1.1. $A = f(P)$: per capita consumption as a function of total population ('more mouths to feed')

For all natural resources, lower P enables higher A through re-employment of the temporarily freed resources. If gross world product (GWP) is like a cake, lower population *enables* each person to consume a somewhat larger piece. Of course to the extent that cakes are products of labour, lower population can mean fewer work-hours and a smaller cake – but we are computing not total cake but cake per person. Higher population inversely means that area and natural resources per capita fall. Impact can remain unchanged [21].

3.1.2. $T = f(P)$: technology as a function of population size (diminishing returns)

To the extent that lower population lessens demand for natural resources it reduces the pressure to use them more efficiently. Higher population density, inversely, is in itself an incentive to produce more efficiently due both to increasing perception of depletion/pollution and to diminishing economic returns from 'land' (soils, minerals, fuels). For instance coal and oil largely replaced wood, as did synthetic fibres much wool and cotton, and incentives are strong to more efficiently process lower-grade ores, oil sands, and soils [22].

3.2. Affluence change

3.2.1. $P = f(A)$: population size as a function of per capita consumption

At lower incomes higher affluence enables survival and often higher population, while at the same time the higher levels of education and women's rights often accompanying greater affluence can lead to smaller families. At higher incomes birth rates drop – but so do death rates [23,24]. Whether overall the sign between P and A is negative or positive remains contested, meaning that policy interventions are uncertain.

3.2.2. $T = f(A)$: technology as a function of per capita consumption (hybrid cars, combined heat and power, lasers)

Tracing influences on technology of the knowledge gains that accompany per capita *wealth* is a tall order. While a wealthy economy can afford to use resources less efficiently, it can also afford to invest more inefficient, cost-cutting technology (in the interest of even higher affluence). The capital junking accompanying technological innovations lowers efficiency, yet wealth enables research and development for lower energy intensity, whether to cut costs or alleviate local environmental impacts. Here, too, the overall sign of the relationship is debatable.

3.2.3. $A[\varepsilon P_x] = f(A[\varepsilon P_y])$: the affluence of one subset [ε] of the population as a function of (changes in) the affluence of another subset

Given limited amounts of labour and natural resources, a unit of consumption by anyone with ability to pay excludes others from that consumption. Relevant to environmental strategies is the fact that if someone for environmental reasons voluntarily lowers his or her affluence, the system-wide result can compensate for this. Fig. 3 shows how the frugality initially lowers energy demand, a demand-function shift meaning lower energy *prices*; this in turn enables marginal consumers to increase their demand, eliminating some or all of the initial, frugality-induced resource saving. This 'sufficiency rebound' means that a net decrease of Impact does not necessarily follow from voluntary frugality [25]. Although the size of this global rebound is even less satisfactorily measured than the efficiency rebound, both

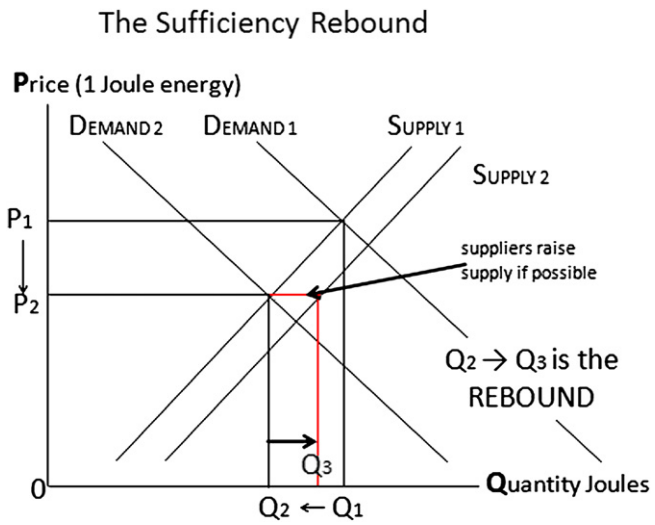


Fig. 3. Rebound after voluntary frugality. Doing without goods and services – either voluntarily or in compliance with political decisions – lowers quantities consumed by assumption, and constitutes a leftward shift of the demand curve. The resulting lower prices attract other consumers who are *not* behaving 'sufficiently' in the interests of the environment. This reaction raises quantities demanded above the level after the 'sufficiency shock'. If suppliers can raise production at the new price level the process is complete, and some rebound assures that for the whole system, voluntary frugality does not result one-to-one in real input savings. Again, prices do not stay the same.

widespread poverty and material aspirations of the well-to-do suggest that all freed resources would likely be snapped up.

3.3. Technology change

3.3.1. $P = f(T)$: population size as a function of technology (green revolution)

Increases for instance in agricultural efficiency have usually caused population increase, with various effects on affluence but likely leaving Impact the same. Increased yield per hectare has never meant that we take land out of production. This rebound effect, which renders P partly *endogenous* in energy-consumption models, has been largely neglected [26].

3.3.2. $A = f(T)$: affluence as a function of technological (fuel-) efficiency (efficient equipment)

Were the right side of $I = PAT$ multiplicative (no interdependencies), lower T (higher efficiency) would automatically lower I. But higher efficiency – either technological or organizational – raises income, consumption, or wealth ($P \times A$). This uncontested rebound means Impact cannot be thereby reduced to the full extent of potential savings, computation of which multiplies energy input per unit of goods-and-services by goods-and-services outputs while holding the *number of output-units constant*. Unfortunately, thirty years after Khazzoom's proof of this, this naïve, non-economic view dominates not only political programmes,[6] but most academic literature researching cleaner production, efficiency standards, barriers to cleaner technology, renewable energy, agricultural productivity, etc.

To my knowledge only the UK government is beginning to acknowledge rebound, in some sectors, when evaluating its energy-efficiency programmes. Otherwise, as a representative of the Swiss Energy Office recently said to me, "Until we know exactly how big rebound is, we treat it as zero" [27]. The jury to be sure is still out on the precise relationship between per-unit efficiency changes, per unit price changes and total units consumed; in fancy terms, the efficiency elasticity of demand has not been micro-economically computed [15]. Ignoring rebound altogether, however, is scientifically inacceptable, analogous to postponing acknowledgement of climate change until scientists unequivocally prove that human activity will raise average temperatures by 2.78 degrees by June 2041.

For even a rudimentary case that rebound equals unity much additional space would be needed. Briefly, nevertheless, note only that there are at least five lines of argumentation that the energy resources temporarily freed by efficiency increases are fully used up by world economic activity:

1. Time series show high correlation between increased production efficiency – mainly business-as-usual attempts to save costs, lower prices and increase sales – and increased energy consumption [17,28,29,30, p. 243, 338] and [31]. Of course correlation is not causality, yet the empirical data seems strong enough to shift the burden of proof onto the position that rebound is less than 100%.
2. A factor of production that becomes more productive thereby enjoys, within substitutability constraints, higher demand compared to other factors of production [9,11,15].
3. Two roles of energy efficiency increases are to date not well-investigated: a) enabling *new uses* for energy and b) saving *time* that is used for further production and consumption; these would have to be booked under rebound [8,19,32].[7]
4. Popular models yielding relatively low rebound are methodologically weak: often only direct rather than *total* rebound is measured[8]; population and GDP are fully exogenous; marginal consumption is assumed to be less energy-'intensive'; monetary metrics neglect that 'income effects' for the consumer are counterbalanced by the necessarily *lowered* income of energy sellers [34].
5. *Labour* input efficiency has risen constantly with economies of scale, stable legal systems, trade, factory-floor re-organisation, faster communication, transport infrastructure, etc. – yet no one maintains that thereby *less* labour employment has been the result [17].

Current evidence is thus such that the *burden of proof* can just as well rest on showing what has never been demonstrated: that per-unit input savings cause overall savings (i.e. rebound <100).

For clarity: high-rebound theory does not claim that energy efficiency increase is the *only* cause of greater energy consumption; labour efficiency increase, new energy sources, some exogenous population increase or rising energy return on energy investment (EROI) do their part. Note as well that an exogenous, increased supply of energy from 'renewable' sources also rebounds, namely in a way similar to the sufficiency rebound: lower prices of non-renewables enable marginal consumers to increase their demand. Thus at least in the longer run consumption of *both* types of energy could continue to increase.

[6] In the past few weeks alone the author has collected around ten newspaper items extolling the 'holy trinity' of greater efficiency, renewables and less waste – either op-ed articles or reports of programmes by Barack Obama, Tony Blair, John Podesta, McKinsey Inc., or the Chinese and Swiss governments – all in complete ignorance of rebound.

[7] It could be that "technology is [only] a catalyst, as it were, to induce the latent ability of a resource to emerge." [33, p. 43].

[8] 'Direct' rebound follows from the increased consumption, post-efficiency-change, of exactly the good or service newly more efficiently (cheaply) produced; e.g. the owner of a more efficient car will drive more kilometres.

Efficiency has positive connotations, always having stood for cost-cutting measures that enable individual households to save, firms to increase profits, and in general greater material comfort and health – all non-environmental goals. As in Jevons' day concerning peak coal, though, efficiency has been co-opted by environmentally concerned citizens and researchers in hopes that it is a tool to delay peak oil or global warming. The existence of rebounds, however, means that policies to reduce population, affluence and energy intensity are *not sufficient* to reduce Impact. Luckily, however, this ineffectiveness need not terribly worry us, for right-side strategies are also *not necessary* to lower Impact. The next section describes several alternatives that do guarantee environmental success, all of which are 'on the policy table'.

4. Section 2: left-side environmental strategies

Since any change in a factor on $I = PAT$'s right-side thus causes changes in the other factors (*ceteris paribus* does not obtain) we should replace $I = PAT$ with $I = f(P,A,T)$, expressing these interactions as in Fig. 4. Sometimes, in fact, the literature accepts that therefore right-side measures at best weakly affect Impact, for instance when it is argued that too much effort has gone into the design and implementation of production-side efficiency measures and not enough into population reduction or into lifestyle changes in the direction of sufficiency and consumer efficiency [2,3,19,35]; focus should shift from T to A (P receives little attention). The conclusion drawn in this paper, however, is to shift attention to the left side of $I = f(P,A,T)$, to strategies that directly proscribe exceeding maximum depletion and pollution rates.[9]

The Swiss forest law of 1876 aimed to maintain a given stand of trees, and took the direct path to guaranteed success. Preventing diminution of the number of trees was not pursued by trying to reduce population, urging people to use less wood and convert less forest to agricultural uses, or increasing wood's efficiency in heating, building, or paper-making: it simply forbid it. Some overfishing has similarly been stopped in recent years. The 'Kyoto' plan says that no more carbon-based energy resources *may* be burned than is consistent with, say, 450 parts CO_2-eq. per million by volume in the atmosphere. One could alternatively cap global *production* of the troublesome substances oil, gas and coal. Andrew Simms for instance quotes the claim that "80 percent of the fossil carbon that ends up as man-made CO_2 in the earth's atmosphere comes from only 122 producers of carbon-based fuels", enabling at low administrative cost reductions to for instance half the 85 million barrels oil-equivalent produced now per day [36, p. 177] and [37]. As in wartime Britain, national caps can be distributed among the population in the form of rations. These policies or strategies are *sufficient* for the environmental goal, giving them *a priori* advantage over strategies whose success is impeded by compensating reactions in other parts of the economic system.

Two types of policies are now distinguished, both limiting consumption at physically defined maximum amounts: 1) *taxing* the offending substances so that their prices are high enough to prevent demand from exceeding the politically decided level; 2) *forbidding* consumption above this level. The second policy is straightforward while the first is indirect (via 'the right prices'), but both achieve the same end.

The Pigouvian taxes limit quantity consumed through the price mechanism, at given demand functions for firms, households and individuals. The taxes can fall either on these entities or, through 'excise' taxes, far 'upstream' [38–40]. Perhaps it is a problem that

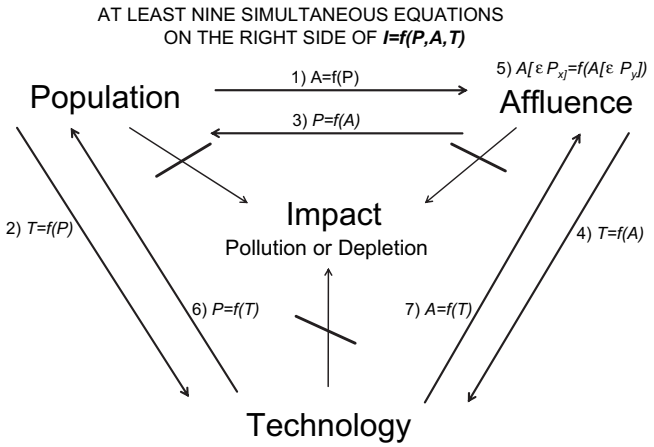


Fig. 4. Loop diagram of seven of the nine interdependencies. The arrows between the terms *P*, *A*, and *T* stand for interdependencies where the signs are usually opposites and represent rebounds. The arrows are numbered according to their appearance in the text. There is no direct or guaranteed effect on Impact of changes in the right-side terms.

the tax revenue then gets spent for, among other things, the taxed substances; yet in theory raising the tax even higher would wipe out this second-order demand or 'eco-tax rebound'.

Bypassing the tax and price system can take several forms.

1. The *production* caps already mentioned can be enforced 'upstream', as they reach the surface of the earth. These are routinely implemented by OPEC, for instance, for non-environmental reasons; groundwater regimes have capped water for the protection of aquifer levels for centuries. Such policies can be measured and enforced purely physically, as can simple *import* restrictions for countries not producing fossil fuels.
2. *Consumption* caps have a long tradition consisting of entitlements to buy or physically distributed rations. Economic analyses of 'sale if and only if coupon' abound.[10] The number of allotments and the amount of resource per allotment are of course deduced from the global maximum but enforced 'downstream' – i.e. well after the energy resource has been mined, refined and embodied in goods and services, implying the problem of measuring how much energy is embodied in a given good or service [47, p. 1073, 1079] and [35]; alternatively, only purchases of energy itself can be rationed.
3. Whereas production and consumption caps implicitly limit emissions as well, the UNFCCC strategy, for instance, aims only at lower pollution Impact, leaving aside the sustainability concerns of declining resource amounts.

Please imagine these policies as global (to avoid free-riding countries) and defined on a country rather than individual basis (to accommodate changes in population size). Current debate concerns not the environmental effectiveness of these strategies, which is given, but rather their relative economic *costs*. The three main rivals are: "domestic tradable quotas, upstream auction or a carbon tax with lump sum recycling." [40, p. 34] For instance taxes might be preferred over consumption quotas because a tax system is already in place, but rations without taxes could be seen as more equitable. This is not the topic of this paper, however, and one can legitimately

[9] Roughly, left-side caps and Pigouvian taxes are 'supply-side', while P, A, and T measures can be called 'demand-side' strategies.

[10] See references [41–49].

ask whether environmental policy should be concerned with economic efficiency and economic growth at all. Their main relevance to environmental goals seems to be that economically more efficient schemes are more easily politically 'sold' to firms and voters [40, p. 5, 10,11, 60,61]. But any left-side strategy renders superfluous a plethora of right-side measures [40, p. 20]. What is left in or on the ground is not yet consumed.

Thus, while causality does not necessarily operate from the right to the left side of IPAT, in the reverse direction it does. Real input limits must lead to large changes in population, affluence and technology since individuals, firms and political units would autonomously and de-centrally adjust their behaviour to maximize their welfare within those limits. Family size might decrease, technology would undoubtedly become more efficient, and a measure of sufficiency would become not only necessary but acceptable [47, p. 1077–79]. Right-side strategies thus actually 'put the cart before the horse', whereas left-side caps would motivate us to get as much utility as possible out of the capped amount. Efficiency, for instance, is then correctly seen as a tool, not for sustainability, but for affluence maximization.

5. Section 3: a typical policy-relevant model

Sections 1 and 2 try to show that environmental goals can be striven for directly or indirectly; that the indirect approaches on the right side of $I = f(P,A,T)$ have no necessary 'impact' on Impact; that where rebounds are at unity they leave Impact untouched; that in any case Impact falls less than the amount computed when $I = PAT$ is used as a multiplicative, static formula innocent of interdependencies; that co-ordinating right-side policies to counteract rebounds is daunting and costly; and that alternatives are available in the form of Pigouvian taxes and caps.

A critique of some well-established and well-funded strategies and research programmes is now possible, and to apply the analysis and integrate it into the more familiar discourse of technological change, cleaner production and lower 'ecological footprints', this section discusses the typical model of Duchin proposing policy "handles" explicitly based on Ehrlich's IPAT equation [3, p. 51] and [50]. In addition to the population strategy (P) it includes "two main avenues for bolder scenarios: technological change [T] and change in the lifestyles of households [A]." [3, p. 20; also p 51, 60] The former is largely the efficiency strategy, while the "lifestyle" category subsumes both personal and community consumption choices, e.g.

> a dramatic reduction of reliance on private automobiles, which could be made possible and desirable only through the increased availability of nonmotorized and public transport and mixed-use community design that satisfies requirements with far less personal displacement. [3, p. 71]

This category, termed "conservation" as opposed to "efficiency", also includes "practically costless improvements in 'housekeeping,' recovery of waste heat, and electronic controls for a variety of processes" as well as "process improvements [and] cogeneration". [50, p. 17, 91–96] Much of this falls under the *structural change* strategy wherein levels of utility and expenditure do not fall but are shifted to less 'environmentally intensive' goods and services [35,51].

In Duchin's structural economics model, one of the main measures "leading to a contraction of factor inputs [is] improved energy efficiency" [3, p. 55], and one such needed technological change is "more fuel-efficient cars" [p 20]. But in this and other models there is no formal integration of system-wide effects like more cars and more driven kilometres: rebound is zero. Actually, Duchin identifies macroeconomic rebound when she writes that "more extensive recycling of materials and more fuel-efficient cars" cause the economic growth necessary for development; "as population and affluence increased, pollution could also be expected to grow" [p. 19]. This indeed seems to describe backfire, i.e. an *increase* in Impact when T, as energy intensity, is reduced.[11]

With the analytical tool of $I = f(P,A,T)$ two further criticisms of this and similar models can be made. *First,* one can in fact accept the simple, multiplicative form of $I = PAT$ as a static *description* of an economy, showing Impact at any given time: Duchin's "structural economics… describe[s] changes in lifestyle and technology in concrete detail" [3, p. 51]. But the model is intended to be policy-relevant: "[A]n explicit focus on households [should not be] absent from work about the restructuring of economies in response to environmental pressures"; "importance for policy" is generally claimed [3, p. xiii, 60, 70]. For the step from environmental *bookkeeping* to environmental *action* to be taken, however, one needs a *dynamic* treatment describing the relations between all four terms.

Second, the efficiency and structural change claimed by the model to reduce Impact are, and can only be, expressed in *ratios*. Efficiency is an intensive variable for output/input, while structural change is to be from a more environmentally intense sector to one less so. But Impact is an *extensive* dependent variable, an absolute number, e.g. of joules or tonnes of CO_2, and thus cannot be deduced from changes in an intensive variable without multiplying by another whole number. Within IPAT, that is, the ratios A and T alone yield no information about I [17]. In anthropomorphic terms, the environment does not 'care about' ratios.

6. Section 4: discussion

What rationing of carbon, once enacted, might mean in terms of 'uses' of equipment emerges, for instance, from the U.K. war experience:

> Between 1938 and 1944 there was an enormous 95 percent drop in the use of motor vehicles in the UK. Even in the United States fuel was strictly and successfully rationed to eliminate unnecessary travel…. Across all goods and services consumption fell 16 percent but with much higher drops at the household level. In just six years from 1938 British homes cut their use of electrical appliances by 82 percent. [36, p. 159]

Statutory, economy-wide reductions in overall fuel consumption *preceded* adjustments in production technology and 'lifestyles'. Similarly, during the period of high fuel prices in summer 2008 news media reported a shift in the US away from heavy, fuel-inefficient cars. If, on the other hand, the reverse is assumed, and the reductions are thought to *follow from* some combination of rich-world frugality and more efficient production and consumption, any resulting expansions elsewhere in the economy stand in the way.

This simplicity of caps or Pigouvian taxation moreover enables full focus on the set goal of changing the left-side term; after all lower rates of reproduction, more frugal consumption and technological 'progress' in the form of greater efficiency are *not* the (environmental) goals. I would suggest that while the debate around 'Kyoto' is salubrious in making no bones about the radical emissions cuts required, it would be even clearer to define these

[11] This environmentally bad effect is then contradictorily laid at the door of *too little* efficiency improvement: pollution rises "not nearly as steeply as if no corrective actions had been taken." [3, p. 19]; also [52] Again, economic growth and population are fully exogenous [53], and efficiency's sign is first negative, then positive.

cuts in terms of less carbon-based *resources* consumed – assuming of course given levels of efficiency, techniques of carbon capture and storage, etc. As one economist sceptical of the environmental effectiveness of the technological 'handle' wrote,

> [i]t would be more straightforward to direct that there should be reductions in 'world economic activity', of specific emissions, or seek worldwide agreement to placing heavy taxes on the offending fuels. [9, p. 201].

Further, "adjustments of efficiency are "oblique" and we would do better to unabashedly "outlaw, ration, and tax." [10, p. 363–64]

There are perhaps three main reasons why right-side strategies are nevertheless widely preferred: 1) they are perceived as more consistent with individual freedom; 2) they are seen as less painful and therefore politically more acceptable; and 3) caps or taxes offer no escape from the harsh fact of the planet's (limited) carrying capacity.

Freedom: Right-side restrictions on biological reproduction, affluent lifestyles and technological inefficiencies can, of course, be legislated. In the real world, however, China is perhaps the only example of the first, and perhaps the Soviet Union and Cuba examples of the second. In contrast, mandatory efficiency standards in buildings and machinery, or waste-minimization, are well-known – yet often take the form of mere encouragement through subsidies, tax breaks, energy-efficiency labels and voluntary agreements. With caps and Pigouvian taxes, however, there are no voluntary agreements, just rules. The call is for mutually agreed upon mutual coercion, for politics rather than individual behaviour change, and for accepting the often-scorned but very human attitude of 'I will only if you will.' [54, p. 147–156, 227–230] and [55].

Political acceptance: Caps and taxes are indeed unpopular, partly due to this high value culturally placed on freedom. Conversely right-side measures promise not only considerable retention of such freedom but a *win-win* vision [25,49]: Doing without some consumption will not only help the environment but is good for you – e.g. bicycling and vegetarianism; or, less consumption requires less income, less work and leaves more free time. Producing more efficiently is said to double affluence at half the environmental cost [56] – a 'lunch you are paid to eat'. Is the choice then between popular, ineffective policies and unpopular, effective ones?

Within the transportation sector Susan Owens and Richard Cowell have similarly observed that because it is so difficult to reduce

> the rate of traffic growth… a view that policy should focus on reducing pollution and congestion, rather than the volume of traffic *per se,* has prevailed, conveniently shifting attention towards vehicle performance, traffic management and selected improvements in the road network. [57, p. 97]

The term 'conveniently' pinpoints the urgent problem of direct strategies: contraction and economic shrinkage ('degrowth') are taboo. The opposing discourse or rhetoric surrounding right-side measures portrays them as painless: save energy and money at the same time.[12]

Carrying capacity: What if preventing global warming is simply not possible at today's world-average level of material affluence, assuming population will grow by another two billion? What if ethical decisions to leave considerably more exhaustible resources for posterity must increase poverty today? Given that poverty persists even at present levels of groundwater use, fishing and fuel consumption, what if reducing Impact to sustainable levels raises this 'opportunity cost' (poverty today) to heights simply inconsistent with our humanism? It is very painful to realize that for the several billion poor in the world there arises a nasty trade-off between sustainability and subsistence; a professed goal of the relatively rich of material equity is put to the test.[13] Framing the environmental question in terms of amounts of resources used up allows no escape from these ethical questions.

Finally, care should be taken not to conflate different policy goals. For instance, lowering population and raising energy efficiency can indeed be said to be 'good' – good for affluence or personal material welfare, good for other species, or aesthetically good. But they are good for lowering environmental impact only indirectly: When right-side strategies demonstrate to us that 'doing without' isn't all that bad, and that technically, efficiency can be increased enough to maintain a comfortable level of consumption, we more readily vote for caps – they become politically more palatable. Similarly, lowering the affluence of the rich under certain institutional conditions raises the affluence of the poor. But this is not *environmental* policy; logically, efficiency and sufficiency contribute only to the 'development' part of sustainable development.

7. Conclusions

In terms of $I = f(P,A,T)$, this paper argues for giving preference to direct, left-side strategies over indirect right-side strategies to reduce Impact, defined as resource depletion and environmental pollution. This judgment applies two criteria: 1) likelihood of environmental effectiveness or success; and 2) simplicity or parsimony. Concerning the first, rebounds among right-side factors sever any necessary connection between right-side improvements and lower Impact, and a case can even be made that these rebounds are large enough to render them fully ineffective; the lack of measurable success of standard strategies for efficiency and structural or lifestyle change is in any case shown by Fig. 5.

Concerning the second criterion, simplicity as invoked here has less to do with lower transaction costs (economic efficiency) than with conceptual parsimony, ease of policy design and political clarity. In Tina Fawcett's words:

> One of the key benefits of carbon rationing is that it provides a framework for carbon reductions. No longer might it be necessary to have separate government policies and programmes to promote everything from cycling strategies to efficient refrigerators. Under carbon rationing, the carbon 'market' should recognise the benefits of renewable energy, household insulation and low carbon methods of transport. [47, p. 1077; also 54, p. 34]

Instead of building codes, demand management, product labelling, work pattern change, urban design, food miles, individual ecological footprints, progressive electricity tariffs and exhortations to leave one's wedding in a rickshaw, we would have one overall tool.

In summary and conclusion:

1. Policies or strategies are usefully classified under the four terms of $I = f(P,A,T)$. They either lower Impact directly, or attempt to lower it by lowering population, affluence (consumption of goods and services per person) or the energy intensity of producing goods and services.

[12] Caps are considered politically odious, but so are income tax, parking restrictions and military service, which we accept.

[13] Even the environmentally and ethically sound strategy of contraction and convergence (like the UNFCCC's 'common but differentiated responsibility') must leave open the carrying-capacity question of what the *ecologically* dictated level of throughput, for a given population, would mean for poverty.

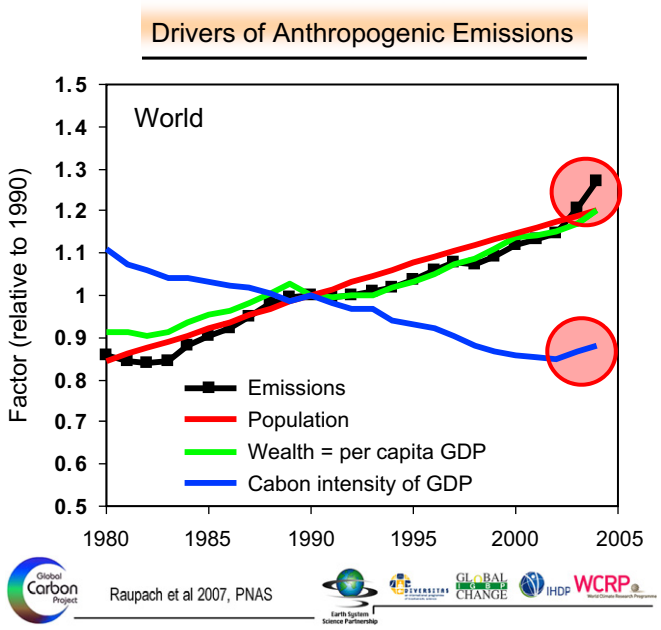


Fig. 5. Energy efficiency and energy consumption rise in lock step. The downward-sloping line is carbon (for this paper, energy) *intensity*, merely the inverse of carbon (energy) *efficiency*. The efficiency line is roughly the same as the depicted upward-sloping lines, of which emissions pertain directly to this paper. Efficiency and emissions are almost perfectly correlated. Contrary to standard interpretations, where emissions rise *in spite of* efficiency rise, high-rebound theory says that efficiency rises *enable* the emissions rises. In any case, these hard facts should give standard theory pause.

2. Right-side policies are numerous, and moreover must be co-ordinated in order to change Impact; in contrast, left-side policies (capping inputs or taxing them heavily) are single and simple.
3. The interdependencies between right-side measures are *rebounds*: reductions in one factor can result in compensatory increases in others, perhaps leaving Impact even untouched; left-side policies cannot, by definition, rebound.
4. Even when the rebounds are 'low' – say, between 30 and 50% – they do not reduce Impact in the one-for-one way that multiplication of the three right-side factors would indicate; left-side policies, on the other hand, need not be measured.
5. As right-side measures become more numerous, and/or require more co-ordination, or as rebounds approach 100%, they become less *cost*-effective compared with left-side policies.
6. If rebounds are 100%, no reduction of Impact occurs, i.e. the policies, even in combination, are *ineffective*; left-side policies, in contrast, *necessarily* achieve the environmental goal.
7. Caps and Pigouvian taxes are therefore superior to right-side strategies in terms of effectiveness, cost-effectiveness and simplicity of design and enforcement.
8. Once energy-input limits are set, people's desire to maintain as much welfare as possible would lead to adjustments in reproductive, consumer and producer behaviour, with little or no need for policy interference.

A wide range of political parties, governments, editorials, NGOs and academics advocates something of a standard set of policies to fight global warming or reduce energy consumption in the interests of sustainability or energy independence: energy efficiency, voluntary frugality, renewable energy, structural change, waste reduction, clean production, recycling and consumer efficiency. This paper has sketched and classified theoretical reasons why these policies do not achieve their environmental purpose – whatever other virtues they may have. Empirically, to my knowledge, there has never been *proof* that these measures or strategies work. Indeed, in spite of efforts along the lines of these strategies, energy consumption continues to climb. The trend is not even broken. In this situation it behoves advocates of these approaches to accept a burden of proof at least as strong as that resting on the position that rebounds are 100% or more. I see no reason to prefer, or continuing pursuing, strategies that are uncertain and neither sufficient nor necessary to reach the environmental goal of depletion and pollution reduction.

Simms describes a meeting with UK government officials searching for ideas to take with them to Johannesburg in 2002. He asked

> [w]hy weren't they honest with the British public and tell them what life would be like if necessary emissions cuts were made. Why not prepare public opinion now, by admitting the scale of required action, so it would be possible to sell the appropriate policies later? There was the sound of choking. Unlike the forthrightness of public communications during the war, the most the civil servants felt able to do now was 'suggest' that people might like to make one less car journey a month. [36, p. 163]

Similarly, forbidding old-fashioned light bulbs, as foreseen by impending 'cutting-edge' Australian or Swiss law, is no more than pussyfooting around.

Some decades ago political economists such as Kenneth Boulding, Herman Daly and William Ophuls advocated rationing, but this tradition within environmental and ecological economics, while never eschewed, has fallen into neglect. Yet caps, either directly or through Pigouvian taxes, would not only enable clear discussion but guarantee policy success. Population, affluence and technological adjustments at the individual level will then help us retain considerable welfare within the decided-upon limits, even if we consciously decide to live to some degree unsustainably.

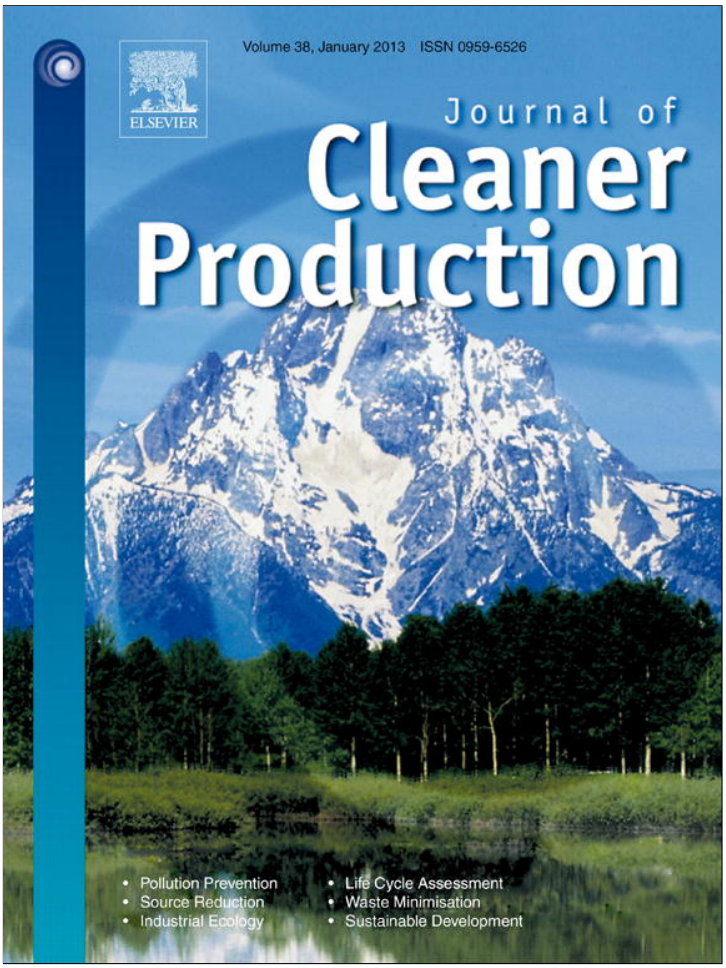
Acknowledgements

I thank the anonymous reviewers, Maurie Cohen, Marcel Hänggi, Roman Nägeli, Christer Sanne, François Schneider, Irmi Seidl, Özlem Yazlik, and the staff and institution of the Zentralbibliothek Zürich.

References

[1] Daly H. The economics of the steady state. American Economic Review 1974;64(2):15–21.
[2] Jackson T. Negotiating sustainable consumption. Energy & Environment 2004;15(6):1027–51.
[3] Duchin F. Structural economics: measuring change in technology, lifestyles, and the environment. Washington, DC: Island; 1998.
[4] Ekins P. The sustainable consumer society: a contradiction in terms? International Environmental Affairs 1991;3:243–57.
[5] Waggoner PE, Ausubel JH. A framework for sustainability science: a renovated IPAT identity. Proceedings of the National Academy of Science USA 2002;99(12):7860–5.
[6] Ehrlich PR, Ehrlich AH, Holdren JP. Human ecology: problems and solutions. San Francisco: W.H. Freeman & Co.; 1973.
[7] Khazzoom JD. Economic implications of mandated efficiency in standards for household appliances. Energy Journal 1980;1(4):21–40.
[8] Jevons WS. In: Flux AW, editor. The coal question: an inquiry concerning the progress of the nation, and the probably exhaustion of our coal-mines. 3rd ed. New York: Augustus M. Kelley; 1905. 1865, reprint 1965.
[9] Brookes L. The greenhouse effect: the fallacies in the energy efficiency solution. Energy Policy 1990;18(2):199–201.
[10] Brookes L. Energy efficiency fallacies revisited. Energy Policy 2000;28 (6/7):355–66.

[11] Saunders HD. The Khazzoom–Brookes postulate and neoclassical growth. Energy Journal 1992;13(4):131–48.
[12] Wirl F. The economics of conservation programs. Boston: Kluwer Academic; 1997.
[13] Sanne C. Dealing with environmental savings in a dynamical economy – how to stop chasing your tail in the pursuit of sustainability. Energy Policy 2000;28(6/7):487–95.
[14] Binswanger M. Technological progress and sustainable development: what about the rebound effect? Ecological Economics 2001;36(1):119–32.
[15] Sorrell S. The rebound effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. UK energy research council. Available from: www.ukerc.ac.uk/Home.aspx; October/November 2007.
[16] Herring H, Sorrell S, editors. Energy efficiency and sustainable consumption: the rebound effect. Basingstoke, UK: Palgrave; 2008.
[17] Polimeni J, Mayumi K, Giampietro M, Alcott B. The jevons paradox and the myth of resource efficiency improvements. London: Earthscan; 2008.
[18] Holm S-O, Englund G. Increased ecoefficiency and gross rebound effect: evidence from USA and six European countries 1960–2002. Ecological Economics 2009;68(3):879–87.
[19] Alcott B. Jevons' paradox. Ecological Economics 2005;54(1):9–21.
[20] Barker T. The global macroeconomic rebound effect of energy efficiency policies: an analysis 2012–2030 using E3MG. Cambridge: Cambridge Centre for Climate Change Mitigation Research. Available from: http://www.landecon.cam.ac.uk/research/eeprg/4cmr/news.htm; 2009.
[21] Bartlett A. Reflections on sustainability, population growth, and the environment. Population and Environment 1994;16(1):5–35.
[22] Barnett HJ, Morse C. Scarcity and growth: the economics of natural resource availability. Baltimore: Johns Hopkins Press; 1963.
[23] Abernethy V. Why the demographic transition got stuck. Population and Environment 1993;15:85–7.
[24] Cohen JE. How many people can the earth support? New York: Norton; 1995.
[25] Alcott B. The sufficiency strategy: would rich-world frugality lower environmental impact? Ecological Economics 2008;64(4):770–86.
[26] Giampietro M. Sustainability and technological development in agriculture. BioScience 1994;44(19):677–89.
[27] Personal communication, Feb. 2009.
[28] Cipolla C. The economic history of world population. Harmondsworth. U.K: Penguin; 1962–1966.
[29] Herring H. Energy efficiency – a critical view. Energy 2006;31:10–20.
[30] Smil V. Energy in nature and society. Cambridge, Massachusetts: MIT; 2008.
[31] GCP. Recent carbon trends and the global carbon budget, updated to 2006; drivers of anthropogenic emissions. Available from: www.globalcarbonproject.org; 2009.
[32] Rosenberg N. Exploring the black box: technology, economics, and history. Cambridge: Cambridge U. Press; 1994.
[33] Mayumi K. Temporary emancipation from land: from the industrial revolution to the present time. Ecological Economics 1991;4(1):35–56.
[34] Madlener R, Alcott B. Energy rebound and economic growth: a review of the main issues and research needs. Energy 2009;34(2):370–6.
[35] Hinterberger F, Luks F, Schmidt-Bleeck F. Material flows vs. 'natural capital': what makes an economy sustainable? Ecological Economics 1997;23(1):1–14.
[36] Simms A. Ecological debt: the health of the planet and the wealth of nations. London and Ann Arbor: Pluto; 2005.
[37] Daly H. Economics, ecology, ethics. San Francisco: WH Freeman; 1973–1980. p. 160–8.
[38] Weitzman ML. Prices vs. quantities. Review of Economic Studies 1974;41(4):555–70.
[39] Nordhaus WD. An optimal transition path for controlling greenhouse gases. Science 1992;258:1315–9.
[40] Tietenberg T. Resources for the future. Washington, D.C: Emissions Trading; 2006.
[41] Scitovsky T. The political economy of consumers' rationing. Review of Economics and Statistics 1942;24:114–24.
[42] Reddaway WB. Rationing. In: Chester DN, editor. Lessons of the British war economy. Cambridge: Cambridge U. Press; 1951.
[43] Tobin J. A survey of the theory of rationing. Econometrica 1952;20(4):521–53.
[44] Hurwicz L. The design of mechanisms for resource allocation. American Economic Review 1973;63:1–30. Papers and Proceedings.
[45] Seyfang GJ. Local exchange trading systems and sustainable development. Environments 1996;38:5–18.
[46] Eger T, Weise P. Gutscheine und zertifikate. In: Tietzel M, editor. ökonomische theorie der rationierung. München: Franz Vahlen; 1998.
[47] Fawcett T. Carbon rationing and personal energy use. Energy & Environment 2004;15(6):1067–83.
[48] Starkey R, Anderson K. Domestic tradable quotas: a policy instrument for reducing greenhouse gas emissions from energy use. Tyndall centre for climate change research. Technical Report 39, December. Available from: www.tyndall.ac.uk; 2005.
[49] Lee M. EU environmental law. Oxford: Hart; 2005. p. 3–9, 183–85, 195–204.
[50] Duchin F, Lange G-M. The future of the environment. Oxford: Oxford U. Press; 1994.
[51] Røpke I. The dynamics of willingness to consume. Ecological Economics 1999;28(3):399–420.
[52] Schipper L, Grubb M. On the rebound? feedbacks between energy intensities and energy uses in IEA countries. Energy Policy 2000;28(6/7):367–88.
[53] Manne AS, Richels RG. CO_2 emission limits: an economic cost analysis for the USA. Energy Journal 1990;11(2):51–74.
[54] Ophuls W. Ecology and the politics of scarcity: a prologue to a political theory of the steady state. San Francisco: W.H. Freeman & Co; 1977.
[55] Sanne C. Willing consumers – or locked in? policies for a sustainable consumption. Ecological Economics 2002;42:273–87.
[56] Von Weizsäcker E, Lovins AB, Lovins HL. Factor four: doubling wealth – halving resource use. London: Earthscan; 1997.
[57] Owens S, Cowell R. Land and limits: interpreting sustainability in the planning process. London: Routledge; 2002.



