Competition and Innovation in the Newly Liberalized European Power Industry

Elizabeth A. Hooper

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It has been a long road, but never, for one moment, did I imagine that I would conclude my formal education by writing a PhD. thesis, and am immensely privileged to have had the opportunity to do so. There were periods when I did not believe that I would ever sit down to write this short passage, and without the love, encouragement and patience of my family and friends, I would not have had the pleasure of doing so.

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Abstract

This thesis is about industrial organization in EU power generation. The power sector is critically important to the efficient functioning of modern economies, and generation is the source of the majority of value-added in the production chain, as well as approximately one third of the EU's greenhouse gas emissions. The European Commission cherishes a vision of a single internal market in electricity (and gas) and to that end has subjected the sector to a sustained reform programme, administered by Directorates General Competition and Energy, aimed at bringing about a less concentrated market structure.

Despite this ambitious objective, little is known about the corporate strategies that have been pursued by leading power generators in response to sector liberalization, or about the cumulative effect of these strategies on sectoral structure at the aggregate EU level. The objective of this thesis is to begin to rectify this omission, and to evaluate progress towards the single market. An intensive data gathering exercise culminated in the creation of a unique and comprehensive database, the market share matrix of EU power generation, which contains estimates of the size of leading generators, disaggregated by member state. The matrix has supported chapters examining concentration and firm growth, firm multinationality and the diffusion of wind turbines.

EU energy policy has been described as "a litmus test for the usefulness of the European Union as an institution". The evidence presented in this thesis suggests that the effectiveness of the liberalization agenda has been limited. Ten years after the First Electricity Directive, the hypothetical single market has become more, not less concentrated as a result of corporate growth strategies, and the new 'competitive' market structure has failed to deliver high levels of diffusion of a carbon-neutral generation technology.
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CHAPTER

ONE

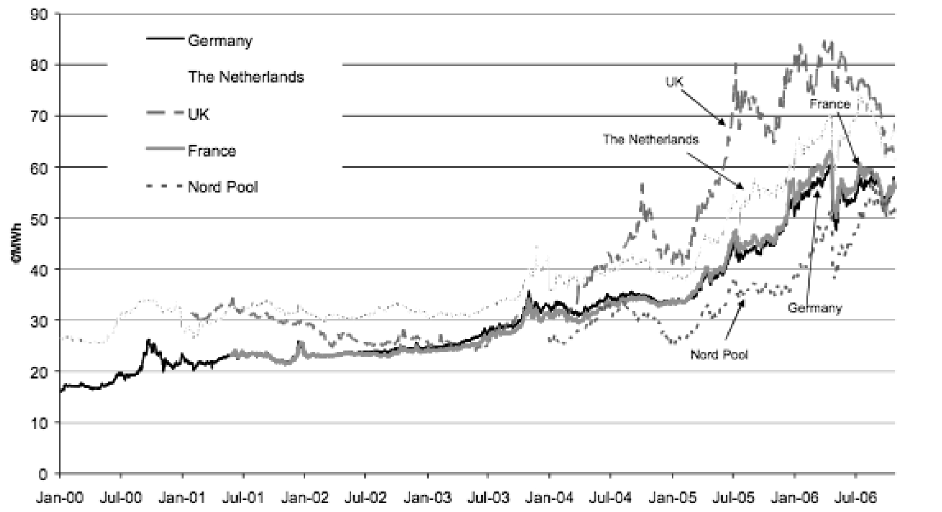
INTRODUCTION

This thesis is about the industrial organization of power[1] generation in the European Union (EU) over a period when market integration was a key objective of EU policy. A focus on this particular sector is warranted since its practical importance is far greater than its share of GDP which is about 2% in typical developed economy (Pollitt, 1999, p.29). Or, as the DG for Energy website puts it "Energy is what makes Europe tick"(DG Tren, 2010). Refining the focus further to power generation is justified by the fact that it is this stage in the production chain that gives rise to the majority of the value-added created in the electricity sector.

By teasing out specific aspects of firm strategy over an extended period, inferences have been drawn regarding the nature of the competitive process in the sector. While the essentially descriptive findings of the work are of significant interest, the thesis is located squarely in the academic literature on industrial organization (IO). By teasing out specific aspects of firm strategy over an extended period, inferences have been drawn regarding the nature of the competitive process in the sector. Given the political context in which it is set and the high degree of politicization in the sector, the findings of the study represent an evaluation of the effectiveness of EU energy and competition policy.

[1]The terms power and electricity are synonymous throughout the thesis.

Contemporary debates in both academic literature and policy circles have motivated and guided the progress of the research project. The European Commission's (EC) liberalization agenda has the declared objective to create a single market for electricity and at first there were positive signs that competition was emerging. A rudimentary assessment of progress can be gleaned from examination of the wholesale power price curve in the EU. Figure 1.1[2] shows price development for year ahead base-load between 2000 and 2006 and for key EU member state markets. The first stages of the EU's liberalization programme were embodied in the First Electricity Directive which came into force in early 1997 (EC, 1996), so by 2000 a price impact may have begun to feed through to forward prices.



Source: Sector Inquiry (EC, 2006, p.111)

Figure 1.1: Wholesale electricity price, year ahead base-load. 2000-2006

The figure indicates that between 2000 and mid 2003 wholesale prices remained largely stable and the dispersion between prices prevailing in different countries was relatively modest. This stability in part reflected stable input prices and the rising trading volumes on power exchanges which increased

[2]Unfortunately the underlying data for this figure was not available. It has been reproduced from the Sector Inquiry and the quality of the image is not ideal.

arbitrage opportunities. During 2004, the pattern changed in three distinct ways. First, the trend turned sharply upward, which may be explained by several factors. Input prices, particularly natural gas, were rising strongly. One possible explanation is that the potential cost savings resulting from liberalization (Newbery and Pollitt, 1997) had in large measure been realized by 2003 so were no longer sufficiently strong to mitigate rising input prices, particularly natural gas. Alternative explanations are that prices are positively related to product market concentration and that low levels of liquidity are associated with high prices, both of which find empirical support in Slade and Thille (2006). Second, price volatility grew substantially, perhaps due to low trading volumes at the power exchanges, a factor that may drive the third observed change in price curve, increasing dispersion. With deep and liquid wholesale markets and absent other constraints such as congestion over the hight voltage network and interconnectors, traders would be expected to realize profit opportunities by trading to minimize price differentials. The data show that there was insufficient activity to prevent significant differentials from persisting which implies the presence of barriers to trade; markets were insufficiently integrated.

The price curve is suggestive of underlying problems, but without additional data it is difficult to identify the price effects of short run factors such as a tight supply/demand balance or the strategic exercise of market power by, for example, withholding capacity. It is well known that detecting (the abuse of) market power in electricity markets is fraught with difficulty (e.g. Borenstein et al., 1999, Smeers, 2009); this route is not pursued in this thesis. Instead, the analysis is focused not on market power, but on competition in a dynamic (neo-Schumpeterian) rather than neoclassical (static) framework. In a dynamic setting the emphasis shifts from the assessment of market power to potential competition and firm behaviour (Sidak and Teece, 2009). A new framework was developed in which the trajectories of both market shares and concentration in capacities were calculated for a ten year period, then by testing behavioral models, key firm strategies that resulted in leadership were identified.

Despite the rhetoric surrounding the single electricity market, both academics and policy makers have neglected the structural aspects of power generation at the EU level, so very little is known about them. The mainstream academic peer-reviewed literature appears to be devoid of any study that examines sectoral structure at the EU level, although the Öko Institute has published two studies that examine one aspect of market structure, concentration in generation at the regional (and national) level (Matthes et al., 2007). Somewhat surprisingly given the EC's single market ambitions and general dissatisfaction with the pace of reform, the recent Sector Inquiry (EC, 2006) conducted by the Directorate General (DG) for Competition focused on the health of competition at the national level. The resultant report that ran to over 360 pages discussed concentration in some detail but was entirely unencumbered by any mention of the concept of aggregate concentration, i.e. concentration at the sectoral level.

Yet aggregate concentration is germane to the entire liberalization project. If the objective is to create a single market in electricity, a study that evaluates progress towards and barriers to the achievement of that objective needs to relate the desired future state to the status quo. The difficulty is that it is not possible to predict the future accurately, however we do know the broad dimensions of the EC's vision; transmission constraints and bottlenecks are non-binding and barriers to trade are low, so a hypothetical market investigation would define 'the market' as the EU. The analysis presented in this thesis was motivated by considering the likelihood that the single electricity market will be achieved given recent developments in the EU power sector.

While many of the the myriad questions that arose during the course of the project must remain as topics for future research, a fascinating story has been crafted by exploring the following questions in the context of the hypothetical single market in electricity that is nevertheless, the stated objective of EU energy policy: What does the structure of the sector look like? How have market participants' strategies have shaped that structure? How dominant are the giant firms in the sector? How have mergers affected the structure of the sector? Will competition help or hinder the goal of attaining carbon-neutral generation sector? What does all this mean for competition policy in the sector?

This chapter is laid out as follows: key features of the policy background is set out in section 1.1 before the academic roots of the thesis are discussed in section 1.2. The methodological foundations of the study are outlined in section 1.3 and key findings summarized in section 1.4. The final section provides a guide to the body of the thesis.

1.1 The policy background

The reform of Europe's network industries was precipitated by several factors: ageing infrastructure and technological advances demanded investment at a time of perceived inefficiency in network utilities and when national governments were more interested in raising cash (by selling assets) than making large capital investments in infrastructure. Newbery (2002, p.1-2) characterizes the problem of network industries as one of balancing the interests of investors and consumers. Network utilities require a fixed network in order to deliver services to final consumers, so the networks are classic natural monopolies which create rents which are persistent because the networks are durable. Network investment is a large sunk cost which means that bargaining power shifts towards consumers, but the large number of (relatively) small consumers must link directly to the network in order to receive the product, so network owners can potentially exploit consumers who have limited substitution possibilities.

Prior to the 1980s Europe's network industries had been under close scrutiny by the state and protected from competition and were in many cases monopolies bounded by national borders. As a result, the shift in European economic policy during the late 1980s which prioritized the removal of barriers to trade and competition and the formation of the single market for goods and services, had particularly large implications for network industries.

Reform in the power sector was formally set in train by the First Electricity Directive 96/92/EC. The key objective of the liberalization programme is not mere harmonization but integration: the creation of a single internal market for electricity (EC, 1996). This is indeed a mighty ambition. In addition to the specific problems associated with network industries, the social and political context of electricity supply is particularly complex. The public service obligation and concerns about fuel poverty, the extent to which the sector is embedded in the political system, and the environmental externalities associated with electricity generation all contribute to the challenge of liberalization as does the path dependency of market structure (Sutton, 1998, Kreps and Spence, 1985) and the universal preference of national governments for energy independence. A final complication related to energy independence is derived from the increasing trend towards the building of 'national champions' (Domanico, 2007). Developing competitive markets at national level and building a national champion may be mutually exclusive. As a consequence of all these factors, the story of power sector reform is one of of hard fought negotiations between the EC, national governments and regulators that is punctuated by legislative packages[3] and the Sector Inquiry (EC, 2006).

Central to reform in the electricity sector is the replacement of monopoly with competition (Olsen and Skytte, 2003, p.179) where possible, and the use of regulation to prevent participants from exploiting market power in the newly competitive set up. Hence the development of regulatory institutions capable of balancing competing interests of consumers and producers/network owners is of critical importance (Newbery, 2002, p.3). The objectives of EU energy policy are to ensure a competitive, secure and sustainable electricity supply so the reality of public policy with respect to electricity is particularly complicated and it falls under the auspices of three different Directorates General: energy, competition and environment. The challenge of reconciling strongly held positions such that the EU does indeed meet its objectives with respect to energy is immense, but is of great importance to the European Union project. If energy policy can fairly be described as "a litmus test for the usefulness of the European Union as an institution" (Roller et al., 2007), then this study may be considered the litmus paper.

[3]The Second Electricity Directive 03/54/ED, the Cross Border Electricity Trading Regulation EC 1228/2003 and the "Third Package".

1.2 Academic roots

The intellectual foundations of the study are found in IO, and a particular emphasis is placed on corporate strategy. Vickers (1995) differentiates between allocative, productive and dynamic efficiency but static analysis remains the central concern of much economic theory (Sidak and Teece, 2009) and a 'healthy' level of competition is widely equated with low prices. Hence academic analysis of the adequacy (or otherwise) of the level of competition in any given market is based primarily on allocative efficiency (e.g Waddams Price and Harker, 2006) or productive efficiency (e.g. Newbery and Pollitt, 1997, Jamasb et al., 2010). In section 1.1 it was argued that reform in the electricity sector was motivated by technological change, i.e. by the desire to introduce product and process innovations, which is precisely the nature of dynamic competition described in Schumpeter (1942) "... it is dynamic competition propelled by the introduction of new products and new process that really counts.", though this definition of dynamic competition is rather looser than the one that has recently become more conventional.