Journal of Cleaner Production 38 (2013) 56–60

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Should degrowth embrace the Job Guarantee?

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ARTICLE INFO

Article history:
Received 30 November 2010
Received in revised form
6 June 2011
Accepted 9 June 2011
Available online 21 June 2011

Keywords:
Degrowth
Unemployment
Job Guarantee
Employer of last resort
Right to work
Guaranteed income

ABSTRACT

Degrowth should consider the right to work – a Job Guarantee (JG) – as a way of making a smaller economy more just and socially sustainable. Economic shrinkage in richer countries is accompanied by increased unemployment, a bad enough problem in itself but also a barrier to voters' acceptance of the degrowth path. Since being out of work is distinct from being poor, anti-poverty income policies should be approached separately. The JG is one of several paths to full employment, including reduced working time. This essay only briefly mentions some real-world JG programs and some technical objections. The main suggestion is to move employment from being a matter of economics, particularly economic growth, to being a political right. A right to work is necessarily effective and would avoid sacrificing the ecological and social goals of degrowth on the altar of full employment.

1. Epigraphs

> If a man has no chance of obtaining work he is in a desperate position, not simply because he lacks an income but because he lacks this nourishing and enlivening factor of disciplined work which nothing can replace… The very start of Buddhist economic planning would be a planning for full employment, and the primary purpose of this would in fact be employment for everyone who needs an 'outside job': it would not be the maximisation of employment nor the maximisation of production.
>
> —— E.F. Schumacher, 'Buddhist Economics', *Small Is Beautiful.*

> I got a job working construction, for the Johnstown Company,
> But lately there ain't been much work, on account of the economy.
>
> —— Bruce Springsteen, *The River.*

2. Introduction

In environmentally over-developed countries needing to degrow, institutions are such that recession increases unemployment. To make a smaller economy more socially sustainable, as well as to make the degrowth project more attractive to voters, the problem of potentially large-scale joblessness therefore deserves attention. Of course the goal of full employment is a worthy one even 'in the best of times' – in a growing economy – and the solution here singled out has indeed a respectable pedigree among left-wing critics of the mixed economy: the Job Guarantee (JG).

This essay – not a full-length academic work but rather a piece of advocacy – defines employment conventionally as work for which payment is received for goods and services provided. However, the unemployment problem is *not* the income problem and I assume that society provides financial assistance to the poorest or even that a guaranteed income (GI) is in place. Those who opt against paid work are free to 'work' creatively for themselves or others. Rather, the focus is entirely on the individual and social values of producing and earning, socially embedded and with some sense of individual achievement and contributing to society (Karst, 1997, pp. 532–543).

That joblessness is distressing for many people is attested not only by the underrated method of introspection but by empirical meta-analyses (Veenhoven, 1994; Murphy and Athanasou, 1999) and happiness studies (Argyle, 2001). The balance between work and free time gets disturbed, one is a burden on society, and feelings of uselessness arise. Social stresses range from sub-lower-class exclusion to higher alcohol consumption (Wray, 2007), perhaps epitomised by Karst's observation that "Shrinking employment

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0959-6526/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jclepro.2011.06.007

opportunity at any level is a seedbed for racial and ethnic scapegoating" (1997, p. 529).

I am controversially urging degrowth research to take people the way they are, whatever sea changes in attitudes towards 'work' may be worth pursuing, and whatever the mixture of socialism and capitalism turns out to be. I believe we should start with the values and institutions of our given societies even if many in the degrowth movement find them pathological. Firstly, these are the voters we must convince, and secondly, the number of years remaining for a managed, humane transition to a smaller economy preclude waiting until deeper attitudes have been changed. In a world where 'the economy' is virtually synonymous with 'jobs', how can degrowth present itself as a job-killer?[1]

A final obvious caveat: JG cannot causally help shrink the materially rich economies; this requires policies addressing high material and energy throughput itself, be they resource caps or taxes, technical changes in equipment and infrastructure, fewer goods demanded by greener consumers, or population reduction. Sometimes working time reduction is seen as a *means* of preventing the economy from exceeding sustainable scale (Spangenberg, 2010), but this is not relevant to JG. The employment challenge is instead how to distribute an already limited amount of paid work justly.

3. What is the Job Guarantee?

Article 23.1 of the Universal Declaration of Human Rights states: "Everyone has the right to work, to free choice of employment, to just and favourable conditions of work and to protection against unemployment." (UN, 1948; Shklar, 1991) A guarantee means the *right* to paid work, no longer contingent on the growth rate and employer-employee details of a given economy. An unemployed work force would for instance no longer be an instrument serving either structural flexibility or low interest rates. Job guarantor is the state or 'employer of last resort' (ELR).[2]

The type of goods and services produced by 'guaranteed' jobs is not restricted to public goods, presently unpaid services or 'green' infrastructure. Whether the state would produce in presently private economic branches would have to be negotiated with workers and businesses in these fields, but some degree of socialisation of production might result. Concerning wage rates the only assumption is that the wage, with or without GI, is at least a socially-defined minimum (Wray, 2007, pp. 10, 18) – superceding minimum-wage laws and countering fears of inadequate wages expressed by Tinbergen (1956, p. 192) and Sawyer (2005, p. 256). Otherwise, contracts would be standard, there being for instance no assumption that the ELR is a 'soft touch' – the "freedom to fire" (Gordon, 1997, p. 832) should be incorporated, especially since financial support for the non-working is assumed. A considerable literature treats these three issues as well as inflationary danger and anti-cyclical fiscal policy (e.g. Mitchell, 1998; Sawyer, 2003, 2005; Mitchell and Wray, 2005; Wray, 2007; Harvey, 2008).

A right, as a strong claim on society, can only be something the honouring of which can cost something. Think of basic education, criminal justice, national defence, the amenties of public space and basic health care: nobody expects these activities to 'pay their own way', and neither must JG. However, fretting about 'how to finance' JG often misses the point that the goods and services could and should generate revenue for the ELR. They could be sold on the market, or booked as public goods (benefits), perhaps including ones presently falling to voluntary and charitable efforts (Gordon, 1997, p. 831) Cost-benefit analysis of JG would book administration and physical overhead as costs covered by normal taxes, but would count on the benefits side income support payments no longer necessary (Karst, 1997; Forstater, 1998; Harvey, 2008) Yet even benefits must not be quantified: in the words of Karst, "What I value most in the state's employment of these [mentally impaired] people is not that the parks are clean and pleasant, but that the workers are afforded the dignity of work. This is not a market calculation; rather, it is an evaluation that gives weight to the inclusion of a group of Californians in our community" (1997, p. 563).

4. Real-life attempts at JG

The United States' experience during the 1930s with the Works Progress Administration, on which an enormous literature exists, fell short of a right to work but did offer a huge number of public-sector jobs (Harvey, 2008)Most countries of the Soviet bloc knew the right to a job, but I have no competence to describe or evaluate that experience. Since however practically all countries that today stand under the degrowth imperative function much less socialistically, comparisons must be cautious. Hopefully, though, degrowth researchers who lived in the Soviet bloc will subject JG to the hard test of its fairness over against non-JG jobholders, the prospect of a huge socialised sector, and more.

Three present-day trials, in Switzerland, India and Argentina, can be briefly mentioned. In Zürich, where I lived for 36 years, the city government offers a subsidised job to any jobless person who wants it and whose unemployment insurance payments have ceased. Obligatory for these long-term unemployed is a 4-week course to assess work capability. Some employment is by bespoke 'social firms' partly under state ownership and some is in the extant private sector, employers in all cases paying a part-wage. As of June 2008, 30% of people targeted by the program were working at 531 jobs delivering goods and services. It is only a few years old and is complementary to traditional policies of re-training and job placement (Zürich, 2011).

A similarly small scheme, moreover embodying only a *de facto* but not *de jure* right to work, is the UK's alliterative 'welfare-to-work' program. It pays private companies such as Working Links for instance £1500 per person successfully guided back into paid work (Guardian, 2010). About 13,000 people per year over the last decade have been so placed, and one has the right to join the program. There can in such schemes be 'leakages' such as non-additionality, replacing current employees, and corruption (Wray, 2007, pp. 7, 14, 34).

In the Indian State of Maharastra the National Rural Employment Guarantee Act of 1965 (expanded in 2005 to include all of India) enabled for instance in 1984–1985 the hiring of 600,000 rural workers for traditional public works. A study of the program claimed it has universal support because it stems the flow of migrants to cities and furthers political peace generally and concluded: "Employment becomes a political as well as an economic issue, and the articulation of political demands becomes a means of securing a livelihood." (Echeverri-Gent, 1988, p. 1304) Wray notes however that this scheme, like the similar Argentinian *Plan Jefes de Hogar* program, is open only to certain poor people, while he himself advocates universality. (2007, p. 10) A detailed evaluation of the Argentine experience is in Tcherneva and Wray (2011).

5. Other paths to full employment

Assuming a JG scheme is workable –the proof is in the pudding – one argument in its favour is that it by definition reaches its goal:

[1] As a Greenpeace activist I often heard nuclear-industry employees, dragnet fishermen and woodworkers angrily asking us, 'And our jobs?' This deserves an answer.

[2] For a short treatment in German *see* www.degrowth.ch > gerecht.

it is a *direct* policy, its effectiveness, if you will, guaranteed. In contrast at least five *indirect* policies can be identified: 1) economic growth; 2) deficit or anti-cyclical spending; 3) job training and brokering; 4) working time reduction (WTR); and 5) a *laissez-faire* labour market.

1) Growth of production and consumption will raise the number of jobs under present mixed systems unless work-hour productivity outstrips labour supply. Neither the actual success nor the theoretical merits of this path are relevant because, in the absence of any decoupling of throughput from the quantity of goods and services, it contradicts the essence of degrowth.
2) When needed, governments can raise their borrowing, or drawdown reserves, to hire people for public tasks, deemed necessary when the jobless rate rises above some determined level. That is, a certain 'frictional unemployment' caused by structural change or geographical relocation of production is traditionally accepted[3] – as is an even higher unemployment rate when the goal of price stability or the interests of powerful employers are simultaneously pursued. (Karst, 1997; Sawyer, 2003, 2005; Mitchell and Wray, 2005) *See* Forstater (1998) for an attempt within the JG tradition to resolve the need for full employment with the need to avoid rigidity in the labour market detrimental to economic efficiency.[4] This path thus does not necessarily lead to, or even strive for, full employment, and specific programs are by nature *ad hoc*.
3) Most rich countries offer job training and brokering as a sort of public service, whether paid out of unemployment insurance funds or general taxes. They have at best dampened unemployment, and do not regard jobs as a right. Some of this is compatible with JG, but what JG/ELR is *not* is stop-gap. Small programs such as the Sheffield or Newcastle Employment Bonds in the UK, or huge ones such as the U.S. Works Progress Administration in the 1930s, are cut from a different cloth – fire-fighting instead of fire prevention; they are non-universal, temporary and usually dripping with free-market rhetoric.[5]
4) In degrowth research the idea of each person's working fewer paid hours over his or her lifetime, theoretically increasing the number of employed, attracts deserved attention (Spangenberg, 2010) and accepts unemployment as a real personal and social nuisance. (nef, 2010; O'Neill et al., 2010) One real application of this is the famous French 35-h week, on which an extensive literature exists. It does not specifically treat paid work as a right, yet the pure maths show that full employment must be the consequence. Like JG, many questions of program design must be tackled, but unlike JG, policing a 'black market' is needed. Comparing the pros and cons of the two schemes is ripe for degrowth research.
5) Although a conceptual minefield, please consider that in theory a totally libertarian, *laissez-faire* labour market would result in work for all due to the tried and trusted laws of supply and demand: lower price (wages) raises demand to meet supply. Minimum wages, much less somewhat higher 'living wages', as well as barriers to self-employment, would be abandoned. (Rothbard, 1983, pp. 21, 43; Hayek, 1984, pp. 16–19) While no purely *laissez-faire* economy has ever existed (except usually the world economy) there are theoretical reasons why in *relatively* private enterprise-oriented economies powerful economic actors, including business-friendly governments or even rival groups of workers, can restrict entry into the labour market.

6. Job policy as politics, not economics

Once the goal becomes the just distribution of working hours rather than the maximisation of their quantity, full employment has moved from the economic to the political realm. I believe this is an effective answer to the ubiquitous opinion in press, politics and academia that growth is necessary 'for jobs'. The JG moreover locates full-employment policy at the extreme end of politics, as a right derived from psychological and historical values in most European societies which treat independence (for both men and women) and earning (as opposed to receiving) as central to social *standing*, distinguishing workers both from slaves and the idle rich (Shklar, 1991, pp. 85–100).

Viewing work radically as a social rather than an economic question means it is no longer necessary, for instance, to defend 'green' policies in terms of their employment effects – arguing based on econometric models that investment in renewable energy, equipment efficiency or public transportaion 'creates' more jobs than are lost in the fossil-fuel sectors. (Hueting, 2010) Environmental policy appraisals would no longer have to include not only effects on energy consumption, greenhouse gases and energy security but also on 'employment' (Infras, 2003). Or as Green Parties everywhere dubiously argue, there is allegedly no conflict between environmentalism and the economy.

Similarly, one group of JG advocates argues for the Buffer Stock Employment method of hiring through deficit spending: "Unemployment arises because the budget deficit is too low. It is always a macroeconomic problem." (Mitchell, 1998, p. 553) The 'buffer' idea subordinates employment policy to booms and busts. On the other hand, the group's website reports exhaustively and usefully on the political right to a job (Coffee, 2010). Sawyer likewise, while raising the key question of the differences between JG and traditional pump-priming, only marginally enters this political realm of discussion, talking moreover in terms of "cost of job loss" in terms of income and lost output rather than psychological or social stress (2003, p. 904).

An argument in favour of JG is that since it is defined legally it is directly successful, as opposed to the five alternative, indirect paths outlined above. In general, once a goal is set why don't we first research straightforward approaches rather than *indirect* measures of uncertain effectiveness? The same issue arises when we weigh proposals to reduce economic scale: we can start with what works, by definition and by legal rather than economic means, such as natural-resource caps or taxes, instead of oblique approaches such as resource efficiency, 'sustainable consumption', population reduction or renewable technologies (Alcott, 2010).

This discussion becomes clearer, moreover, if we don't conflate the issues of income and work. They can be mentioned in the same breath if a 'decent', perhaps subsistence amount of purchasing power is contingent upon a job, i.e. in the absence of 'welfare benefits' as in many poorer countries. The single Millennium Development Goal #1, Target #2, thus calls for "full and productive employment and decent work for all", mainly to alleviate "extreme poverty". JG cannot replace the welfare safety net because some people are 1) unwilling or 2) unable to work or 3) personally unsuitable as employees (Wray, 2007). Guaranteed job and guaranteed income are distinct, yet our customary way of thinking regards poverty as part and parcel of job loss.

[3] JG is compatible with a separate, parallel unemployment *insurance* program.
[4] It is doubtful that degrowth should worry about economic efficiency, which can surely be left to economic actors within the prescribed scale limits.
[5] Evaluation of such programs moreover consistently ignores the opportunity costs of such investments, or in Frédéric Bastiat's (1850) clearer formulation: what is not seen as well as what is seen.

The broad lesson is Tinbergen's rule that at least in the first analysis the number of policy "instruments" should be equal to the number of policy "targets", and he in fact illustrated this by means of the two targets "full employment and monetary equilibrium" (1956, pp. 55–56, 63–68). Unfortunately the advent of 'Keynesian' anti-cyclical spending did cause the problem that financing jobs could be inflationary, and the tendency grew to conflate just these two goals. A case of their intermingling, if not their conflation, is in fact the debate between Sawyer (2003, 2005) and Mitchell and Wray (2005) over JG. The lesson for us now, though, is that being involuntarily idle poses different problems than being poor, each deserving separate policy instruments.[6]

7. More pros and cons

The best presentation of JG I have found offers a summary of the argument up till now:

> The UN World Summit in 2005 and the ECOSOC Ministerial Declaration of 2006 stressed… that employment can no longer be considered a derivative of economic policies… An ELR is a direct job creation programme that provides employment at a basic wage for those who cannot otherwise find work. It is not meant to be an emergency programme or a substitute for private employment, but rather a permanent complement to private sector employment… No other program can guarantee access to jobs at decent wages (Wray, 2007, pp. iv, 1).

He rejects Keynesian pump-priming and covers issues like potential conflicts with labour unions, the possible stigmatisation of ELR jobs, decentralised administration and earmarking the program to 'good' public works.[7]

Several additional arguments for JG can be culled from the literature. In its role as employer society would gain increased say over the type of goods and services delivered. A high demand for JG jobs might bring socialisation of some recently privatised public services such as post offices or railroads. Job security would remove fear of job loss in the same sense that compulsory pension schemes offer a relaxed view of old age. Greater self-confidence in normal jobs means one could more easily quit obnoxious employment and/or employers (Mitchell, 1998, p. 551).

In a challenge to the proposals of Wray and Mitchell, Sawyer argues for traditional or "mainline… public-sector employment programs" when "private sector demand is inadequate to generate [high] levels of employment." (2003, p. 882; 2005, p 257) Jobs are thus for him not a right; programs can come and go. In his words, JG has at least seven major weaknesses:

1) Are there enough jobs, enough things to do, suitable for Job-Guarantee jobs?
2) Do such jobs match the skills of the unemployed – or would the job-takers be overqualified and thus 'underemployed'?
3) Could jobs be offered in the places where the unemployment is?
4) Are the types of work really of public value, i.e. would they be productive enough in the usual sense to warrant their cost? Would they prolong 'structural' obsolescence?
5) What effect would low ELR wages have on similar jobs in the private sector?
6) What becomes of capital investments and administrative staff when, in boom times, such jobs are not in demand?
7) What would a JG program cost? (2003, pp. 882, 884, 891, 894)

Mitchell and Wray (2005) replied to these objections, eliciting in turn a response from Sawyer (2005), followed up by Wray's manifesto for the ILO (2007). I find these criticisms by Sawyer salient,[8] but dealing with this degree of detail is beyond the scope of both this paper and my expertise. A few political comments might nevertheless be worthwhile.

All three authors write of a "buffer stock" of labour, close to the related "industrial reserve army", concepts with histories that seem unnecessary for this discussion. JG's insistence on the right to work is after all designed to counter exactly these dangers of disciplining workers by fear of unemployment. Also, should labour productivity fall as a result of extreme job security, degrowth should to some extent be able to live with this. On the other hand the effect of JG on wages of similar height in the non-JG sector seems a serious question, perhaps answerable only by experience. Finally, there seems no good answer to the fear that JG jobs would carry low social prestige –a stigma – except that being on the dole is also stigmatised.

Open questions, if not criticisms, concern JG's relation to the "maintenance economy" which cares for both the natural world and our social relationships and "where the 'wage' of the work is its very product" (Jochimsen and Knoblauch, 1997, p. 109; also Karst, 1997, pp. 562–569; nef, 2010, p. 16). Also needing attention are gender differences in perceptions of 'work', including the commodification of (traditionally female) house and voluntary work and the general societal preconditions for conventional paid work. (see Mellor, 1997, pp. 131–132, 134–137) Finally, where does the clearly socialist JG stand in relation to minority degrowth thought advocating action less reliant on national government and that rubs shoulders with a more localist anarco-libertarian tradition (Bookchin, 1991, pp. 54–62, 82–86)? Perhaps JG or other institutions protecting social rights would be better at sub-national level, say in communities between 200 thousand and 2 million people.

8. Conclusions

This paper is a tool for further research in three ways:

1. It gives a working knowledge of the Job Guarantee – a definition and its place in relation to other policies with the same aim.
2. It identifies important theoretical literature and some cases where JG has been practiced.
3. It treats full employment as an example of an area deserving separate conceptualisation, namely the social marketing of degrowth – how to increase its acceptance among voters. We are after all always faced with the threat: economic growth, or else!

Work is both fun and irksome, good and bad, wish and duty. Its social psychology includes identification with a skill, a relatively broad social network and assuming responsibility for one's

[6] Similarly, when high 'eco-taxes' on fuel are opposed because they burden the poor, the answer is rather to simultaneously employ anti-poverty policies rather than abandon the environmental ones.

[7] Wray is associated with the Center for Full Employment and Price Stability at the University of Missouri, Kansas City.

[8] One can on the other hand answer some of his more minor criticisms, e.g. that a JG worker can simply leave the job without notice (2003, pp. 892, 896; 2005, pp. 256, 260), or that the system must be able to create jobs on short notice (2003, p. 883); work contracts would be normal, and unemployment insurance would offer the ELR time to react. The specter of "punitive workfare" (2005, p. 256), as well, addresses income support issues rather than the problems of those who want to work.

sustenance. It seems at most a half-truth, therefore, to say that what we 'really' want is the wage, not the work (Shklar, 1991, pp. 91–93).

Since economic shrinkage means less resource depletion and pollution, it in turn means lower affluence at any given population level. Social peace and sustainability are thereby threatened. In decoupling jobs from economic growth the Job Guarantee addresses, and by definition solves, one such social problem. Resistance to planned degrowth is moreover lowered when a policy is in place guaranteeing all who want to work a paid place in production.

References

Alcott, Blake, 2010. Impact caps: why population, affluence and technology strategies should be abandoned. Journal of Cleaner Production 18 (6), 552–560.

Argyle, Michael, 2001. The Psychology of Happiness. Routledge.

Bastiat, Frédéric, 1850. Ce qu'on voit et ce qu'on ne voit pas, ou, l'Économie politique en une leçon. Guillaumin, Paris.

Bookchin, Murray, 1991. Defending the Earth: a Dialogue between Murray Bookchin and Dave Foreman. South End Press, Boston.

Coffee, 2010. Center of Full Employment and Equity. http://e1.newcastle.edu.au/coffee/job_guarantee/JobGuarantee.cfm.

Echeverri-Gent, John, 1988. Guaranteed employment in an Indian state: the Maharastra experience. Asian Survey VIII (12), 1294–1310.

Forstater, Mathew, 1998. Flexible full employment: structural implications of discretionary public sector employment. Journal of Economic Issues 32 (2), 557–563.

Gordon, Wendell, 1997. Job assurance: the job guarantee revisited. Journal of Economic Issues 31 (3), 826–834.

Guardian, 2010. Society Guardian, 3 March, p. 5.

Harvey, Philip, 2008. Is there a progressive alternative to conservative welfare reform? Georgetown Journal on Poverty Law and Policy XV (1), 157ff.

Hayek, F.A., 1984. 1980s Unemployment and the Unions (also Hobart Paper 87), second ed. Institute of Economic Affairs, London.

Hueting, Roefie, 2010. Why environmental sustainability can most probably not be attained with growing production. Journal of Cleaner Production 18 (6), 525–530.

Infras, 2003. Begleitende Evaluation der Wirkungsanalyse 2002 von EnergieSchweiz. Energie Schweiz, Bern.

Jochimsen, Maren, Knoblauch, Ursula, 1997. Making the hidden visible: the importance of caring activities and their principles for any economy. Ecological Economics 20 (2), 107–112.

Karst, Kenneth, 1997. The coming crisis of work in constitutional perspective. Cornell Law Review 82, 523–571.

Mellor, Mary, 1997. Women, nature and the social construction of 'economic man'. Ecological Economics 20 (2), 129–140.

Mitchell, William F., 1998. The buffer stock employment model and the NAIRU: the path to full employment. Journal of Economic Issues 32 (2), 547–555.

Mitchell, William F., Wray, L. Randall, 2005. In defense of employer of last resort: a response to Malcolm Sawyer. Journal of Economic Issues 39 (1), 235–244.

Murphy, Gregory, Athanasou, James, 1999. The effect of unemployment on mental health. Journal of Occupational and Organizational Psychology 72, 83–99.

NEF (New Economics Foundation), 2010. 21 Hours. http://www.neweconomics.org/sites/neweconomics.org/files/21_Hours.pdf.

Rothbard, Murray, 1983. America's Great Depression. Richardson & Snyder, New York.

Sawyer, Malcolm, 2003. Employer of last resort: could it deliver full employment and price stability? Journal of Economic Issues 37 (4), 881–907.

Sawyer, Malcolm, 2005. Employer of last resort: a response to my critics. Journal of Economic Issues 39 (1), 256–264.

Schumacher, E.F., 1973. Small Is Beautiful. Blond & Briggs, London.

Shklar, Judith, 1991. American Citizenship: the Quest for inclusion. Harvard U. Press, Cambridge US.

Spangenberg, Joachim H., 2010. The growth discourse, growth policy and sustainable development: two thought experiments. Journal of Cleaner Production 18 (6), 561–566.

The Report of the Steady State Economy Conference, Leeds, UK. In: O'Neill, D.W., Dietz, R., Jones, N. (Eds.), Enough Is Enough: Ideas for a Sustainable Economy in a World of Finite Resources. Center for the Advancement of the Steady State Economy (Arlington, Virginia, USA) and Economic Justice for All (Leeds, UK).

Tcherneva, Pavlina R., Wray, L. Randall, 2011. Employer of Last Resort: a Case Study of Argentina's JEFES Program. http://www.cfeps.org/pubs/http://www.epicoalition.org/docs/ArgentinaJefes.htm.

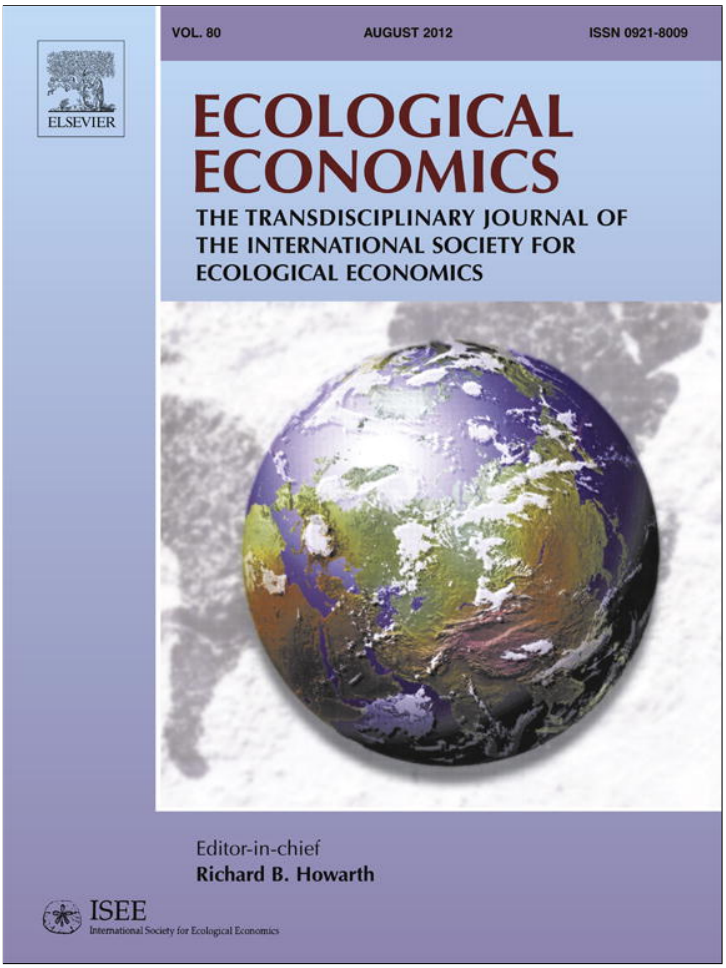
Tinbergen, Jan, 1956. Economic Policy: Principles and Design North Holland, Amsterdam.

UN, 1948. http://www.un.org/en/documents/udhr/.

Veenhoven, Ruut, 1994. Correlates of Happiness. RISBO, Rotterdam.

Wray, L. Randall, 2007. The Employer of Last Resort Programme: Could It Work for Developing Countries? International Labour Office (ILO) Working Paper 2007/5. http://www.cfeps.org/elm07-5.pdf Geneva.

Zürich, 2011. www.stadt-zuerich.ch > sozialdepartement > teillohn.



Ecological Economics 80 (2012) 109–120

Contents lists available at SciVerse ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Population matters in ecological economics

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ARTICLE INFO

Article history:
Received 31 July 2011
Received in revised form 28 May 2012
Accepted 4 June 2012
Available online 22 June 2012

Keywords:
Population size
Limits
I = PAT
Food production
Cultural carrying capacity
Rights and responsibilities

ABSTRACT

It is an axiom of ecological economics that resource depletion and environmental pollution depend on the number of people and how many goods-and-services each consumes, modified by the technological efficiency of production. The paper reviews some studies quantifying the contribution of human numbers to environmental impact. It warns against playing this factor off against that of high consumption in rich countries. It asks whether from the environmental point of view complacency about either present or predicted population size is warranted. The answer depends both on fertility and mortality assumptions and on constraints such as resource and food availability. The concept of cultural carrying capacity would aid societies in determining their optimal population when account is taken not only of subsistence, but of quality of life. A population-control toolkit for both rich and poor societies is sketched, and some controversial, 'coercive' policy possibilities analysed.

Epigraphs: "I was born in a family of 11, so after the death of my father, because we were many, my mother could not help us all. So, everybody has to go and look for his own life. So that's how I came to Kibera." — Joseph Djemba "I've never seen a problem that wouldn't be easier to solve with fewer people." — Sir David Attenborough

1. Introduction

Ecological economics seeks ways to lower environmental impact to sustainable rates of resource consumption and pollution, necessitating analysis of the factors contributing to the impact. For this it has for four decades applied the formula *I = PAT*: amounts of natural-resource consumption and pollution (*Impact*) are a function of number of people (*Population*), how many goods-and-services the average person consumes (*Affluence*), and the amount of natural-resource input or pollution per unit of goods-and-services (*Technology* as efficiency).[1]

I = PAT is more accurately written *I = f(P,A,T)* to indicate that a change in any of the three right-side factor affects the other two (Alcott, 2010). For instance higher population, *ceteris paribus*, means lower affluence (Boserup, 1981, pp ix, 4–5; Cohen, 1995, p 6). Higher affluence lowers mortality and can both raise and lower fertility (Lin, 2010, pp. 260-261).[2] By increasing resource scarcity, higher $P \times A$ increases pressure for greater resource efficiency (lower *T*) (Boserup, 1981; Simon, 1996).[3] Lowering *T* – raising efficiency, *e.g.* in cars or steel production – in turn enables more goods-and-services to be produced (higher *A*, the rebound effect) (Alcott, 2005). Due to this interdependence, autonomous reduction of any right-side factor does not necessarily result in lower impact.[4]

Concerning population reduction, the lesson is that after its first-order effect of freeing up resources, it enables higher affluence. Should a community decrease in numbers whilst the supply of resources remains the same, the smaller number of people can then use the resources for further economic activity; in this case this rebound effect raises present affluence (hopefully reducing poverty) but does not affect impact. Lower *P* is thus not a sufficient condition

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[1] Refinements of *IPAT* include *MEPAT* (Myths and Entitlements) (Swaney, 1991), *STIRPAT* (Stochastic effects) (Dietz and Rosa, 1994, 1997), *I = PACT* (Culture) (Durham, 1992), and *IHAT* (Households) (MacKellar et al., 1995). Each right-side factor can also be endogenous. Note also that *I = PAT* is not an 'identity' but a formula, since each right-side factor is independently measurable (Ehrlich et al., 1973), and that the numerator of *A* is not *I* but goods-and-services.

[2] The demographic transition model shows a stage of relative poverty with high death and high birth rates, followed by decreasing mortality as living standards rise, in turn followed by decreasing fertility as income, education, and female autonomy rise, and finally population stabilisation. Researchers however sometimes observe fertility decline before mortality decline and fertility increase when affluence rises (Abernethy, 1993; Engelman, 2010, p 11; Haub, 2011; Sardon, 2006).

[3] Boserup's position on limits to population size is not as extreme as Simon's (1996/1981) and is reconcilable with Malthus' theory, as shown by Lee (1986), who sides with Malthus against Simon.

[4] Strictly, changes in the *absolute* number *P* cannot be compared with changes in the *ratios A* (whose denominator is *P*) and *T* without further assumptions; *e.g.*, higher *A* means higher *I* only if *P* rises or stays the same or *A* rises faster than *P* falls. Elasticities between the 3 right-side factors are not meaningful.

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doi:10.1016/j.ecolecon.2012.06.001

for lower *I*. It is not even a necessary condition, because if *A* and *T* decrease sufficiently, *I* could decrease even with rising *P*.

There are two main reasons why population size is nevertheless relevant for ecological economics. (1) Any particular environmental problem – *e.g.* overdrawn groundwater or toxic emissions into groundwater – is easier to solve when there are fewer groundwater consumers. To lower impact the required adjustments in affluence (greater frugality) and technology (greater efficiency) would be physically and psychologically less burdensome; the costs of the benefits of lower impact would be lower. (2) Even if no impact reduction results from population reduction, it raises affluence, and if accompanied by policies for less economic disparity helps alleviate poverty — another goal of ecological economics.

2. Population matters

Because dozens of studies have demonstrated the significant role of (change in) population size in (change in) impact severity, usually by means of regression analysis,[5] this section does not attempt any further proof. It merely looks at several of these studies to show their methods and quantitative results, concluding with challenges to the positions (1) that population doesn't matter and (2) that we must *either* reduce population *or* rich-world consumption.

Using $I = PAT$, Shi (2003) analyses CO_2 emissions in 93 countries between 1976 and 1995. After noting that *A* itself is partly a function of *P* he submits evidence not only for the obvious result that impact rises with population, but for the hypothesis "in the Malthusian tradition" that impact rises disproportionately with population: using the further variables GDP *per capita*, percentage of manufacturing in GDP, and percentage of population in the work force, the population elasticity of CO_2 comes to 1.42 — moreover higher in developing than developed countries.

Brown and Kane (1994, p 56) compare grain production in Western Europe and Africa from 1950 to 1993. Europe saw a 152% (2.5-fold) rise in grain output, Africa one of 118% (2.2-fold). Yet whilst *per capita* output in Europe more than doubled, in Africa it fell, "leaving millions of Africans hungry and physically weakened." Since the ratio of rates of change of total production (2.5:2.2) is much smaller than that of the rates of change in *per capita* production, Africa's higher population increase is a strong explanatory variable.

For deforestation and water use McNeill likewise shows that population size usually outstrips consumption per person (2011, pp 185–187), and decomposition analyses by Bongaarts show that population growth is a key factor in GHG emissions growth (1992, pp 309, 316). MacKellar et al., covering the years 1970–1990 at world scale, attribute roughly one-third of CO_2 emissions to population, a percentage that more than doubles when *P* is households rather than individuals (1995, p 860) — although one could of course subsume smaller households under the affluence rather than the population factor.

Engelman similarly deduces from the simultaneous decrease of *per capita* emissions and increase of total emissions that the number of emitters must be a significant factor (2010, pp 12–13, 27). Raskin, although emphasising large differences in *per capita* resource consumption (affluence), finds that the "impact of population growth in the more developed regions, acting on much higher intensities, was 2.6 times greater than in the less developed regions." (1995, p 230). This in fact suggests that from an environmental point of view population stabilisation in richer countries should take priority over that in poorer countries (*see* Section 5, Fig. 1).

Some voices nevertheless play down the role of population. Princen et al. for example claim that affluence is the main driver of depletion and pollution, boldly stating "It's not population." (2002, p 6). However, not only is there no evidence denying population's contribution, a *reductio ad absurdum* invalidates this view: if 'it's not population', then the next human being has no environmental impact and neither would the 400-billionth. Other economists more explicitly assert the compatibility of limitless growth in population with the planetary resource base (*e.g.* Simon, 1996, pp 11, 579–580, *passim*).[6]

In fact Princen et al.'s empirical findings support neither their extreme conclusion nor their vaguer claim that "increases in resource use can only be explained in part, and often only in small part, by increases in population." (2002, p 6). Their own graphs show worldwide increases between 1965 and 1995 in population compared with (1) forest-products consumption, (2) meat, milk and fish consumption, and (3) water withdrawals. Although regression results are lacking, their own animal-food example shows that *without* the 70% population increase, and holding eating habits (affluence) constant, much less meat and milk would be consumed.[7] For forest products and freshwater as well, population change explains more than a "small part" of total consumption change, and for the claim that affluence growth is "eight to twelve" times as strong a factor as population growth (p 4) no proof is offered.

Satterthwaite similarly negates the population factor after noting the low *per capita* greenhouse gas emissions of the world's two billion poorest (2009, pp 545–548). He rejects *IPAT* in favour of *ICAT* (Consumers) because the poorest purportedly consume nothing at all.[8] To do justice to the kernel of truth in this observation, one could differentiate within $I = PAT$ between various *P*s: each additional person would be given a co-efficient proportionate to their likely (future) affluence, setting at 1 the co-efficient of the poorest new-born child living at subsistence, or "weighting" a country's population growth proportional to its affluence (Lucas, 1976, p 20). Both theory and empirical work indicate, though, that playing off lower consumption among the rich against lower fertility among the poor is illegitimate, if only because population is also increasing in most rich countries, and the affluence of the poor born today is likely to increase (Engelman, 2010, pp 9–10; 26–27).[9]

[5] *See* Commoner (1971); Ehrlich and Ehrlich (1990); Smil (1990); Holdren (1991); Ehrlich (1991); Bongaarts (1992); Hardin (1993); Brown and Kane (1994); Jørgensen (1994); Dietz and Rosa (1994, 1997); Cohen (1995); Engelman (1995, 2010); Harris and Kennedy (1999); Seidl and Tisdell (1999); Turner and Tschirhart (1999); DeHart and Soulé (2000); Brown et al. (2000); Shi (2003); van Vuuren and Bouwman (2005); Atkinson and Gundimeda (2006); Pimentel and Pimentel (2006); Pan et al. (2007); Heinberg (2007); Gonzalez-Martinez et al. (2008); Timah et al. (2008); Feng et al. (2009); Krausmann et al. (2009); McNeill (2011); Brown (2011); Fox (2011).

[6] The journal *Ecological Economics* has published similar work. For Binswanger (1998, p 10) a positive rate of consumption of a non-renewable resource is "sustainable", with the resource "lasting forever". Turner and Tschirhart (1999, p 163) call ever-increasing population not absurd but merely "optimistic". Bazhanov (2007, p 192) asserts that "long-run consumption… can grow infinitely." Krutilla and Reuveny (2006, p 264) seem to regard only "exponential" population growth as inconsistent with a steady-state economy. Cheviakov and Hartwick (2009, pp 2969–2970) allow "never-ending population growth [even assuming] a finite stock of the essential resource input."

[7] Population grew 70% from 3 to 5.1 billion, meat consumption 140%. If, say, 1965 meat consumption was 60 billion kg/year, it would thus rise to 144 billion in 1995. Since per capita consumption rose from 20 to 28 kg/person (+40%), *without* population increase total consumption would be only 84, not 144 billion kg (Princen et al., 2002, p 7).

[8] Apparently unaware of the overwhelming academic consensus, single-solution authors include Monbiot (2009), who relies on Satterthwaite's article to claim that "Population growth is not a problem — it's among those who consume the least." The New Economics Foundation likewise disregards population because it is a "distraction from tackling overconsumption in wealthy countries… — the real problem." (nef, 2009, pp 2, 13) Pearce (2008, 2010a) weighed in with the claim that "green fascism" is expounding "the overpopulation myth."