IO studies continue to reflect the dominant logic that market structure is the primary determinant of innovation, and by implication, dynamic competition, despite theoretic inadequacies (Sidak and Teece, 2009) and mixed empirical evidence (Cohen and Levin, 1989). This may be in part due to the pervasive and restrictive interpretation of the term industrial structure whereby it is equated with concentration; see for example, (Sutton, 1998, p.5), (Hay and Morris, 1991, p.207) as well as the Sector Inquiry (EC, 2006) and Matthes et al. (2007) discussed above.

A broad definition of industrial structure can be decomposed into its constituent parts from which evidence of the strategic decisions of market participants may be recovered. For example, Aghion et al. (2009, p.2) have recently argued forcefully in the context of the adoption of green technologies "the portfolio of technologies available tomorrow depends on what is done today". It seems obvious that modelling the various elements of structure as a set of characteristics that depend delicately on each other lays the basis for research capable of generating a fuller and more nuanced understanding of structure than one derived from a more restricted conceptualization.

Examining the nature of competition in the long run is interesting because it is possible to observe firm behavior and together with some measure of firm performance, evidence can be assembled regarding the strategies that give rise to leadership and some predictions made about the way in which competition may develop in the future. Given this interest in the long run development of the competitive environment, installed capacity was the chosen measure of firm size. While not unprecedented, capacity is an unusual choice and its special significance in electricity markets is addressed in chapter 2. The majority of the analysis in the academic literature is indeed static and in the short run capacity is not a good measure because it is the marginal cost of the marginal plant that sets prices and the relationship between capacity and marginal cost is not clear. However capacity as a measure of size over the long run has two tremendous advantages. First, it is the realization of firm strategy in the sense that the capacity of a firm today is the outcome of their investment decisions in the past and beliefs about their likely position in the market in the future. Thus firm strategy may be inferred from changes in firm size, and predictions made about the effect of different strategies on competition in the future. Second, as Nilsson (2005) argues, capacity is the obvious measure of firm size because capacity can be expected to exert negative pressure on prices in the long run.

The case study is capable of generating an array of detailed information about a sector which can be particularly helpful in the sector is particularly complex, undergoing reform or that for some other reason merits specific attention. Electricity qualifies on all three criteria. However, the approach taken in the thesis provides a blueprint that could be applied in many other sectors undergoing, particularly telecommunications and perhaps more pertinent in the current political climate, water. In the context of induced market integration, conducting analysis under the 'what if' assumption is a valid and indeed important step that links the (desired) future with the present and the past.

1.3 Methodological contribution

Based on an original data set, the thesis assembles for the first time a wealth of new information about the sector and provides a unique and comprehensive overview of the dynamics of sectoral structure that is at the same time abundant in detail.

The study is faithful to the methodology developed by Davies and Lyons (1996) which examined the industrial structure of the EU across sectors and which is extended in two respects which makes it better suited to the objectives of this work. The beauty of the matrix methodology is its ability to generate a rich and complex story of the evolution of industrial structure but at the same time being relatively concise. It is flexible enough to permit analysis of structure at the firm, member state, regional or EU level and is therefore capable of supporting research that seeks to provide an overview of sectoral (or industrial) structure but that also drills down to examine questions such as, what is the role of firm nationality or the membership of a regional market in changing structure?

Key objectives of the study were the examination of the way in which sectoral structure had changed since the liberalization process began, and the identification of the firm strategies that result in sectoral leadership. However absent significant resources available for large scale data collection, specific firm strategies for example R&D expenditure or prices, are unobservable. But the *outcomes* of past strategies are observable, for example in the form of market shares or firm multinationality. The desire to generate a comprehensive dynamic view therefore necessitated the collection of at the very least, two cross-sections of data separated by a number of years – this approach was taken by Clarke (2002). However in view of the emphasis on the response of firm strategy to the policy environment it was decided that a panel of ten years should be constructed. Outcomes observed over a ten year period represent a reliable and consistent record of the effect of firm level decisions on several aspects of industrial structure. The panel approach had the added advantage of easing any econometric problems associated with the relatively small number of firms on which data was to be gathered.

The second respect in which the power generation matrix differs from the industry matrix of Davies and Lyons is in scale. The latter based their presentation of the first comprehensive picture of the industrial structure of the EU on a matrix that covered all 11 member states[4]. The present study is similarly representative of the EU as a whole, but a series of EU expansions required the inclusion of 25 countries[5]. The generation matrix is four times larger than the industry matrix.

1.4 Summary of results

The thesis does not provide evidence that could lead the EC to the conclusion that the reform programme initiated by the First Electricity Directive is an overwhelming success. Progress towards a single internal market in power generation is slow and the current trajectory does not inspire optimism that this objective will be reached in the short term.

Concentration has risen as a consequence of the growth strategies of leading firms which have been executed very largely through merger, and firms have become considerably more multinational. It is possible that and environment in which there are fewer, larger firms reflects the fact that the most efficient firms have prospered at the expense of their inefficient rivals, which may be of benefit to consumers (if firms pass through cost savings). Another possibility is that as a result the strategies pursued by leading generators, the structure of the sector was more conducive to tacit collusion at the end of the period than it was at the start. However, the study does not provide evidence which could inform choosing between these possibilities.

The new 'competitive' market regime has not brought forth high levels of low carbon generation technologies, and since diffusion was found to be inversely related to concentration in a firm's domestic market, the trend towards more concentrated markets may have a negative effect on the diffusion of low carbon generation technologies. However, by implementing a method-

[4]Belgium and Luxembourg were treated as one.

[5]EU27 plus Norway, minus Luxembourg, Cyprus and Malta. See chapter 2 for full details.

ology which allowed us to decompose overall diffusion into its component parts, we showed that the constraint on more intense diffusion lies within the firm, not between firms. This is an important finding which has direct policy implications.

1.5 A guide to the thesis

The body of the thesis is organized as follows: the data underlying the empirical analysis that is at the heart of the work is put through its paces in the next chapter. The project was data-intensive and the methodological contribution of the thesis relies on the market share matrix for generation, which makes the 'data chapter' particularly important. Since the three substantive chapters are drawn from distinct but related literatures, each chapter discusses the relevant literature.

The first aspect of sectoral structure examined is the distribution of firms. In chapter 3 patterns of firm growth are analyzed in detail and changes in the distribution traced out. A particularly interesting aspect of the analysis concerns the contribution of mergers to the firm enlargement story. Chapter 4 presents analysis of the multinational strategies pursued by leading firms by asking the question, why does a firm decide to locate their generation assets across member states? The final aspect of firm strategy that is scrutinized concerns the diffusion of wind turbines both across and within firms, and is the subject of chapter 5. The final chapter brings together the key findings and discusses directions for future research.