[9] Many emphasize one *PAT* factor without denying the others: *e.g.* Fox (2011) and to some extent Commoner (1971, pp 133–136, 235) focus on technology; Durning (1992, pp 58–60) and Engelman (1995) weight affluence; Ehrlich and Ehrlich (1990) and Brown and Kane (1994) attribute much to population.

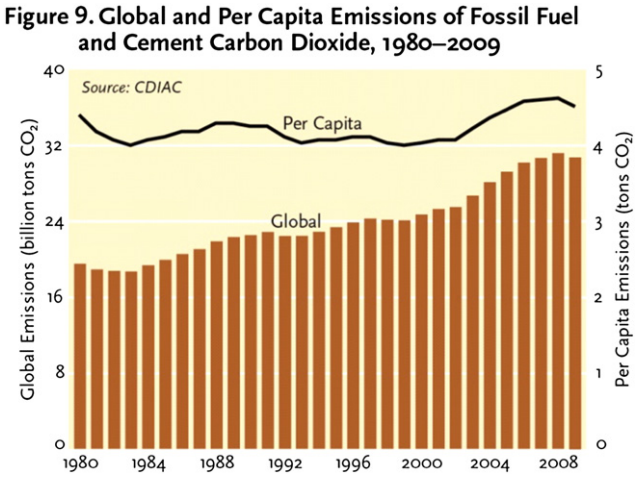


Fig. 1. Per capital consumption increase explains only part of total consumption increase. Source: Worldwatch Institute, Worldwatch Report 183: Population, Climate Change, and Women's Lives; www.worldwatch.org.

3. Complacency *versus* quality of life

Even when accepting that population size burdens the environment to some extent, one can regard population growth with *complacency*: either increased natural-resource efficiency or voluntary sufficiency among richer people will free up environmental and literal space for more people (or higher material living standards among poorer people); or, however *T* and *A* develop, population growth rates are slowing and population size will come to rest within sustainable scale without population policies.[10]

One seminal contribution to the establishment of the *IPAT* paradigm held that solutions should be sought in the realms of affluence and technology rather than population, where we can count on "tendencies for self-regulation." (Commoner, 1971, p 237). Similarly, Schneider et al. regard 8 billion people as sustainable and oppose "state-imposed population control policies." (2010, p 514). Petrucci's (2000) sanguinity is due to his confidence in Marxist environmental solutions without direct attention to population, whilst Hartmann (1998) in like vein chastises "the population lobby" (p 114) for regarding scarcity as biophysical reality rather than an outcome of dominance by large corporations and wealthy governments. Sen's "general case against coercion" in family-planning matters derives from his view that "empirical issues" around food availability and environmental scarcity are not particularly severe, although in the future limits on "reproductive rights" might be necessary on consequentialist, as opposed to purely rights-based, grounds (1996, pp, 1036, 1051, 1039). The most vociferous advocate of the complacency position, though, is Pearce, for whom "the population 'bomb' is being defused." (2010b, pp 4, 170).

The argument is two-pronged: (1) Population will stabilise or decrease without unacceptable loss of welfare and life. (2) The end number is consistent with sustainable resource consumption (and pollution). That is, either our numbers will increase less than usually predicted, and/or the environment can produce more than usually assumed — although nobody claims that Western-style affluence is possible for everybody.

(1) Although most technical aspects of projecting population are beyond the scope of this paper, three parameters warrant mention.

1. UN population studies are not clear concerning mortality trends. A typical one mentions fertility far more often than mortality (UNPF, 2011).[11] It also assumes on the one hand stable crude death rates (between 8 and 13 per thousand), but by 2050 inconsistently predicts an increase in average life expectancy of ten years (*see also* UNDESA, 2009). Other studies note that many now living could see their ninetieth birthdays.[12] Yet declining mortality *per se* weakens the case for complacency.
2. Whilst 2050 world population will be 8 to 11 billion (UNDESA, 2012), uncertainty marking assumptions about changes in education, women's empowerment, and whether crude birth rates in some richer countries will again rise to replacement level seems to speak for caution rather than complacency. Whilst demographic transition theory holds that in addition to contraceptives themselves, 'development is the best contraceptive', empirical data remain ambiguous. When does an additional child become seen as a liability rather than an asset? (Cohen, 1995, pp 46–75, 371–378; *also* footnote 2).
3. UN projections are to a large extent mathematical and demographical only, *i.e.* there is little input of environmental facts on resource availability and tolerable pollution (Brown and Eckholm, 1975, p 191; Cohen, 1995, pp 15, 110–111).

It is with environmental and technological facts, though, that the second argument for complacency mentioned above (non-severe environmental limits) must be addressed.

(2) On this issue of the *human carrying capacity* of either the planet or of individual societies or countries, this paper limits itself to some observations on food production, referring only in passing to the planet-wide meta-analyses of Smil (1994), Cohen (1995) or van den Bergh and Rietveld (2004) and to ongoing work on global environmental footprints (EF) and human appropriation of net primary production (HANPP).[13] Food-production estimates, upon which judgments of maximum *sustainable* population depend, deserve special attention on both environmental and humanitarian grounds.

Based on a survey of literature close to ecological economics,[14] it seems fruitful to group the parameters for judging food production capacity around four questions:

1. What is the net change in the *amount* of arable land and pasture in a given time period — counting loss to building-over, erosion, salinisation, nutrient depletion and other soil degradation?
2. How *productive* is the remaining land — counting both input availability (fertiliser, water, pesticides, herbicides, and high-yield seeds) and limits to input uptake of crops?
3. How sustainable is present, especially 'green-revolution', agriculture compared to bio-organic agriculture that does not *mine* soil, water, fertilisers and fossil fuels?
4. What are the logistics, politics and ethics of food *distribution*?

The agricultural economists surveyed believe yields per hectare can in some places be raised (Brown, 2011, pp 169–170) but in others will fall due to unsustainable systems. They point to sobering facts:

[10] Pro-natalist *values* also play a role; *vide* religious groups and the analyses of Satterthwaite (2009), Pearce (2010b) and Simon, who thought greater numbers would increase the likelihood of geniuses who would solve environmental problems (1996, pp 408, 559–560). Even mainstream demography often regards increasing populations as a good thing (*e.g.* Sardon 2006, pp 198, 219).

[11] The report mentions 'fertility' or 'birth rate' over 120 times, but 'mortality' or 'death rate' 8 times, and omits 'crude death rate' from its tables of demographic indicators (pp 116–121). The relative inattention received by mortality stems perhaps from its non-amenability to policy; in fact, for emotional and ethical reasons societies universally pursue mortality decline, *ceteris paribus* increasing population growth.

[12] https://www.cia.gov/library/reports/general-reports-1/Demo_Trends_For_Web.pdf Ehrlich and Ehrlich (1990), Pearce (2010b, p 286) and Royal Society (2012, pp 30, 42, 101) do treat mortality and fertility on equal footing.

[13] www.footprintnetwork.org and http://www.ecoeco.org/pdf/2007_march_hanpp.pdf or http://www.earthportal.org/?p=777.

[14] Whittaker and Likens (1975); Brown and Kane (1994); Giampietro (1994); Smil (1994); Harris and Kennedy (1999); Brown et al. (2000); Kates (2004); Pimentel and Pimentel (2006); Brown (2011).

- After *intensification* of grain production in some countries, maxima have been reached, *e.g.* for rice in Japan, Indonesia and South Korea, at about five tons (Brown and Kane, 1994, pp 26–27).[15]
- Grain production *per person* rose until 1984 to about 346 tons, fell to 313 tons in 1993 and has continued to fall (Brown, 2011; Brown and Kane, 1994).
- *Irrigation water* presents a limit already overstepped in hundreds of river systems and aquifers.
- Productivity predictions must take into account today's dependence on (decreasing) supplies of *fossil fuels* for fertiliser, machinery, water-pumping and distribution.[16]
- Pesticides, herbicides and monocultures necessary for high-yield agriculture *degrade* the broader environment.
- Arable land and pasture are continually *lost* to erosion, salinisation and building-over for housing and infrastructure (Brown and Kane, 1994, pp 24, 27, 105; Ehrlich, 1991, pp 221–224).
- Fertiliser inputs see *diminishing returns* (Brown and Kane, 1994, p 164).
- Labour and energy costs of *phosphorus supply* are rising (Ashley et al., 2011; Cordell et al., 2009; Smil, 2000).
- Marginal *seed* productivity has declined since the era of Borlaug and the Green Revolution.[17]
- Between 1975 and 2005 the absolute number of *hungry and starving* has increased in 50 least-developed countries (UNCTAD, 2008), as did from 1950 to 1990 the number of "very poor" (Ehrlich and Ehrlich, 1990, p 41; *also* Giampietro, 1994; Pimentel and Pimentel, 2006); worldwide the number has stayed constant for decades.
- The precarious state of fish stocks is common knowledge.
- Bio-engineering and water-desalinisation entail at present little-known risks and costs.

Taken together, the above results caution against complacency, and the agricultural task would obviously be easier were there fewer people to feed. A healthy diet moreover doesn't consist of grain alone.

These facts as well as the widely accepted precautionary principle strengthen the case for higher priority for population policies. In her critique of complacency Kates (2004) adds that demographic transitions happen slowly, that population projections are statistically highly uncertain, and that demographic momentum should not be underestimated.

Aside from environmental or inter-generational considerations, it is often argued that more equitable *intra*-generational food distribution deserves priority; after all, the numbers of the overweight and the hungry are roughly equal. A practical consideration in answer to this is offered by Ehrlich and Ehrlich: There is not time for "waiting for the demographic transition" or for the rich to "change their ways." (1990, pp 214, 40; *also* Daily et al., 1994, pp 470–471; Blake, 1994). That is, can we wait for such re-distribution to occur, a process that would involve widespread changes not only in ethical attitudes but in eating habits?

A conservative conclusion to this section is that, concerning all resources, lower population growth can only help to alleviate poverty — regardless of one's estimate of (1) future population size or (2) carrying capacity. If for instance world-wide no more than 10 tons of GHGs per year is sustainable, the average allowed per person on a contraction-and-convergence basis will be higher with lower population (Engelman, 1995, p 124; Engelman, 2010, pp 10–13, 23). A parallel economic argument is that public finance faces trade-offs between the health and education infrastructure required by additional citizens (Dillard, 2007, pp 29–31) and, for instance, the infrastructure needed for renewable-energy technology. A complacent stance requires moreover the belief that technology can prevent higher impact: population is after all assumed to rise, with no fall in average world affluence (Ekins, 1991).

4. Cultural carrying capacity: $P = I/AT$

This section derives from $I = PAT$ a method by which a country can calculate the population size it desires. To solve for P both sides of $I = PAT$ are divided by AT: $P = I/AT$. The method was formulated rigorously by Penck (1925), an early physical "anthropogeographer" (ecological economist), and used in China before implementing a one-child policy: within the constraints of "economic development,… food resources and the composition of the diet,… and ecological balance and fresh water resources" the guiding studies arrived at a "desirable population size" of 700 million (Song, 1981, pp 27–30).[18]

Penck derived this formula from the facts that total food production is equal to both (1) the number of people times their average food needs and (2) the amount of arable area times its average product. The two right sides being thus equal, we divide both by average nutritional need, and again, P= arable area times product per unit of area divided by average nutritional need (1925, pp 331–332). Product per unit area he calculated using the factors climate, natural soil productivity and technological efficiency; for arable area he had to subtract land needed for clothes, wood, transportation and houses (p 347), but he did not include above-average nutritional requirements or further demands on productive capacity by other species and above-subsistence consumption. The result was carrying capacity as a maximum number.[19]

The term 'cultural' carrying capacity[20] is used to distinguish between carrying capacity at subsistence level – sometimes called the 'giant human feedlot' approach[21] – and the sustainable number at levels of affluence and a style of public life higher than subsistence, always assuming given technologies. That is, not only does desirable carrying capacity depend on environmental givens and the efficiency with which we use natural inputs, but society seeks quality as well as quantity of life (Cohen, 1995, 263–267, 279–287, 317; Whittaker and Likens, 1975). The A variable must be employed in the sense of lifestyle and environmental amenities (Cohen, 1995, pp 165–167, 262; Daly and Cobb, 1989, p 239). Instead of asking how many people the earth *can* support, we can consider *inter*-generational justice as well and ask how many it *should* support (Dillard, 2007, p 7). Fig. 2 shows some categories upon which cultural carrying capacity depends.

To quantify *impact* we rely on biophysical sustainability sciences and seek ever-more accurate estimates of resource supply, climate change, *etc.* In terms of depletion we use the straightforward concept of sustainable harvest of renewable resources, whereas since for non-renewables there is no sustainable harvest, we can only politically decide how long we *want* reserves to last.[22] In terms of local pollution, social optima seem tractable. Required are global cost–benefit analyses in terms of mitigation and adaptation, well-known to ecological economics.

[15] *Also* e.g. http://www.nationmaster.com/graph/agr_cer_yie_kg_per_hec-cereal-yield-kg-per-hectare.

[16] Whittaker and Likes quantified the proportion of food depending on fossil fuels at one-fourth (1975, p 318).

[17] Borlaug himself in 1970 saw that higher hectare productivity merely gave us breathing space because we are not "decreasing the rate of human reproduction." http://nobelprize.org/nobel_prizes/peace/laureates/1970/borlaug-acceptance.html *Also* Brown and Eckholm, 1975, pp 140, 145, 179–196.

[18] 'Development' in the Chinese study means greater resource efficiency, equivalent to this paper's lower T in $I = PAT$; desired were 85 g protein per day.

[19] Penck points out that the point is not Malthus's of the contrast between 'arithmetical' or 'exponential' growth rates: due to physical limits, *no* growth rate is sustainable (1925, p 342).

[20] *See* Boulding (1964, p 135); Hardin (1991, pp 54–56) and Goodland et al. (1991, pp 494–495) [both in Costanza, 1991]; Seidl and Tisdell (1999).

[21] According to Ehrlich (1971, p 91) Colin Clark set the 'human-feedlot' maximum at 157 billion people; the Food and Agricultural Organisation later floated the relatively sober figure of 33 billion [*New Scientist*, 9 August 1984, p 16].

[22] The computations of Hotelling (1931) and Hartwick (1977) notwithstanding, the dilemma is that it is just as 'stupid' to sit freezing on a pile of coal as it is to use it all up.

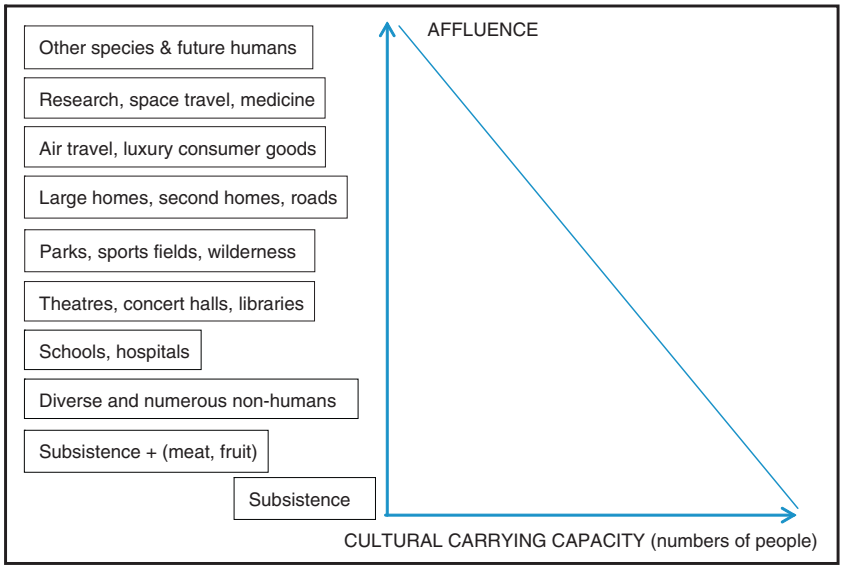


Fig. 2. Within sustainability limits, a society determines its carrying capacity after determining the lifestyle, or affluence, it wishes; natural-resource efficiency could likewise be on the vertical axis, but with efficiency in *descending* scale.

The strength of the *technology* factor *T* is next estimated in terms of the energy costs of harvesting and mining resources and the efficiency with which they are employed in production (food, transport, buildings, *etc.*), always correcting for acceptable risk. The efficiency parameter (metric: GDP/resource input) could be estimated using historical trends. More difficult but more important in the long run, after deciding the *rate* at which we deplete non-renewables, is quantifying *T* assuming no use of fossil fuels.[23]

To illustrate the meaning of this last constraint, it seems that were the work required only for our present mobility to come entirely from biomass, we would have little or nothing left to eat. Brazil, for example, devotes about 10% of its farmland to sugarcane, each hectare yielding about 109 GJ/year of ethanol and meeting about 14% of its vehicles' needs. At the present ratio at which a cane plant is used for sugar and ethanol, meeting *all* Brazil's vehicle demand would require 70% of its farmland.[24] Applying this to the more mobile UK, assume realistically that 'croppable' land is 6,200,000 ha and unrealistically that ethanol productivity equals Brazil's. All UK land could then deliver about 675 PJ/year for vehicles. Yet assuming 30,000,000 autos in the UK, each moving 20,000 km/year, auto-mobility alone requires about three times this much energy.

The third and last factor to quantify is *A*, the socially desired level of affluence. Remember that unless throughput is lower than sustainable scale, any rise in *A* entails a carrying-capacity decline; we face trade-offs between numbers of people and consumption per person.

The political discussion could start with an *A* of mere subsistence — the level of *per capita* throughput consistent with maximum population, yielding *brute carrying capacity*. Estimates of population at this level vary wildly (Cohen, 1995; van den Bergh and Rietveld 2004). A plausible maximum of around 10 billion has been argued (Martinez-Alier, 1987, pp 102–104). However, if we consider only water constraints, and allow for no industrial water use, the figure is more likely between 4 and 7 billion (Cohen, 1995, pp 314–318). In deriving these numbers one must only identify the nutritional level for health; the availability of water, fossil fuels, fertilisers and arable soil has already been calculated under the heading 'impact'.

After assuming perhaps 3000 kcal of food per day and starting with such a maximum, we then begin to calculate the smaller number, *cultural carrying capacity*, by making a series of deductions. First, the society might want more animal protein and fruit in the diet (Smil, 1994, pp 265–266). Under constant assumptions of agricultural input availability and starting from a low plausible maximum under a vegetarian, subsistence-level diet of, say, 6 billion, cultural carrying capacity might then be as low as 2.5 billion (Ehrlich and Ehrlich, 1990, pp 66–67). Another estimation using the same variables yielded the corresponding figures of 5.9 and 2.9 billion (Cohen, 1995, p 209; *also* pp 183–190, 200–205).[25] It should not be forgotten that all such estimates must be based on *sustainable* agriculture; Kates reports an estimate that such a restraint would reduce the sustainable population of the US from about 350 million to about 210 million (2004, p 55).

We then make further deductions based on whether or not we want to keep pets, or use some arable land for sports fields and parks. Further, shall there be room for beauty for its own sake, *e.g.* in museums and as landscape, and for wilderness and habitat for non-human species? These were the factors, after all, that led Mill to argue originally for a stationary-state economy with a stable population (1848, Book IV, Chapter VI; *see also* Gowdy and McDaniel, 1995). However, this trade-off between human population size and such amenities often remains unaddressed by conservationists. The International Union for the Conservation of Nature for example cultivates 15 programme areas, but none addresses human population size (IUCN, 2012).[26] Whatever specific lifestyle a society might choose, it will include not only some comfort and pleasure, but also some *dignity* in its definition of the 'good life'; Heinberg, for one, argues that in addition

[23] On this under-researched question *see* MacKay (2009) , who tallies the land-area and embodied-energy requirements of wind, solar, etc. installations. *Also* Smil (2008).

[24] www.eoearth.org > 'Growing plants for biofuel'.

[25] FAO's website is largely silent on the population issue, focusing more on socio-demographic *structure* than on *size* — a narrowing of the field of 'demography' to exclude size that afflicts much of the literature (Cohen, 1995, pp 12, 235–236); *but see also* http://www.fao.org/docrep/U3550t/u3550t02.htm *and* http://www.fao.org/sd/WPdirect/Wpre0085.htm.

[26] I have not received replies from the IUCN to queries about its views on population size. The World Wildlife Fund employs the concept of Human-Wildlife Conflict (HWC), offering land-use planning and payment for ecosystem services as solutions but taking human population expansion as a given: "If we plan properly, there's room for everyone." http://www.worldwildlife.org/species/humanwildlifeconflict.html WWF's Population, Health, and Environment (PHE) programme mentions only in passing 'voluntary family planning' (http://www.worldwildlife.org/what/communityaction/people/phe/populationhealthenvironment.html) but together with the Population Reference Bureau may be increasing its attention to population stabilisation (De Souza, 2008; Royal Society, 2012, p 102). Conservationist and humanist approaches are contrasted in Bookchin and Foreman (1991).

to dignity, living together democratically in peace depends on a quite low number for cultural carrying capacity (2007, pp 119–122).

P as cultural carrying capacity thus follows from measured or chosen *I*, *T* and *A*. The method outlined here would clarify policy goals and remind us that population size is not just an ecological given but also a social choice.[27] It is moreover best applicable at the country rather than the global level, with countries deciding on trade-offs between higher population and higher affluence (Kates, 2004, p 71). The approach moreover overcomes objections that the concept of carrying capacity is either too static or not subject to empirical investigation (Sayre, 2008). Ecological economics has the tools for doing this work. The question can be re-framed: *Under what assumptions* of *I*, *T* and *A* can we be complacent, or even happy, about *P*?

5. Policies

As seen in the Introduction, population policy is subject to the caveat that isolated reductions of *P*, *A* or *T* do not necessarily reduce *I* because rebound effects induce rises in the other right-side factors; *necessarily* effective ways to reduce *I* would have to be direct, *i.e.* capping or taxing depletion and pollution (Alcott, 2010; Hardaway, 2008). Even lower affluence through voluntary sufficiency among the rich enables higher affluence among the poor, most likely neutralising effects on impact (Alcott, 2008).

There are nevertheless good reasons for separate population policies. As already mentioned, demands on people to increase efficiency and get by with fewer resources *per capita* are less onerous at lower population levels. Locally, moreover, when rebounds are limited by lack of capital and natural-resource imports, reduced environmental pressure can result. However, lower or stabilised population mainly serves *humanitarian* goals.

First, it is commonly estimated that 215 million women wish to have modern birth control technology but don't, meaning 50–70 million unwanted pregnancies per year (perhaps 75% of annual population increase) (Engelman, 2010, p 20; PRB, 2012). Second, at the local level food and water shortages, and thus illness and starvation, could immediately be ameliorated if natality fell (PACCAF, 2010; Royal Society, 2012, p 92). Third, wherever throughput is unsustainably high additional people can only, *ceteris paribus*, raise throughput and thus unethically decrease the welfare of future people (Fletcher, 1976, pp 58–62). Fourth, it is likely that any international agreement capping fuel consumption or GHGs on a *per capita* basis would freeze relative populations in the permit-distribution equation, meaning that population growth among the poorest signatories would lower affluence painfully (Engelman, 2010, p 24).[28] This mirrors earlier agreements between food donors and recipients making aid contingent upon family planning (Fletcher, 1976, pp 57–59).

Consider next population policies for *developed* countries. It is after all a fact that a UK child might consume 22 times as many resources as one in Malawi.[29] As shown in Section 2, it does not follow from this that the elimination of capitalism or over-consumption are sufficient environmental solutions deserving exclusive attention — as argued by Hartmann (1998), Petrucci (2000) or Satterthwaite (2009). It would seem on the contrary to be an argument for population reduction in rich countries.[30]

Since in developed countries women's empowerment, birth-control technology, low infant mortality and legal abortion have largely been achieved, policy could start by removing subsidies for parenting, for example:

- per-child deductions from taxable income per dependent child (often several thousand Euros);
- employment contracts that include monthly supplements per child;
- rewards for births with a one-off payment[31];
- incentives such as pre-school child care, parental birth leave and relatively cheap housing for large families.[32]

By contrast, general tax and benefit structures, including pensions, could favour the childless or at least couples with fewer than three children.[33]

Of course the interests of already-born children deserve priority, even if there are real trade-offs between their welfare and the welfare of those present or future people who would benefit from a smaller population (Blaustein, 1971, p 1860). But if subsidy cuts do lead to unacceptable poverty, these should be addressed with anti-*poverty* policies, not by rejecting environmentally and ethically sound population policies (Engelman, 2010, p 24).[34] Public money saved by removing subsidies could moreover be combined with binding transfers of purchasing power to poorer countries, perhaps tied to education, health, family planning or broader environmental programs.

Many relatively rich people do desire to lower their footprint. In choosing among various behavioural changes thought to reduce individual impact, however, it helps to have a rough idea of relative effectiveness, and the surprising result is that having one less child is many times more effective than several other possible actions taken together — such as cycling, recycling, insulating, avoiding flights, *etc.* (Hall et al., 1994; Murtaugh and Schlax, 2009). This is called the 'offspring effect' (Engelman, 2010, p 11).

The range of *indirect* population-control policies is well-known and includes easy choices such as government propaganda and those associated with the demographic transition such as better education, reproductive health and income security. Sen relies on these – after noting Malthus' underestimation of voluntary fertility reduction and calling on empirical evidence from India and China – to justify his complacent stance that no legal incentives or prohibitions are necessary to limit fertility (1996 pp, 1045–1049, 1053). Cohen lists "six commandments: promote contraceptives; develop economies; save children; empower women; educate men; and do all of the above!" (1995, p 69; *also* 17, 371).

Common to all these measures, as well as to direct ones such as free or cheap medical pregnancy-prevention, is that they are desirable for humanitarian reasons alone, having nothing to do with lowering fertility (Cohen, 1995, p 374; Ehrlich and Ehrlich, 1990; Raina, 1988). They are also relatively cost-effective (Engelman, 1995, pp 116–117; Hardaway, 2008, p 993; Population Matters, 2012) and have been continually discussed.[35] Considerably less discussed in recent years, and absent from Cohen's list, are a range of binding policies:

1. financial incentives and disincentives influencing family size, including taxes on third-plus children, payment for sterilisation, and devolving full financial responsibility for children onto parents
2. rules foreseeing sanctions for non-compliance, including a higher legal age for marriage and child quotas (tradable or non-tradable)[36]

[27] Brown et al., 2000, pp 127–128, 169–170.

[28] Hardin reports that Chinese "production groups" received rice rations with no population inflator (1993, p 269).

[29] Population Matters (2012) http://populationmatters.org/2010/press/climate-change-process-ultimately-fail-populations-stabilised/.

[30] In the words of Ehrlich & Ehrlich, "The world can't afford more Americans." (1990, p 64; *also* pp 42–44, 132–134, 193) nef, in contrast, claims that concern over population means concern over it only among poor countries (2009, p 9).

[31] *See* UNDESA (2009, Table 2) for a list of 36 countries with pro-natalist policies, 22 of them in "more developed regions." On current payouts, land plots and abortion restrictions in Russia *see* IHT (2011). Spain discontinued its 2500-Euro payouts on 1 January 2011.

[32] Daily et al. (1994); Sardon (2006); Thévenon (2011).

[33] *See* Brown and Eckholm, 1975, pp 189–190; Dillard, 2007, p 18.

[34] That is, we should follow Tinbergen's rule of *one problem, one policy* (1956, pp 55–68).

[35] For completeness one must also name the Malthusian 'positive checks' and 'misery' such as war and sickness, as well as infanticide (Harris and Ross, 1987; Hill and Hurtado, 1996; Hrdy, 1999).

[36] Difficult questions around the enforcement of such rules are beyond the scope of this paper.

Because procreation is inter-relational – it quintessentially affects others, and not only offspring themselves – Dillard asks, "Is procreation in all circumstances just… without being subject to law and regard for others?" (2007, p 3). The next section explores more controversial policies in a de-polarising way.

6. Political restrictions on procreative freedom

Today's placement of individual above societal or collective rights has moved several birth control measures to the 'politically incorrect' end of the spectrum — quite obviously for example birth quotas. At least since the 1994 UN International Conference on Population and Development in Cairo an absolute individual right to procreate ('reproduce') dominates population politics (Kates, 2004, pp 56–57; Royal Society, 2012, pp 12–13, 83). It is explicitly upheld for instance by Commoner (1971, pp 234–235, 296), by the dissenting group of most African Academies of Science (Jayaraman, 1993), by Simon (1996) and by the New Economics Foundation (2009, p 10). Sen offers two options – "a big dose of government bullying" and "leaving matters to the responsible [*sic.*] reflection of the people themselves" – and opts for the latter (1996, p, 1044, *passim*).

However, a serious problem attaches to this *laissez-faire* position: Alongside freedoms and rights we also have responsibilities, the more so as the present obese scale of the human economy means the rights of people today conflict with those of people tomorrow. This led Boulding to advocate tradable offspring quotas, arguing that they combine "the minimum of social control necessary to the solution of the problem with a maximum of individual liberty and ethical choice." (1964, p 135).[37] Daly and Cobb likewise do not shy away from this policy, regarding reproduction in the "full-world economy" no longer as a "free good" (1989, pp 236–237, 244–245). For further, more general defences of the rights of society and the future that counterbalance absolute procreative freedom, *see* Engelhardt (1976), Lee (1995), Kates (2004), Heinberg (2007), Dillard (2007) and Brown (2011).[38]

This issue fits neatly into ecological economics' paradigm of the 'commons' (Blaustein, 1971, pp 1904–1911; Kates, 2004, pp 56, 65). If reproduction is an absolute individual right we have "open access reproduction and [a] second tragedy of the commons" (Cohen, 1995, pp 257–258), and it is uncontested that commons problems cannot be solved without limiting access. We limit for instance the number of cows on an alp or GHGs put into the atmosphere, freedom taking a back seat so that one person's rights are not at the expense of another's. But directly limiting the number of people born at all, touching as it does on human intimacy and evolution, is a stark limitation of freedom. Since there are cogent arguments for rejecting anti-natalist measures that intrude upon the physical body, such as forced sterilisation and abortion, or insertion of intrauterine devices (Abrams, 2000), this paper excludes these from consideration.

Nevertheless, the relatively recent severity of global pollution and resource scarcity leads to both rights-based and consequentialist arguments for derogating at least the claimed right to have as many offspring as one wishes (Blaustein, 1971, pp 1891–1893; Lee, 1995, pp 339–340). Justification for limiting this individual freedom closely resembles that for taxation of environmental 'external costs'. Whether seen as a "liberty interest" or a "fundamental right… procreation is inherently interpersonal, and without limitation becomes injurious to others, [involving] limiting duties, and thus countervailing state interests" (Dillard, 2007, pp 11, 20, 24, 49–51). Not least the interests of the yet unborn, under conditions of poverty-inducing environmental constraints, alter the social utility function away from absolute procreative freedom. (*ibid.* pp 11, 19, 41–42; Mainwaring (2004).

Suppose, though, a society does define its cultural carrying capacity as a political goal, but that society adheres to voluntarism in as many realms of life as possible.

> How will the often-asserted right of couples and individuals to control their fertility be reconciled with national demographic goals if the way couples and individuals exercise that right happens not to bring about the demographic goals? (Cohen, 1995, p 378)

Even in terms of their own children, alongside parents' procreative rights stands parental responsibility to support them, a responsibility harder to fulfil as resource supply decreases (Dillard, 2007, p 7; Engelhardt, 1976; Fletcher, 1976; Hardin, 1976).

If procreative rights are absolute (non-derogable), policy options are restricted to education and propaganda or cajoling. One might consider some combination of subsidies and tax rules that influence productive decisions, as mentioned in Section 5, but it would be argued that these, too, abrogate the individual right as much as birth quotas (Abrams, 2000). On the other hand such incentives, as well as cultural norms, today in fact constrain our actions in a *pro*-natalist way, and subsidies could be removed without violating voluntarism (Blake, 1994; Blaustein, 1971, p 1870).[39]

Thus, before deciding between indirect ('soft') and direct ('hard') policies, societies must decide whether individual reproductive rights are absolute or derogable (to be balanced over against the rights of others or society).[40] Arguments for inalienability can be based on principle – either on religious beliefs or a strict *laissez-faire,* individualist philosophy. More contingent arguments could on the other hand be made on the basis of how much society values amenities and the welfare of other species and future humans (*see* Fig. 2).

Also affecting the decision on whether to curtail individual behaviour are empirical estimates of just how severely society is exceeding environmental limits. Even those relatively sanguine on this point, however, concede that significant scarcity is soon quite conceivable (Sen, 1996, pp 1036, 1051). At some point, that is, the rights of future people, whether to resources or procreation, compete with those of present people (Dillard, 2007, pp 57–60; Lee, 1995, p 339). Moreover, as claimed in Section 3, even *intra*-generationally each addition person impedes the fight against poverty — the more so if norms do not change considerably towards more distributive justice. But because they underlie the entire concern with sustainability, it is *inter*-generational ethics that should carry great weight specifically within ecological economics. In terms of present political decisions, moreover, the fact comes into play that neither other species nor future people have any voice, perhaps strengthening the case against unfettered procreative freedom.

The idea of material social justice, however, is still conceptually and emotionally rooted in the present, in the suffering and injustice we can see. When Bookchin, for instance, talks of "social ecology" whilst denying any conflict between "insatiable needs [and] scarce natural resources" (1994, pp 21–24), future humans are not in the equation. Foreman's *inter*-generational and non-anthropocentric answer to Bookchin is that his "biggest worry about the limited perspective of a socially-oriented ecology is that it can all too easily become overwhelmingly social and

[37] Proposals to restrict procreation to licensed parents seek to protect the welfare of children rather than limit population size (Eisenberg, 1994).

[38] On our sacred freedoms Ehrlich and Ehrlich note, "The cost [of deciding for sustainability] would include giving up many things that we now consider to be essential freedoms: The freedom not to consider society's needs when planning a family, freedom to drive gas-guzzling cars,… freedom to use and discard huge amounts of non-biodegradable plastics, and… the freedom to consume more and more" (1990, p 181).

[39] In an earlier, similarly pronatalist context the rebellious 'neo-Malthusian' reaction of sexual intercourse without offspring — by means including illegal contraception and abortion, was of course 'voluntary' and has been called 'bottom-up', although it did advocate the repeal of some laws (Encyclopedia of Ecological Economics, 2012). For a definition of 'neo-Malthusianism' *see* Kates, 2004, p 72).

[40] Cohen for instance questions a land-owner's 'right' to degrade soil, positing society's right to prescribe agricultural practices (1995, p 294).

insufficiently ecological" (Bookchin and Foreman, 1991, p 118). However, since an egalitarian society could still step beyond biophysical limits, the concept of social justice cannot be co-opted by the present.

As with all commons goods we are dealing with an exclusive public good and must decide whether other species and future human beings have rights of access. If and when we find ourselves at an unsustainable level of throughput, we face a trade-off between intra-generational, intra-species individual freedom and inter-generational, inter-species justice. "At issue is how to balance the reproductive rights of the current generation with the survival rights of the next generation" (Brown and Kane, 1994, p 207).[41]

Alongside the issue of whether policies legitimately abrogate or at least derogate individual freedom is the political question of *how* the policies are decided, on a spectrum from authoritarian to direct-democratic. Our debate over regulationist *versus* voluntary approaches is however hindered because key terms such as 'coercion' and 'compulsion' are used ambiguously. In Sen's discussion, for instance, especially when speaking simply of "the Chinese example", the issues of the policies themselves and how the policies are decided are conflated (1996, pp, 1044, 1054). The same ambiguity plagues the terms 'top-down' and 'bottom-up' (*also* Hardin, 1993, p 274). The unhappy result is that one can for instance reject 'coercion' by a dictator, or 'top-down' rule, yet be in favour of measures that 'coercively' restrict freedom if decided by popular majority.[42]

Ehrlich for example writes, "We must have population control at home, hopefully through changes in our value system, but by compulsion if voluntary methods fail" (1971, pp xi–xii). *Population Matters* "opposes coercive population restraint policies."[43] All laws, however, 'coerce' or 'compel' – if left free we would act otherwise – including laws for taxation or compulsory schooling and against bigamy or driving on the wrong side of the road. Since anti-natalist rules are by definition coercive, the anti-coercion position would preclude anything but educational measures and perhaps eased access to contraceptives (Abrams, 2000; but see Lee, 1995; Dillard, 2007, pp 48–49).

But what do the terms 'compulsion' and 'coercive' mean? Dillard's analysis of restrictions on procreative freedom, drawing on U.S. court practice, international law and Locke's theory of government, sees a spectrum of subjective definitions as well as disagreement over when coercion, manipulation, and incentives are unacceptable on human-rights grounds (2007, pp 32–34, *passim*). On the spectrum are the legal policies mentioned at the end of Section 5 (financial incentives and rules such as birth quotas) and intrusions into the body (*e.g.* sterilisation) which we are rejecting. Even the hoary concept of 'mutual coercion, mutually decided upon' misleads because it implies unanimity rather than majority rule. The concept 'coercion', therefore, whilst useful in distinguishing political decision-making regimes, is not useful in discussing population-control policies themselves (Dillard, 2007, p 37; Lee, 1995, pp 335–337).

The equally ambiguous terms 'bottom-up' and 'top-down' likewise have validity only concerning the rule-making *process*. The rules themselves could perhaps always be taxed as 'top-down' – the more so since a government enforces them – but if they are wished and voted in by a majority of the people, the process is 'bottom-up' in contrast to imposition by a non-elected elite. Finally, the hackneyed example of the 'tyranny of the majority' – that not even a 95% majority of voters can legitimately condemn red-heads to jail – reveals that whatever the decision-making regime, society's rights are likewise not unlimited. Again, it is here assumed that surgical intrusions (*e.g.* forced abortions) fall into this category.[44]

It can be safely assumed that most ecological economists would rather 'go to hell democratically' than to heaven autocratically; the 'green authoritarian' option of purely 'top-down' decision-making is not on the table. Consider however for instance large popular majorities for incentives for sterilisation, disincentives for people already having two children,[45] banning trade in sperm and eggs, or closing borders to immigration on environmental grounds? (Löpfe and Vontobel, 2011) The question of which particular (coercive) population policies are out of bounds in a democracy remains wide open.

7. Discussion

In the early years of ecological economics analysis of population size was often explicit, including advocacy of population-reducing policies (Boulding, 1964; Brown and Eckholm, 1975; Daly, 1974; Ehrlich, 1971). The topic has since diminished in importance. Despite a number of articles, albeit analytical as opposed to policy-oriented ones (*see* footnote 5), the journal *Ecological Economics* has published more on technological resource efficiency, renewables and sustainable consumption than on population. Furthermore, to my knowledge no ecological-economics conferences have held sessions on population until the European Society's meeting in Istanbul in 2011.[46] Two *Ecological Economics* textbooks likewise mention population size only briefly and analytically,[47] whilst the seminal anthology of that title (Costanza, 1991) featured among its 32 contributions only one specifically on human numbers (Hardin), two others attesting a positive connection between people and resource consumption (Daly; Goodland et al.), and one adopting a complacent stance towards population growth (Fig. 3) (Cavalcanti).[48]

Neglect of human population size is indeed wider-spread:

> Despite its key contribution to climate change, population plays little role in current discussions on how to address this serious challenge, particularly at the governmental level. Although many policymakers would welcome slower population growth, there is a concern that policies to slow growth will violate the right of couples to determine their own family size. Moreover, population is associated with sensitive issues including sexuality, contraception, abortion, migration, and religion. As a result, the debate on climate change tends to focus on the role of human technologies and their economic foundations, rather than on critical human numbers and behaviours. (Engelman, 2010, p 5).