CHAPTER

TWO

THE MARKET SHARE MATRIX

2.1 Introduction

A principal objective of this thesis is to document and present empirical analysis of the structural changes in EU power generation since the start of the sector liberalization process. Data on leading firms that is essential to a comprehensive description of the industry have been assembled into the market share matrix for EU power generation, which is discussed in detail in this chapter.

In the next section the chosen measure of firm size is explained, and in section 2.3 existing publicly available sources of data on the European generation sector discussed. As it happens, this section provides the rationale for the resource intensive exercise involved in the creation of the matrix. The next three sections outline the logic for the creation of the matrix, the methodology used in its construction and the data gathering process. The dimensions of the matrix and some preliminary analysis are reported in sections 2.6 and 2.8. Finally, both the capabilities and deficiencies of the matrix are discussed in section 2.9.

2.2 Measuring firm size

Firms in this sector report their size according to several different measures, including revenue, production volumes and installed capacity. For the purposes of this study, installed capacity is the chosen measure since we wish to capture the long run adjustments to the structure of the sector that are reflected in changes in capacity. The selection of this measure yields at least two significant advantages over the alternatives. First, the longevity (20–60 years) and high capital cost of generation assets implies that investments in capacity reflect the beliefs of firms regarding their ability to generate revenue in a particular market in the long run. Second, it permits abstraction from short run supply and demand factors which, given the requirement for continual balancing of supply and demand, are likely affect other measures of size.

The choice of size as a measure is far from unprecedented. For example Nilsson (2005) argues that it is the appropriate measure given that in the long run downward pressure on prices will be determined by spare capacity or, equivalently in his set-up, the intensity of post-merger competition by idle capacity. Similarly, for the cement industry Jans and Rosenbaum (1997) study concentration based on kiln capacity as the measure of firm size. Finally, the European Commission (EC) report shares of available installed capacity as a measure of concentration in the Sector Inquiry (EC, 2006) that was carried out by the Directorate General for Competition. Available capacity is equal to the sum of maximum operating capacity for each unit in a firm's portfolio, so takes account of derating due to hot weather and also capacity that is off the system having been mothballed, or due to planned or unplanned outages. Total installed capacity is arguably at least as good a measure since it does not reflect strategic withholding that may affect estimates of available installed capacity.

2.3 Existing sources of data

Existing data sources were identified by following a three step approach. First official data sources were explored, then proprietary sources examined, and finally the possibility that data from existing academic studies may be available was assessed.

For the UK, the Department for Energy and Climate Change (DECC) publishes data on the ownership of power plants in its Digest of UK Energy Statistics (DUKES) database, but the same is not true for most other member states. The EC does not publish data on plant capacities or ownership. During the course of the the Sector Inquiry (EC, 2006) the EC collected data on ownership of capacity in their member state of origin, from which the domestic share of available capacity for each firm was estimated. However, the data do not include capacity owned in member states other than the member state of origin, which given high levels of multinationality and the single market ambitions of the EC, seems to have been a missed opportunity. Subsequent to the Sector Inquiry, market studies were commissioned from consortia lead by London Economics, but again these were restricted to national markets, and no underlying firm level data were made available.

In the absence of official data, the availability of proprietary data was investigated. The Yearbook of the European Energy and Raw Materials Industry (Meller, 2008) claims to provide comprehensive details of more than 4000 companies and organizations, including operational and locational information, and was recommended as a useful source of data. The publication certainly appears to regard itself as the standard reference guide[1]. Data from this source was obtained for 2004 but checks on its robustness[2] revealed it to be inaccurate in respects that rendered it unsuitable for the current project. Unfortunately the cost of other proprietary sources of data, for example Platts' Electric Power Plants Database, exceeded the limited resources available for this project.

The last avenue explored was the academic literature. Matthes et al.

[1] http://www.energy-yearbook.de/

[2] Ownership data on UK generation plants was compared with the DUKES database discussed above.

(2007) assess the evolution of concentration between 1996 and 2004 in a limited number of member states, and for regions defined by physical power flows. The data employed in the analysis was taken from the Öko-Instiut's power generation database, itself gathered from company annual reports and other sources. However, the unit of observation was net power generation, which is likely to be influenced by short term supply and demand factors as well as strategic issues including the control of power generation assets, and there is no way to disentangle short and long run effects. The paper claims to present "a clear picture of market concentration in the liberalized power generation markets in Europe" (Matthes et al., 2007, p.18). While the report is helpful because it begins to address the striking lack of analysis of concentration in power generation at higher levels of aggregation than the member state, this claim seems a little exaggerated. The analysis is focused at the market (national or regional) level and does not attempt to make connections that become obvious if the EC is considered as a whole. For example, the study fleetingly asserts the importance of mergers in the increasing concentration in German power markets but does not consider the wider potential for mergers to increase concentration at a higher level of aggregation.

In summary, an extensive search revealed that with the possible exception of costly proprietary data, high quality and publicly available data on the ownership of power plants in Europe is virtually non-existent. Given the high profile of the sector and the prominence of the EC's goal of creating a single internal market in electricity, this is remarkable in itself and is a plausible explanation for the absence of analysis of the structure of the industry at the aggregate EU level. It had become clear that it would be necessary to compile a new database specifically for the purpose of this analysis. The next section introduces the database concept.

However before moving on, it is worth discussing the likely accuracy of the data. The quality of the data is as good as the source material, largely annual reports and websites. It is probable that firms know their own capacities but there may be changes in measurement and reporting that are obscured from the reader. Errors introduced in this way could not be detected. Further, the lack of a common reporting framework meant that the exercise of judgement and in one or two cases guesswork, was required. The novelty of the thesis is derived in part by the lack of existing data, so it was not possible to evaluate the accuracy of the data against a comprehensive existing source. However, partial checks against other sources suggest the resulting estimates to be broadly correct.

2.4 The market share matrix

2.4.1 The concept

The matrix is based on a concept developed by Davies and Lyons (1996) to study the structure of manufacturing in the EU, and employed subsequently by Clarke (2002) to examine the structure of food retailing in the EU. The idea is to compile a database that gives the size of each leading firm in each EU country. Such a database would support the examination of the structure of firms and the sector as a whole at the aggregate EU, regional or member state level. Given the interest in the degree to which large firms have shaped industry structure it seems logical to concentrate on firms that are among the largest in their member state of origin. A fragment of the matrix is presented below, but before discussing that, several definitional issues are dealt with.

2.4.2 Definitions

The precise definitions used in construction of the matrix are given in this section.

The industry

The electricity industry is comprised of four vertically related segments, generation, high-voltage transmission, low-voltage distribution and finally supply (or retail). The focus throughout the thesis is power generation, for three reasons. First power generation is responsible for the large majority of value-added created by the entire production chain; second, generation was the first segment to be opened to competition; and third, power generation is responsible for approximately on third of greenhouse gas emissions in developed economies.