To be sure, current deliberations of the Intergovernmental Panel on Climate Change on responsibility for historic emissions have revived earlier discussions over the roles of both population and affluence (Agarwal and Narain, 1991; O'Neill et al., 2010). However, the development/environment discussion since the UN Cairo meeting in 1994 has been largely silent on population size (Kates, 2004, pp 57, 68–69; Kysar, 2003, p 727), the topic for instance finding no place

[41] I have framed the possible trade-offs in population ethics in terms of rights; they are treated in terms of interests or utility (well-being) in the 'positional utilitarianism' of Mainwaring (2004, p 354).

[42] Blake observes that "The historical record does not allow us to equate economic and social influence with 'voluntarism' and government policy with 'coercion'." (1994, p 176).

[43] http://populationmatters.org/documents/ethical_implications.pdf *Also* Royal Society (2012, pp 8, 102).

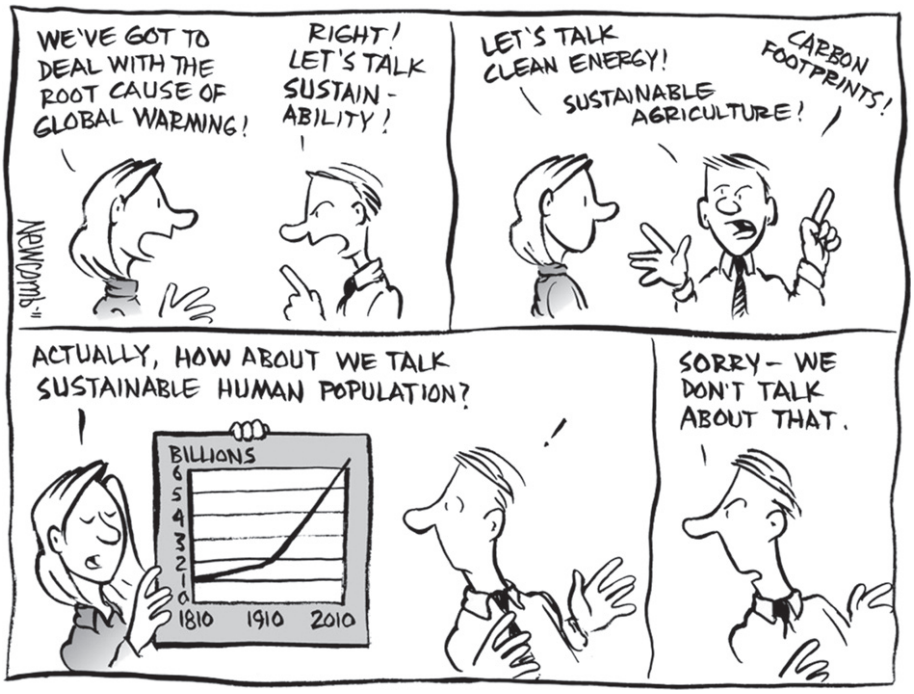
[44] Max Frisch on Swiss radio in 1989 imagined nine people on a cable car from a mountain-top restaurant to the valley station. Seven are drunk and find it great fun to rock and sway the cabin. The two sober passengers are frightened to death. Does the majority have the right to do whatever it wants?

[45] Dillard posits a limited right to self-replacement, congruent with society's interest in perpetuating itself, but not to unlimited numbers of offspring (2007, pp 44–45).

[46] Even for the Istanbul conference the 20 pieces on its website sketching environmental problems in Turkey contained only two peripheral mentions of population — in a republic whose population has quintupled since its founding.

[47] Daly and Farley (2004); Common and Stagl (2005).

[48] For coverage of population issues one must turn *e.g.* to the journals *Population and Environment* and *Population and Development Review* or the organisations Population Council (2002, 2012), Population Reference Bureau (2012), Population Matters (2012), Worldwatch (2012) and – for those with a sense of humour – Voluntary Human Extinction Movement (2012).



With the kind permission of Tim Newcomb.

Fig. 3. With the kind permission of Tim Newcomb.

in the report of the Millennium Summit in 2000 (Hardaway, 2008, pp 987–988; Royal Society, 2012, pp 12–13, 83).

To re-open the population debate one can imagine a conference or special issue on the population views of people and governments of poorer countries. Many developing-country women have long wished fewer children,[49] and there is recent renewed demand that the issue be given priority both locally and in international aid budgets.[50] In the least developed countries "…population growth will increase vulnerability to many of the most serious impacts of climate change", leading 37 of the 49 countries to "explicitly make linkages between climate change and population" for their National Adaptation Programmes for Action (Hardee and Matunga, 2010, pp 115, 118).

One could also revisit controversies over responsibility for environmental stress that arose in New Delhi in 1993, where the scientific academies of 56 developing countries called for zero population growth whilst a majority of the African ones dissented (Jayaraman, 1993; New Delhi Science Summit, 1994).[51] One could learn from China, whose officials routinely cite the demands of a huge population when analysing their fight for instance against desertification.[52] Finally, pro-natalist incentives in rich countries could be rigorously researched.

Emotional and political reasons *not* to look closer at population size are beyond the scope of this paper. Warranting brief mention, though, is the history of links between population control and eugenics (Bookchin, 1994) as well as opposition to food charity and immigration (Lucas, 1976) — despite the fact that contemporary arguments for reduced population maintain neutrality over which groups 'should' reduce. Feminist opposition to low-fertility policies, as well, raised manifold gender issues relating to reproduction (Kates, 2004, pp 58–64). Finally, the issue touches the fact that our humanistic hopes must conform to planetary limits.[53]

8. Conclusions

Six main conclusions of this paper are:

(1) Using the $I=f(P,A,T)$ formula, both population and affluence contribute to the size of impact. Instead of playing these two factors off against each other, research is better directed at measuring their relative contributions with regard to specific impacts.
(2) If it is the case that at desirable levels of affluence *(A)* and realistic increases in resource efficiency (*T*) the present population is not sustainable, it is unwise to complacently ignore population size and/or rely on its natural peaking in several decades. Limits to food production, the precautionary principle and declining death rates all argue against complacency.
(3) Whatever the net effect on impact of lower or stable population, it substantially eases the task of alleviating poverty.
(4) There is a method with which individual countries can approach decisions on optimal population size ('cultural carrying capacity'): After determining sustainable and desirable levels of impact and the desirable level of affluence – including the welfare of future humans and other species – a realistic level of technological efficiency increase in the use of resources can be estimated.

[49] Farley and Leavitt (1971, p 31).
[50] *Also* Daly and Cobb (1989, p 242); UNPF (2011, pp 34–35); PACCAF (2010), a joint statement of NGOs from nine countries in the Horn of Africa, where at the time of writing a new famine is reported. (http://www.independent.co.uk/news/world/africa/starvation-returns-to-the-horn-of-africa-2306001.html).
[51] One document (BBC, 2009) illustrating the need to shift away from Western perspectives asks African focus groups where they place blame for environmental degradation and climate change. The interviewees emphasised deforestation, localised pollution, and overpopulation, generally regarding themselves as responsible and not supporting the researchers' hypothesis that developed-country consumers are to blame. Yet the document's 'Conclusions' avoid population policy, calling principally for teaching the Africans about the guilt of the rich.
[52] *Guardian*, 5 January 2011, p 20; Engelman (2010, p 22).
[53] In the experience of this writer, it is moreover depressing to research the facts of human hunger and crowdedness in the context of dwindling natural resources, disappearing non-human creatures, deaths during childbirth, overfishing, and topsoil degradation — alongside obesity and SUVs.

Using $P = I/AT$ the number of people compatible with these assumptions can then be derived.

(5) When population stabilisation or reduction policies are debated, it should be remembered that they pertain to rich as well as poor societies, and that all policies 'coerce' us, even 'soft' financial (dis-)incentives.

(6) Societies should confront the debate between procreative rights and procreative responsibilities to decide whether reproductive behaviour falls within the realm of activities legitimately controlled by democratic majority.

Ecological economics is well-equipped for many specific tasks:

1. measuring the relative contributions to *I* of *P*, *A* and *T* analytically, using biophysical units;
2. comparing the *cost*-effectiveness of the marginal impact-reduction investment, again in terms of *P*, *A* and *T*;
3. rejecting high estimates of maximum human population, often based on 'huge feedlot' standards, whether on grounds of ecology or present utility;
4. defining sustainable agriculture and measuring its yields per hectare, as well as sustainable fuel use;
5. computing realistic estimates of national cultural carrying capacity so that society can formulate population-size goals;
6. identifying and re-evaluating pro-natalist subsidies;
7. recognising that humans compete with other species for space and resources;
8. answering ethical questions surrounding policies for population constraint within the frameworks of *inter*-generational justice and the dangers of open-access commons; and
9. applying the principle of multi-disciplinarity by explicitly discussing legal and rights issues.

Whilst any given policy to reduce population, affluence, toxicity, or inefficiency can unfortunately be compensated by expansion in other human-ecological realms, negotiating political paths to sustainability requires clear decisions on desirable population goals.

To close with a concrete issue, consider some questions raised by EU efforts for a biological corridor from Orkney to the Black Sea, or American efforts for one from Guatemala through the Darien Gap. Do the EU and the Americas have a moral obligation to use these entire areas agriculturally in order to feed undernourished humans? Are these corridors harder, or easier, to establish if human population grows?

Finite resources imply that population *must* eventually stabilise. Our only choice is to control it consciously, humanely and democratically or to wait for real limits to do it for us. The intent of this paper has been to make room within ecological economics for fresh discussion of our sheer numbers.

Acknowledgments

The paper was presented at the 9th International Conference of the European Society for Ecological Economics, Boğaziçi University, Istanbul, June 2011. Thanks to Özlem Yazlık, Roger Martin, Begüm Özkaynak, and the anonymous reviewers.

References

Abernethy, Virginia, 1993. The demographic transition revisited: lessons for foreign aid and U.S. immigration policy. Ecological Economics 8 (3), 235–252.
Abrams, Paula, 2000. Population politics: reproductive rights and U.S. asylum policy. Georgetown Immigration Law Journal 14, 881–905.
Agarwal, Anil, Narain, Sunita, 1991. Global warming in an unequal world: a case of environmental colonialism. Centre for Science and Environment, New Delhi.
Alcott, Blake, 2005. Jevons' paradox. Ecological Economics 54 (1), 9–21.
Alcott, Blake, 2008. The sufficiency strategy: would rich-world frugality lower environmental impact? Ecological Economics 64 (4), 770–786.
Alcott, Blake, 2010. Impact caps: why population, affluence and technology strategies should be abandoned. Journal of Cleaner Production 18 (6), 552–560.
Ashley, K., Cordell, D., Mavinic, D., 2011. A brief history of phosphorus: from the philosopher's stone to nutrient recovery and reuse. Chemosphere 84, 737–746.
Atkinson, Giles, Gundimeda, Haripriya, 2006. Accounting for India's forest wealth. Ecological Economics 59 (4), 462–476.
Bazhanov, Andrei V., 2007. The transition to an oil contraction economy. Ecological Economics 64 (1), 186–193.
BBC (BBC World Service Trust), 2009. Least responsible, most affected, least informed: public understanding of climate change in Africa. Policy Briefing #3, www.bbcworldservicetrust.org.
Binswanger, Hans-Christof, 1998. Making sustainability work. Ecological Economics 27, 3–11.
Blake, Judith, 1994. Fertility control and the problem of voluntarism (1972) Population and Development Review 20 (1), 167–177.
Blaustein, Albert, 1971. Legal analysis and population control: the problem of coercion. Harvard Law Review 84, 1856–1911.
Bongaarts, John, 1992. Population growth and global warming. Population and Development Review 18 (2), 299–319.
Bookchin, Murray, 1994. Which Way for the Ecology Movement? AK, Edinburgh and San Francisco.
Bookchin, Murray, Foreman, Dave, 1991. Defending the Earth. South End, Boston.
Boserup, Ester, 1981. Population and Technology. Blackwell, Oxford.
Boulding, Kenneth, 1964. The Meaning of the Twentieth Century. Harper & Row, New York.
Brown, Lester, 2011. World on the Edge: How to Prevent Environmental and Economic Collapse. Earthscan, London.
Brown, Lester, Eckholm, Erik, 1975. By Bread Alone. Pergamon, Oxford.
Brown, Lester, Kane, Hal, 1994. Full House: Reassessing the Earth's Population Carrying Capacity. Norton, New York.
Brown, Lester, Gardner, Gary, Halweil, Brian, 2000. Beyond Malthus: Nineteen Dimensions of the Population Challenge. Earthscan, London.
Cheviakov, Alexei F., Hartwick, John, 2009. Constant *per capita* consumption paths with exhaustible resources and decaying produced capital. Ecological Economics 68 (12), 2969–2973.
Cohen, Joel Ephraim, 1995. How Many People Can the Earth Support? Norton, New York.
Common, Michael, Stagl, Sigrid, 2005. Ecological Economics: an Introduction. Cambridge U. Press, Cambridge UK.
Commoner, Barry, 1971. Closing the Circle. Jonathan Cape, London.
Cordell, Dana, Drangert, Jan-Olaf, White, Stuart, 2009. The story of phosphorus: global food security and food for thought. Global Environmental Change 19, 292–305.
Costanza, Robert (Ed.), 1991. Ecological Economics: the Science and Management of Sustainability. Columbia U. Press, New York.
Daily, Gretchen C., Ehrlich, Anne H., Ehrlich, Paul R., 1994. Optimum human population size. Population and Environment 15 (6), 469–475.
Daly, Herman E., 1974. The economics of the steady state. American Economic Review 64 (2), 15–21.
Daly, Herman E., Cobb, John W., 1989. For the Common Good. Beacon, Boston.
Daly, Herman E., Farley, Joshua, 2004. Ecological Economics: Principles and Applications. Island, Washington, D.C.
De Souza, R.-M., 2008. Scaling up Integrated Population, Health and Environment Approaches in the Philippines: a Review of Early Experiences. World Wildlife Fund and the Population Reference Bureau, Washington, DC, http://www.worldwildlife.org/what/communityaction/people/WWFBinaryitem8788.pdf.
DeHart, Jennifer, Soulé, Peter T., 2000. Does I = PAT work in local places? The Professional Geographer 52 (1), 1–10.
Dietz, Thomas, Rosa, Eugene A., 1994. Rethinking the environmental impacts of population, affluence and technology. Human Ecology Review 1 (2), 277–300.
Dietz, Thomas, Rosa, Eugene A., 1997. Effects of population and affluence on CO_2 emissions. Proceedings of the National Academy of Sciences of the United States of America 94 (1), 175–179.
Dillard, Carter, 2007. Rethinking the procreative right. Yale Human Rights and Development Law Journal 10, 1–63.
Durham, D.F., 1992. Cultural carrying capacity: I = PACT. Focus 2 (3), 5–8.
Durning, Alan Thein, 1992. How Much Is Enough? Earthscan/Worldwatch, London.
Ehrlich, Paul, 1971. The Population Bomb (Revised). Sierra Club/Ballantine, N.Y.
Ehrlich, Anne, 1991. People and food. Population and Environment 12 (3), 221–229.
Ehrlich, Paul, Ehrlich, Anne, 1990. The Population Explosion. Hutchinson, London.
Ehrlich, Paul R., Ehrlich, Anne H., Holdren, John P., 1973. Human Ecology: Problems and Solutions. W.H. Freeman, San Francisco.
Eisenberg, Howard, 1994. A 'modest' proposal: state licensing of parents. Connecticut Law Review 26, 1415–1452.
Ekins, Paul, 1991. The sustainable consumer society: a contradiction in terms? International Environmental Affairs 3, 243–257.
Encyclopedia of Ecological Economics, 2012. Neo-Malthusianism in the early twentieth century, http://www.ecoeco.org/pdf/Neo-malthusianism.pdf 2012.
Engelhardt, H. Tristram, 1976. Individuals and communities, present and future. In: Lucas, George, Ogletree, Thomas (Eds.), Lifeboat Ethics: the Moral Dilemmas of World Hunger. Harper & Row, N.Y.
Engelman, Robert, 1995. Imagining a stabilised atmosphere: population and consumption interactions in greenhouse gas emissions. Journal of Environment and Development 4, 111–140.
Engelman, Robert, 2010. Population, climate change and women's lives. Worldwatch Report 183, www.worldwatch.org.
Farley, John U., Leavitt, Harold J., 1971. Marketing and population problems. Journal of Marketing 35 (3), 28–33.

Feng, Kuishuang, Hubacek, Klaus, Guan, Dabo, 2009. Lifestyles, technology and CO_2 emissions in China: a regional comparative analysis. Ecological Economics 69 (1), 145–154.

Fletcher, Joseph, 1976. Feeding the hungry: an ethical appraisal. In: Lucas, George, Ogletree, Thomas (Eds.), Lifeboat Ethics: the Moral Dilemmas of World Hunger. Harper & Row, N.Y.

Fox, Tim, 2011. Population: One Planet, Too Many People? Institution of Mechanical Engineers, www.imeche.org.

Giampietro, Mario, 1994. Sustainability and technological development in agriculture. BioScience 44 (10), 677–689.

Gonzalez-Martinez, Ana Citlalic, Schandl, Heinz, 2008. The biophysical perspective of a middle income economy: material flows in Mexico. Ecological Economics 68 (1–2), 317–327.

Gowdy, John, McDaniel, Carl, 1995. One world, one experiment: addressing the biodiversity–economics conflict. Ecological Economics 15 (3), 181–192.

Hall, Charles A.S., Gil Pontius Jr., R., Coleman, Lisa, Ko, Jae-Young, 1994. The environmental consequences of having a baby in the United States. Population and Environment 15 (6), 505–524.

Hardaway, Robert, 2008. Carbon markets in context: into which component of Holdren's equation do they fit? Denver University Law Review 85 (4), 983–994.

Hardee, Karen, Matunga, Clive, 2010. Strengthening the link between climate change adaptation and national development plans: lessons from the case of population in National Adaptation Programmes of Action (NAPAs). Mitigation and Adaptation Strategies for Global Change 15 (2), 113–126.

Hardin, Garrett, 1976. Carrying capacity as an ethical concept. In: Lucas, George, Ogletree, Thomas (Eds.), Lifeboat Ethics: the Moral Dilemmas of World Hunger. Harper & Row, New York.

Hardin, Garrett, 1993. Living within Limits. Oxford U. Press, Oxford.

Harris, Jonathan M., Kennedy, Scott, 1999. Carrying capacity in agriculture: global and regional issues. Ecological Economics 29 (3), 443–461.

Harris, Marvin, Ross, E.B., 1987. Death, Sex, and Fertility: Population Regulation in Preindustrial and Developing Societies. Columbia U. Press, New York.

Hartmann, Betsy, 1998. Population, environment, and security: a new trinity. Environment and Urbanization 10 (2), 113–127.

Hartwick, John M., 1977. Intergenerational equity and the investment of rents from exhaustible resources. American Economic Review 67, 972–974 (December).

Haub, Carl, 2011. What if experts are wrong on world population growth? http://e360.yale.edu/feature/what_if_experts_are_wrong_on_world_population_growth/2444/2011.

Heinberg, Richard, 2007. Peak Everything: Waking Up to the Century of Decline in Earth's Resources. Clairview, Forest Row, UK.

Hill, Kim, Hurtado, Magdalena, 1996. Ache Life History: the Ecology and Demography of a Foraging People. Aldine de Gruyter, Hawthorne, N.Y.

Holdren, John, 1991. Population and the energy problem. Population and Environment 12 (3), 231–255.

Hotelling, Harold, 1931. The economics of exhaustible resources. Journal of Political Economy 39 (2), 137–175.

Hrdy, Sarah, 1999. Mother Nature. Pantheon, New York.

Voluntary Human Extinction Movement, http://www.vhemt.org/2010.

IHT (International Herald Tribune), 2011. Russia enacts law opposing abortion, http://www.nytimes.com/2011/07/15/world/europe/15iht-russia15.html?_r=1&scp=2&sq=abortion%20in%20russia&st=cse2011.

IUCN (International Union for the Conservation of Nature), 2012. www.iucn.org2012.

Jayaraman, K.S., 1993. Science academies call for global goal of zero population growth. Nature 366, 3.

Jørgensen, Sven Erik, 1994. The application of global models for comparison of different strategies on sustainable living. Ecological Economics 11 (1), 1–8.

Kates, Carol A., 2004. Reproductive liberty and overpopulation. Environmental Values 13, 51–79.

Krausmann, Fridolin, Gingrich, Simone, Eisenmenger, Nina, Erb, Karl-Heinz, Haberl, Helmut, Fischer-Kowalski, Marina, 2009. Growth in global materials use, GDP and population during the 20th century. Ecological Economics 68 (10), 2696–2705.

Krutilla, Kerry, Reuveny, Rafael, 2006. The systems dynamics of endogenous population growth in a renewable resource-based growth model. Ecological Economics 56 (2), 256–267.

Kysar, Douglas, 2003. Law, environment, and vision. Northwestern University Law Review 97 (2), 675–729.

Lee, Ronald, 1986. Malthus and Boserup: a dynamic synthesis. In: Coleman, David, Schofield, Roger (Eds.), The State of Population Theory: Forward from Malthus. Blackwell, Oxford.

Lee, Luke T., 1995. Population: the human rights approach. Colorado Journal of International Environmental Law and Policy 6, 327–344.

Lin, C.-Y. Cynthia, 2010. Instability, investment, disasters and demography: natural disasters and fertility in Italy (1820–1962) and Japan (1671–1965). Population and Environment 31, 255–281.

Löpfe, Philipp, Vontobel, Werner, 2011. Aufruhr im Paradies. Orell Füssli, Zürich.

Lucas, George R., 1976. Political and economic dimensions of hunger. In: Lucas, George, Ogletree, Thomas (Eds.), Lifeboat Ethics: the Moral Dilemmas of World Hunger. Harper & Row, New York.

MacKay, David, 2009. Without the hot air, www.withouthotair.com2009.

MacKellar, F. Landis, Lutz, Wolfgang, Prinz, Christopher, Goujon, Anne, 1995. Population, households, and CO_2 emissions. Population and Development Review 21 (4), 849–865.

Mainwaring, Lynn, 2004. Comparing futures: a positional approach to population ethics. Ecological Economics 48, 345–357.

Martinez-Alier, Joan, 1987. Ecological Economics: Energy, Environment and Society. Blackwell, Cambridge, UK.

Population Matters, 2012, http://populationmatters.org/2012.

McNeill, J.R., 2011. Population and the natural environment: trends and issues. Population and Development Review 37 (1), 183–201.

Mill, John Stuart, 1848. Principles of Political Economy. In: Robson, J.M. (Ed.), U. of Toronto Press, Toronto. 1965.

Monbiot, George, 2009. Stop blaming the poor: it's the wally-yachters who are burning the planet. *Guardian*. 29 September.

Murtaugh, Paul A., Schlax, Michael D., 2009. Reproduction and the carbon legacies of individuals. Global Environmental Change 19 (1), 14–20.

nef (New Economics Foundation), 2009. The consumption explosion 25 September, http://www.neweconomics.org/publications/consumption-explosion.

New Delhi Science Summit, 1994. Population summit of the world's scientific academies. Population and Development Review 20 (1), 233–238.

O'Neill, Brian, et al., 2010. Impact of demographic change on future carbon emissions: a global assessment. Proceedings of the National Academy of Sciences 17521–17526 12 October.

PACCAF (Population, Climate Change African Forum), 2010, http://populationmatters.org/documents/paccaf_statement.pdf.

Pan, William, Carr, David, Barbieri, Alisson, Bilsborrow, Richard, Suchindran, Chirayath, 2007. Forest clearing in the Ecuadorian Amazon: a study of patterns over space and time. Population Research and Policy Review 26, 635–659.

Pearce, Fred, 2008. *New Scientist* blog 22 April 2008, http://www.newscientist.com/blog/environment/2008/04/green-fascism.html.

Pearce, Fred, 2010a. *Prospect Magazine* blog 15 March 2010, www.prospectmagazine.co.uk.

Pearce, Fred, 2010b. Peoplequake: Mass Migration, Ageing Nations and the Coming Population Crash. Eden Project, London.

Penck, Albrecht, 1925. Das Hauptproblem der physischen Anthropogeographie. Zeitschrift der Geopolitik 2 (5), 330–348.

Petrucci, John, 2000. Population: time-bomb or smoke-screen? Environmental Values 9, 325–352.

Pimentel, David, Pimentel, Marcia, 2006. Global environmental resources *versus* world population growth. Ecological Economics 59 (2), 195–198.

Population Council, 2002. Supplement/special issue: population and environment: methods of analysis. Population and Development Review 28.

Population Council, 2012, www.popcouncil.org.

PRB (Population Reference Bureau), 2012. Unmet need for family planning http://www.prb.org/DataFinder/Topic/Rankings.aspx?ind=54.

Princen, Thomas, Maniates, Michael, Conca, Ken, 2002. Confronting Consumption. MIT Press, Cambridge, USA.

Raina, B.L., 1988. Population Policy. B.R. Publishing/D.K. Publishers, Delhi.

Raskin, Paul, 1995. Methods for estimating the population contribution to environmental change. Ecological Economics 15, 225–233.

Royal Society, 2012. People and the planet, http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/people-planet/2012-04-25-PeoplePlanet.pdf.

Sardon, Jean-Paul, 2006. Recent demographic trends in Europe and the other developed countries. Population 61 (3), 197–266.

Satterthwaite, David, 2009. The implications of population growth and urbanization for climate change. Environment and Urbanization 21, 545–567.

Sayre, Nathan, 2008. The genesis, history and limits of carrying capacity. Annals of the American Association of Geographers 98 (1), 120–134.

Schneider, François, Kallis, Giorgos, Martinez-Alier, Joan, 2010. Crisis or opportunity? Economic degrowth for social equity and ecological sustainability. Journal of Cleaner Production 18 (6), 511–518.

Seidl, Irmi, Tisdell, Clem, 1999. Carrying capacity reconsidered: from Malthus' population theory to cultural carrying capacity. Ecological Economics 31, 395–408.

Sen, Amartya, 1996. Fertility and coercion. University of Chicago Law Review 63 (3), 1035–1061.

Shi, Anqing, 2003. The impact of population pressure on global carbon dioxide emissions, 1975–1996: evidence from pooled cross-country data. Ecological Economics 44 (1), 29–42.

Simon, Julian, 1996/1981. *The Ultimate Resource*. Princeton U. Press, Princeton.

Smil, Vaclav, 1990. Planetary warming: realities and responses. Population and Development Review 16 (1), 1–29.

Smil, Vaclav, 1994. How many people can the earth feed? Population and Development Review 20 (2), 255–292.

Smil, Vaclav, 2000. Phosphorus in the environment: natural flows and human interferences. Annual Review of Energy and Environment 25, 53–88.

Smil, Vaclav, 2008. Energy in Nature and Society. MIT Press, Cambridge, USA.

Song, Jian, 1981. Population development: goals and plans. In: Liu, Zeng, Song, Jian, et al. (Eds.), *China's Population: Problems & Prospects*. New World Press, Beijing.

Swaney, James A., 1991. Julian Simon *vs.* the Ehrlichs. Journal of Economic Issues 25, 499–509.

Thévenon, Olivier, 2011. Family policies in OECD countries: a comparative analysis. Population and Development Review 37 (1), 57–87.

Timah, Emmanuel Ambe, Ajaga, Nji, Tita, Divine F., Ntonga, Leonard M., Bongsiysi, Irene B., 2008. Demographic pressure and natural resources conservation. Ecological Economics 64 (3), 475–483.

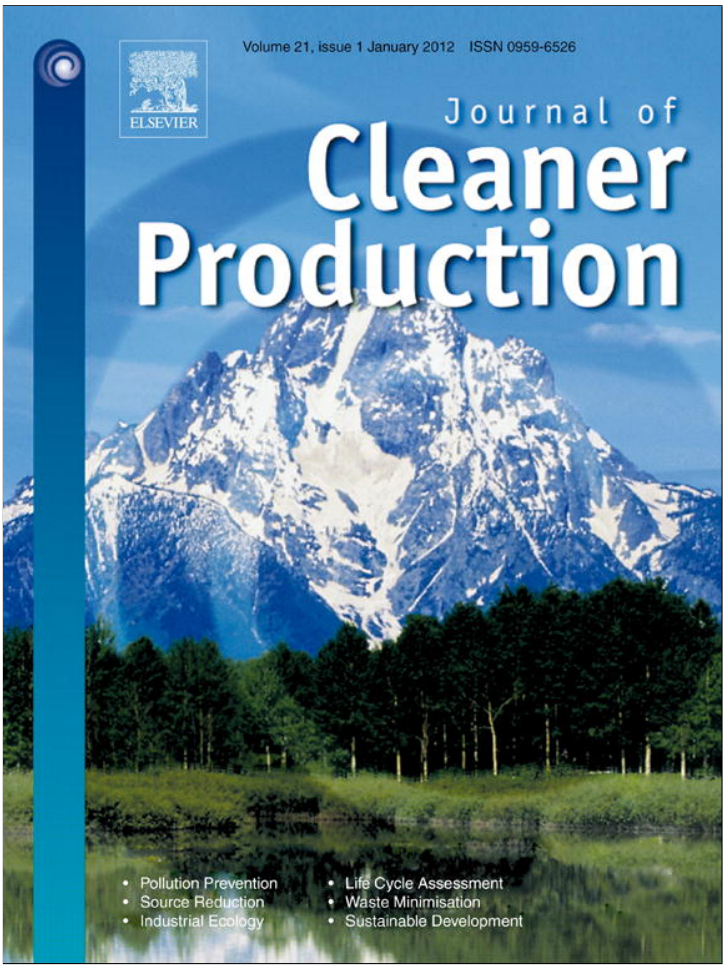
Tinbergen, Jan, 1956. Economic Policy: Principles and Design. North Holland, Amsterdam.

Turner, Paul, Tschirhart, John, 1999. Green accounting and the welfare gap. Ecological Economics 30 (1), 161–175.

UNCTAD (United Nations Conference on Trade and Development), 2008. Despite rapid economic growth, number of poor still rising in Least Developed Countries, www.unctad.org/Templates/webflyer.asp?docid=10126&intItemID=1528&lang=12008.

UNDESA, 2012. http://esa.un.org/unpd/wpp/unpp/panel_population.htm2012.

UNDESA (UN Department of Economic and Social Affairs, Population Division), 2009, http://www.un.org/esa/population/publications/wpp2009/Publication_index.htm2009.
UNPF (United Nations Population Fund or UNFPA), 2011. The State of World Population 2011, http://www.unfpa.org/swp/2011.
van den Bergh, Jeroen, Rietveld, Piet, 2004. Reconsidering the limits to world population: meta-analysis and meta-prediction. BioScience 54 (3), 195–204.
van Vuuren, Detlef P., Bouwman, Lex F., 2005. Exploring past and future changes in the ecological footprint for world regions. Ecological Economics 52 (1), 43–62.
Whittaker, Robert, Likens, Gene, 1975. The biosphere and man. In: Leith, Helmut, Whittaker, Robert (Eds.), Primary Productivity of the Biosphere. Springer, N.Y.
Worldwatch, 2012, www.worldwatch.org2012.



Journal of Cleaner Production 21 (2012) 83–92

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Mill's scissors: structural change and the natural-resource inputs to labour

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ARTICLE INFO

Article history:
Received 13 July 2010
Received in revised form
20 June 2011
Accepted 10 August 2011
Available online 22 August 2011

Keywords:
Environmental intensity
Structural change
Energy costs of labour
EIO-LCA
Services
Petty's Problem
Mill's scissors

ABSTRACT

The environmental structural change strategy claims that by shifting our expenditures to economic sectors with lower environmental intensity, absolute resource consumption and environmental impact can be lowered. Environmental Input–Output methodologies for computing these intensities attribute no resource consumption to labour or households because these are not classified as sectors. The suggestion that service sectors entail less environmental impact, however, loses force if a unit of labour contains embodied energy, and attributing these inputs to labour drastically reduces intensity variation between sectors. Relative growth of service sectors has furthermore not been accompanied by decreased resource consumption; thus models whose intensity computations cover not only inter-firm payments but also labour earnings and household expenditures may have superior predictive power. If moreover natural-resource and labour inputs to product are incommensurable, intensity ratios themselves have perhaps only monetary, rather than real, significance.

Epigraph

> Some writers have raised the question, whether nature gives more assistance to labour in one kind of industry or in another; and have said that in some occupations labour does most, in others nature most. In this, however, there seems much confusion of ideas. The part which nature has in any work of man, is *indefinite* and *incommensurable*. It is impossible to decide that in any one thing nature does more than in any other. When two conditions are equally necessary for producing the effect at all, it is unmeaning to say that so much of it is produced by one and so much by the other; it is like attempting to decide which half of a pair of scissors has most to do in the act of cutting; or which of the factors, five and six, contributes most to the production of thirty. (John Stuart Mill, 1848, 28–29)

1. Introduction

The *environmental structural change strategy* holds that when keeping expenditures at a constant level but shifting them to economic sectors deemed to have relatively low environmental intensity, depletion and pollution can fall (Costanza, 1980, 1222). There is however no empirical evidence that structural change towards services or tertiary sectors has been accompanied by lower environmental impact if imports, air travel and shipping are rigorously measured (Brookes, 1972; Rothman, 1998; Jackson and Marks, 1999; Vringer and Blok, 2000; Torras, 2003; Helm et al., 2007; Peters, 2008; Ausubel and Waggoner, 2008; Miller and Blair, 2009, 421–423; Holm and Englund, 2009). The strategy thus relies on theory, in particular on methodologies for attributing resource consumption to certain sectors of the economy that omit labour from the analysis. Yet since shifting from resource-intensive sectors means shifting *to* labour-intensive 'service' ones, depletion and pollution can fall only if labour-hours themselves require low or no environmental inputs. This paper re-opens a debate that was truncated around 25 years ago over the environmental consequences of buying a unit of labour.

The search for explanations of levels of pollution and natural-resource consumption has yielded mature methods for counting the material and energy embodied in physical products such as cars, plastics or bottles, but no clarity on the same things embodied in the labour that is bought with every expenditure: Does an hour's work have zero environmental impact, or must we count the worker's metabolic and muscular needs, plus perhaps the energy costs of his or her physical workplace, clothes and commuting, or even all of the energy, either directly utilised or embodied in goods and services, that the worker's hourly wage purchases?

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0959-6526/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jclepro.2011.08.012

The paper combines literature review and conceptual analysis to argue for attributing natural-resouce consumption not only to goods, processes and firms, but to individuals as labourers and final consumers. In light of strong evidence that *if* this is done the environmental intensity of expenditures is virtually constant among sectors (Costanza, 1980), the methodological decision of where to draw system boundaries is of central importance for structural-change hopes within sustainable consumption.

Concerning terminology, please accept four simplifications:

1. When characterising inputs and intensities 'environmental', 'natural-resource' and 'energy' are used synonymously; the more specific 'energy' is often used, but the analysis pertains to any natural-resource input into production.
2. For brevity, and since many co-efficients exist for converting amounts of resource consumption into emissions, the paper speaks of natural-resource depletion rather than pollution, species loss, climate change, etc.
3. The term 'labour' as both a physical and an income category subsumes not only wages but categories such as capital and entrepreneurial services, profits, and rent. For any given expenditure it is contrasted with payments for goods and services or raw materials delivered by firms as taxonomised in National Accounts.
4. The paper uses 'EIO' or 'EIO(-LCA)' (Environmental Input-Output(-Life-Cycle Assessment)) for any environmental accounting using National Accounts sectors, input–output co-efficients and cradle-to-grave summation.

Section 2 describes the environmental structural change strategy. Section 3 describes the *direct* and *indirect* natural resource inputs or 'costs' entailed by any expenditure, loosely within the framework of Life Cycle Assessment. Section 4 presents arguments for including the natural-resource costs of labour in environmental accounting. Section 5 presents two objections to including these costs. Section 6 points to several open questions and lists the far-reaching repercussions of drawing wider boundaries.

2. The environmental structural change strategy

Holding expenditure level constant, a given consumer or an entire economy can alter its "spending patterns" so that a greater percentage of expenditures goes to sectors or economic activities deemed to be less environmentally harmful (Vringer and Blok, 1995, 901). The analysis upon which the strategy rests "only explores the effects of changes in *patterns* of consumption without any change in the *level* of consumption" (Alfredsson, 2004, 517). This 'dematerialisation' is by the same token however a 'labourisation': holding total outlays constant, the less spent on physical goods, materials and energy the more spent on labour. The strategy is one of several indirect environmental strategies including population reduction, lower affluence, and greater technological and consumer efficiency.

The call is for shifting expenditures

> Obviously, different consumption activities differ very much with regard to their environmental impact, and in principle it is easy to imagine a continuous growth in economically defined consumption without a corresponding growth in the consumption of resources… if the population used income increases to buy labour-intensive goods and services: theatre and music performances, courses in new skills, lectures on interesting topics, art objects, high quality clothes and houses made as handicrafts, child care, and massage treatments. (Røpke, 1999, 401).

This paper analyses such an "art object", a new *painting*, to show that buying such a "labour-intensive" product causes significantly lower environmental impact only if the resource consumption of the painter is ignored.

In terms of Material Input Per unit of Service (MIPS), if we buy from sectors with smaller "ecological rucksacks", input could fall while units of service rise; the two ratios MIPS + LIPS (labour input per unit of service) add up to unity; since we spend the same amount we must not "do without" (Schmidt-Bleek, 1994, 21–24, 115–119, 184–185).[1] In EIO terms the "value-added" portion of an expenditure can rise, "diluting" its greenhouse-gas intensity and recommending itself to environmentally responsible consumers (Suh, 2006, 6559).

"Structural economics" describes the strategy in terms of "change in the lifestyles of households" (Duchin, 1998, 2, 20, 51). Using the methodology of counting energy inputs from all sectors into any sector we can thus identify "more sustainable consumption patterns" by households (Kerkhof et al., 2009, 1160–1161) and reduce expenditures in those "consumption clusters activating the most resource flows throughout the product life-cycle" (Spangenberg and Lorek, 2002, 134). We can compute emissions intensities for say 27 consumption sectors, yielding a sector ranking (Common and Stagl, 2005, 132–133). In Brazil for example the "food" sector is computed to use 10.1 MJ per $, "recreation" 8.7, "clothing" 6.4, and "communications" 3.6 (Cohen et al., 2005, 557). "Ecological structural change" is when "material-intensive sectors shrink, others grow" (Hinterberger et al., 1996, 101). LCA's role is in society's "dematerialisation and substitution" (Robèrt et al., 2002).

Let us define the strategy as follows:

1. The economy's structure is the portions of monetary exchanges (GDP) spent in economic sectors numbering from three highly-aggregated ones (agriculture, manufacturing and services) to around 1000.
2. The environmental inputs into each expenditure, sector, or GDP are the natural resources (N) in input–output processes measured in either monetary or physical units; as in all economy-wide EIO monetary units are unavoidable, and using natural-resource prices one can derive physical quantities.
3. The environmental intensity ratio is the amount of input in physical or monetary units per unit of output (Q) in monetary units.
4. All other inputs into Q purchased by the expenditure are subsumed under the generic term 'labour' (L) – paid work time; for a $1000 expenditure, $-value of N/$1000 plus $-value of L/$1000 = unity.
5. If sectors have different intensities, shifting a given level of expenditures to less N-intensive ones would reduce N-consumption.
6. To enable commensurability between expenditures the strategy makes no assumptions about the relationship between expenditures and psychological satisfaction or utility (Ròbert et al., 2002, 200–206).

4) and 5) together mean that after shifting, the consumer is purchasing *more* units of labour than before. The strategy is distinct from that recommending purchases within a sector of goods with less natural-resource input but the same utility – e.g. a wooden

[1] *Also* Kaufmann, 1992, 38–39; Hinterberger et al., 1996, 84–97; Ritthoff et al., 2002, 9.

instead of a metal table (Hannon, 1982, 271). Not only would the wooden table be cheaper, but product comparisons do not yield intensities since the denominator is simply 'a product'. Like the strategy, and unlike process analysis, this paper compares expenditures, not products.

3. Indirect energy inputs into an artist's work

The inconclusiveness of empirical work and the fact that many variables determine resource-consumption levels renders it necessary to turn to theory. As a start suppose that we abide by the structural-change strategy and use our earnings for a new $1000 painting instead of a $1000 plane trip. The artist we buy the painting from, however, could use the proceeds for a plane journey, and oil is consumed merely by a different person (Lloyd, 2007, 5815–5816).[2] While we don't know that the artist would board the plane in our stead, the assumption is legitimate that the environmental intensity of his or her expenditure is society's average.

Again, if a given expenditure is responsible for less natural-resource consumption than another of the same size, it is responsible for *more* labour consumption, and the amount of the theoretical decrease in *N*-inputs due to the shift thus depends on whether the purchase of these additional labour units entails zero, or some, embodied natural resources – and if not zero, how much. Conventional EIO ignores labour, entering the environmental intensity of a pure service, e.g. Herendeen's sectors "domestic service" and "auto registration and fees", as zero (1998, 173; *also* Wright, 1974, 309; Spreng, 1988, 138–140; Graedel, 1997). This holds equally for physical input–output analysis (PIOT) if it traces only inter-industry transactions, without final demand (Miller and Blair, 2009, 399). An early diagram showed the inputs and outputs of an oil refinery: extraction energy, energy costs of tankers, materials, plant, and fuels used for organic chemicals, but nowhere a human being able and willing to work (Chapman, 1974, 100). Even if the output-denominator metric is physical, the issues are whether labour is a sector at all and whether inputs to labour include household consumption (Spreng, 1988, 7, 136).

This section describes the contrasting method of accounting total household consumption, leaving for Section 4 some arguments for it. Middle positions are also tenable whereby the energy cost of labour-hours "offsets some fraction of the direct energy savings" – reducing, but not eliminating, variation in sector intensity (Kaufmann, 1992, 49–54). One could count only energy use over and above what an unemployed person would consume (Hall et al., 1986, 106–108). Appendix I shows a spectrum of consumption enabling the production of labour, some or all of which could be counted.

It is universally accepted that in energy accounting energy inputs for metabolism and muscular movement differ in no way from the energy needed to run a car factory. Since EIO counts the energy embodied in steel reaching the factory, consistency would mean counting the parallel category of that embodied in workers – yet even basic metabolism cannot be counted if labour is not a category in input–output tables. From the beginnings of energy accounting it was seen that there is "some arbitrariness" in what to count:

> [I]s it the physical energy contributed by the labourer to the production process, or the energy content of the food he eats, or the primary energy needed to produce all the goods and services he enjoys?… Excluding [labour] is appropriate to [regarding] people enjoying consumption for its own sake rather than to facilitate their contribution to the production process. (Wright, 1974, 309–310; *also* Chapman, 1974, 93; Gilliland, 1975, 1052)

The course was set for recognising that labour is produced, yet ignoring it.

Supporting the arbitrariness of choosing system boundaries, Smil asks:

> Once the decision is made to account for the energy cost of labor, which approach is more rational: the minimalist choice of counting just the thermodynamic equivalent of the invested muscular exertion or the maximalist option of finding the total existential energy requirements?… These challenges have no satisfactory solutions. (2008, 273–274)

This paper nevertheless argues that the 'maximalist' solution is, for the purposes of environmental policy, satisfactory. If our research question covers the entire energy system, why draw boundaries at all?

To be clear what is meant by the *indirect* natural-resource costs of or inputs into labour, Table 1 analyses a hypothetical purchase of a $1000 painting requiring 30 h of labour.

Following conventional EIO, this product from a purportedly low-impact sector entails environmental inputs beyond the paint, frame, canvas and gallery wall (Cell 1); the expenditure entails further the 'ecological rucksack' or natural resources embodied in or required for the production and delivery of the paint, frame, canvas, etc., plus the atelier's amortisation (Cell 2).[3] The painter's *time* requirements are similarly divided into the hours we are billed for (Cell 3) and those previous to these without which the artist would be *incapable* of painting (Cell 4). Returning to the environmentally relevant natural-resource inputs, there is the metabolism of the painter while actually painting plus less obvious inputs like protective clothing and coffee breaks (Cell 5). Finally we have our bone of contention, the inputs into the daily life of the artist that are necessary because, were the wages part of our expenditure not large enough to buy them, the artist would not work (Cell 6). Cells 4 and 5 thus supply the time and energy for the capacity (ability) to work while Cell 6 constitutes the consumption necessary for the *willingness* to work.[4] Cells 2, 4 and 6 might also include the physical and institutional support labour receives from the community, similar perhaps to a study suggesting the inclusion of government because its resource use is "an upstream part of household consumption" (Spangenberg and Lorek, 2002, 135).

A rough quantification of the amounts of energy included in Cells 5 and 6 shows that choosing system boundaries makes a large difference. Basic metabolic consumption is about 0.5 MJ h^{-1} (Fluck and Baird, 1980, 101–105; Odum, 1995, 265; Smil, 2008, 124–131) and approximately ten times this amount is embodied in the food enabling this metabolism (Hall et al., 1986, 107). Taking total primary energy consumption of 160GJ/European/year (Smil, 2008, 258) and assuming 2000 working hours per year, roughly 80 MJ is attributable to an hour's work. Cells 5 and 6 are a percentage of lifetime energy consumption proportional to the percentage of the 30 h in this example to total labour-hours.[5]

Some research does address the hidden energy requirements of labour beyond basic metabolism (moving from Cell 5 to Cell 6) using the example of the service *"a day in a hospital"*: To computations for the hospital's buildings, machines and transport, and the

[2] The alternatives "holidays abroad" and "works of art" (Druckman and Jackson, 2009, 2067) are common in the literature.

[3] Ratios between Cells 1 and 2 could be in tonnes/tonne (Robèrt et al., 2002).

[4] Hall et al. reject maximalist accounting because they emphasise ability, rather than willingness, to work (1986, 40, 107–108).

[5] Assuming 45 working-years, or 90,000 h, also yields 80 MJ h^{-1}.

Table 1
Six categories of inputs into a painting. The direct and indirect labour-time and natural-resource *preconditions for* the production of a painting.

OUTPUT (*Q*)a painting	Natural-resource INPUT (*N*)	Labour INPUT (*L*)	*N*-INPUTS *into L*
direct inputs	Cell 1 weighable canvas, paint, frame; utilisation energy *during painting* for light & heat etc.	Cell 3 time (hours) actually painting the painting	Cell 5 (direct) artist's food, water, etc. *during painting*; required for metabolism, comfort & muscular exertion
indirect inputs	Cell 2 natural resources 'cradle-to-grave'; *N* embodied in atelier; 'ecological rucksack'; transport; waste	Cell 4 time spent for *ability* to paint: health, education, inspiration, rest; commuting	Cell 6 (indirect) *N*-inputs for Cell 4 and during commuting; lifestyle, affluence, entertainment; *willingness* to paint

utilisation matter-energy in heating, electricity, laundry, etc., the analysis breaks convention by adding "the education, further training and maintenance of the hospital employees" (Schmidt-Bleek, 1994, 185–187). Although "maintenance" could be interpreted in a minimalist or maximalist way, it is here at least 'on the map' and raises this paper's question, as did another conventional study identifying "energy used in acquiring and maintaining knowledge" and arguing that "ignoring… the energy cost of labor is a deficiency" (Stern, 1999, 388–393).

Maximalist analysis is distinct from the result, using conventional EIO-LCA, that so-called service sectors, "whose own product is actually immaterial, e.g. banking, consulting, trade and transport, [are] responsible for about one-fourth of all material movements" (Hinterberger et al., 1996, 96). The insight is rather that these service sectors are *defined by* the (large) percentage of expenditures in them going to employee compensation or entrepreneurial income and that this part, whatever its size, is left out of embodied natural-resource calculations.

One rare study of the environmental intensity of service sectors, for example, notes that although wages make up 45–80% of costs, they "were assumed not to cause any material or energy flows", leaving the entire environmental burden on office premises, business travel, office equipment, etc.; although personnel income has environmental impact through private consumption, wages are given zero intensity in spite of the fact that even "expanding the system boundary" to include commuting would result in the 'wages' sector having the second highest impacts of all measured sectors (Junnila, 2009, 424, 428, 431).

Table 2 monetarily compares a new painting with a plane trip, the metal sculpture illustrating that products in any sector lie on a spectrum of conventionally-tallied intensity. At one extreme in an 'art objects' sector would be an Andy Goldsworthy work consisting of only natural objects, labour receiving perhaps $990 with $10 going for photographs of the work. Carl Andre's *144 Magnesium Square*, consisting of metal floor plates, would be even less labour-intensive than Table 2's sculpture. Note that there are approximately 2,000,000 artists in the US (florists, news announcers, singers, dancers, writers and architects) each earning yearly on average $34,800 (Tages-Anzeiger, 2008). Is the environmental impact of these professional groups, whose livelihood is supported by purchases in these sectors, zero?

The maximalist method can be cast not only in terms of the 'downstream' expenditures of wage recipients but also the 'upstream' acquisition of a consumer's purchasing power in the first place. In terms of time the artist's flight looks forward, while the analytical boundary can be expanded backwards to the precondition of the purchases made by the addressee of the structural change strategy: productive activity entailing natural-resource consumption. Consistent with the normative tenet of consumer responsibility, the observation is that the consumer chose to work and earn, and it seems justifiable to assume that the material-energy implications of the economic activity are the average of the economy. Conventional analysis, however, considers the past history of labourers/consumers to be "outside the domain of the analyst" (Ayres, 2004, 431). EIO excludes as a matter of principle "investments made in the past", even in "capital goods" (Tillman et al., 1994, 22).

4. Including indirect resource costs of labour

Two arguments have thus emerged for including the entire natural-resource consumption of the labourer:

1. The logic is no different from that behind LCA's widest possible computation of 'ecological rucksacks': "Just as a machine tool must be manufactured and have an end of life, a worker must have a childhood and an end of life" (Zhang and Dornfeld, 2006, 190). The natural-resource costs of labour input should include non-working hours.
2. Our painter must be willing to work. The condition for non-slaves is a wage proportional to their lifetime consumption of energy, etc., for hygiene, housing, cooking, clothes, transport, entertainment, further education, hobbies and holidays – consumption induced by his or her wages.

This section also examines the arguments that labour is in reality produced, and that the incommensurability of labour and natural resources prevents the computation of real intensities in the first place.

4.1. A double standard?

Counting only metabolism is analogous to counting the utilisation but not the embodied energy of a car – a battle won long ago by conventional energy analysis. Buying a car is buying also the steel entering the car factory, the energy embodied in the steel, and so on, and just as metal, glass and rubber cross the boundary into an automobile factory, so do the workers. It must be tractable to measure the energy embodied in a hour of their work – if we cease focussing only on physical objects and materials – since well-developed analytical tools can be used for any factor of production. However, even writers who in principle accept the energy cost of labour as a category of indirect inputs often in the end ignore all but metabolism: For Spreng, for instance, "proper accounting" excludes energy input into labour unless "a special camp has to be built to house workers… or where travel to work is exceptionally long…" (1988, 138–140, 260–261).

Researchers of social metabolism, as well, have attested the soundness, in principle, of explicitly counting the the wages sector:

> Typically, only the technical infrastructure… is considered as material stocks [and thus within the accounting system] and not

Table 2
Three consumer choices. A breakdown – fictitious but consistent with real intensity estimates[a] – into the part of the $1000 going in the first analysis of natural resources and labour.

Inputs ↓ Q →	Painting	Sculpture	Flight
hours worked á $30/hour (Table 1, Cells 3 & 4)	30, = $900 artist	20, = $600 sculptor	13.3, = $400 pilot, ground crew, attendants, CEO
natural resources (Table 1, Cells 1 & 2)	$100 wood, canvas, paint, atelier, transport	$400 metal, torch, polishing, atelier	$600 kerosene, aeroplane,airport, meal
Total price	$1000	$1000	$1000

[a] Wright, 1974; Costanza, 1980; Hannon, 1982; Spreng, 1988; Druckman and Jackson, 2009.

> the… human and livestock populations. From a strict input–output perspective, this results in inconsistencies, and theoretically this shows an 'industrial' bias that is hard to justify. (Fischer-Kowalski and Hüttler, 1998, 116)

One must apparently not infer, though, that counting them renders sector intensities more or less equal (Giampietro, 2006, 179).

Only one recent study, however, makes a full attempt to attribute part of society's primary energy supply to labour, counting moreover much more than work-hour metabolism:

> We argue that the energy associated with human labor must include the energy of infrastructure in addition to that of food, where infrastructure includes housing, transportation, health care, etc. If defined in this way, the energy use of labour can be a significant contributor to manufacturing energy use. (Zhang and Dornfeld, 2006, 189–190)

Even after subtracting specifically *industrial* energy supply, the authors must adjust the energy intensities of labour-intensive processes upward: standard "process-based LCA would in fact grossly underreport the environmental costs of a service or an entirely handmade product" and exaggerate sector variance (192). Only by applying a double standard can one count the utilisation and embodied energy of the machine tool with which a machinist works but not the (larger) amount of the machinist (189–190).

Before moving to further arguments for the maximalist position please note that we must not re-invent the wheel. Classical economics was well aware of hidden material inputs into services, deconstructing the notion of 'immaterial products': doctors, teachers, musicians or prostitutes require not only tools or places of work but also material investments in themselves for upbringing, education, housing, and entertainment.[6] Furthermore, just as EIO-LCA shows how services presuppose physical inputs, Mill listed the labour inputs into a physical loaf of bread: bakers, millers, sowers, reapers, carpenters, bricklayers, hedgers, ditchers, miners, smelters, and transporters "so back to the origin of things" (1848, 31–32; *also* Chapman, 1974, 92). The inverse question arises: Were we computing the indirect *labour* inputs into goods, would we ignore the labour put into the transformation of raw materials and the fashioning of a final consmer object? Surely not, since transformation through labour is a condition of a good's or service's price. Just as goods are not purely material, neither are services pure labour.

We can also refer back to Leontief, in whose input–output matrices labour was endogenous (in monetary units as "wages and salaries"/"capital and entrepreneurial services") – an industry like any other because the economy of households is like "the production of an enterprise" (1936, 106–107; Table 5; 1951, 41–42). Only the 1970s and 1980s departed from this practice, influenced perhaps by the search for engineering responses to oil-supply shocks, and the norm today is the full exogenisation of labour and households as value added and final demand (Wright, 1974; Bullard and Herendeen, 1975; Hannon, 1982; Miller and Blair, 2009). To be sure, two workshops of the International Federation of Institutes for Advanced Study in 1974 and 1975 debated exactly which natural-resource costs of labour might be counted, but without resolution (Spreng, 1988, 126). The default position became to ignore them.

4.2. Hiring labour induces energy consumption

One early study retaining Leontief's personal-consumption column and employee-compensation row argued that individual expenditures as well as inter-business ones "induce" energy effects (Penn et al., 1976, 664–665). This is of course the most basic argument for doing any embodied energy analysis at all, as expressed clearly by Spreng who, after comparing energy accounting in the 1970s to a game without any rules, formulated an abstract rule that "all the energy requirements necessary for the operation of [an economic] activity" be counted, i.e., if the "economic activity otherwise would not be done" (1988, 125–126, 137, 155). Since labour, and the activities of households/consumers, are undeniably 'economic', and since full wages are a necessary condition for labour's being done, it should follow that we count total rather than only intermediate expenditures. We should furthermore *attribute* these energy requirements to labour. Again in terms of willingness to work, would the labour be brought to market had the labourer not commuted, had a good night's rest, pursued hobbies and looked forward to a holiday?

Another early study (Fluck and Baird, 1980, 100–105) was maximalist in counting lifetime "lifestyle support energy…, that energy sequestered in the goods and services purchased by the wages earned by working." In contradiction to Wright (1974, 309–310) but in line with Cell 6, Table 1, the authors believe we work for family members and leisure, not merely for muscular energy, and counting only the exosomatically-powered machines used by the worker is also not enough. For them the strengths of this position outwiegh the danger of possible double-counting. Røpke recently sympathised, suggesting that "the consumption of food, shelter, education etc. could just as well be seen as intermediate products, and then the concept of final consumption disappears" (1999, 400). Consistent application of LCA logic would seem to entail treating the consumer/earner as part of the analysed system (Boustead, 1996, 150; *see* Appendix I).

In more economic terms the claim is that the energy used up when a worker is hired to do X hours of labour is a proportion of his or her lifetime energy consumption equal to the proportion of these X hours to the worker's total lifetime working hours. A plausible proof of this is that if these costs were omitted, output would be significantly cheaper than it is. Using Puntí's example, counting metabolic energy per working hour but not even the energy costs of producing food for this metabolism masks large differences between, say, Andalusian manual/animal agriculture of the 1940s and U.S. mechanised/fertilised agriculture of the 1970s (1988, 80–83). Energy analysis of service sectors is in principle difficult with conventional EIO, and "if wages earned in the service sector are the same or higher, then there is no reason to expect a decrease in energy consumption" (82). Socio-economic context matters.

Finally, it is an unrealistic result of EIO's exclusion of induced energy costs of labour that there is little or no environmental

[6] Say, 1803, 119–127, 301–319, 373; Mill, 1848, 154–159.

difference in buying, at going wages, a painting from a Ghanan artist and a U.S. artist; process analysis and to a lesser extent EIO would yield similar material intensities. What's more, the curious policy implication is that for environmental reasons we should shift our expenditures from, say, Ghana to the US, since richer countries have lower MJ/$ ratios.[7]

4.3. Labour is produced

Herendeen succinctly sums up the two arguments above: just as in the energy analysis of a car, "the energy consequences of the labor force's spending of its wages is as important as the energy needed to make the steel" (1981, 616). The next concept deserving separate attention is labour as a *product*: following Leontief, each household is a factory producing (among other things) labour. This requires, however, a consistently ecological approach to the human economy – inclusion of humans in the environment rather than the separation associated with neo-classical economics.

Recalling the double standard discussed above, Ayres similarly argued that if we regard "human labor as an independent primary input – not an intermediate input", an inconsistency arises:

> if a handloom is replaced by a power-loom (capital), the energy required to operate (and also to make, or replace) the power-loom… is taken into account explicitly [but] economic theory does not count the food, clothing, housing, and other consumption by workers – nor their education and training – as part of the cost of production. (2004, 431)

An EIO matrix including labour as an industry, and not separating final and intermediate demand, might well resolve this inconsistency.

Assuming we do choose, supported by the above three arguments, an expanded system, what then are the consequences of shifting outlays to categories otherwise deemed to be more environmentally friendly? In reality, since expenditure size is held constant, the shift means buying more labour (or capital), and Costanza's (1980) empirical exercise confirmed that therefore energy consumption remains much higher than predicted by the narrower matrix. Adding government and labour/household sectors to the 90 intermediate supply-and-demand sectors of the 1967 US economy and correspondingly re-attributing energy inputs vastly reduced intensity variation between sectors. Taking sector energy input as the independent and sector dollar output as the dependent variable, the measure of correlation R^2 rose from about 0.55 to about 0.99.

4.4. Mill's scissors – monetary vs. physical economics

Let us identify at least briefly some apparent anomalies in the use of monetary metrics in analysing physical impacts of production and consumption. To draw environmental consequences from structural economics by comparing sector intensities, one must measure the relative sizes of L and N, requiring aggregate metrics for them as numerators – a task known as Petty's Problem.[8] Yet common physical units for labour and natural resources (as well as for 'goods and services' in the output denominator) are impossible. Forming and comparing intensities must therefore rely on prices – monetary metrics – enabling quantification of labour-hours/GDP and natural-resources/GDP. Moreover, joules per dollar, or labour-hours per dollar, cannot be added to input-dollars per output dollar (Gilliland, 1975, 1051; Miller and Blair, 2009, 406). For this reason Mill (Epigraph) denied that Petty's Problem, in real terms, makes sense.

Wright (1975, 34–35) noted the further problem for energy accounting that although labour and profits are not included in counting energy inputs, because they are excluded from the total requirements matrix, they are part of commodities' prices. Another anomaly arises concerning a $1000 gift. Similar to our earlier questions concerning a Goldsworthy artwork involving only the rearrangement of natural objects, it would be counted in the GDP income accounts but would not fall into any industrial sector – no product or material is bought from the recipient. Environmental impact is implied, however, in the fact that the $1000 was earned by productive activity. In both these examples, in any case, it should be clearer what is exogenous and what endogenous. It is even ironic that the structural change strategy begins with consumer responsibility for household expenditures, a category outside the intermediate matrix.

Further analytical difficulties arise concerning the primary energy sectors. When tracing environmental flows through monetary proxies the energy intensities of primary energy sectors themselves are so high they must be treated, unsatisfactorily, as outliers (Costanza, 1980; Spreng, 1988, 146). What's more, payments for primary energy at the wellhead, say, actually consist fully of payments to people as wages, profits and rents. These of course eventually appear exogenously as household income or value added, but natural resources themselves have no bank account and literally receive nothing, entering the physical transaction matrix with positive values but the monetary matrix for free (Gilliland, 1975, 1053). Purchases from these sectors would thus logically belong to value added and fall outside the boundaries of the conventional EIO matrix.

For illustration let us pursue Suh's observation that while services are allegedly material-free, each dollar spent in the U.S. in service sectors includes about twenty-five cents for purchases from the non-service sectors manufacturing, utilities, transport (2006, 6560). These $0.25 expenditures in the manufacturing sectors would in turn contain a percentage going to labour, and so on until we see that an expenditure is entirely attributable to personal income. But if all are ultimately wages, profits and rents, and natural resources and labour-hours are physically incommensurable, how can one establish that a given good-or-service costing $1000 is caused to certain percentages by labour or nature? All is nature, all is labour or: with his scissors analogy Mill was suggesting that we cannot compare labour and natural-resource intensities at all.

5. Arguments against including labour

Why, then, should the consumer be responsible only for the environmental consequences of the non-labour, inter-industry parts of an expenditure? Two reasons have emerged in the literature: reluctance to regard labour, and thus people, as produced; and the intricacies of double-counting.

5.1. People are produced

It seems at least internally consistent to regard output bought by households as input into the members of the households, and thus into their hours of labour. To accept this analytical framework, however, one must be willing to regard people themselves as sustained and even produced by economic processes, presuming

[7] In $ of purchasing power parity (PPP), a Bolivian (8.8 MJ/$) should spend in Argentina (5.0 MJ/$), a Chinese (8.4/$) in Germany (5.9/$), a Togoan (12.6/$) in Switzerland (4.2/$), a Bulgarian (10.9/$) in the U.K. (4.6/$) and a Jamaican (15.5/$) in the U.S. (8.0/$) (IEA, 2010; EIA, 2010; CAIT, 2010).

[8] Classical economics' standard example was a watch spring, the price of which was perhaps 90% labour, 10% metal. Finding an aggregate physical unit for all natural resources is a separate problem.

a normative or cultural judgement on the "propriety of removing humans from their 'controlling' position outside the economy and making them endogenous…" (Costanza and Herendeen, 1984, 157). When treating households exactly as any other industry, Leontief had similarly urged us to discard our "psychological resistance to this type of approach – due to memories of ill-conceived subsistence cost theories of wages…" (1951, 41).

As Puntí observes, this is Marx's uncontested concept of the reproduction of the labourer, who had to be produced, physiologically maintained and, for example, trained – entailing natural-resource costs (1988, 81–82; *also* Hall et al., 1986, 107). Labour does not fall exogenously from heaven but is a function of previous labour and natural resources. The classical concept was the 'natural price of labour' in terms of real physical inputs.[9]

While this perspective is out of fashion in economics, it is not fully unknown within environmental accounting, e.g. in Kaufmann's concept of energy "used to produce and support factors of production (e.g., labor and capital)" (1992, 53–54). The basic principle has also re-emerged more recently in the concept of the environmental consequences of having a child (Hall et al., 1994; Shi, 2003). Murtaugh and Schlax (2009) even performed an environmental impact analysis for the act of reproduction, estimating natural-resource consumption induced throughout several generations. Another recent study used the Japanese EIO category of a "labor coefficient vector [representing] the number of workers needed for a unit of total output" – analogous to a vector showing per sector amounts of MJs (Nansai et al., 2007, 882). In the study treating labour thus as produced led to the unique finding that shifting to low-environmental-impact commodities would reduce employment, in contradiction to the usual view that shifts in spending to low-impact sectors help combat unemployment. (883–884) In sum, endogenising households/labour requires a normative break with current philosophy.

5.2. Double-counting

Agreement reigns on how much energy a nation consumes, measured either physically or by its price; it is only accounting systems that are in dispute. Therefore Costanza (1982) answered Huettner's (1982) objection that including labour must double-count energy by noting that the additional labour and government sectors required merely a bookkeeping redistribution of energy – in the case of labour proportional to the proportion of employee compensation to total financial outlays. The number of industries or sectors varies anyway among national accounts systems, requiring redistribution done successfully without double-counting. Similar criticism by Herendeen (1981) led to a joint paper by Costanza and Herendeen (1984) showing that the two new endogenous rows (sectors) received joules no longer attributed to the conventional sectors; the system, not the amount of energy, had been expanded.[10]

While not as sanguine about double-counting as Leontief (1936, 111) or Ayres, for whom it is "a no no" only occurring in the first place only because economics regards labour only as an input but not an output (2004, 431–432), this paper can only hint at formal solutions. Within EIO, one could partition each conventional inter-industry cell into 1) wages and salaries and 2) all eslse paid on to other firms. This parallels the treatment of "secondary production" where each cell contains information on two "products" (Miller and Blair, 2009,140–143; Wright, 1974, 309; Bailey et al., 2004). In his endogenous labour services row Leontief analogously debited each industry with wages and salaries (1936, 112, 126). Alternatively, Zhang & Dornfeld merely deduct already-counted *industrial* primary energy supply from total consumed joules, implying perhaps that conventional EIO must under-count (2006, 189–190).

Other possible templates include the "by-product correction method" (Strømman et al., 2009) and "disaggregating industry sectors" by subtracting energy values in the non-labour part to avoid double-counting (Suh and Huppes, 2005, 691–692) – the opposite of Leontief's "consolidation of accounts" (1936, 108). For example $30 for a meal in a restaurant buys not only physical food prepared in a physical kitchen and served at a table on plates, but also the services of the cook, dishwasher and waiter. "When more than one product is produced, the environmental loadings are distributed among the product studied and its by-products or other secondary functions, according to certain rules of allocation" (Tillman et al., 1994, 23). We must only be willing to perceive working hours as *produced*. Appendix II shows rudimentary construction of such tables.

6. Discussion

Evidence referenced in the Introduction points to a shift in many economies to more labour-intensive service sectors; since 1992 for example the primary, secondary and tertiary sectors have on average grown respectively 1.0, 2.6 and 3.0% per year (OECD, 2008; *also* Hannon, 1982, 276). However, several studies taking this change in consumption patterns as the independent variable, while holding expenditure level constant, have found no correlated reduction in resource depletion or pollution (Wright, 1974, 314; Vringer and Blok, 2000; Alfredsson, 2004). Brookes (1972) even showed cross-country correlation between high services proportions of GDP and high energy/GDP ratios; energy/GDP ratios were moreover higher than energy/industrial-output ones. Holm & Englund similarly found for up to 139 nations a positive correlation between "per capita energy use and the proportion of GDP that can be attributed to the service sector…" (2009, 884; *also* York et al., 2005, 150). General time trends show moreover no dematerialisation, neither absolutely, nor per unit of GDP, nor per capita under roughly $26,000 (Luzzati and Orsini, 2009; *also* Smil, 2008, 243, 338; DOE, 2009). Since these correlations are necessarily inconclusive, all that can be said is that the theory that natural-resource consumption is a function of the size of expenditures, not their type, better explains the data. At least it seems incumbent upon EIO-based theory to name the factors that *do* drive resource consumption, counter-acting the claimed conservation effect of structural change.

Perhaps the language of EIO-LCA should be revisited, employing as it does a discourse largely in physical terms: material inputs, products and processes, goods, commodities, equipment, tons of steel or chemicals. While this is appropriate for product or process analysis, it seems lacking for comparison of *expenditures* of constant size and analysis of whole socio-economic systems (*see* Tillman et al., 1994, 21, 28). Even if the vocabulary of structural change shows a bias towards treating services as somehow immaterial it is to be welcomed that energy accounting is "changing focus from commodity to services" (Robèrt et al., 2002, 200) – services defined in the first place by their high percentage of labour costs.

Finally, if including labour is realistic and if, correspondingly, environmental intensities of sectors or expenditures do not significantly vary, there are far-reaching consequences in research areas depending on environmental-intensity concepts as

[9] Ricardo, 1817, 93–94; Malthus, 1820, 130, 113–114, 177–182, 250–252; McCulloch, 1825, 115; Mill, 1848, 33–35, 245.

[10] Herendeen later puzzlingly decided that "Labor and government services are assumed to have zero energy intensity relative to the consumer", the justification being "to avoid double-counting" (1998, 172). The issue haunts the debate.

conventionally computed. In addition to the structural change strategy these include:

1. specifically targeting consumption 'clusters' in the field of sustainable consumption (Spangenberg and Lorek, 2002; Druckman and Jackson, 2009);
2. shifting taxes revenue-neutrally onto natural resources from labour (Common and Stagl, 2005, 419, 434);
3. computing, on the basis of an income effect, relatively low energy-efficiency rebound because marginal expenditures will likely be less energy intensive (Binswanger, 2001, 126);
4. bookkeeping for UNFCCC country inventories that takes the energy intensities of exports and imports into account (Helm et al., 2007, 20–21; Peters, 2008);
5. the European Communities' Integrated Product Policy (Kerkhof et al., 2009, 1167).

In light of these implications it is hoped this paper will draw critical examination.

7. Conclusions

We are led by conventional methods of quantifying implied natural-resource consumption per expenditure of a given size to believe that $1000 spent on a concert or painting impacts the environment less than $1000 spent on a flight or a set of cast-iron garden furniture. This paper's analysis of the alternative method of regarding labour as a product requiring natural-resource inputs casts doubt on this. Perhaps no such expenditure is less environmentally intensive than another. Keeping in mind Environmental Input–Output (EIO) analysis's goal of reducing natural-resource depletion, the paper argues for adding labour as an input–output category and holding consumers responsible for the natural-resource consumption entailed by labour's total wages.

For environmental strategy it matters greatly whether the input–output bookkeeping system attributes no natural-resource consumption to a work-hour, as in conventional EIO, or pro-rates one's total lifetime consumption to that hour, as here suggested. Since shifting expenditures to sectors computed to have higher labour intensity entails correspondingly greater *indirect* resource use – for households to produce labour-hours – the case is strengthened for consuming and producing *less*, rather than merely *differently*. While it is widely accepted that at least metabolism, working-clothes, commuting and energy embodied in the workplace could be atttributed to labour as such, this cannot be done if the EIO system used to rank economic sectors according to their environmental intensity lacks a labour sector in the first place. An alternative matrix, with a labour sector receiving its share of resource consumption, reveals that the economic sectors of national accounts differ practically not at all in energy intensity (Costanza, 1980). Indeed, since labour and resource inputs are commensurable only if monetary metrics are adopted, Mill was moreover probably correct in saying that labour or resource intensities cannot, in real terms, be compared at all.

While much empirical evidence shows strong correlation between GDP and resource use/pollution, there seems to be none between observed structural change to environmentally 'less intense' sectors and lower resource use/pollution – results better explained by a model wherein hiring labour at the rate necessary for the labourer to be willing to work entails consumption at the average level of the society. The paper has therefore pursued a debate truncated in the 1980s over exactly which indirect resource inputs into production should be included to best guide conservation strategy and concludes that we must choose between the painless strategy of shifting expenditures and the tougher one of less absolute resource consumption, achieved either voluntarily or by caps or taxes.

Acknowledgements

Thanks to the editors, anonymous reviewers, and to Dave Abson, Bastien Girod, John Lintott, Bob Lloyd, Rodrigo Lozano, Marco Sakai, Özlem Yazlik and the staff and institution of the Zentralbibliothek Zürich.

Appendix I. Countable inputs to labour

If we accept labour (row) and households (column) as additional sectors or industries in an inter-industry matrix, what embodied natural-resource inputs could we count? Imagine a pure 'service' (labour) sector of receptionists or masseurs. Most items are taken from the literature, and the list moves from the minimal to the maximal ends of a spectrum.

1. Basic metabolism (desk job)
2. Physical exertion (carpenter, athlete)
3. Workplace: building, heating, lighting, water
4. Commuting
5. Special (e.g. protective) clothing
6. Education and training
7. Sleep in a house
8. Bodily repair and care (teethbrushing, haircut, medical care, holiday)
9. Fun, psychological repair and care (games, books, art, religion)
10. Furniture, cutlery, briefcase
11. Beauty (clothes, body, landscape, flowerbeds)
12. Tools (hammer, laptop)
13. Offspring
14. Institutions (physical infrastructure, laws, government, charity)

Part of any payment recorded in EIO goes directly for wages and salaries; for the same reason that steel entering a factory is 'accountable for' its embodied energy, paying a wage entails a worker's total embodied energy. How many of the listed items should be counted? A reasonable rule is that if what a wage purchases is a *necessary condition* for an hour's work to be done, it should be counted and moreover attributed to the wages part of the expenditure.

Appendix II. Incorporating a labour sector into input–output tables

Tables 3–5 show radically simplified transactions matrices with inputs and outputs in energy units. Table 3 is a conventional table with only 2 sectors. Table 4 divides each cell (arbitrarily) in half, the lower figure attributed to labour and the upper to all other deliveries to or inputs into the sector and measuring embodied energy conventionally. Parallel to standard treatment of joint products, this treats joint *inputs* and applies Herendeen's insight that "every economic sector pays wages… and these expenditures are a large fraction… of the total". (1981, 617). Table 5 alternatively attributes these quantities to the new row and new column entitled 'labour' whose cells can be seen as quantities previously exogenous – the 'employee compensation' part of value added and the 'household consumption' part of final demand. Energy outputs equal energy inputs; they are re-distributed rather than counted again. If the treatment of primary energy sectors can be resolved, future work should update Costanza's (1980) similarly expanded matrix – where net output is not GDP but capital formation – using real, international data.

Table 3
Transactions table in energy units.

	Sector 1	Sector 2
Sector 1	10	25
Sector 2	20	10

Table 4
Transactions table with energy disaggregated into energy related to labour and that from other 'inter-industry' sources.

	Sector 1	Sector 2
Sector 1	5 / 5	12.5 / 12.5
Sector 2	10 / 10	5 / 5

Table 5
Expanded transactions matrix with a labour sector.

	Sector 1	Sector 2	Labour	Total energy output
Sector 1	5	12.5	17.5	35
Sector 2	10	5	15	30
Labour	15	17.5	0	32.5
Total energy input	30	35	32.5	

References

Alfredsson, E.C., 2004. 'Green' consumption – no solution for climate change. Energy 29, 513–524.

Ausubel, J., Waggoner, P., 2008. Dematerialization: variety, caution and persistence. Proceedings of the National Academy of Sciences 105 (35), 12774–12779.

Ayres, R.U., 2004. On the life-cycle metaphor: where ecology and economics diverge. Ecological Economics 48 (4), 425–438.

Bailey, R., Allen, K., Bras, B., 2004. Applying ecological input–output flow analysis to material flows in industrial systems. Journal of Industrial Ecology 8 (1–2), 45–68.

Binswanger, M., 2001. Technological progress and sustainable development: what about the rebound effect? Ecological Economics 36 (1), 119–132.

Boustead, I., 1996. LCA – how it came about. International Journal of Life-Cycle Assessment 1 (3), 147–150.

Brookes, L.G., 1972. More on the output elasticity of energy consumption. Journal of Industrial Economics 21 (1), 83–92.

Bullard III, C.W., Herendeen, R.A., 1975. The energy cost of goods and services. Energy Policy 3 (4), 268–278.

CAIT (Climate Analysis Indicators Tool), 2010. http://cait.wri.org/cait.php 28 April 2011.

Chapman, P.F., 1974. Energy costs: a review of methods. Energy Policy 2 (2), 91–103.

Cohen, C., Lenzen, M., Schaeffer, R., 2005. Energy requirements of households in Brazil. Energy Policy 33 (4), 555–562.

Common, M., Stagl, S., 2005. Ecological Economics: An Introduction. Cambridge U. Press, Cambridge.

Costanza, R., 1980. Embodied energy and economic evaluation. Science 210, 1219–1224.

Costanza, R., 1982. Reply to huettner. Science 216, 1143.

Costanza, R., Herendeen, R.A., 1984. Embodied energy and economic value in the U.S. economy: 1963, 1967 and 1972. Resources and Energy 6 (2), 129–163.

DOE, 2009. U.S. Department of Energy, http://www1.eere.energy.gov/ba/pba/intensityindicators/total_energy.html 28 April 2011.

Druckman, A., Jackson, T., 2009. The carbon footprint of UK households 1990–2004: a socio-economically disaggregated, quasi-multi-regional input-output model. Ecological Economics 68 (7), 2066–2077.

Duchin, F., 1998. Structural Economics: Measuring Change in Technology, Lifestyles, and the Environment. Island, Washington, D.C. & the United Nations University Institute of Advanced Studies.

EIA (Energy Information Administration), 2010. http://tonto.eia.doe.gov/country/index.cfm 28 April 2011.

Fischer-Kowalski, M., Hüttler, W., 1998. Society's metabolism. Journal of Industrial Ecology 2 (4), 107–136.

Fluck, R.C., Baird, C.D., 1980. Agricultural Energetics. AVI Publishing, Westport, Connecticut.

Giampietro, M., 2006. Comments on 'The energetic metabolism of the European Union and the United States' by Haberl and colleagues. Journal of Industrial Ecology 10 (4), 173–185.

Gilliland, Martha W, 1975. Energy analysis and public policy. Science 189 (4208), 1051–1056.

Graedel, T., 1997. Life-cycle assessment in the service industries. Journal of Industrial Ecology 1 (4), 57–70.

Hall, C.A.S., Cleveland, C., Kaufmann, R., 1986. Energy and Resource Quality: The Ecology of the Economic Process. Wiley, New York.

Hall, C.A.S., Pontius, R.G., Coleman, L., Ko, J.-Y., 1994. The environmental consequences of having a baby in the United States. Population and Environment 15 (6), 505–524.

Hannon, B., 1982. Energy costs of economic activities: 1963 to 2000. Energy Systems and Policy 6 (1), 249–278.

Helm, D., Smale, R., Phillips, J., 10.12.2007. Too good to be true? The UK's climate change record. http://www.dieterhelm.co.uk/node/656 28 April 2011.

Herendeen, R., 1981. Energy intensities in ecological and economic systems. Journal of Theoretical Biology 91, 607–620.

Herendeen, R., 1998. Ecological Numeracy: Quantitative Analysis of Environmental Issues. Wiley, New York.

Hinterberger, F., Luks, F., Stewen, M., 1996. Ökologische Wirtschaftspolitik: Zwischen Ökodiktatur und Umweltkatastrophe. Birkhäuser, Berlin, Basel, Boston.

Holm, S.-O., Englund, G., 2009. Increased ecoefficiency and gross rebound effect: evidence from USA and six European countries 1960–2002. Ecological Economics 68 (3), 879–887.

Huettner, D., 1982. Economic values and embodied energy. Science 216, 1141–1143.

IEA (International Energy Agency), 2010. www.iea.org/stats indicators 28 April 2011.

Jackson, T., Marks, N., 1999. Consumption, sustainable welfare and human needs – with reference to UK expenditure patterns between 1994 and 1954. Ecological Economics 28 (3), 421–441.

Junnila, S., 2009. Environmental impact and intensity of processes in selected service companies. Journal of Industrial Ecology 13 (3), 422–437.

Kaufmann, R., 1992. A biophysical analysis of the energy/real GDP ratio: implications for substitution and technical change. Ecological Economics 6 (1), 35–56.