A firm is taken to be active in power generation if it controls generation assets through either direct ownership or the ownership of shares in other generators. Shareholdings were recorded is as follows: imagine an industry containing two independently owned firms, firms A and B, with capacities of 100 MW and 50 MW respectively in period one. In period two firm A acquires a 50% shareholding in firm B. This transaction would be recorded on the matrix by firm A's period two share increasing to 125 MW and firm B's falling to 25 MW. Patterns of cross shareholdings in this industry are extremely complex, so it is inevitable that some have been missed. Capacity for self-generation by, for example large aluminium plants is excluded.

The organizational forms of firms in the industry are many and varied. For example many firms are diversified either horizontally - they are multinational in their power generation activities, or vertically - upwards into gas, for example, or downwards into wires businesses or supply. Indeed for some, power generation may be a minority activity in terms of revenue or sales. Since sole focus of this thesis is power generation, all other activities are excluded, which is not to deny their importance but rather to shine the spotlight on generation.

Member states

This is a comprehensive data set covering the EU plus Norway, which is a pivotal player in Northern Europe. The only countries excluded from the sample were Cyprus, Luxembourg and Malta whose combined capacity in 2007 amounted to less than 0.5% of total EU installed capacity.

Leading firms

As explained above, the matrix focusses only on 'leading firms'. There are many possible definitions of what a leading firm is, and at first sight there was no clear rule to choose between them. The Sector Inquiry presents shares of available capacity for each undertaking[3] in selected member states in 2004 (EC, 2006, pp. 336-339). Examination of these graphs was helpful with the formation a definition of what constitutes a leading firm[4]. For 11 of the 13 countries for which data was presented in the Sector Inquiry, the share of available capacity of the largest two firms was in excess of 50%, and for 8 of the countries, over 65%. On the other hand, the country with the largest number of moderately sized generators was the UK, where the largest five firms accounting for 66% of available capacity. Since the interest lies in the activity of the largest firms it was therefore decided to set the threshold at five, therefore:

> **A leading firm is defined to be one the five largest generators in at least one Member State.**

Whilst the setting of this threshold was inevitably somewhat arbitrary, this approach has several advantages: it can be expected that in theory, all leading players will be captured; the coverage of the sample firms is likely to be high relative to the combined system size of all member states[5], and by eliminating the smallest players, some control was exercised over the size of the database, which is a non-trivial benefit given the limited resources available and the magnitude of the data collection exercise.

2.5 Data collection process

Having defined the selection criteria, the data collection process could be started. The vast majority of the data required was firm level, and this part

[3]Undertakings were unidentified in the Sector Inquiry, but their identities could generally be established by virtue of informed guesswork and cross-checking with the matrix data.

[4]While available capacity may be the same if the firm has for example, no mothballed plant, in the presence of capacity unavailable for whatever reason, available capacity will always be less than installed capacity, and thus underestimate the extent of control of capacity in the long run.

[5]The concept of system size will occur throughout the thesis. For the purposes of this study, system size is defined as the total net electrical capacity of all power plants in a given member state, as reported by Eurostat.

of the process consisted of four steps. First, the set of potential candidate firms that were among the five largest in their member state of origin in 2004 was identified in the following way; for each member state, candidate firms were extracted from the Materials and Energy Yearbook (Meller, 2008) and from the Öko-Instiut's study (Matthes et al., 2007) discussed in section 2.3. Repeating this process for each of the 25 sample member states, produced a list of 61 sample leading firms [6].

The second step was to extract each firm's installed capacity in their domestic market, and to rank firms originating in each member state in reverse size order. This revealed that, for example, in 2004 there were 9 potential leading firms in the UK. In total, 54 firms qualified for inclusion in the database i.e. they were among the largest 5 in their member state of origin, as explained above.

The third step was to extract each firm's installed capacity in each of the 25 member states, by examination of the annual reports of each of the 54 sample firms for each of the 10 sample years. The scale of the data collection exercise may be understood by considering that each firm was potentially active in 25 member states, therefore for each sample year, it was necessary to check the capacity of each firm in each member state, which amounted to 1,325 observations. The resultant database therefore contains 13,250 observations.

Step three was complicated by two factors; the absence of a common reporting format, and the absence of annual reports for the earlier years of the sample. Concerning the second, over the sample period it has become the convention for firms to post annual reports on company websites, which made collecting the data for the later years relatively straightforward. However

[6] This is significantly less than the theoretical maximum number of leading firms which is 125 (5 firms in each of 25 member states). The difference between the theoretical maximum and the actual number is explained by the fact that many countries did not have five generators. More than a quarter of the member states analyzed in the Sector Inquiry and discussed in the section above had fewer than five generators. Countries that acceded to the EU later include a majority of Eastern European countries where the norm was for an incumbent monopolist. The mean proportion of firms with (significantly) fewer than five generators is therefore likely to be higher for a sample that includes such countries.

where reports were missing from websites, they had to be acquired by making requests directly to the firms concerned. The lack of a common reporting format, and the related issue that the reporting format for any given firm typically changes over time, meant that close analysis of each report was required.

The production of a comprehensive, strongly balanced panel of data was achieved as the result of this data collection process which was conducted over a period of well over a year, though the degree of intensity varied over the period. The full list of sample firms and their basic characteristics is presented in 2.4 in the Appendix to this chapter.

In order to analyze member state level effects, total installed capacity (system size) for each member state was gathered directly from Eurostat.

Finally, a note on the sample period. The data covers the period 1998 – 2007. The liberalization agenda pursued by the EC got underway in 1997 when the First Electricity Directive (EC, 1996) came into force[7] and the sample period was chosen to capture industry dynamics in the context of sectoral reform.

2.6 The power generation matrix

The matrix contains the generation capacities of 54 firms leading firms (as defined above) for each year in the period 1998 – 2007, disaggregated over 25 member states. The magnitude of the necessary data gathering exercise may be appreciated by noting that Davies and Lyons (1996) matrix consisted of data on 313 firms in 11 member states for a single year, and Clarke (2002) on 56 and 61 firms in 14 member states for two separate years. The power generation matrix that was created is large. The long form has 13,250 rows (54 firms in 25 countries over 10 years) and there are associated with it and additional set of matrices, one for each of the seven regions (see section 2.8). The wide form has 540 rows and 25 columns. It is therefore not feasible to visually reproduce either version of the matrix here.

[7]Though some member states, notably the Nordic countries and the UK, had already begun the process of reforming their electricity sectors.