Kerkhof, A.C., Nonhebel, S., Moll, H.C., 2009. Relating the environmental impact of consumption to household expenditures: an input–output analysis. Ecological Economics 68 (4), 1160–1170.

Leontief, W., 1936. Quantitative input and output relations in the economic system of the United States. The Review of Economic Statistics 18 (3), 105–125.

Leontief, W., 1951. The Structure of the American Economy. Oxford U. Press, Oxford.

Lloyd, B., 2007. The Commons revisited: the tragedy continues. Energy Policy 35 (4), 5806–5818.

Luzzati, T., Orsini, M., 2009. Investigating the energy-environmental Kuznets curve. Energy 34 (3), 291–300.

McCulloch, J.R., 1825. The Principles of Political Economy, 5th ed. 1864. A. & C. Black, Edinburgh (Reprint 1965, Augustus M. Kelly, New York). [1st ed. 1825: William and Charles Tait, Edinburgh and Longman & Co., London.].

Malthus, T.R., 1820. Principles of Political Economy. 1836/1986. In: Wrigley, E.A., Souden, D. (Eds.), second ed. William Pickering, London.

Mill, J.S., 1848/1965. Principles of Political Economy, with Some of their Applications to Social Philosophy. In: Robson, J.M., (ed.), Toronto and London, U. of Toronto and Routledge & Kegan Paul [original: 1848, London, John W. Parker, West Strand].

Miller, R.E., Blair, P.D., 2009. Input–Output Analysis: Foundations and Extensions. Prentice-Hall, Englewood Cliffs.

Murtaugh, P.A., Schlax, M.G., 2009. Reproduction and the carbon legacies of individuals. Global Environmenal Change 19 (1), 14–20.

Nansai, K., Kagawa, S., Moriguchi, Y., 2007. Proposal of a simple indicator for sustainable consumption: classifying goods and services into three types focusing on their optimal consumption levels. Journal of Cleaner Production 15 (10), 879–885.

Odum, H.T., 1995. Environmental Accounting. Wiley, New York.

OECD, 2008. http://www.oecdilibrary.org/docserver/download/fulltext/3008011ec018.pdf?expires=1278443939&id=0000&accname=freeContent&checksum=87BE4F6F470C9E261AC7AD50DED21983 6 June 2010.

Penn, J.B., McCarl, B.A., Brink, L., Irwin, G.D., 1976. Modeling and simulation of the U.S. economy with alternative energy availabilites. American Journal of Agricultural Economics 59 (4/I), 663–671.

Peters, G.P., 2008. From production-based to consumption-based national emission inventories. Ecological Economics 65 (1), 13–23.

Puntí, A., 1988. Energy accounting: some new proposals. Human Ecology 16 (1), 79–86.

Ricardo, D., 1817. 18211951. In: Sraffa, P. (Ed.), On the Principles of Political Economy and Taxation, third ed. Cambridge U. Press, Cambridge.

Ritthoff, M., Rohn, H., Liedtke, C., 2002. MIPS berechnen: Ressourcenproduktivität von Produkten und Dienstleistungen. www.wupperinst.org/de/suchergebnis/index.html?searchart=publikationen_uebersicht 28 April 2011.

Robèrt, K.-H., Schmidt-Bleek, F., Lardarel, J., Basile, G., Jansen, J.L., Kuehr, R., Price, P., Thomas, P.P., Suzuki, M., Hawken, P., Wackernagel, M., 2002. Strategic sustainable development: selection, design and synergies of applied tools. Journal of Cleaner Production 10 (3), 197–214.

Røpke, I., 1999. The dynamics of willingness to consume. Ecological Economics 28 (3), 399–420.

Rothman, D., 1998. Environmental Kuznets curves: real progress or passing the buck?: a case for consumption-based approaches. Ecological Economics 25 (2), 177–194.

Say, J.-B., [1803] 1836. A Treatise on Political economy. Intro Munir Quddus, M., Rashid, S. Transaction, New Brunswick, New Jersey and London.
Schmidt-Bleek, F., 1994. Wieviel Umwelt braucht der Mensch?: MIPS – Das Mass für ökologisches Wirtschaften. Birkhäuser, Berlin, Basel, Boston.
Shi, A., 2003. The impact of population pressure on global carbon dioxide emissions, 1975-1996: evidence from pooled cross-country data. Ecological Economics 44 (1), 29–42.
Smil, V., 2008. Energy in Nature and Society. MIT Press, Cambridge, Massachusetts.
Spangenberg, J., Lorek, S., 2002. Environmentally sustainable household consumption: from aggregate environmental pressures to priority fields of action. Ecological Economics 43 (2–3), 127–140.
Spreng, D., 1988. Net-Energy Analysis. Praeger, New York.
Stern, D.I., 1999. Is energy cost an accurate indicator of natural resource quality? Ecological Economics 31 (3), 381–394.
Strømman, A.H., Peters, G.P., Hertwich, E.G., 2009. Approaches to double-counting in tiered hybrid life-cycle inventories. Journal of Cleaner Production 17 (2), 248–254.
Suh, S., Huppes, G., 2005. Methods for life-cycle Inventory of a product. Journal of Cleaner Production 13 (7), 687–697.
Suh, S., 2006. Are services better for climate change? Environmental Science and Technology 40 (21), 6555–6560.
Tages-Anzeiger (Zürich), 1 July 2008, 49.
Tillman, A.-M., Ekvall, T., Baumann, H., 1994. Choice of system boundaries in life-cycle assessment. Journal of Cleaner Production 2 (1), 21–29.
Torras, M., 2003. Global structural change and its de-materialization implications. International Journal of Social Economics 30 (6), 700–719.
Vringer, K., Blok, K., 1995. The direct and indirect energy requirements of households in the Netherlands. Energy Policy 23 (10), 893–910.
Vringer, K., Blok, K., 2000. Long-term trends in direct and indirect household energy intensities: a factor in dematerialisation? Energy Policy 28 (10), 713–727.
Wright, D.J., 1974. Goods and services: an input–output analysis. Energy Policy 2 (4), 307–315.
Wright, D.J., 1975. The natural resource requirements of commodities. Applied Economics 7, 31–39.
York, R., Rosa, E.A., Dietz, T., 2005. The ecological footprint of national economies. Journal of Industrial Ecology 8 (4), 139–154.
Zhang, T.W., Dornfeld, D.A., 2006. Energy Use per Worker-Hour: Evaluating the Contribution of Labor to Manufacturing Energy. doi:10.1007/978-1-84628-935-4_33. http://www.springerlink.com/content/u39k13h66664l21n/ 28 April 2011.

Sustainability politics: The consequences of rebounds

Vol. 1

critical analysis of submitted work

for the PhD by Publication, Norwich Business School

University of East Anglia

by Blake Alcott

March 2013

This essay is submitted in fulfilment of requirement §5 (3), 594 PhD by Publication Regulations, UEA, viz: *'a critical analysis of the work submitted (between 10,000 and 20,000 words in length covering the development of the candidate's submitted work and its contribution to the field in general'.*

It has not been submitted for any other degree.

Length of text + footnotes: 17,100 words

Abstract

To achieve a sustainable or steady-state economy a society must be able to hold negative environmental impacts, whether defined as resource depletion or as pollution, to desired maxima. That is, it must control throughput defined as resource inputs plus low-value outputs. This can be done directly through capping input substances or approached indirectly through various sustainability paths, fruitfully classified into three groups: control of the number of people, control of the quantity of goods and services per person, and increasing the ratio of goods and services per unit of either resource consumption or pollution. This taxonomy coincides with the formula $I = PAT$.

It is found that each indirect path suffers from rebounds: whatever inputs are left temporarily fallow after reducing population, and/or the affluence of some people, and/or the technological ratio of inputs to economic output, are merely consumed to support more people, raise the affluence of others, and/or increase the amount of economic output. In order however to decrease throughput to sustainable levels – solving the primary problem of human ecology, that of the scale of the human economy in relation to biophysical limits – we needn't measure exact levels of rebound: directly imposing caps achieves this goal. Once overall caps are in place, population, affluence and efficiency will find their levels decentrally and democratically.

Social problems to be addressed in a lower-throughput economy concern the just distribution of rights to consume or pollute common property, unemployment that can result from economic shrinkage, and in general just distribution of the pie when the pie is getting smaller. It is suggested that environmental research should focus on winning democratic majorities for sustainability and identifying the ethical, aesthetic and quality-of-life benefits of a smaller economy. Only worldwide political action – not that of individuals, firms or even countries – is likely to achieve sustainability.

List of contents

Paper 5 co-authored with Reinhard Madlener

Madlener, Reinhard, & Blake Alcott, 2009. Energy rebound and economic growth: A review of the main issues and research needs. *Energy* 34: 370-376.

In respect of (a) design of the investigation, (b) conduct of the research, (c) analysis of the outcome, and (d) preparation of the work for publication, Dr. Madlener and I contributed roughly equally. Dr Madlener has confirmed this per email to Dr Hing Kai Chan and Dr Giovanni Baiocchi.

List of submitted work (published papers)

(1) Alcott, Blake, 2004. John Rae and Thorstein Veblen. *Journal of Economic Issues* 38 (3): 765-786.

(2) Alcott, Blake, 2005. Jevons' Paradox. *Ecological Economics* 54 (1): 9-21.

(3) Alcott, Blake, 2008. The sufficiency strategy: Would rich-world frugality lower environmental impact? *Ecological Economics* 64 (4): 770-786.

(4) Alcott, Blake, 2008b. 'Historical overview of the Jevons Paradox in the literature' in: Polimeni, John, Kozo Mayumi, Mario Giampietro and Blake Alcott (eds.), *The Jevons Paradox and the Myth of Resource Efficiency Improvements*. Earthscan, London.

(5) Madlener, Reinhard, and Blake Alcott, 2009. Energy rebound and economic growth: A review of the main issues and research needs. *Energy* 34 (3): 370-376.

(6) Alcott, Blake, 2010. Impact caps: Why population, affluence and technology strategies should be abandoned. *Journal of Cleaner Production* 18 (6): 552-560.

(7) Alcott, Blake, 2011/2013. Should degrowth embrace the Job Guarantee? *Journal of Cleaner Production* 38: 56-60. [*was online since 2011, but final date 2013*]

(8) Alcott, Blake, 2012. Mill's Scissors: Structural change and the natural-resource inputs into labour. *Journal of Cleaner Production* 21 (1): 83-92.

(9) Alcott, Blake, 2012. Population matters in ecological economics. *Ecological Economics* 80: 109-120.

[except for submission #4 all publications are accessible at www.blakealcott.org]

Additional work not peer-reviewed and/or in German, and not submitted in hard copy

(10) Alcott, Blake, 2006. Kenneth Bouldings Wegweiser von 1966. *Vereinigung für Ökologische Ökonomie Heft* 7: 25-29. An analysis of Kenneth Boulding's seminal article 'The Economics of the Coming Spaceship Earth' in the German-language journal of the society for ecological economics, including the first German translation of the essay
http://www.blakealcott.org/pdf/Kenneth%20Bouldings%20Wegweiser%20neu.pdf

(11) Madlener & Alcott, 2011. 'Herausforderungen für eine technisch-ökonomische Entkoppelung von Naturverbrauch und Wirtschaftswachstum unter besonderer Berücksichtigung der Systematisierung von Rebound-Effekten und Problemverschiebungen. Enquete Kommission des deutschen Bundestages. Contract work for the 'Enquete' committee of the German Parliament investigating the decoupling of natural-resource consumption from economic growth
http://www.bundestag.de/bundestag/gremien/enquete/wachstum/gutachten/m17-26-13.pdf

(12) Alcott, Blake, 2006. Assessing energy policy: Should rebound count? Dissertation for the degree of Master in Philosophy, Department of Land Economy, University of Cambridge http://www.blakealcott.org/pdf/Masters%20Dissertation.pdf

(13) Madlener, Reinhard & Blake Alcott, 2007. Fluch und Segen einer effizienteren Energienutzung. *Energiewirtschaftliche Tagesfragen* 57, Heft 10: 70-71. A brief literature review in German of the efficiency-rebound problem
http://www.blakealcott.org/pdf/et-problem-oder-loesung.pdf

(14) Alcott, Blake, & Tyler James Marangi, 2013. A Granger-causality test for worldwide rebound – under submission to *World Review of Entrepreneurship, Management and Sustainable Development.* [available on request]

Curriculum Vitae

Undergraduate study: 1963-65: Oberlin College (Ohio, USA); 1965-66: Osmania University (Hyderabad, India) in the University of Wisconsin's Junior Year in India program; 1966-68: Wesleyan University (Connecticut, USA) – B.A. in philosophy.

Work: Mainly as a self-employed cabinetmaker (joiner, carpenter) until 2001.

Further study: self-taught except for 2005-2006 when earning an MPhil in Environmental Policy in the Department of Land Economy, University of Cambridge. I spent 2010 as a PhD student at the University of Leeds studying the land, labour production function in classical economics, but discontinued without a degree.

Work related to ecological economics: some lecturing and supervising in the MSc in Ecological Economics at the University of Edinburgh; some lecturing at the ZHAW (Zürich University of Applied Sciences) in Wädenswil; and occasional lectures at the Swiss Federal Institute of Technology, the Centre for Alternative Technology in Machynlleth, Wales, and the NGO Population Matters. I have presented at conferences in Cambridge, Paris, Barcelona, Oldenburg and Friedrichshafen.

Acknowledgements

Leaving self-employed cabinetmaking in middle age, it was great to receive support from Cecilia Roa, John Lintott, Tim Jackson, Irmi Seidl, Reinhard Madlener, Steve Sorrell, Bastien Girod, Marcel Hänggi, Özlem Yazlık, Annela Anger, Mario Giampietro, Kozo Mayumi, Steve Stretton and Steve Usher. Thanks to Klaus Hubacek and Jouni Paavola who supervised me during my year doing a research PhD at U. Leeds' Sustainability Research Institute and to my co-workers there Vivek Mathur, Julia Steinberger, Mireia Pecurul, Dan O'Neill and Marco Sakai. For turning a blind eye to my weaknesses thanks are due to several journal editors and conference organisers including Glen Atkinson, Cutler Cleveland, Don Huisingh, Philip Vergragt, Bernd Siebenhühner, Begüm Özkaymak and François Schneider. Special thanks to Salman Hussain for many things, to Konstantinos Chalvatzis, and to Giovanni Baiocchi who generously agreed to supervise this PhD by Publication. And to the Peartree Bindery, Norwich.

List of Tables and Figures

Epigraph

> There has always been something rather refreshing in the view that we should live like the birds, and perhaps posterity is for the birds in more senses than one; so perhaps we should all call it a day and go out and pollute something cheerfully. As an old taker of thought for the morrow, however, I cannot quite accept this solution; and I would argue, furthermore, that tomorrow is not only very close, but in many respects it is already here.
>
> -- *Kenneth Boulding* (1966)

Part 1 Development of my work

1.1 Introduction

My academic interest in what turned out to be *ecological sustainability* arose slowly as I engaged in 'green' political action from about 1980 onward. Locally the issues were less traffic, better air, more recycling, preservation of old houses and the de-sterilisation of public green. As a Greenpeace activist I worked on over-fishing, nuclear waste and danger, air quality, sustainable forestry, less transport, and weaning off fossil fuels. I became aware that sooner or later individuals and our productive economic system will have to adjust to a state of increased resource scarcity and a steady-state (non-growing) economy.

The writings of Herman Daly put my crude perceptions into an overview. I had for instance asked myself, 'What if 1.3 billion Chinese lived (materially) like even I do, a relatively low-income Swiss person?' Daly conceptualised the quantitative limits to natural resources and natural pollution sinks; limits to technological efficiency increases; protection of non-human animals; limits to human population size; poisons in the environment; the distinction between renewable and non-renewable resources; quality of life; the rights of future people; and the material-energy *throughput* of the human economy, i.e. its inputs plus its outputs, including what we anthropocentrically call 'waste'. *See* **Table 1**.

I soon chose to define 'sustainable' to characterise human (economic) activity that can continue *forever* – in Aldo Leopold's phrase "in the longest run". At the end of the 1980s Daly, Kenneth Boulding, Joan Martinez-Alier and like-minded scientists

chose the name ‘ecological economics’ for this new school of thought, but ‘human ecology’ would have done just as well.

input	**good-or-service**	**output**
rubber, plastic, cloth, leather, metal	sneakers	stuff in landfill or incinerator
“cog” (coal, oil, gas)	heated room	high-entropy heat
silicon, energy	glass	waste heat, waste water, shards
fertiliser, water, sun	food	dispersed (e.g.) phosphorus, straw, excrement
iron, coal	steel beam	rust, scrap, waste water
metal, grease, fuel	engine	noise, waste heat, scrap, fats
wood, bricks, mirror, metal	haircut	hair, light, heat, waste water

Table 1: Input + output = throughput; inputs deplete, outputs pollute, goods-and-services provide utility. It is the scale of current throughput that can be too big for the planetary biosphere and for preserving resources for future humans and other species. It is throughput that must ‘de-grow’, not utility or even GDP.

Future people who cannot now vote, and other species, are the essence of the *ethical* concept of sustainability. Preserving resources and a productive natural environment is the pre-condition of future well-being. At current economic scale present people must therefore limit some combination of their numbers and their throughput per capita. While it might be just as stupid to sit freezing on a pile of coal as to use it all up, in light of its exhaustibility and our ethical obligation to bequeath a sufficiently good world to future people, we must *do without some of this resource input.* If we grasp this principle and prepare for a life with fewer ‘energy slaves’, for instance, we will be emotionally and technically ready at the onset of either politically-decided or naturally-occurring scarcity.[1]

It appeared that many or perhaps most people behave according to some combination of not caring that much about future people (or non-human animals) and caring about a comfortable, even prestigious, high-throughput lifestyle. A row of questions thus emerged:

[1] The Transition Town movement does exactly this.

1. What do psychology and anthropology tell us about the human actors who are being asked to live sustainably? What are the chances for a voluntary shift to greater frugality?
2. Does the more efficient consumption of resources really contribute to less resource consumption and throughput?
3. How can human population size be kept no higher than a sustainable level, and what is that level?
4. Do lower fertility and living more frugally require political action over and above voluntary efforts of living by example, explaining and cajoling?
5. Must we politically and democratically agree to let ourselves be legally forced – as with for example the income tax and sending our kids to school – to reach a sustainable number of people times resources consumed by each?

The formula *I* = *PAT* says that the quantity of (negative) environmental impacts *I* (depletion and pollution, i.e. throughput) depends on (1) the number of impacters *P* (population), (2) their average *per capita* goods-and-services consumption *A* (affluence), and (3) throughput per unit of goods-and-services as an efficiency ratio *T* (technology). **Table 2** classifies my submitted papers accordingly.

paper #	Impact	Population	Affluence	Technology	Politics
1 Rae & Veblen			X		
2 Jevons' Paradox				X	
3 Sufficiency Strategy			X		
4 Classical Economics				X	
5 Rebound methodology				X	
6 Caps vs indirect paths	X				
7 Job Guarantee					X
8 Mill's Scissors			X	X	
9 Population Matters		X			X
10 Spaceship Earth	X				X
11 Rebound Germany				X	X

Table 2 Classification of submitted papers. Shows the main topic(s) covered by each paper classified according to *I* = *f(P,A,T)* and an added 'Politics' column. Papers 10 & 11 are in German; *see* 'Additional work…' above, p 5.

1.2 **Evolutionary psychology** (paper 1, ‘Rae and Veblen’)

I read quite a bit of evolutionary psychology mainly in order to solve problems in my personal life, e.g. relations with others, attitude towards work and play, feelings of guilt, generosity, envy or self-esteem. It seemed that our evolutionary endowment – more or less hard-wired yet amenable, within limits, to our surroundings – enables us to predict certain environmentally relevant behaviours such as:

- procreation as an individual choice
- high levels of material consumption
- need for cosmetics
- meat-eating
- a short time horizon in making practical and ethical decisions.

Tribalism and wars between tribes are also relevant to throughput because they constitute production and destruction (consumption), yielding a perverse kind of utility and requiring repeated production or replacement. On the other hand we seem to have inherited inclinations towards:

- intra-human co-operation
- love and aesthetic appreciation of nature (including other animals)
- workmanship
- giving our offspring a beautiful and productive world
- Kant’s ‘moral law within’ (a desire to in some sense be good).

From this large pile of topics I chose to look more closely at consumption *over and above that* necessary for a life that is physiologically sufficient and even comfortable.

Out of this came **paper 1**, distilled out of a long treatise covering everything from bower birds to trophy wives and huge, shiny public works. I looked first at previous work on ‘prestige’, ‘competitive’, ‘conspicuous’ or simply ‘over-’ consumption – relevant to today’s subdiscipline of ‘sustainable consumption’. This led to Thorstein Veblen (1899), John Rae (1835) and, some time after writing the paper, Jean-Baptiste Say (1803).

The meta-issue of the value of such history of thought is beyond my ken, except that it seems one way of clarifying concepts and finding the logic necessary to approach questions. **Paper 1** is thus either literature review or intellectual history. (**Papers 2** and **4** are likewise histories of thought.)

Paper 1 looked at tendencies in our evolved behaviour for (1) survival/comfort and (2) procreation, leading directly and indirectly, respectively, to a higher-consuming lifestyle. While the question of why we seek status in the first place seems under-researched, I built on or at least described the specific, almost universally observed sociological tie between status and visible, verifiable wealth (hence Veblen's phrases *conspicuous* consumption and conspicuous waste). The unsurprising phenomenon of lifestyles that are opulent rather than 'sufficient' is however the driver of high per capita throughput. I myself never undertook empirical measurement of people's motivations for what I came to call, under the influence of the peacocks, colours, antlers, bowers and rich human males, *display consumption*. One under-used framework for this researched is that of Darwin's (1871) inter- and intra-sex *sexual selection*. In general, if people are to be convinced to vote for painful cuts in their affluence, we need better understanding of the evolution of our emotions.

1.3 **The efficiency cure-all** (paper 2, 'Jevons' Paradox')

As embodied in the book *Factor Four* (von Weizsäcker et al., 1997), it became axiomatic for politics, journalism, green thinking and academic writing to propound policies for increasing such input efficiency or, alternatively, finding substitutes for scarce or harmful inputs (e.g. windmills instead of oil, amounting as well to an increase in oil efficiency). In 1998 during a period when I attended ecological economics conferences as an interested layman I met Christer Sanne, whose article two years later, in a special issue of *Energy Policy* on the rebound effect, caught my eye. It mentioned Jevons' Paradox: the more efficient consumption of a natural resource (a higher output-input ratio in any process requiring it) might even lead to more consumption of that resource than would be the case without the efficiency increase. This counterintuitive insight seemed well worth pursuing, and I turned to Jevons' 1865 book.

Research on Jevons' Paradox and energy-efficiency rebound remains to this day largely theoretical. Empirical research has been mostly micro-economic, limited to certain sectors and countries, and thus mournfully inconclusive; researchers for and against 'Jevons' heatedly resorted to counter-factual formulations when depicting the macro-economic results of technological efficiency increases, and many micro-researchers publicly declared it impossible to trace demand changes in all sectors following increases in efficiency in any particular sector.

Under the sway of the dominant sociological-academic paradigm which assumed that engineering (per-unit-of-output) savings must be real, the research entailed the study of marginal consumers, price elasticities of supply and demand, and the efficiency elasticities of prices. The paradigm required that rebound, rather than resource savings, be demonstrated. However, I've since concluded that the reverse would be correct: observable, uncontested technological efficiency increases have for decades been accompanied at macro level by observable, uncontested resource consumption increases, a *prima facie* empirical situation that shifts the burden of proof onto the anti-Jevons position. But perhaps because of the strong and seductive hope that efficiency offers a painless road to conservation, hundreds of researchers started with the plausibility of the theory that theoretically possible 'engineering' savings would actually be realised by human economic actors themselves constantly increasing in number.

I only later realised that Jevons' opinion – that rebound is *greater than* 100%, i.e. that efficiency increases 'backfire' in terms of conservation – is not relevant for environmental policy: as rebound reaches even say 80 or 90%, efficiency policies become *cost*-ineffective. Thus Jevons' very difficult *paradox*, while fascinating, diverted research from policy relevance.

Figure 1 shows the rebound research question from a broad social-science view. Through technological efficiency increase[2] an amount of the newly more efficiently used natural resource lies temporarily fallow – temporarily: for oil in the international

[2] Taking a simple natural resource, labour production function $Q = f(N,L)$ the analogous situation holds for labour (work-time) inputs: if economies of scale, factory-floor rationalisation or machine power and knowledge raise labour efficiency, a certain amount of work-time lies for one instant fallow; we *could* save this input by working less and consuming the same amount of goods-and-services. But we usually choose to work the same length of time and consume more goods-and-services. For labour inputs all analysts and historians agree with Jevons.

market for perhaps one instant, in the case of somebody's private wood-lot perhaps a few months. If the cost of supplying the resource – the supply function – remains constant, and if the price of the resource doesn't fall enough that it lowers profits so much that some suppliers quit supplying, the same amount of the resource as before remains for sale. Economic history shows that some combination of more people and more per capita goods-and-services has meant the 'fallow' amount has been snapped up. But *must* it be? **Paper 6** also contains an elaboration of **Figure 1**.

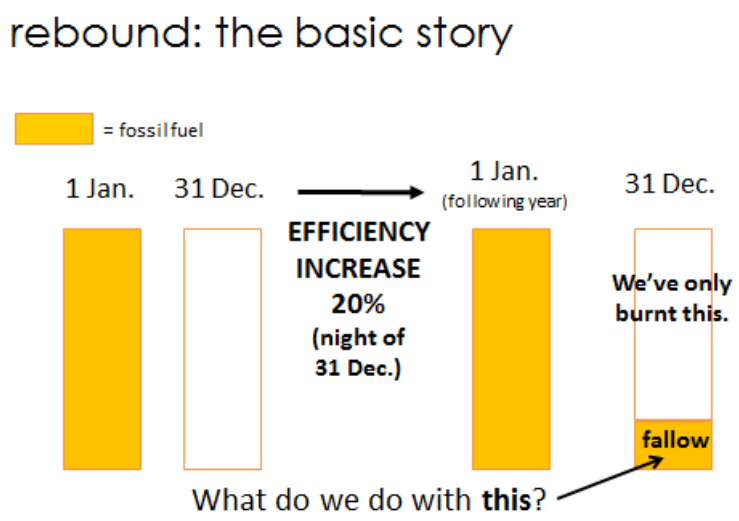


Figure 1: Fallow resources Does an increasing world population desiring comfort, perhaps luxury, or just to rise out of poverty, leave the fallow resource untouched?

To answer this question we should look not only to economics but also to psychology, anthropology and history. We should *not* look to engineering science, which can only calculate the *per-unit* changes in the efficiency ratio but not the post-efficiency reactions of consumers. An empirical route is also open, but, due to globalisation and the 'leakage' of embodied imported material and energy, only at world rather than sector or country or group-of-countries scale. (Alcott & Marangi, *under review*) Only recently, more than thirty years after Brookes' and Khazzoom's work,[3] is a consensus emerging that not only is it invalid to assume a one-to-one proportion between theoretically possible 'engineering savings' and real savings, but that rebound is high enough to warrant measures to 'counteract' rebound, namely *necessarily* effective resource caps and/or taxes. (Madlener & Alcott, 2011)

[3] Not referenced here because ubiquitously referenced in my papers.

As searches for policy advice **Papers 2, 4** and **5** were thus questionable: policy tools have always been on the table (caps and taxes) that are by definition effective, raising the question of the rationale for efficiency policy and the painstaking, methodologically difficult calculation first of efficiency increase, then rebound. That is, for *effective* policy there is no need to compute rebound, and studying efficiency is relevant only for the task of showing voters that possible increases are large enough to save a considerable amount of our material standard of living. (Similarly, showing the potential of renewables tells the voter: within the newly restricted fossil-fuel budget renewables are capable of delivering a certain level of goods-and-services.) It is scientifically non-controversial that caps and taxes do the 'sustainability job'. It is only the hope that efficiency might *also* be a *sufficient* condition for real input savings, and a much less painful one than caps, that lends the study of rebound any apparent policy relevance.

1.3.1 My MPhil dissertation[4] looked at some governments' *evaluations of* their energy policies, including efficiency policy. With very minor exceptions rebound was at most briefly acknowledged in principle but treated as zero. In 2009 I asked a top employee of the Swiss *Bundesamt für Energie* about this; I'd just had to point out to him the distinction between direct and total rebound. He replied that until they know an exact percentage for rebound, they will ignore it. I argued that this is scientifically irresponsible and suggested we enter a co-efficient of 0.5 for total (macro-economic) rebound (real savings = 50% of engineering savings). To my mind this was a reasonable bridge between academic uncertainties and the exigencies of lowering depletion and pollution.

1.4 **Sufficiency rebound** (paper 3, 'The sufficiency strategy')

To the extent that sufficiency – voluntarily doing without a certain amount either of a natural resource or of goods-and-services – temporarily lowers demand and thus price, there is also a *sufficiency* rebound. Marginal consumers and an increasing population replace the environmentally-motivated ones who, for the sake of a sustainable economy, lower their ecological footprint. Even if people would change

[4] 2006, http://www.blakealcott.org/pdf/Masters%20Dissertation.pdf

their high-consumption behaviour – some difficulties of which were investigated in **paper 1** – the problem remains that if the supply schedule remains unchanged, latent demand springs into the breach, consuming the temporarily fallow-lying resource. **Paper 3** describes this rebound in economic terms and criticises other aspects of the currently *en vogue* 'sustainable consumption' discourse, primarily the alleged disjunct between happiness and consumption. At any rate, the path of sufficiency does not necessarily lead to lower impact, and one can again with good reason ask how this discourse is at all relevant to the environmental task.

Figure 2: The Consumer Society The sustainable-consumption strategy assumes over-consumption as both a societal and a personal 'bad'.

1.5 **Efficiency rebound again** (papers 4 & 5, Earthscan and *Energy*)

Also dealing with rebound are **paper 4** (book chapter on classical economics' bearing on Jevons' Paradox) and **paper 5** (methods for measuring rebound). Concerning the former, the study of pre-Jevons political economy was rewarding to a degree I can't overstate, and enabled me to identify the basic chain of concepts needed in rebound discussion:

- What is technological efficiency (productivity)?
- What is output?
- What are the price effects of efficiency increases?
- What is the 'societal' income effect?

- What general preconditions are conducive to high rebound?
- What would satiation and indolence mean for rebound's size?
- What is backfire (rebound > 100%), what new products can efficiency increase lead to?
- What effect does technological efficiency increase have on population size?
- What does the study of *labour*-efficiency rebound tell us?

The writers from Sir William Petty through John Stuart Mill were not concerned with overall resource conservation or with pollution but with overall growth and entrepreneurial profit. If we identify two sources of profit in classical economics – 'expansion of the market' and 'productivity' increases – it seems that the new paradigm of sustainability means an end to the former source. Under great tension, a fundamental shift is also perceptible from an economics focussed on macro growth and micro profit, in markets as free as possible, to one subordinating both producers and consumers to collective regulation of throughput (caps, taxes, or sector-wide standards). Jevons understood this fully; bitter-sweetly, Britain's days of greatness would have to end.

Figure 3: ***The Coal Question*** William Stanley Jevons in 1865 predicted increased coal production alongside increased efficiency in using coal.

Concerning **paper 5**, in contemporary rebound research I found the lack of definitions alarming and the focus on direct rebound limiting. The smaller literature adopting the macro approach used econometric models not open to inspection, or for instance incorrectly treated population and GDP as exogenous, causal variables.

But extensive reading also shows that the final word has not been spoken. I suspect the metaphor of a 'race' between efficiency and GDP is misleading because it implies that efficiency increase's causal arrow does point towards less input consumption. At any rate, much better models of energy consumption are needed: If efficiency increase does cause real net savings, what opposing factors do cause the uncontested rise in consumption? They must even be strong enough to compensate for efficiency's alleged consumption-reducing effect.

1.6 *I = f(P, A, T)* (paper 6, 'Impact caps')

I am aware of criticisms of this formula for quantifying environmental impact. I defend it, however (*see* **Section 1.10**), as a powerful way to taxonomise environmental approaches, strategies, and policies as illustrated by **Table 2**. A key development in my work is that I saw that while left-side policies *must* work, right-side ones might not, due to interdependencies, due to simultaneous equations whose results, because of rebounds, most likely cancel each other out. *See* **Figure 4**. Thus a process of elimination led to the conclusion that academic energy would better be invested in describing, designing and arguing for the left-side measures that are by definition environmentally effective: caps and/or taxes.

Paper 6 sketches six inter- and three intra-factor dependencies among *P, A,* and *T,* and concludes that computing each one and designing policies to counteract each rebound is cost-ineffective in terms of intellectual and labour effort compared to direct left-side measures. The paper also criticises the bottom-up/top-down dichotomy common in the literature (pursued in **paper 9**) – and suggests that we move away from individual, voluntary approaches at the level of firms and households towards an institutional or political approach whereby a majority of voters decides whether to change *laws*. (van den Bergh, 2010, p 542) The motto is 'I will if you also have to' or, catchier, 'I will if you will'. Both producers and consumers should prepare for a combination of natural and socially-legislated scarcity.

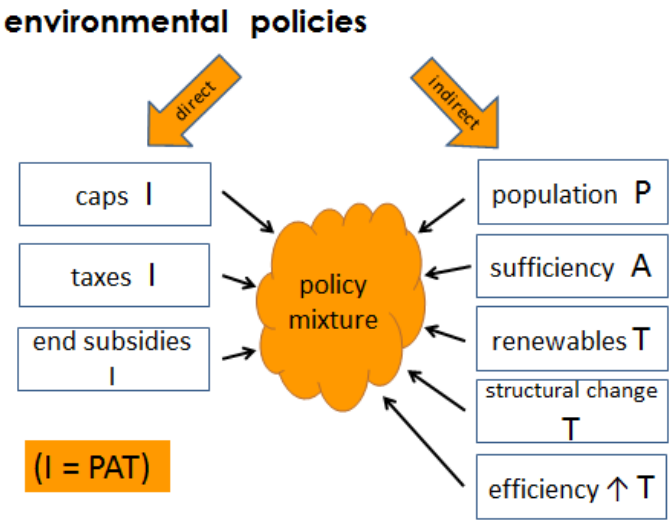


Figure 4: Classification of strategies Starting with right-side policies only might be the tail wagging the dog. For structural change *see* **paper 8**.

1.7 **Unemployment** (paper 7, 'Job Guarantee')

A steady-state economy is consistent with full employment (paid work for all who want it) because the employment rate is a social, political decision, not (only) a function of market forces or the size of the economy or its growth, stagnation or shrinkage. Lack of paid work is not synonymous with lack of enough purchasing power to live well, and the two should not be conflated; it is a psychological and social problem in its own right. Societies adopt various *indirect* policies to decrease unemployment: job brokering, abolition or lowering of legal minimum wages, retraining, deficit spending (usually for public works), etc. However, a *direct* policy is available (and existent in India and Argentina): a Job Guarantee with the state either as employer of last resort or as subsidiser of private-sector jobs. This role for the state has far-reaching and largely uninvestigated effects on the private sector and its job market. But it boldly delivers full employment.

The general issue is the economics not only of sustainable scale but of social justice. (Daly, 1992) On their interrelations my work is unfortunately mostly silent. For instance, is the availability of a continually growing supply of cheap labour a necessary condition for the increasing scale of throughput?[5] Or, are disputes over

[5] Gratitude to my supervisor, Giovanni Baiocchi, for reminding me of this and other related issues.

the just distribution of river and aquifer waters, for instance in historic Palestine, perhaps drivers of their unsustainable use – not to mention the demographic race in that same country.[6] Returning to jobs – once one arrives at the opinion that a steady-state economy is good and/or eventually unavoidable, and that reaching it requires degrowth (economic shrinkage or 'contraction'), and that in most economies degrowth means loss of jobs, this issue becomes acute for reasons of justice and psychological well-being. To convince voters to accept a degrowing economy, moreover, an answer to the problem of jobs is essential. **Paper 7** suggests a paradigm shift rendering the employment rate no longer dependent on the growth or size of the economy but rather on social decisions.

1.8 **The structural-change strategy** (paper 8, 'Mill's Scissors')

We can distinguish between two types of economics. One is intra-human, dealing with the just and economically (Pareto) efficient distribution of resources and purchasing power once goods and services have been produced. It deals with capital, interest, wages, transaction costs, social justice and poverty alleviation. The other deals with production, with the interface between the human and natural-resource spheres. Some call it 'biophysical' economics.

Paper 8 surprised me, over the three years of its writing, by raising a question: Can biophysical economics be done quantitatively at all? Re-reading the classical economists while researching **papers 2, 4** and **6,** I kept running into Petty's Problem, a conundrum that has repeatedly plagued the history of economic thought. About 8 people reviewed the paper, some of whom were outraged, some of whom rejoiced. The questions the paper tries to answer have to do with basic economic theory after the decline of classical economics in the last decades of the 19th century. The paper's conclusion, that expenditures of the same amount do not differ in environmental impact, has far-reaching consequences.

The structural change strategy falls into the *A* category of *I* = *PAT*, urging changes in consumer, rather than producer, behaviour; because it does not ask us to

[6] Soon ready for submission is a paper together with Ramzi el-Houry on aquifer-water distribution in Palestine.

consume *less*, just differently, there is to be no decline in affluence. As with efficiency, impact is to painlessly fall. Buy a ticket for a tennis tournament (*see* **Figure 5**) instead of an airline ticket, and *voilà*. On a hunch that this might not be right, and encouraged by an earlier, ignored macroeconomic paper (Costanza, 1980), I started deconstructing the strategy's underlying concept of the *resource intensity of an expenditure.* In sum, if one includes the natural-resource inputs into labour, the differences in natural-resource intensity between 'sectors' seem to disappear.[7]

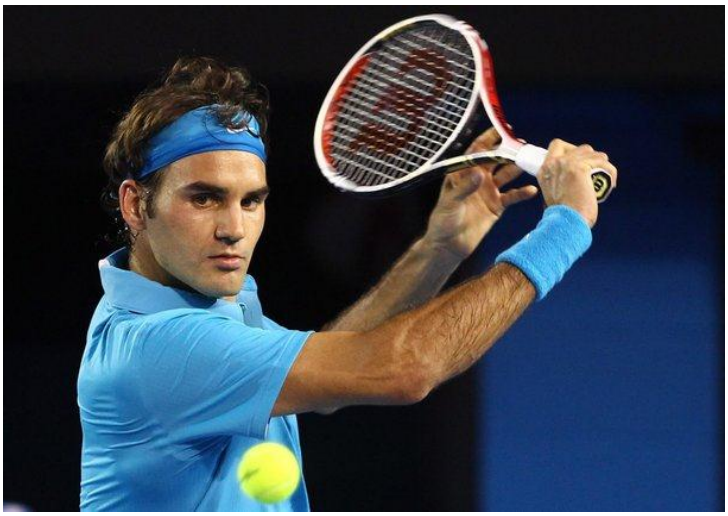


Figure 5: Spend differently, not less Does a ticket to a tennis match have a lower 'environmental intensity' than for example a car journey?

What's more, again in the same *prima facie* sense as in the rebound discussion above, the empirical evidence did not support the strategy: alongside universally attested structural change towards sectors alleged to be less environmentally intensive there has been no decrease in depletion or pollution rates. Again, only a full model of impact and the appropriate multivariate regression analyses could show whether without structural change impact would have been even greater; but the burden of proof would seem to fall on the strategy.

Models of environmental impact that endogenise population change, include feedback from impact to the right-hand factors, and study the impact-GDP relationship add to our understanding of policy choices. However, I suggest that they should not lose sight of the fundamental sustainability goal of reduced fossil fuel consumption, sustainable levels of which are based on ecological sciences;

[7] Ironically, Leontief himself did this for some decades!

models of GDP itself, by contrast, serve other purposes. We should also observe the rule of choosing from among rival theories the one that *best explains* what is empirically observed, in this case the one claiming significant environmental impact for labour inputs.