Table 2.1 reports data on the broad dimensions of the matrix in 1998 and 2007, based on which a number of remarks can be made about the changing structure of the power sector in the EU.

1. Of the 54 matrix firms that were leading in their home member state in 2004, 51 were active in 1998, implying that 3 firms entered the market between 1998 and 2004. This appears to be a modest level of entry given the objective of the reforms to induce entry, however it is consistent with an industry in which barriers to entry are high.

2. By the end of the sample period, 48 firms were active in the sector, which means that 6 firms exited the industry in the interim.

3. The extent of firm multinationality can be estimated by the extent to which they are geographically diversified – that is to say the number of member states in which the own capacity. Given the structure of the matrix, horizontal diversification can be calculated by dividing the number of non-zero values for installed capacity by the number of active firms. By this calculation the average number of countries in which active firms owned capacity increased from 1.3 to 2.2 over the period[8].

4. Finally, the proportion of the total aggregate system size covered by the sample firms rose from 75% to 77%. The remaining capacity was owned by firms that were not leading firms. While many countries have a monopoly generator, others for example Austria and more importantly, Germany and the UK have fragmented generation sectors.

[8] A detailed study of firm multinationality may be found in chapter 4.

	1998	2007
Countries	25	25
Number active firms	51	48
Non-zero S_{ik}	68	107
Mean number member states	1·3	2·2
Coverage of system(%)	74·6	76·7

S_{ik} is the capacity in GW of firm i in country k

Table 2.1: Scope of the matrix. 1998 and 2007

Table 2.2 presents a small section taken from the market share matrix for illustrative purposes. Each entry is the capacity S of firm i in country k in year t. To illustrate, consider the row covering Eon's capacities. Eon owns capacity in five of the six example countries in this fragment, the size of their generation capacity in each is given and the last column shows that their total size in 2007 was 51.5 GW. It is important to note that this number represents an estimate of Eon's capacity in the EU only, so excludes for example, capacity owned in the USA.

Now looking down the column headed ES (Spain), it is clear that in 2007 EDP, Endesa, Enel and Eon own capacity in Spain, and that the total capacity of matrix firms for Spain was 56.4 GW (penultimate entry in column). A measure of the proportion of the total installed capacity of any sample country covered by matrix firms may be calculated by dividing the penultimate row, which summarizes matrix firm capacity, by the last row which contains Eurostat's estimates of total system size in each country.

For three countries shown in the table, Denmark, Estonia and Finland, the Eurostat data suggest the total system size to be smaller than that resulting from our calculations, though not substantially. In the case of Estonia (EE), this is due to rounding. For Denmark (DK) and Finland (FL), installed capacity data is not routinely reported in annual reports. Rather in the Nordic markets the convention appears to be to report firm size in terms of production (TWh). Thus a variety of third party sources had to be relied upon, which may have resulted in some inaccuracy. However cross checking with production data suggests the data to be approximately correct. One final issue concerns the accuracy of the Eurostat data given in the bottom row of the table. Eurostat aims for accuracy, but acknowledge that there is a balance to be struck between timely publication of data and accuracy (Eurostat, 2004).

Comparison of the last two rows of table 2.2 shows that, for example in Germany (DE), the matrix firms cover 68% of total system size in 2007. On average the coverage by matrix firms of the total system capacity as reported by Eurostat is around 73%, so even restricting the analysis (and data gathering exercise) to 54 firms a high proportion of the actual installed capacity is captured.

Firm	Origin	Capacity (GW) in country k						
		DE	DK	EE	ES	FI	FR	$Total$
. . .								
EDF	FR	7					98	123
Edison	IT							0
EDP	PT				3·9			12·5
EE2	DK							0
Eles Gen	SL							2·5
Elsam	DK							0
Endesa	ES							
Enel	IT				21·7			69
Eni	IT							3·3
Eon	DE	26·2	0·03		2·8	0·03	2·49	51·5
. . .								
Total Matrix		82·6	12·9	2·4	56·4	15·0	10·0	576
Total EU		122	12·4	2·3	82·1	14·3	109·4	750

Sources: Company annual reports; EU capacities from Eurostat (2005, 2008)
Cells are populated by S_{ikt}; firm i's capacity in GW in country k in year t
Country codes are given in the Appendix

Table 2.2: Fragment of the market share matrix. 2007

In order to develop a fuller picture of the database, summary statistics for key variables are presented in the Appendix, as is a table listing all sample firms and summarising their key features.

2.7 Coverage by country of origin

Table 2.3 reports the proportion of the total matrix capacity covered by firms from particular member states in 1998 and 2007 for the six countries with the largest shares. It shows that in 1998 there were three firms on the matrix that originated in France (EDF, GDF and Suez), and that their combined share of the capacity of all matrix firms that year was 30.8%, while France accounted for only 16.2% of the total size of the EU system. The fact that the French share of the French matrix firms is about twice as large as France's share of the total EU system, reflects the very large non-domestic generation assets of Suez. In the UK the situation is reversed, which suggests the ownership of assets by non-matrix firms based in the EU or firms from non-matrix countries, e.g. the USA. In fact ownership of capacity in the EU by firms from non-matrix countries is negligible, so the majority of the difference is accounted for by non-matrix firms, which is an indication of a fragmented generation sector. Further, matrix firms based in Germany (DE) accounted for only 8.7% of matrix capacity in 1998, but by 2007 controlled 16.5% of matrix capacity.

These results are interesting because they identify the strongest member states and changes in their relative positions, but they should be interpreted with caution since the generation capacity in a country reflects the size of its population and GDP, so it is to be expected that relatively large and rich countries enter the ranks of the largest six in the sample.

Origin	Number of firms	Share matrix capacity	Country share system
1998			
FR	3	30.8	16.2
IT	5	15.6	9.6
ES	3	9.0	7.2
DE	2	8.7	15.7
UK	3	4.0	10.8
SE	1	3.9	5.1
Total	17	71.9	64.8
2007			
FR	3	23.3	14.6
DE	2	16.5	16.3
IT	4	16.5	11.3
UK	4	5.9	10.0
SE	1	6.2	4.4
ES	3	5.8	10.9
Total	17	71.9	67.4

Table 2.3: Matrix share of capacity, by member state of origin. 1998 and 2007

2.8 Concentration in power generation

The matrix is flexible enough to support data analysis at any level between the firm and the EU. In this section concentration at the EU and regional levels is reported. It is worth restating that a principal objective of the thesis is to provide an analysis of the (hypothetical) EU single internal market in electricity.

2.8.1 Concentration at the EU level

The matrix reveals that by 2007, just three firms owned 36% of total EU capacity. The sheer scale of the largest firms is remarkable. To get a slightly different perspective on aggregate concentration at the EU level, the Herfindahl Hirschman Index (HHI) was calculated and is shown in figure 2.1. While there have been periods of decline and increase, the overall trend of the line is upward. This finding and its implications will be investigated in depth in chapter 3.

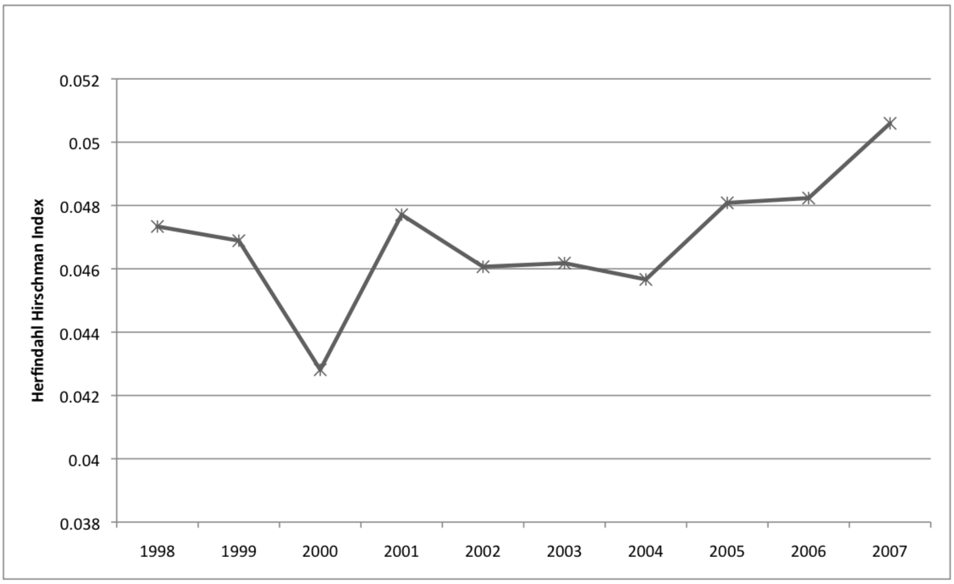


Figure 2.1: HHI, aggregate EU. 1998–2007

2.8.2 Concentration at the regional level

The slow progress towards meeting the EC's single market ambitions (e.g. Smeers, 2009) lead to frustration in many quarters and in early 2006 Energy Regulators Group for Electricity and Gas (ERGEG) and the Council of European Energy Regulators (CEER) launched a Regional Initiatives (RI) plan[9]. The idea was to create 7 regional markets for electricity in which neighbouring member states could work together to tackle barriers to competition and trade, such as balancing arrangements and the lack of transparency. The RI can be thought of as a set of interim goals on the pathway to a single electricity market.

The Herfindahl Hirschman Index (HHI) of concentration for each of the seven RIs was calculated. The participants in the RIs are given in the Appendix and HHIs are presented in figure 2.2. The first thing to notice concerns the levels of concentration. For only two regions, Central East and Northern, is the value of the HHI below 0.1 the threshold below which all competition authorities in the EU regard as unconcentrated. One region, Central South, falls into the moderately concentrated category (HHI$<$ 0.18) while the HHI for South West, Baltic, Central West and the UK, France and Ireland take values above 0.18 that place them in the highly concentrated category.

The second noticeable feature are the trends in the HHIs; the most dramatic is the sharp downward movement of the HHI in the South West region, which is largely the result of entry into the Spanish market by firms based outside the South West region. The Baltic region shows a sharp increase from 2004 to 2005, the result of capacity being withdrawn from the market. Central West, Central East, the UK, France and Ireland, and Central South all exhibit modest declines, while Northern exhibits a modest increase.

Two things should be emphasized at this point. First, caution should be exercised when comparing figures 2.1 and 2.2 because the scale of the vertical axes is different. There is considerable variation between regional HHIs. The second point to note is that the decision to focus only on power genera-

[9]It is interesting to note that while the EC supported the RI, they were not the initiating party.

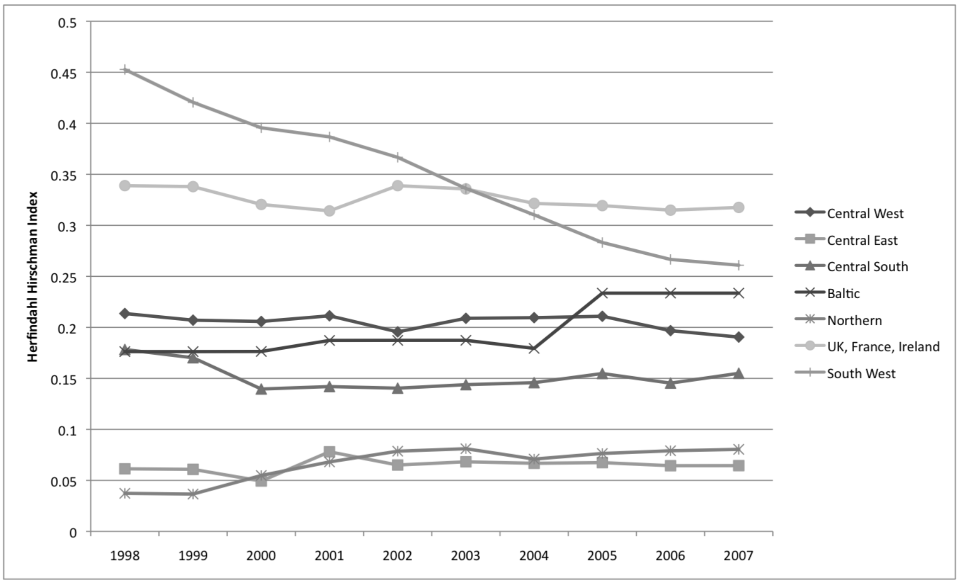


Figure 2.2: HHI, regions. 1998–2007

tion means that these estimates of concentration will underestimate the true level of concentration that would be observed if firms' up and downstream activities were taken into account.

It would be interesting to compare these results with the Öko Institut (Matthes et al., 2007) study of concentration in power production discussed in section 2.3, however meaningful comparisons cannot be readily made since the research on which the the Öko Institut study is based pre-dated the ERGEG RI, and regions were defined in a different way. However the Öko Institut findings for 'Scandinavia' appear to be broadly consistent with our estimate for the Northern region. Considering southern Europe, while the trend for their 'Portugal and Spain' is downwards it is not as steep as our estimate for the South West region (which includes France), however there is a substantial difference in the levels of concentration, no doubt influenced by the presence of France in the RI South West region.