Mill had gone even further, claiming that comparing natural resource inputs with other inputs into any good or service of monetary value X is absurd; that is, Petty's Problem is not coherent and thus not a problem. Mill's analogy was with a pair of scissors, about which it is absurd to ask which blade does more cutting. Furthermore, contemplating the distinction between labour and natural resources leads to the realisation that economics' hoary distinction between goods and services can only be defined by reference to the relative amounts of labour and natural resources are in whatever is bought, yet these are incommensurable. Joan Robinson (1956) had also chuckled about the undefined and perhaps useless phrase 'goods and services'.[8]

1.9 **Population** (paper 9, 'Population matters')

Mini-epigraph: We were looking for Turkish bananas in Istanbul but found only Chiquitas, so we asked the store-owner why. He answered, *"Başka ülkelerden muz almamız lazım, bizdeki yetmiyor. Çünkü nüfus durmadan artıyor ve baksana, her yere bina yapıyoruz."*[9]

Beginning work on the *P* factor in *I* = *PAT*, I assumed that interdependencies meant that lower population is likely compensated for by greater affluence. I know of no research asking specifically this question, only a number of studies I cited or quoted in **paper 9** that regressed impact on population. I still assume that population reduction does not necessarily, or perhaps only in the short run, cause impact reduction. Smaller population size seems however advisable for humanitarian reasons in poor societies where an increase in affluence is exactly what is needed. I discovered that the topic is a taboo in richer countries but not in poorer ones where

[8] Consider the concept of 'energy services', which becomes meaningless when we realise that *every* so-called service requires energy input. Just as every 'good' requires labour input, every service requires water, but we don't speak of 'water services'. There is no way to rigorously define this ubiquitous concept.

[9] "We have to sell imported bananas, we can't grow enough here. The population grows constantly and we keep building."

poverty and resource scarcity render it obvious that problems are easier to solve with fewer people.

Two of the insights of **paper 9** are (1) a society can use *P = I/AT* to set itself an optimum population goal, and (2) to talk about population policy we need to clarify concepts like ‘coercion’, ‘compulsion’, ‘top-down’ and ‘bottom-up’, inherited from earlier debates on overpopulation, mandatory sterilisation, eugenics, immigration and eco-dictatorship. A normative conclusion emerged as well, namely that rich countries should cease subsidising child-bearing, if only on intra-generational ethical grounds. I also noticed that the literature mentions fertility twenty times more often than mortality – at a time when life expectancy is unprecedentedly rising. Demographic transition theory, itself not fully substantiated by empirical evidence, should in any case pay careful attention to mortality development.

1.10 *I = f(P, A, T)* itself

[Sections 1.10 – 1.13 cover topics in my ‘in-tray’ to which my work has led.]

I = PAT is parsimonious – a scientific blessing but at the ‘cost’ of lacking formulas for *P*, *A* and *T*. These formulas must include each of the other three factors and all sorts of other factors with exogenous lives of their own. Examples of its flexibility: (1) Co-efficients for each factor can be determined, e.g. *A = f(I, P, T* plus *cultural attitudes, Gini co-efficient, life expectancy)*. (2) Apparently non-subsumable factors can be added, e.g. *culture* in *IPACT* (Durham, 1992), where perhaps an individualistic society shows high *A* due to display consumption. (3) *Renewable* energy sources would affect *T* whenever *T* is defined as the efficiency of *non-* renewable energy sources.

That *I = PAT* is a formula rather than an ‘identity’ is seen in its original exposition by Ehrlich & Holdren (1971), where *I* is lead exhaust and one can measure each right-side factor independently. Given coefficients, we can determine desirable *I* then derive combinations of *P*, *A* and *T* yielding this result; or we can start on the right side and predict what *I* results if a right-side factor changes, *ceteris paribus*.

1.11 Caps

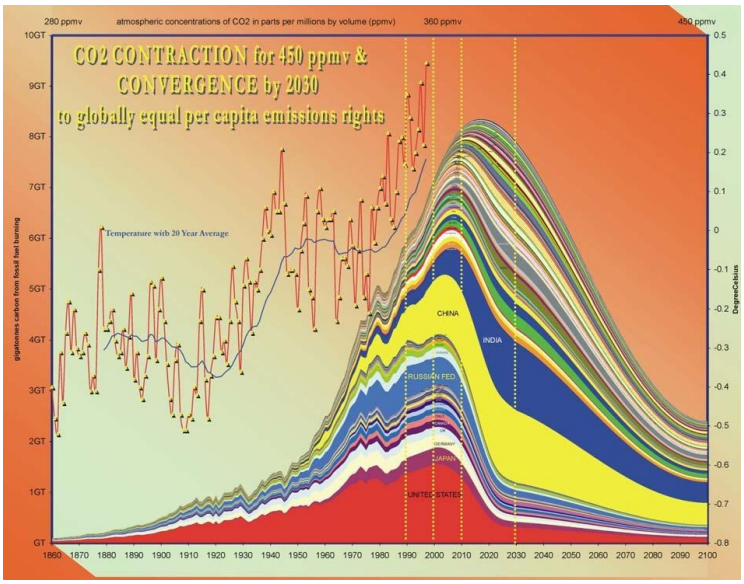


Figure 6: 'Contraction and Convergence' A graphic vision of the stabilisation then reduction of total worldwide emissions (contraction) and an equalisation of per capita emissions (convergence). www.gci.org.uk

When thinking of *fossil-fuel caps* it is useful to use the simpler model of an aquifer being overdrawn. Its users can choose paths of drip-irrigation, garden-hose bans, a higher water price, growing less, or general belt-tightening. Or they can just cap withdrawals and let each part-owner of the commons decide how to allocate his or her newly-lowered aquifer-water budget – an effective solution with low transaction costs. **Figure 6** shows one proposed scheme; permits could be grandfathered, auctioned or given away, and could be tradable or not.

I've only just arrived at the point where study of real caps systems is next on my research list. My submissions contain only a few paragraphs focussing on their (necessary) effectiveness, how they can be made politically more palatable, and how they compare with the allegedly equal but alternative route of (sufficiently high) resource taxes. (*See* Tickell, 2008.) Pertaining to the tax alternative, I've at least asked whether taxes do not also suffer from rebound: Since the government spends the tax revenue, even at the higher price of the taxed resource, isn't this equivalent to an amount of the resource *at no cost* for the tax collector? If so, the same amount of the resource might be used, simply by the government rather than the taxed subjects, meaning it is still necessary to… cap.

I unsuccessfully submitted a paper on a related issue, an epistemological analysis of the concept of 'cap and trade' showing that this phrase is a misleading conflation between the environmental tool (cap) and the *economic* efficiency tool (trade). One refers derivatively to 'carbon trading systems', removing all focus on the caps and permits that do the environmental work. If we accordingly categorise 'caps-and-trade' as an 'economic' or 'market-based' instrument, we simply make a mistake: caps are a legal, regulatory instrument, not an economic one – they are pre- or exo-market, and moreover conceivable without trading. The way of distributing permits (grandfathering, auction, per capita) arises, but this, again, pertains to the intra-generational realm of justice, irrelevant to the ecological issue of scale. (Daly, 1992)

Since the reviewers readily conceded my main epistemological points, I am now working only on *why* the discourse developed in the market-centred way it did. Free markets and individualism have for instance dominated the discourse of the last few decades. Perhaps, though, the 'market' language aids caps' political acceptance. But if less impact is the goal of our research, we should probably focus on the caps, not their tradability or their price. Otherwise we risk neglecting the level of the overall cap, exhibit A being the European Union *Emissions Trading* [sic.] System. I came to agree with a sizeable literature in the field of environmental *law* calling for 'revisiting the language' of environmental regulation. (Macrory, 2001; Rittberger & Richardson, 2003; Lee, 2005)[10]

1.12 Production functions

For anyone studying human ecology it is unsettling to see a production function with capital instead of natural-resources as the term next to labour: $Q = f(K,L)$ instead of $Q = f(N, L)$. Unless one subsumes natural resources under 'capital' the function implies there can be product without environmental inputs, which since at least the writings of Aristotle has been recognised as an absurdity. Sociology of science is needed to explain this bizarre development in post-classical economics. (Ryan, 2002; Czech, 2009) After neo-classical moves to add resources (*R*) to the

[10] The lack of interdisciplinarity between ecological economics and environmental law seems to constitute myriad missed opportunities.

K,L function (Solow, 1970, pp 33-38), ecological economics developed *K,L,E,M* functions adding energy and materials.

Figure 7: Nature, Labour, Capital Three factors of production as depicted by *Mill Stream, John Constable (1776 – 1837)* at the time the classical economists wrote.

Classical economics insists that this is wrong: the two basic factors of production are labour (*L*) and natural resources (*N*); capital (*K*) is a subset of *Q*.[11] A person might usually use tools and machines to transform raw materials into something with perceived utility, but only a person acting on materials, without tools, can make the first tool. In the original version stated precisely by Cantillon (1755), which survived through Marshall (1890) and, barely, Schumpeter (1912), product depends on *quantities* of land and labour and their *productivity:*

Q = f(L, Q/L; N, Q/N)

Productivities depend partly on the capital subset of product and partly on knowledge, skill and organisation.

In unpublished work I've recorded the development of this function since Petty and the various related debates; I would relish testing it against rival functions in spite of the necessity of quantification using monetary units (*see* **Section 1.8**). Forgive my apodictic tone, but it is tempting to start again with a production function that is epistemologically impeccable: *the land, labour function*. As with the right-side terms

[11] James Mill proves the reducibility of capital by arguing *ad absurdum*: the first tool would assume an even earlier tool, and so on. (1824, pp 17-18) Anthropologists tend to agree. (Herskovits, 1940, p 303)

in *IPAT*, the four elements of land and labour and their productivity co-efficients could then be endogenised.

1.13 Scale, allocative justice, allocative efficiency

Another paradigm, or taxonomy, has turned out to be indispensable for me, namely Daly's (1992) tristinction between the economy's scale (throughput's 'Plimsoll Line'), ethical decisions about the initial distribution of economic product, and welfare decisions about the overall level of utility or the size of the pie to be distributed. Something known as the Tinbergen Rule says that policies must fit specific goals: If we're after greater affluence, we have to do X, if we want to conserve resources we have to do Y, and if we want more economic equality we have to do Z. We otherwise for instance vote down a petrol-tax increase because it hurts the poorest. Only later should we discuss serendipitous policies that kill several birds with one stone.

1.14 Conclusion of Part 1

My main interest has always been *policies* for the conservation of natural resources. Even allowing for efficiency increases, we must eventually abandon the 'cowboy economy' for the 'spaceship economy' – in the terms of Kenneth Boulding's beautiful and seminal 1966 essay. It is more humane to degrow to a steady-state economy in an organised, relatively slow, democratic manner. Developed out of this interest and these assumptions:

1. That space and natural resources are limited is axiomatic, but also limited are increases in the amount of goods-and-services to be gotten from a given amount of resources. Only in a metaphorical sense can efficiency increases be regarded as 'equivalent' to finding more resources. Moreover, the energy investment in energy production – EROI or 'energy return on (energy) investment' – should be foremost in our minds.
2. Resource efficiency is merely a ratio, with resource amounts in the denominator and physically defined output (lumens, ton-kilometres) in the

numerator. A change in this ratio tells us nothing about the amount of resources consumed – because it tells us nothing about the number of units or output. Yet this is the environmentally relevant magnitude.

3. Social scarcity is different from natural scarcity (always taking account of increases in EROI and production-process efficiency increases). It is a deliberate, legal capping of the yearly extraction of a resource (or type of pollution). Examples: planning laws, restricted parking spaces, restricted fishing, caps on fossil fuels.
4. The *I* = *PAT* tool is indispensable for categorising and prioritising policies aimed at controlling the scale of the economy defined in terms of space and material-energy throughput.
5. Sustainability requires many disciplines: biophysical sciences first and foremost, then economics, psychology, anthropology, history and aesthetics. My little research corner neglects most of these areas.
6. The most important 'development' of my work has been from the individual/household/firm approach to the *political* approach. Sustainability requires rules, laws, democratic political decisions. Even worse: unless we rescind globalisation, the phrase 'Think globally, act locally' should make way for *'Think globally, act globally'*.
7. Due to the difficulty of getting agreement on global action, combined with an unavoidable population size of around 10 billion, my faintly optimistic feelings have changed into pessimism.

Turning away from my work's development, **Part 2** criticises and comments on the papers in detail, one by one.

Part 2 Detailed corrections and emphases

I would like to go through some mistakes, omissions, open questions, strong points and links between the papers; the papers' page numbers precede the comments.

2.1 Rae & Veblen (paper 1)

Paper 1 seems to be an original contribution to the field, but it's a tiny field even if Mandeville, Smith, Say, Rae, Bellamy, Foley and Veblen find room on it. The last 30 years have seen a lot of literature on the sociology of consumption, and the insights do, I believe, shed light on environmentally problematic over-consumption. Some recent literature, however, has not realised it was re-inventing the wheel.

1) 766t (top) Rae's analysis of capital or 'instruments' deserves more space. He assumes that products or 'events' are commensurable in labour hours, then distinguishes between the efficiency and durability of a capital good or 'instrument'. His third factor is the events *embodied in* the capital good, again measured in labour units. A machine wouldn't be made at all if it could not, before it wore out, produce more 'events' than went into its making; the machine would not be 'brought to market' at all.

We can measure all three things: How much labour or equivalent events, measured in labour units, was consumed by the instrument's making? How many years pass before it produces twice this amount (its 'payback time', to use one of today's equivalent terms)? The ratios of these two quantities for each instrument are then found and ranked. A 'quickly' returning instrument would produce in 1 year double what it cost to make it. These are Category *A* instruments, and so on up to 'slowly returning' Category *Z* machines needing 26 years to double the amount of events embodied in them. Instruments can wear out (be 'exhausted') before they double the investment, so the number of years of their durability must be controlled for; the ratio for its ranking could however still be worked out by measuring how long it *would* take to double its investment even if it wears out beforehand.

Rae compares France and England. The former likes luxury, 'mode and fashion' while the latter sticks to 'comfort and convenience'. He describes this by saying that England has 'wrought its instruments up to orders' approaching category *Z*. The middle term of this syllogism is that it shows the English are not so frivolous as to

avoid making instruments that embody a whole lot of labour and material inputs, instruments lasting a long time; the French don't bother.

2) 767t Rae is normatively on the side of low social discount rates, against too much frivolity, and loves capital goods. One society decides to macadamize its roads, another does not; but macadamization is *good.* He is on the side of inventiveness, caring not only for oneself but one's children, and caring not only for one's children but one's grand-children – sentiments akin to the reasons why sustainability has become an issue.

So we have a relationship between profitability (produced events/invested events) and productivity (produced events/time). (Rae 118-119 & 766m,b) And we can explain a society's desire for more slowly returning instruments only in terms of morals and psychology. (Rae 118-129) We have a glimpse of why J.S. Mill, Eugen Böhm-Bawerk, Joseph Schumpeter and many others have praised him. 765 Such detail is missing from **paper 1.**

3) 769b (bottom) - 770t This is the hypothesis most relevant to understanding the quest for affluence over and above mere needs that is at war with sustainability, and thus I should have referenced Low & Heinen, Morrison and Jackson (*see* the paper's bibliography) to illuminate the concept of *sexual selection*. I should also have paraphrased Darwin's theory of sexual selection – intra-sexual selection akin to natural selection and inter-sexual selection akin to artificial selection – in two sentences.

4) 770b & 779tm (top-middle) It would be good to cross-reference these two passages, which mention the same theme, the desire for novelty for its own sake, which I moreover wrongly call 'nonexplanatory'.

5) 771m I should have explained *why* the concept 'market failure' can be seen to apply to conspicuous consumption, even if today I doubt its applicability to this case.

6) 772m I should have given Bellamy's *list* of items of societal waste: the military; tax collecting; 'judiciary, police, sheriffs and jailers'; the 'criminal class'; the 'lame, sick and debilitated'; 'financial operations of all sorts'; small households; transporting, distributing and repeatedly handling goods; 'private enterprise' in general entailing 'competition' like on a 'battlefield'; 'mistaken undertakings'; business crises (cycles

of 5 -10 years); idleness of a lot of capital; advertising (*cf.* Veblen's hate of advertising).

7) 772mb The 'organized matter' Darwin is talking about (in 1871) seems to be simply *food* described in terms of the 2nd Law of thermodynamics.

8) 773m Cronin's detailed treatment in *The Ant and the Peacock* should be referenced here. The passage at 'status-driven pecuniary utilities' is not intelligible. It means only that we have to look at (often dire) costs as well (*see* **Figure 8**), never only at benefits ('utilities'), and then at cost-benefit *ratios*.

Figure 8: Bowerbirds Inter-gender sexual selection explains some consumption.

9) 774m p 97, not p 96.

10) 774mb It is good, I think, that **paper 1** points out there is a deeper, entirely different question outside the scope of economics, namely why we want status at all. Perhaps even sociology takes this more as an axiom than an *explicandum*.

11) 775b Bellamy (pp 97ff, 126-128) was as explicit as Rae on display, but gives a much shorter rendering. Veblen took more from Bellamy than I indicate.

12) 776b I should have footnoted that Veblen here uses 'accumulation' as consumption – acquiring goods that advertise one's wealth – whereas Rae uses it as capital formation, making 'instruments'.

13) 779tm,m I should have made it clearer that Rae is identifying three distinct types of utility: ordinary survival/health/comfort; beauty or pleasure; and prestige or what derives from 'rarity' (Veblen's 'pecuniary superiority').

14) 781m In aesthetic theory neither Rae and Veblen were subjectivists, or 'positivists', like Santayana. They *look behind* both economic purchases and beauty rather than taking them as the starting point of the disciplines of economics resp. art theory.

15) 782t To manage Veblen's use of as many synonyms as possible for one and the same thing (his conspicuous production of words), I should have referenced 'ornamental' and 'ceremonious' as well – the more so as the secondary Veblen literature often chooses the latter as the key one for this half of Veblen's basic dichotomy between the useful and the merely ostentatious (which motivates robbery and fraud).

16) 784tm I should have pointed out that Tilman is wrong in not seeing that Veblen was laughing at himself in using the 'latinates and mordant wit' for their 'ceremonious', non-functional beauty.

What makes this paper important to me is that most writing in the field of sustainable consumption remains within the discourse of systems and -isms: capitalism, consumerism, growth fetishism, advertising, individualism, and infrastructure systems, all of which are said to stand in the way of people's voluntarily downsizing to sustainable scale. We must change the system or the -ism. I am convinced that such social or sociological categories are fatally shallow. Until we quit treating them as *sui generis* (Kroeber, 1915, 1917; Geertz, 1984), and ask *why* these systems and ideologies exist and dominate (Bloch, 1977; Barkow et al., 1992; Brown, 1992), how can we work for political majorities to change them? Society, culture, or learning are said to cause behaviour, but what causes society, culture, and what is learned?

To understand the 'unsustainable ape' we need evolutionary psychology.

2.2 **Jevons' Paradox** (paper 2)

In the 1860s Jevons dealt with Britain's perceived looming coal scarcity, refuting the popular position that 'economy' (efficiency) in using coal in production will avert shortages. The same issues returned in the 1960s. Jevons' methodological contribution is that it is pointless to approach the relation between efficiency and consumption (of an energy resource) from a geological or engineering perspective: What matters are *P* and *A* in *I* = *PAT*. The policy world is finally accepting Khazzoom's 1980 proof that input consumption cannot decrease proportionately with input intensity. Because we desire painless solutions we place the burden of proof on demonstrating rebound rather than demonstrating savings. Due also to lack rigorous definitions and microeconomic methods, estimates of total rebound today vary by more than an order of magnitude. *The Coal Question* contains wisdom.

1) 9 **r (r**ight column) b The opening paragraph's assertion that "greater efficiency… must raise… environmental impact" misleads by failing to distinguish between Jevons' *backfire* position (rebound > 100%) and the more modest conclusion that post-efficiency-increase demand for the more efficiently used resource is equal to or just below 100%. Of course, modelling the observed increase in energy consumption is a valid academic pursuit that can profit from Jevons' insights, but the backfire paradox, however fascinating, is a wild goose chase that has tied up research interest..

2) 10 **l (l**eft column) b footnote 2 Sanne's definition of rebound includes *organisational* (labour) as well as technological efficiency, and like most researchers I missed the opportunity to broaden the discussion to cover *labour* and *total-factor* efficiency. Nobody doubts that demand for labour and capital increases as their productivity rises, yet with natural-resources the opposite is expected or hoped for. Another topic for the sociology of science thus crops up. **Paper 4** has a fuller discussion of fears that labour-efficiency rebound is less than 100%, i.e. that unemployment chronically rises.

3) 10 l tm I should have more precisely written that it is *energy input* consumption that I was regarding as proportional to or equal to impact in *I* = *PAT*, not the goods-and-services consumption that is the numerator in the *A* and *T*-efficiency factors.

4) 10 l b footnote 4 Like too many others I relegated the efficiency elasticity of *supply* to a footnote. I touch briefly on this in **paper 3** but only recently has this gaping hole in rebound theory been better investigated. (Turner, 2009; Wei, 2010)

5) 10 r mb Again, is it backfire or merely very high rebound that is being attested? The phrase 'more people consume more' is misleading. The rebound literature in general often similarly fails to distinguish between 'more than' before the efficiency increase (rebound > 100%) or 'more than' what engineering calculations and some micro-economic extrapolations lead us to believe (rebound 0 – 100%).

6) 10 r b-11 l t The sentence beginning 'If the ratio…' seems accurate, but too dense, and the word 'demand' in economics is ambiguous: it can be either the quantity demanded *X* (in physical units) or *X* times price per unit (in monetary units). Here it means the former. An example would have helped: Say the pre-change output-input ratio is 100 ton-kilometres (tkm) per **10** megajoules (MJ) and 1000 tkms are 'consumed' worldwide pre-change. Pre-change MJ consumption is then 100. Say the post-change output-input ratio is 100 tkm/**9** MJ and the post-change amount of tkms is 1,111 tkm. Input consumption then remains 100 MJ. The possible 'engineering savings' were 10 MJ, but they were not realised; the 'direct' (sector-specific) rebound was 100%.

7) 11 l b footnote 7 There are misprints, mainly in the sentence beginning 'Now, the decline…', where *A'* should be simply *A,* and just after that *I"* should be *I'.* The journal editor declined to print a Correction.

8) 12 r m & 13 l m Given his thought context (see **paper 4**), Jevons thought his "paradox" easy to resolve. It now fascinates me that it was ironically the 'marginal revolution' of Jevons himself that led to today's focus on micro-economic approaches and in turn rebound research's penchant for trying to build total rebound on the initially zero rebound of the non-economic, engineering approach. Without better energy-consumption models that identify the direction of the causal arrow of energy efficiency, macro-economic approaches to rebound remain difficult.

9) 13 l mb, 15 r t I should have explicitly covered Jevons' insight that only absolute indolence, consumer satiation and population stabilisation could result in zero rebound. The first two are advocated by 'sustainable consumption' advocates within

ecological economics for richer societies. Jevons would have found this (and population non-growth) unrealistic – as we also should today, especially when we include poorer societies in the investigation.

10) 13 r m, r b & 14 l mb Jevons' mention of "new activity in most other branches" is sketchy, yet this is what could explain backfire (the 'Khazzoom-Brookes Postulate') as opposed to rebound of only 100%. For this subject we need the concept of society's *production possibilities frontier*. *See* **Figure 9**.

Figure 9: Litter Litter is a luxury enabled by expanding production possibilities frontiers, with aesthetic consequences.

11) 14 l tm Here Khazzoom is arguing not for backfire but for indirect rebound, which Jevons likewise clearly describes. This should not be conflated with the backfire-vs-rebound distinction.

12) 15 l m & 15 r mb Again, although Jevons' backfire theory is the best and most parsimonious explanation of the enormous increase in input consumption during the last 200 years, the assumptions about consumer insatiability and reproduction above replacement rates should be made more explicit. Efficiency's effect on population, in particular, is sorely neglected (*see* **17)** below). Rebound theory depends crucially on the concept of the *efficiency elasticity of demand* (for the more efficiently used resource), implicit in Jevons and explicit in Sorrell & Dimitropoulos (2008, p 637). Yet without behavioural assumptions we cannot know either of the two components, the efficiency elasticity of price (the supply-function *shift*) and the price elasticity of demand.

13) 15 r b footnote 14 Veblen was saying that consumption does not even decline at higher incomes – challenging any macro-economic Engel curve. As laid out in **paper 1**, this behavioural assumption supports the high-rebound hypothesis, but I missed the chance to continue the links from Mill (the *only* author Veblen cites in 400 pages) through Jevons to Veblen. Almost no rebound research today finds it necessary to consult earlier geniuses; econometric tools are everything.

14) 17 l mb Not even in **paper 4** did I give this insight of Say the place it deserves in explaining both economic growth and input-consumption growth – even if Say's argument concerns the other irreducible factor of production, labour.

15) 17 r m The phrase "pounds of coal per horse power per hour" is perhaps more understandable if it reads "MJ per kWh". Or: How many *energy* joules does it take to produce a certain amount of *work* joules for sixty minutes?

16) 18 l m It is amazing that in the debate, such as it was, between Mundella and Jevons practically all of today's rebound concepts and methodologies are there.

17) 18 r t, tm Jevons himself noted that with coal & increasing efficiency the English were growing "rich and numerous", so I should have written "… to consume more *and multiply*." The endogenisation of population size attested by Jevons remains under-researched (Giampietro, 1994); population's exogeneity and its status as a taboo subject are closely related. **Paper 9** tries to reopen these issues.

18) 19 r t That "costs" are down a mere 1% is incorrect; it should be "prices" (of the goods, under perfect competition).

19) 19 r mb In the debate over caps vs taxes this 'eco-tax rebound' means perhaps merely free resources for the tax-collecting entity, in which case caps (on government consumption of the resource) would still be necessary. Then we might as well just cap in the first place.

20) 19 r b The interdependencies I nebulously noted led to **paper 6**.

The bittersweet subtext of Jevons' book is the author's knowledge that the party can't last. The book's epigraph is Adam Smith's words on the gloominess of the stationary and declining states. In linking coal to our feelings, the book is an important cultural document.

2.3 **The sufficiency strategy…** (paper 3)

In a world with two people, if one voluntarily decided to lower his or her consumption of coal from a commonly-owned coal pit of limited size, what would happen? The coal momentarily left in the ground would stay in the ground only if the other person made no change in his activities – was warm enough, heated enough rooms, didn't want to use any steam engines or small smelters for new economic activity, and didn't reproduce. The first person's 'sufficient' behaviour is thus a necessary, but not sufficient, condition for conserving coal.

The sub-discipline of *sustainable consumption* addresses the few wealthy, not the billions desiring to avail of fossil fuels to raise their health and living standards. Millions of people in Turkey can now afford to fly, and they fly. I believe that before **paper 4** the sufficiency rebound had not been identified, yet a voluntary leftward shift of the macro demand function *must* move fuel prices downwards.

1) 770 r b footnote 1 Reducing sinks to sources would be parsimonious, but whether it is accurate is a delicious question for the future.

2) 770 r b Technological efficiency is the ratio of goods-and-services to input – inputs which are the same as impact. I should have noted the larger problem of aggregating both *I* and *T* in *I = PAT.* Turvey (1966, pp. 48-49) and Ekins (1991, p. 244) for example offer partial lists of impacts whose aggregation in physical terms is impossible. One should neither skip over this problem nor unquestioningly adopt monetary metrics.

3) 771 l t The depiction of *IPAT* is fuzzy. *P* x *A* gives the total of goods-and-services, e.g. 10 people at 5 tomatoes per person per week = 50 tomatoes; the *A* factor is a quantity of goods-and-services over the denominator of 1 (one person). *T* then shows *X* litres of water per (one) tomato (intensity, the inverse of efficiency which would be one tomato over *X* litres of water). Taking intensity, 10 people x 5 tomatoes x 3 litres = 150 litres, the impact.

4) 771 l m (*also* 772 l m & 778 l t) It muddles the issue if we don the hair shirt, use the imprecise terms 'North' and 'South', and somewhat arrogantly claim without proof

that “Third World” countries are “imitating” the north. These criticisms of the sustainable-consumption literature deserve more attention than I gave them.

5) 771 l mb, 775 b, 776 r m I need to do much more work on the effects of shifts of demand curves on shifts of supply curves. It is for instance probable that lower prices render initially steep supply functions more elastic (flatter) *over time. S*upply curves of any slope moreover might shift rightward only after a delay, entailing some lowering of the *rate* of consumption of the resource used more efficiently or sufficiently.

6) 772 l t, mb, 772 r t, mb Goodland and Daly’s phrase “impact of each unit of consumption” made me ask the question of the coherence of this ratio, and I started toiling on **paper 8.**

7) 772 l m The normally undefined term ‘overconsumption’ (exception: Princen, 1999) raises many questions, mainly whether the consumption is ‘too much’ for an ecologically sustainable society, or for the individual (**Figure 10**), as when it is claimed that the marginal utility of consumption levels off to zero, after which it is ‘over’-consumption and individually harmful if only because it means more work effort.

Figure 10: A small, good thing Quality vs. quantity of life.

8) 772 l m, 779 r tm That “affluence and overconsumption do not increase welfare” is an early example of the literature’s overstatement of the case that money can’t buy you happiness. The literature abounds with sloppy renderings of the Easterlin Paradox, which as **Figure 11** shows only says that *marginal* benefit decreases. Furthermore, why we keep working, earning and consuming when the benefit/cost ratio is so low

raises the questions ‘Why are we so stupid’ addressed in **paper 1**. Or perhaps the premise equating utility and happiness is challengeable.

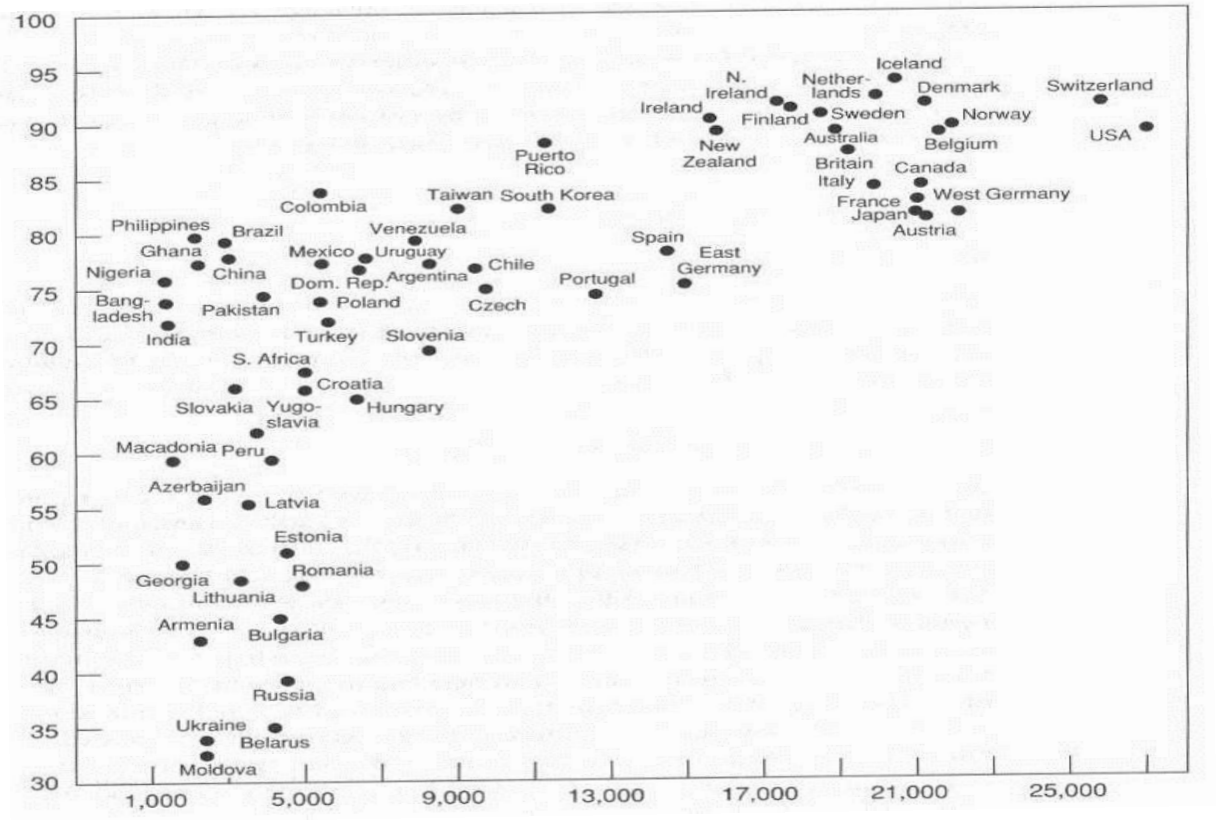


Figure 11: Still positive elasticity As of a certain income, *marginal* increases in happiness decline, but they do not disappear. (Source: http://www.sd-commission.org.uk/data/files/publications/prosperity_without_growth_report.pdf , p 33)

9) 773 r m I once again conflate backfire and 100%-rebound.

10) 774 r b Much sustainable-consumption literature deals with conspicuous consumption, or what the psychological limits to consumption might be, issues raised in **paper 1**.

11) 775 l m, r tm Here I again conflate growth in input consumption and growth in the consumption of goods-and-services.

12) 775 r tm Like most research, this paper lamentably focuses on energy inputs to the neglect of water, space, phosphorus, other species, and human labour.

13) 775 r m I should have written “leaves 20% of their purchasing power *for fossil fuels* unused.”

14) 775 r m That the consumers must "work less" is not always the case; I should have said that they by definition spend less, so they could also bury this income and use it later. Over time they would probably work (produce) less.

15) 776 r mb I can't explain why I inserted "(despite?)" into the sentence.

16) 777 r b The paragraph's cryptic last sentence is trying to say that the equivalent of the sufficiency rebound is widely recognised at the international rather than interpersonal level: if a country voluntarily reduces its fuel consumption (within 'Kyoto' or the EU ETS for example), then others increase theirs, leading to competitive advantage[12] and 'leakage' of emissions to more profligate nations. The phrase "democratically mutually coerced" is also muddled, a question I treat more rigorously in **paper 9**. All laws coerce, so the term "mutual" is redundant.

17) 778 l m, r tm, r m "Traditionally ethical reasons of human equity" means *intra*generational ethics: fairer material-welfare distribution, fair start in life, feeding and housing the poor through charity or the welfare state, remaining within the calculus of present people rather than the 'longest run' that includes all future people. The *inter*generational calculus is here called "the newer ethical grounds of environmental concern". The quotation from Brown & Cameron similarly struggles with this vocabulary. At 778r m I think I got the vocabulary more or less right.

18) 778 r t, m If I transfer some of my purchasing power to a poorer person, this is unmitigatedly good in terms of intragenerational ethics; but if concerted efforts in this direction lead to population increase some unintended consequences must be faced. *See* **paper 9.**

19) 780 l m, r mb This distinction between exhortation from the green pulpit and setting the goal at winning 51% of voters has become central for me. The theme reappears in **papers 6 & 9**.

20) 780 r b $I = PAT$ is not an "identity". 781 l tm A_2 and A_1 are in the wrong order.

21) 782 l t Friends have objected to the assertion that the concepts of North and South are not relevant to the consumption discussion. I was trying to say that the

[12] Unless the WTO is scrapped or one otherwise restricts trade between voluntarily frugal countries and the rest.

relevant concepts are ‘rich’ and ‘poor’, and that ‘North’ and ‘South’ are only code, a misleading shorthand.

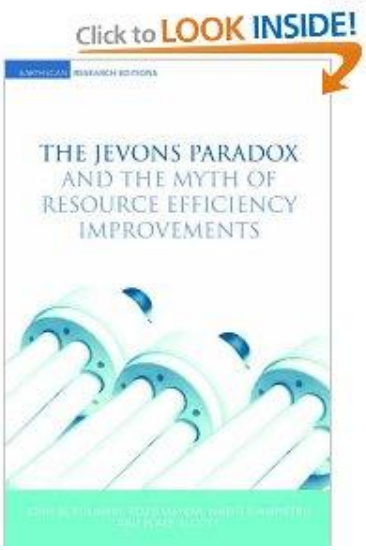
The Zeitgeist *went against government regulation and towards voluntarism at the same time environmental problems rose into consciousness. The sufficiency strategy aims at individual and firm-level change in a-political contradiction to the political, ‘commons’ nature of the problems.*

2.4 **Rebound in classical economics** (paper 4)

I suppose the only lesson from this paper is that our choices of environmental policies, and even methods, depend on current dominant economic theory, or even political ideology. Hotelling came at the end of another era:

> The method ordinarily proposed to stop the wholesale devastation of irreplaceable natural resources, or of natural resources replaceable only with difficulty and long delay, is to forbid production at certain times and in certain regions or to hamper production by insisting that obsolete and *inefficient methods* be continued. (1931, 137, *emphasis added*)

Hotelling thus accepted without question that rebound is 100%, but it is hard for us to move from ‘economics’ back to the ‘political economy’ still extant in 1931. We innocently ask, How big is rebound? But our definitions and initial approaches are embedded in premises very different from those for example of classical economics.



2.5 **Rebound concepts and methodology** (paper 5)

This article doesn't succeed very well in disentangling the three variables 1) technological efficiency, 2) energy consumption (throughput growth) and 3) economic (GDP) growth. The problem is that economic growth, i.e. an increase in number of goods-and-services, is often treated as an independent, causal variable. Of course there are causal economies of scale, but an exogenous 'wealth of nations' factor would have been inconceivable to classical economists; it was the thing to be explained.[13]

It is at any rate inefficient to first investigate efficiency's effect on economic growth then measure the degree of 'decoupling' of economic growth from input-consumption growth. Within this same 3-factor paradigm we have suffered endless tests of the Environmental Kuznets Curve postulate – a discourse that doesn't even put *absolute* quantities on its vertical axes, but instead the environmentally irrelevant metrics of impact *per* capita or *per* unit of GDP.

1) 370 r mb Showing that increased technological efficiency increases the number of goods-and-services begs the question of whether it increases the amount of *inputs* into this increased quantity of goods-and-services (the environmental question). For this we need a full model. The literature likes the picture of a race between efficiency and scale effects. This passage is not written precisely enough.

2) 371 l m This argument from the 'income effect' isn't this simple. We should perhaps rather think in terms of **Figure 1**, where there is a societal (macroeconomic) income effect, or in terms of an outward shift in the production possibilities curve. The fallow amount of the resource is like an increase in our resource budget, or an increase in goods-and-services we can 'purchase' with the *same* budget. This is reasonably coherent. But in terms of money there is a trap: Whatever money is left in the ***consumer's*** pocket at the end of the month is no longer in the *supplier's* pocket, and the effects even out. Suppliers, after all, also spend and demand in the form of salaries, profits and investment, all entailing resource-input consumption. (*See also* **papers 4** and **6**.)

[13] Petty treated population and infrastructure *density* exogenously, not absolute size, though they are related, and the concept of the extent of the market flirts as well with exogeneity.

3) 371 l m If we ask after consumers' marginal expenditures, we see that they can be for anything, not just more of the goods-and-services now rendered cheaper (direct rebound). However, the notion that rebound is low because the marginal expenditure tends to be in a less-resource-intensive *sector* (one doesn't drive the Prius much more, but rather buys more books or concert tickets) is criticised in **paper 8**.

4) 371 l mb Again, the key to the rebound puzzle has something to do with the energy "freed", enabling Jean-Baptiste Say's additional output that 'nobody pays for' quoted at 372 l t.

5) 371 l b I do not now agree with our assertion that capital costs affect the size of rebound. Rebound measures only the percentage of the fallow resource that we consume but that *could be* saved if we were lazy and satiated and didn't reproduce. This is not dependent on the energy costs of the technological efficiency change itself, energy combusted before the arrival of the rebound question, which *begins* after the technological efficiency change. The embodied energy costs of the new, more efficient equipment must be deducted from engineering savings, not rebound. Our term 'cost-neutral' in the last sentence at 371 r b somewhat corrects our false statement. The physically-measured average efficiency change over the entire equipment park is all that is relevant for reboundology.

6) 372 r mb The ludicrous estimate of 0% rebound for residential-appliance direct rebound is found in Greening et al. (2000). This is ludicrous because only direct rebound is considered, ignoring sources of rebound such as 1) purchases of *more* white goods and 2) purchase of white goods with greater size or cooling (freezing) capacity – omissions that must be criticised in the strongest terms. Similarly, the 'nano-study' of de Haan et al. (2006) measures the number of cars in the fleets of households who recently bought a Prius, but not the number of kilometres driven. Such limited studies have no scientific value.

7) 373 l m, 373 r mb Contrary to the claim here, the numerator in the efficiency metric, GDP, seems after all to be a good proxy for total physical goods-and-services produced and consumed, in spite of the fact that only those are included that are sold and bought. We could add some percentage to it, perhaps 10%, for producer-consumed goods and those given away or bartered. But since a global time series

would regress *change in* energy consumption on *change in* GDP/energy, this is not a drawback. (Alcott & Marangi, *under review*)

8) 373 r m In the meantime I think TPES is the relevant metric, if only because environmental policy has an interest in reducing energy consumption of both sorts, renewable and non-renewable. Whether to include nuclear fission, non-human animal work and food for human metabolism is still debated.

9) 374 l t It is now widely accepted that in some sense energy (any natural resource or 'ecosystem service') contributes a much larger percentage to economic growth than its percentage of the monetary values in the national income accounts and input-output tables (Cleveland et al., 1984; Kümmel et al., 2002), but I now doubt that this vexing question is relevant to natural-resource rebound study, which takes energy consumption, not GDP, as dependent variable and motivation. *See* **Figure 12**.

Figure 12: Combustion, energy slaves The dependent variable of environmental-impact research and the major dilemma of human ecology.

10) 374 r m Item 3) touches on the sorely neglected effect of technological energy-efficiency increase on *energy* prices (rather than goods-and-services prices) in the rebound literature. Of course much else affects energy prices, so teasing this out is difficult.

11) 374 r m Items 3) & 4) include the view that "Ultimately, what consumers want…" is energy services. But the concept of energy services makes no sense since every

service as well as every product needs energy inputs. One does buy *energy*, either literally or embodied.

12) 374 r m Item 5): The question of direct rebound's relevance in measuring total rebound deserves a separate paper. Can one 'build on' individual direct-rebound amounts, adding indirect-rebound amounts, or is total-rebound estimation impossible using microeconomics?

13) 374 r mb Item 7) is a crass understatement of the problem of using country rather than world data. If country or country-group data are taken, either leakage must be measured using environmental input-output analysis (see **paper 8**), or – in my opinion more reasonably – energy consumption must be treated as strictly proportional to GDP. At world level these problems don't arise.

14) 374 r mb The attempt in items 8) and 9) is once again to point to the necessity of measuring consumers' reactions; these depend on their degree of saturation with goods-and-services, their cost-benefit ratios (e.g. work vs enjoyment of purchases) and other things. We need psychology, history, and anthropology.

15) 375 l t The arguments made in **paper 8** would refute the sentence "Unfortunately,… resource-intensive…". *See also* **3)** above.

16) 375 l tm I delved into the analogous study of labour-efficiency rebound in **paper 2** and in more detail in **paper 4**.

17) 375 l m Item 12) and the last paragraph are trying once again to comment on the psychology of how economists, engineers, historians and anthropologists look at efficiency. The sociology of science ('psychoscience') would study philosophical and emotional assumptions made by all of us that bias our approach and outcome.

Given the lack of clarity on definitions and methods, and given that only total rebound is environmentally relevant, I was not motivated to do empirical research in this dominant tradition.

2.6 **Caps** (paper 6)

Paper 6 makes the embarrassingly simple point that to save a resource a polity can do it directly, putting legions of academic policy-designers out of work. Think of river and aquifer water, and alpine meadow grass, that have been capped and distributed for centuries. Wartime energy rationing gives us further experience.

But wiping out half of fossil-fuel production has obvious consequences for affluence unless there are simultaneous and successful efforts to increase efficiency and the use of solar-based energy, and decrease population. These consequences are fruitful areas for academic study.[14] Scale issues are by definition solved by the caps, and affluence-retention will happen decentrally as people enact the Holy Trinity of efficiency, renewables and sufficiency, the indirect strategies located on *IPAT*'s right side. Academic work should compute how much affluence is salvageable (at what population level) under a halving or more of the throughput of various biophysical subsystems.

1) 553 l t The categorisation of consumer efficiency is not as clear as I make out, but I would still lodge it within *T* because it is not frugality, not 'doing without'; there is no loss of utility except that one must alter some habits.

2) 553 l tm Whilst end-of-pipe measures do not affect depletion, but only emissions, *T* can also be expressed with an emissions metric.

3) 554 l m I write that lower *A* lowers *I* only if *P* and *T* stay the same, but should have also mentioned the topic of **paper 3**: $A_1 = f(A_2)$ where A_1 and A_2 are two different sets of people. I do describe it better in Section 3.2.3.

4) 554 l m I should have defined "demographic transition" theory which holds that rising affluence causes lower mortality (raising population size) and somewhat later lower fertility (lowering population size), population's ending up lower and more stable than before. As I note in **paper 9** the theory does not yet integrate current and predicted falling mortality well enough.

[14] Cuba after its desertion by the Soviet Union provides a case study of reactions to a decrease in throughput.

5) 554 r tm The *ceteris paribus* condition is important to the claim that higher population lowers affluence; it probably holds for very poor countries in the medium run. The second-order effect where higher population lowers *T* (raises efficiency), attested by Simon (1981) and less universally by Boserup (1981), is criticised in **paper 9**.

6) 554 r mb "inefficient" should of course be "in efficient"!

7) 555 l m Greater hectare productivity has enabled us to take some land out of agricultural use for golf courses, shopping centres and nature reserves. Thus the more accurate claim is that we don't take land *net* out of food production, but this lacks empirical support requiring a model of hectares in food production regressed on both agricultural productivity and population.

8) 555 r m Item 1): Work under review (Alcott & Marangi) starts with world data on efficiency defined as GWP/joules and TPES as joules, then attempts various regression analyses. We note, though, the epistemological situation: Time series show a very high coefficient of correlation, as shown in the two graphs in **Figures 13a** and **13b**. Should policy-makers wait for academics to find perfect models for multi-variate regression analyses? The precautionary principle would advise not thus waiting. We only need to know the direction of the causal arrow, and perhaps *no* Granger causality is what is predicted by the hypothesis that rebound is 100%.

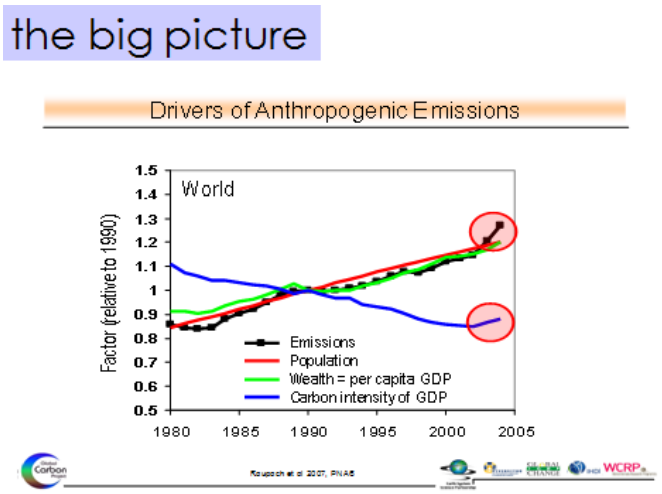


Figure 13a: Efficiency and consumption in lockstep The black and blue lines – for energy consumption and the inverse of energy efficiency – have more or less the same slope.

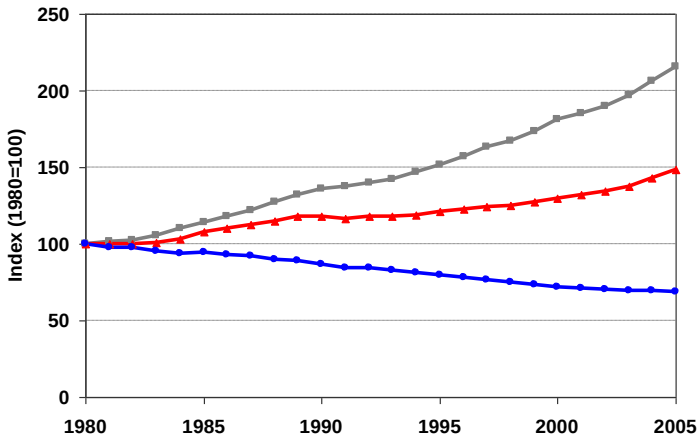


Figure 13b: The input-efficiency/input-consumption race A generic graph showing world GDP in grey, energy consumption in red, and energy intensity in blue. If not efficiency increase, what does, then, cause consumption increase?

9) 556 l t It helps me to return again and again to the epistemological distinction between necessary and sufficient conditions. What are we to do once we see that to solve the *environmental* problems of depletion and pollution, the Holy Trinity are not *necessary*?

10) 556 r mb Here I at least identify the choice between upstream and downstream caps; upstream caps (at the mine- or well-head) entail lower measurement and enforcement transaction costs. But this issue needs another whole paper. (*See* Tickell, 2008.)

11) 556-557 It might even be original to ask whether *environmental* policy must concern itself with *economic* efficiency at all. On the level of gaining political acceptance, yes; but in the world of cause and effect, no. Discuss.

12) 557 l t & 558 r b This cart-and-horse question likewise needs better exposition.

13) 557 l b The criticised model includes the structural change strategy, examined in **paper 8**.

14) 557 r b footnote 11 I should have included these points in the main text: the criticised model is not clear about the direction of the causal arrow starting at exogenous efficiency increase; it makes the counter-factual, hypothetical, purely theoretical claim that resource consumption *would have* gone up even more without

efficiency increases. What's more, it is in my opinion mistaken to treat GDP and population exogenously. *See* **paper 5**.

15) 558 l-r Calculating the effects of caps on affluence and population seems important in the intragenerational, political sense, to give a realistic idea of the mix of population reduction, efficiency, renewables, and sufficiency or even poverty that is required. There would be some originality in work on the ethical dilemma of present versus future material welfare, an extremely uncomfortable topic. *See* **paper 9**.

16) 559 l mb I make the unproven claim that the costs of left-side policies need not be measured because I believe they are low; I'm mainly wary of the transaction costs that would be necessary to implement and co-ordinate the various right-side policies. The task of 'countering rebound effects' (a phrase popping up more and more in the literature) can be approached both directly (caps, taxes) or indirectly (*P, A, T*).

I suggest that sustainability research lacks policy focus to supplement its analytically central concept of biophysical limits, and that this can be provided by caps as in the Kyoto framework.

2.7 **Degrowth & Job Guarantee** (paper 7)

The right to paid work would remove sentences containing the phrase 'economic growth and jobs' from public discourse. This issue is certainly relevant to the transition to the steady-state economy required by sustainability. Like the concept of property (private, state, commons, free access), rights are not an 'economic' issue but rather pre- or exo-market ones, so **paper 7** is on the 'political economy' end of the spectrum 'economics'.

1) 57 l m I should have put the Declaration's relevant text in a footnote. Article 23.1 reads, "Everyone has the right to work, to free choice of employment, to just and favourable conditions of work and to protection against unemployment." 23.3 adds the right to "favourable remuneration" sufficient for a family's "human dignity", but

since this conflates having a job itself with how much purchasing power the job bestows, I left it out.

2) 58 l t In item 1) [in the paper's text] the sentence including "unless work-hour productivity outstrips labour supply" is cryptic. It merely intends to say that a growing economy might not entail more jobs in absolute numbers if labour productivity increases very fast, such that the economy does not absorb the net increase of people into the job market. But this is the labour-efficiency rebound question, and for this factor of production a consensus attests backfire.

3) 58 l t Also in item 1) I should have written "in the absence of *absolute* decoupling of throughput from the quantity of goods and services", i.e. when not only GDP rises faster than resource consumption, but the latter actually decreases. Just as the phrase 'absolute decoupling' makes a category mistake (decoupling is a *ratio*), 'relative' decoupling' is redundant. Worse, the concept of decoupling is irrelevant to an economy's sustainable size, which is a function only of the amount of throughput, whatever the (relative) developments in the realms of goods-and-services or utility.

4) 58 l mb Item 4) should stress that reduced working time (RWT) per person and JG are rivals.

5) 58 l b Item 5): Unless we throw out the laws of supply and demand, we have to concede that absolute *laissez-faire* is full-employment (non-)policy; the paper should have been less timid in stating this (I knew the editors were socialists). I should have accordingly framed the paper as: *Unless* the labour market is absolutely free, meaning wages low enough to 'clear the market', society needs either an economic-growth or a social solution. *See* **7)** below.

6) 58 r mb Because there are so few examples of JG we need a fuller description of its possible mechanics.

7) 59 r b The 'dirty secret' of this paper is that it is motivated by the need to *sell* degrowth politically. Degrowth is unavoidable for sustainability, but only if advocates of the steady-state economy can show voters that there is a solution to the unemployment problem will society perhaps choose voluntary rather than naturally-inflicted degrowth.

The paper is an essay, a piece of advocacy, but it identifies the main questions and proposes moving the jobs issue from the economic to the political realm.

2.8 **Expenditures and intensities** (paper 8)

Several times after realising that the 'service' of a haircut requires physical inputs – a barbershop, the barber's chair, the scissors, razor blade and lighting – I quit thinking in terms of 'services' altogether. The term is not scientific. It had long been said that the 'service' economies of the richer world were 'dematerialising'. This positively-connoted language promised some relief from environmental woes, but did it make sense?

The wisest thing I read doing my literature review was Martha Gilliband's statement that natural resources don't have bank accounts. (*See* 88 r m and **19)** below.) I also came to the opinion that Costanza's 1980 study is just as fatal for Environmental Input-Output analysis (EIO) as is Khazzoom's 1980 study for the engineering approach to 'efficiency savings'.

1) 83 r mb I believe the basic flawed premise of EIO is that buying labour does not raise throughput. Some EIO researchers have opened the door by including human metabolism during an hour's work, and I build on that.

2) 84 l tm, 84 l m, 85 r m, 86 l m The term "system boundaries" is fancytalk for where to draw the line on the identifiable throughput of an hour's labour. More narrowly it refers to the input-output tables where the categories of household consumption, government expenditure, employee compensation or 'final demand' are conventionally excluded. *See* **9)** below.

3) 84 l mb I classify the (indirect, right-side, demand-side) structural change strategy under *T* because an expenditure shift to a sector with a higher percentage of 'service' is claimed to enlarge the ratio of output to input, i.e. lower *T* in *IPAT*.

4) 85 l mb, r t The concepts of the production of labour and people were common in classical economics but are foreign to today's discourse. But that might be the gist of the matter.

5) 85 l-r The quotation from Wright and the cited passages from Chapman and Gilliland indicate that we need philosophy and epistemology to approach this issue.

6) 85 r m, 87 r m, 89 l b What are the conditions for an work-hour's being 'brought to market'? At what level of throughput per worker, in a given society, is the work-hour offered in the first place (labour's supply function)? I should have tied this more closely to the 'upstream inputs' concept at 85 r mb. *See* **8)** below.

7) 86 l-r, 88 r tm Extending the analysis to the throughput implied by the consumer's *purchasing power* might be a bit shaky. It seems legitimate to 'holistically' observe that the consumer had to sell labour in order to get the purchasing power for the expenditure under examination. But there is danger of circularity.

8) 87 r m, 88 l m The concept of 'intermediate expenditures' describes the transactions normally counted in EIO. If we insert labour as an industry, wages would then seem to be intermediate. A follow-up paper would have to deal with several such technical issues.

9) 88 r m A dollar that is booked for a ton of steel or, further back, iron ore and coal, goes partly to wages and partly to owners and lenders, but in no part literally to iron, coal and steel. I'm still testing this idea, but it seems the buck stops at rent; Gilliland's insight is that the phrase 'buying natural resources' is ambiguous.

10) 89 l m Nansai et al.'s finding that expenditure shifts to sectors with allegedly lower resource intensities *lowers* employment supports my thesis, and I will try to find out more about their approach.

11) 89 r m Perhaps this should have been the centre of the paper – the empirical starting point: natural-resource consumption's rising along with the shift to purportedly less environmentally-intensive sectors (as percentages of GDP). As in the case of rebound, I believe researchers should concede that the burden of proof lies with the position that stands in contradiction to a first-order reading of the macro data. What *are* the factors that cause rising input consumption if structural change (or efficiency increase) are purportedly working in the direction of lowering it? Again, multiple regression models addressed to these specific questions are needed.

If true, this paper has consequences for many areas of research and policy.

2.9 How many human beings? (paper 9)

Having read Malthus' various editions of the *Essay* on population, like everybody else I mulled over the Population factor in *IPAT* and fretted over the fact that the topic was largely taboo. Is it possible to argue against the proposition that all 'environmental' problems – ones caused by pollution or scarcity or the quality of air, soil, water, etc. – would be easier to solve were there fewer people? Why has the subject been taboo? Why are Malthus and 'Malthusianism' and 'neo-Malthusianism' so venomously attacked? Because one suspects Malthus was onto something? Malthus has been declared dead so many times there might be quite a bit of life in the old boy yet. I discovered that there is recent literature, but it leads a life of its own separate from the mainstream. What became clear is that to determine optimum population size we must first decide what quality of life we want. (**Figure 14**)

Figure 14: Do we want beauty? Do we want to sustain, or let the devil take tomorrow? Do we want large human feedlots, or space for quality of life?

1) 109 r b footnote 2 I forgot to cite the important article by Lin (2010, pp 260-261).

2) 110 l mb, b I am trying to show how absurd it is to totally sideline the issue of population size: Had Africa's population risen less, the change in its *per capita* grain production might have been positive rather than negative. As in my criticism of Princen at 110 r tm, it is mathematically very easy to assume no change in *P* then calculate what affluence and impact would have been. As usual Engelman is succinct and to the point: If per capita impact falls, but total impact rises, *P* must

have risen. If *I/P* falls from 100 to 50 but *I* rises from 100 to 150, *P* must have risen by a factor of 3.

3) 111 l m, 114-116 I yearn to attempt a paper on the emotions with which we approach environmental issues. Schneider et al.'s use of the term 'state-imposed' is a good example of the need to re-visit the language – and feelings – of population policy. The phrase is actually imprecise (ambiguous), as is Sen's term 'coercion'. My strong claim, to be explored, is that this is emotion, not science. I suggest that more research into 'psychoscience' would speed up academia's process of delivering policy *solutions*.

4) 111 r m A model of food production based on the named parameters would be valuable, but first a literature survey is needed to avoid re-inventing the wheel.

5) 111 r mb In retrospect it seems that point 3) is almost identical to point 1). Modelling would increase rigour.

6) 112 l b The simple example using GHGs is an illustration of *A = f(P)* in **paper 6**.

7) 112 r mb The sentence beginning "Instead of asking…" conflates inter- and intragenerational justice. They are both involved in computing *culturally desirable* carrying capacity.

8) 113l mb This would have been the place to add that if *inter*generational justice looms big in a society's utility function, it constitutes a cultural value that would reduce current *A* – an example of endogenising *A*.

9) 113 l b The phrase "such a maximum" refers to the maximum ('feedlot') *population*, not kilocalories per person.

While defending this submission in light of reviewers' comments I drew up this list of perhaps 'innovative' contributions:

- an explicit method for deriving *P* using *IPAT* which obviously must place *P* as the *explicandum* (*P = I/AT*)*;*
- raising the issue of complacency ('no population policies are necessary'), what speaks for and against it, and that there is non-complacent view;
- rejecting the attempts on both sides to deny either *A* or *P*, with many references to this literature (*see* footnote #3 and throughout);
- noting overemphasis on fertility as opposed to mortality;

- unpacking the concepts of ‘coercion’, ‘compulsion’, ‘bottom-up’ and ‘top-down’;
- viewing the question from the standpoint of poor countries, documenting that they are less complacent than rich-country academics;
- identifying pro-natality policies in rich countries that could be rescinded;
- stressing the point that *ceteris paribus* each additional person lowers affluence – very pertinent when we leave our rich-world perspective;
- mentioning that post-Durban UNFCCC agreements will freeze population per country when doing the bookkeeping on the amounts of allocated emissions rights;
- the point that due to rebounds (factor interdependency on the right side of *I=PAT*) population policies alone do not *necessarily* affect impact;
- a useful list of agricultural parameters;
- briefly claiming that we should calculate what it means, exactly, to *replace all* fossil-fuel energy with ‘renewable energy’; and
- discussing the issues of rights vs responsibilities in terms of access to commons.

Mainly for reasons of justice rather than scale, the environmental policy discourse should break this taboo.

2.10 Boulding’s 1966 masterpiece

[Sections 2.10 and 2.11 briefly discuss two works in German, the first peer-reviewed and the second a contract study for the *Enquete Kommission* of the German *Bundestag*.]

Paper 10 would be a short analysis of Kenneth Boulding’s 1966 essay ‘The Economics of the Coming Spaceship Earth’. As there was no German version of the essay, a group of us put together a special issue of the German-language ecological economics magazine with a professional translation and three commentaries (one of them mine). It is homage to a seminal contribution and a great pioneer. Doing sustainability research is an ethical commitment with normative assumptions. But this essay has much more to offer.

Figure 15: Spaceship earth is heating up The Cowboy Economy model is obsolete, but growth still gets the votes.

2.11 Rebound vs absolute decoupling [sic]

Paper 11 would be work for the German parliament on the topic of efficiency's chances of achieving so-called 'absolute decoupling' of natural-resource consumption from growth in material welfare. We still plan to use some of its findings for a paper in English. Its literature review notes several trends in rebound research:

- away from direct rebound to total rebound;
- towards higher estimates of total rebound;
- away from efficiency policies towards sufficiency advocacy within the broad demand-side approach;
- towards the conclusion that direct policies must supplement efficiency, which either suffers from unduly high rebound or is inherently limited by engineering and thermodynamic limits; and
- in other words, a shift towards supply-side thinking.

Other relatively new aspects include:

- detailed discussion of the conceptual differences between 'absolute' and 'relative' decoupling;
- efficiency, rebound and caps pertaining to *non-energy* natural-resource inputs;

- consequences of caps for other resource substitutes, e.g., if fossil fuels are capped, caps on biomass combustion must be in place to prevent deforestation or land use change away from edible crops; and
- challenge to the discourse of *ecological modernisation* that has for three decades focussed on efficiency and decoupling rather than absolute quantities of depletion and pollution per year.

Part 3: Contributions to the field

It has been strange and tiring, writing about one's writing. As if it were important, worthy of such scrutiny. It has at least helped me identify what I'd like to work on in the future. But the task is 'even worse' of claiming to have made contributions to the field:

1) I believe *IPAT* is better than its reputation; it is parsimonious and offers a chance to endogenise each right-side factor: $I = f(P, A, T)$.

2) I try to shift academic focus to *direct* policies as our 'first stop'. The reasons for first seeking indirect routes to lower depletion and pollution are emotional and political in nature, not strictly speaking part of a scientific approach to environmental policy. These aspects would I think better belong to later stages.

3) Since the caps tool is available, and in the absence of empirical evidence that efficiency increases have caused real savings, justification of the study of efficiency and rebound must from the point of view of *environmental* policy be based on further considerations, e.g. politically acceptability.

4) The term 'economic growth', central to the discussion of ecological scale, is meaningless if not defined. I believe the definition relevant to environmental policy is in terms of throughput, not utility or monetary GDP. I agree with van den Bergh (2010) that we can perhaps "relax about GDP growth", but *not* about throughput growth.

Figure 16: Something new Solving the scale problem is conceptually simple; academics will have to work less.

5) The literature often conflates affluence-raising and impact-lowering goals. Perhaps with one eye on political acceptability one seeks to kill two birds with one stone. I believe we should proceed scientifically: determine the 'optimal' scale where marginal costs exceed marginal benefits, then solve this relatively new problem first. Growth and welfare (justice) economics are older and more widely practiced.

6) Environmental policy draws on an insufficiently sophisticated picture of human psychology. It seems at a loss to explain why people are so resistant to *inter*generational justice and why they seem even to act against their own self-interest when remaining on the 'treadmill' of work-and-spend. Most of the literature on environmental psychology seems to go no deeper than sociology.

7) I seem to have successfully applied the rebound concept to sufficiency as well as efficiency.

8) Perhaps identifying the main three *popular* indirect strategies (the Holy Trinity of efficiency, renewables and sufficiency) is useful in contrasting demand-side to supply-side measures as well as highlighting how cultural norms affect approaches to policy-making.

9) Who can prove the usefulness of the history of economic thought? If one is so inclined, visiting our predecessors is its own reward, but whatever its relevance to environmental policy, I believe I have added something by looking at classical

economics through specific environmental-policy questions. Literature review is a means of avoiding ‘re-inventing the wheel’.

10) I believe the effectiveness of the ascendant ‘sustainable consumption’ doctrine needs to be challenged. Its target audience is small, it suffers from rebound, and its emphasis on the saintly-green, voluntary actions by individuals and firms diverts attention from *political* approaches.

11) I’ve tried to raise the question of the cart and the horse, the right-side of *IPAT* representing the cart. Laudably, the Transition Town movement, for instance, *begins with* the assumption of lower fossil-fuel availability, then asks what we can do to maintain our affluence without claiming that embracing the Holy Trinity *causes* less resource consumption.

12) I hope to have helped clarify definitions and methods of research in the efficiency-*cum*-rebound discourse.

13) The challenge to Life Cycle and Environmental Input-Output analysis is cheeky but has some merit; the idea that various *sectors* are more or less harmful to the environment pervades every corner of policy discourse.

14) I’ve added to the relatively small literature on population size. *P = I/AT* is useful, as is my attempt to de-conflate discussions of coercion (which all laws do within limits set by human rights) and *how* policies are decided (democratically or not).

15) I’ve tried to raise neglected questions about some basic concepts used in economics: ‘goods-and-services’, ‘the economy’, capital as an irreducible factor of production, confusion between ratios and absolute numbers (for which Malthus famously chastised Ricardo), the monetary nature of aggregate metrics, and our economy’s dependence on natural resources.

16) My work has raised some relatively new questions:

- What would life look like were we to live without combusting fossil fuels?
- Where lies the burden of proof when seeking policy effectiveness?
- Why are direct, necessarily effective policies seemingly the last ones considered?
- Isn’t social scarcity preferable to natural scarcity?

17) I believe I am contributing to a move towards democratically-decided rules and away from voluntarism and reified, allegedly ‘free’ markets. As with defence, taxation, schooling, infrastructure, and general fair and truthful behaviour, we should accept the psychological necessity of the paradigm “I will if you also must.”

18) I’ve neglected the field of ‘environmental justice’, but am working on a study of freshwater in Palestine and Israel with Ramzi El Houry.

19) At least **paper 1** mentions the criminally neglected environmental topic of beauty, aesthetics. Noise, sights and smells, landscape, visible stars, biodiversity, building shapes and materials, harmony between land and machine – a few examples of issues which, if explored more deeply, would probably strengthen the case that beauty’s *utility* can compete with that of throughput. Aldo Leopold advised us to simply ask what path has most ‘integrity’; we might also ask, with hope of consensus, what path is most beautiful.

Figure 17: Daffodils in Perbioi

Part 4: Conclusions

My work has focussed on that part of economics that studies the sustainable scale of human production and consumption defined in terms of throughput. It only briefly considers other areas such as intra-generational distribution of wealth, broader welfare issues, and economic (Pareto) efficiency. Concern with scale presumes that economic growth in the sense of throughput growth must at some point end. While this proposition is logically unassailable, quantitative estimates of limits to growth for the multifold inputs into production and outputs from consumption have similarly only been touched on in my work. For example, my work on population scale starts with the assumption that 40 or 400 billion people cannot even subsist on earth, but does not try to quantify sustainable levels, only offering parameters for approaching the question for a given society.

My interest in rebound arises from the *prima facie* plausibility of the road of efficiency towards lower pollution and depletion. After nine years' work I believe in a strong conclusion, namely that if research is normatively to further the goals of lower depletion and pollution, the study of technological energy-efficiency increases and their effects on overall consumption are not *necessary:* the goals can be reached with necessary effectiveness and low transaction costs by the well-known measures of caps or, with less certainty, high energy taxes. They are sufficient and, if rebound is indeed close to or at 100%, necessary.

Whether technological efficiency increases might be *sufficient* to reach the goals is the rebound question. If one suspects that this hopefully sufficient policy road is preferable to (less painful than) caps, the research must be undertaken. In my extensive reviews of the literature since 1980 (not counting Jevons' study of 1865) I have however found a divergence in estimates of total rebound of an order of magnitude. There is often lack of unity on definitions, misuse of terms, and extreme difficulty finding water-tight methods – mainly concerning the vexing question of how to proceed if and when relatively accurate direct rebounds are known. One needs models (theory) before one can proceed, but there is no consensus on any energy-consumption model. One can only say with certainty that rebound < 100% is highly uncertain and that therefore responsible policy-making should focus on effectiveness.

A further discovery has been that rebound research has taken place within a *Zeitgeist,* within various ideologies, within various dominant scientific discourses – not in a vacuum. The dominant paradigms have dictated that the burden of proof is on proving rebound, not real savings, i.e., the research question has not been whether real input savings have been achieved by input-efficiency increases, but rather what percentage of real savings are wiped out by the additional consumption enabled by input-efficiency increases. One has started with zero rebound and tried, without reaching anything near consensus in 30 years, to work up to an evidence-based percentage of engineering savings.

However, while waiting for economic science to produce models of energy consumption that name its drivers aside from Jevons' main candidate, input-efficiency increase, and guided by the crass observable correlation between energy-efficiency increase and energy-consumption increase, the policy tool of *caps* could have been used. We have lost many years in braking depletion and climate warming. Khazzoom (1980) already pointed to this bias towards an 'engineering approach' to the question, but due to the *Zeitgeist* and perhaps also to a natural desire to have our cake and eat it, too, he was not heeded.

Concerning my work on voluntarily restricting one's consumption I've identified the sufficiency rebound and the discouraging fact that huge numbers of poorer people are already involuntarily consuming 'sustainably'. Whether in order to advocate voluntary frugality or to market resource caps as a solution, our model of human behaviour should include insights from evolutionary psychology. There is strong evidence that our evolutionary past influences not only our bodies but our feelings and social relationships. Fortunately, some sustainable-consumption literature is shifting the focus away from sociology towards evolutionary psychology.

While most of my work is literature review, it is at least extended farther into the past than most other contributions. Although I have contributed a small amount to the history of economic and environmental thought, I cannot show any proof that knowledge of previous writers is a necessary condition of good policy analysis.

For my research focus, the *prices* of natural-resource inputs are of only derivative importance. While prices might be exogenous for firms and individuals, for macroeconomics they must be explained – yet to what purpose? Since the socially-

decided resource scarcity that is necessary for sustainability can be achieved without reference to prices, i.e. with laws physically defining limits alone, their importance seems limited to the intragenerational social sphere. Unless price controls are enacted, caps necessarily entail price rises with consequences for 'fuel poverty', mobility, health and the alleviation of poverty worldwide. To solve these (non-environmental) justice problems we must then resort to policies of income *distribution*. My work has led me to conclude that these problems should be strictly distinguished from the 'environmental', sustainability problems.

My work is thus relevant to the productive and commercial sectors only in its focus on socially-decided scarcity and population stabilisation. Once scale and distribution issues are decided, firms, households and individuals would decide decentrally, without government interference, how best to react through some combination of sufficiency, renewables, and greater efficiency. The government interference or 'regulation' has already occurred in setting overall caps. Innovation programs would be superfluous, and socio-economic problems would be dealt with by socio-economic policies.

Using *IPAT*, I've identified some interdependencies needing more study: How does population size influence labour supply, on the one hand, and how does this influence both affluence and impact defined as the amount of fossil fuel taken out of the ground? Is a supply of labour at subsistence wages a necessary condition for present levels of impact, or would consumption for comfort and prestige achieve the same levels? How does technological efficiency in agriculture and building-heating – obviously raising affluence *ceteris paribus* – influence population size? How much can technological efficiency increases, including the 'free' use of solar energy, raise affluence in the future? Such study should, however, in my opinion be aimed not at finding impact-reducing policies – we already have caps and/or taxes at our disposal – but at describing to voters the costs and benefits of a reduced-throughput economy.

My work has tried to analyse the effectiveness of environmental strategies usefully classified according to the $I = PAT$ formula, according to which the amount of problematic depletion and pollution is determined by population size, good-and-service consumption per person, and depletion or pollution per unit of goods-and-

services. Through regulation, society can control the three right-side factors, but interdependencies make it highly uncertain that impact is thereby reduced. Caps, on the other hand, *constitute* impact reduction. If we decide to move towards a sustainable economy, we must shift our research focus to the political conditions for the democratic acceptance of caps and to solving social issues that arise due to economic shrinkage such as unemployment, income disparity, absolute poverty, possible limits on reproductive freedom, and probably even international tensions. They all arise from scarcity, the subject matter of economics.

Thank you for reading.

Bibliography

Alcott, Blake, & Tyler James Marangi, *under review*. A Granger-causality test for worldwide rebound. *World Review of Entrepreneurship, Management and Sustainable Development.*

Barkow, Jerome, Leda Cosmides, & John Tooby, 1992. *The Adapted Mind.* Oxford U. Press, N.Y. and Oxford.

Bloch, Maurice, 1977. The past and the present in the present. *Man* 12: 278-292.

Boserup, Ester, 1981. *Population and Technology.* Blackwell, Oxford.

Boulding, Kenneth, 1966. The economics of the coming spaceship earth. http://www.ub.edu/prometheus21/articulos/obsprometheus/BOULDING.pdf

Brown, Donald Edward, 1991. *Human Universals.* Temple U. Press, Philadelphia.

Cantillon, Richard, 1755. *Abhandlung über die Natur des Handels im allgemeinen,* translation by Hayek, Hella, introduction by Hayek, Friedrich A., 1931. Verlag von Gustav Fischer, Jena.

Cleveland, Cutler, Robert Costanza, Charles A.S. Hall, and Robert Kaufmann, 1984. Energy and the U.S. economy: A biophysical perspective. *Science* 225: 890-897.

Costanza, Robert, 1980. Embodied energy and economic evaluation. *Science* 210: 1219-1224.

Czech, Brian, 2009. The neoclassical production function as a relic of anti-George politics: Implications for ecological economics. *Ecological Economics* 68 (8-9): 2193-2197.

Daly, Herman E., 1992. Allocation, distribution and scale: Towards and economics that is efficient, just and sustainable. *Ecological Economics* 6: 185-193.

Darwin, Charles, 1871/1874. *The Descent of Man and Selection in Relation to Sex.* Gibson Square, London.

de Haan, Peter, M.G. Mueller, & A. Peters, 2006. Does the hybrid Toyota Prius lead to rebound effects? Analysis of size and number of cars previously owned by Swiss Prius buyers. *Ecological Economics* 58: 592-605.

Durham, D.F., 1992. Cultural carrying capacity: I = PACT. *Focus* 2 (3): 5-8.

Ehrlich, Paul R., & John P. Holdren, 1971. Impact of population growth. *Science* 171: 1212-1217.

Geertz, Clifford, 1984. Distinguished lecture: Anti anti-relativism. *American Anthropologist* 86 (2): 263-278.

Giampietro, Mario, 1994. Sustainability and technological development in agriculture. *BioScience* 44 (19): 677-689.

Greening, Lorna A., David L. Greene, & Carmen Difiglio, 2000. Energy efficiency and consumption – the rebound effect – a survey. *Energy Policy* 28 (6/7): 389-401.

Herskovits, Melville J., 1940. *Economic Anthropology*. 2nd ed. 1952, W.W. Norton, New York.

Hotelling, Harold, 1931. The economics of exhaustible resources. *Journal of Political Economy* 39 (2): 137-175. Also in: Adrian C. Darnell (ed.), 1990. *The Collected Economic Articles of Harold Hotelling*. Springer-Verlag, New York.

Khazzoom, J. Daniel, 1980. Economic implications of mandated efficiency in standards for household appliances. *Energy Journal* 1 (4): 21-40.

Kroeber, Alfred L., 1915. Eighteen professions. *American Anthropologist* 17 (2): 283-288.

Kroeber, Alfred L., 1917. The superorganic. *American Anthropologist* 19 (2): 163-213.

Kümmel, Reiner, Julian Henn, & Dietmar Lindenberger, 2002. Capital, labor, energy and creativity: modelling innovation diffusion. *Structural Change and Economic Dynamics* 13: 415-433.

Lee, Maria. 2005. *EU Environmental Law.* Hart, Oxford.

Lin, C.-Y. Cynthia, 2010. Instability, investment, disasters and demography: Natural disasters and fertility in Italy (1820-1962) and Japan (1671-1965). *Population and Environment* 31: 255-281.

Madlener, Reinhard, & Blake Alcott, 2011. Herausforderungen für eine technischökonomische Entkoppelung von Naturverbrauch und Wirtschaftswachstum unter besonderer Berücksichtigung der Systematisierung von Rebound-Effekten und Problemverschiebungen. *Enquete-Kommission des deutschen Bundestages.* http://www.bundestag.de/bundestag/gremien/enquete/wachstum/gutachten/m17-26-13.pdf

Macrory, Richard. 2001. Regulating in a risky environment. *Current Legal Problems* 2001: 619-648.

Marshall, Alfred, 1890. *Principles of Economics,* 7th ed. 1916. Macmillan, London.

Mill, James, 1824. *Elements of Political Economy*, 2nd ed. Baldwin, Cradock, and Joy, London.

Princen, Thomas, 1999. Consumption and environment: some conceptual issues. *Ecological Economics* 31: 347–363.

Rittberger, Berthold and Jeremy Richardson. 2003. 'Old wine in new bottles? The Commission and the use of environmental policy instruments'. *Public Administration* 81: 575-606.

Robinson, Joan, 1956. *The Accumulation of Capital*, 2nd ed. 1965. Macmillan, London.

Ryan, Christopher K., 2002. Land as a factor of production. *American Journal of Economics and Sociology* 61 (5): 7-25.

Say, Jean-Baptiste, 1803. *A Treatise on Political Economy*, translation by Prinsep of the 1836 edition, introduction by Quddus, Munir & Salim Rahsid. Transaction Press, New Brunswick, New Jersey and London.

Schumpeter, Joseph, 1912. *Theorie der wirtschaftlichen Entwicklung*, 2nd ed. 1926. Duncker & Humblot, München & Leipzig.

Simon, Julian, 1996/1981. *The Ultimate Resource.* Princeton U. Press, Princeton.

Solow, Robert M. 1970. *Growth Theory: An Exposition*. Clarenden, Oxford.

Sorrell, Steve, & John Dimitropoulos, 2008. The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics* 65: 636-649.

Tickell, Oliver, 2008. *Kyoto2: How to Manage the Global Greenhouse.* Zed Books, London.

Turner, Karen, 2009. Negative rebound and disinvestment effects in response to an improvement in energy efficiency in the UK economy. *Energy Economics* 31: 648-666.

van den Bergh, Jeroen C.J.M., 2010. Relax about GDP growth: Implications for climate and crises policies. *Journal of Cleaner Production* 18: 540-543.

Von Weizsäcker, Ernst, Amory B. Lovins, & L. Hunter Lovins, 1997. *Factor Four: Doubling Wealth – Halving Resource Use*. Earthscan, London.

Wei, T., 2010. A general equilibrium view of global rebound effects. *Energy Economics* 32: 661-672.