Aggregating member states into regions in this way clearly provides more detail than examination of the EU as a whole; at the level of the RIs the picture becomes much more varied. This may suggest a preference for analysis at the member state rather than RI level which necessarily results in the loss of some detail compared to analysis at the individual member state level. For example, the UK, France and Ireland region is dominated in size by France which has a system size of more than twice the combined size of the other participants, and in both France and Ireland one firm enjoys single dominance. However, since the underlying objective of the thesis to expose the structure of the sector in a way that is consistent with the goals and objectives of EU energy policy, and given the requirement to place limits on the size of the project, it seems to be legitimate to conduct the analysis at both the EU and regional level and leave member state level analysis for future research.

2.9 Conclusion

The market share matrix of power generation is the structure on which most of the empirical analysis in the thesis is based. In this chapter the outline of this unique panel data set has been presented. Specifically, the wide form of the matrix can be used to provide the following information for each year:

- Along the rows, the extent of each firm's horizontal diversification across the sample countries and their total capacity in the sample member states.

- Down the columns, the structure of the market in each sample country – the number and size distribution of market participants and their identities, and the coverage of the total installed capacity in each country by matrix firms.

The regional sub-matrices can be analyzed to reveal the same information by region.

The coverage of the matrix is high, accounting for 73% of EU installed capacity in 2007, so the sample data is representative of the sector as a whole, and despite the focus on the largest power generators, not much detail has been lost. On the downside, cross ownership of assets is pervasive and some have certainly been omitted. Nevertheless, the major shareholdings have been captured and recall that the objective is to provide a high level overview of changes in the structure of the industry bearing in mind the high degree of politicization in the sector.

The matrix is a flexible and powerful tool for the analysis of structural changes in EU power generation. Among other insights, it has already been established that firms are increasingly multinational and that the concentration picture varies considerably between the ERGEG regions, and appears to be high in at least some locations.

2.10 Appendix

2.10.1 Matrix firms in 2007

Rank	Firm	Origin	Size (GW)	MNAT
1	EDF	FR	123·40	7
2	ENEL	IT	68·67	6
3	EON	DE	51·53	10
4	RWE	DE	43·52	3
5	VATTENFALL	SE	35·94	5
6	IBEDROLA	ES	29·47	4
7	CEZ	CZ	16·49	3
8	STATKRAFT	NO	12·87	3
9	EDP	PT	12·50	2
10	BRITISH ENERGY	UK	11·74	1
11	FORTUM	FL	10·81	3
12	SSE	UK	10·50	1
13	DEI	GR	10·26	1
14	PGE	PL	10·00	1
15	DONG	DK	9·95	1
16	AEM	IT	9·08	1
17	SUEZ	FR	8·82	7
18	VERBUND	AT	8·78	2
19	INTERNATIONAL POWER	UK	7·11	8
20	SC HIDROELECTRICA	RO	6·00	1
21	ESB	IE	5·84	1
22	ESSENT	NL	5·51	2
23	PKE	PL	5·00	1
24	CENTRICA	UK	4·57	2
25	NUON	NL	4·00	1
26	ACCIONA	ES	3·68	6
27	SC NUCLEARELECTRICA	RO	3·5	1

Continued on the next page

Rank	Firm	Origin	Size (GW)	MNAT
28	PVO	FL	3·50	1
29	ENI	IT	3·30	1
30	INPP	LT	3·00	1
31	SC ELECTROCENTRALE	RO	2·81	1
32	E-CO VANNKRAFT	NO	2·75	1
33	KOZLODUY	BG	2·72	1
34	NEK	BG	2·57	1
35	MVM	HU	2·50	1
36	ELES GEN	SL	2·50	1
37	E ENERGIA	EE	2·37	1
38	SLOVENSKE ELECTRARNE	SK	2·31	1
39	CE TURCENI	RO	2·06	1
40	JSC LATVENERGO	LV	2·05	1
41	GDF	FR	1·97	3
42	TEPLAREN KOSICE	SK	1·65	1
43	WIENENERGI	AT	1·62	1
44	EVN	AT	1·60	1
45	SC TERMOELECTRICA	RO	1·50	1
46	TIWAG	AT	1·39	1
47	NEWAG	AT	1·35	1
48	SPE	BE	0·60	1
49	ENDESA	ES	0·00	0
49	EDISON	IT	0·00	0
49	SCOTTISH POWER	UK	0·00	0
49	EE2	DK	0·00	0
49	ASM	IT	0·00	0
49	ELSAM	DK	0·00	0

MNAT denotes the number of member states in which the firm owns capacity

Firms ranked 40 had become inactive by 2007

2.10.2 Summary statistics of key variables

Variable		*Mean*	*Std·Dev.*	*Min*	*Max*	Observations	
sizefirm	overall	13·58	20·33	0	123·40	N=	390
	between		20·08	1·90	113·35	n=	39
	within		4·41	−13·33	36·02	T=	10
sharesys	overall	0·02	0·03	0	0·18	N=	390
	between		0·03	0·00	0·18	n=	39
	within		0·01	−0·02	0·05	T=	10
originsize	overall	52·78	36·07	4·26	121·76	N=	390
	between		36·16	5·38	112·40	n=	39
	within		4·89	36·49	72·93	T=	10
*cr*3	overall	0·32	0·01	0·31	0·36	N=	390
	between		0	0·32	0·32	n=	39
	within		0·01	0·31	0·36	T=	10

sizefirm is firm size in GW
sharesys is firm share of total system size (%)
originsize is the size of the firm's member state of origin in GW
*cr*3 is the 3 firm concentration ratio in the member state of origin
N denotes total number of individual-time observations
n denotes the number of individual firms
T denotes the number of time periods

Table 2.5: Summary statistics, key variables

2.10.3 EU country codes

AT	Austria	IT	Italy
BE	Belgium	LT	Lithuania
BG	Bulgaria	LV	Latvia
CZ	Czech Republic	NL	Netherlands
DE	Germany	NO	Norway
DK	Denmark	PL	Poland
EE	Estonia	PT	Portugal
ES	Spain	RO	Romania
FL	Finland	SE	Sweden
FR	France	SK	Slovakia
GR	Greece	SL	Slovenia
HU	Hungary	UK	United Kingdom
IE	Ireland		

Table 2.6: EU Country codes

2.10.4 ERGEG Regions

Region	Members
Baltic	EE, LT, LV
Central East	AT, CZ, DE, HU, PL, SK, SL
Central West	BE, DE, FR, NL
Central South	AT, DE, FR, GR, IT, SL
Northern	DE, DK, FL, NO, PL, SE
South West	ES, FR, PT

Source: ERGEG
http://www.energy-regulators.eu/portal/page/portal/EER$_{H}OME/EER_{I}NITIATIVES$
$accessed$23$July$2010.

Table 2.7: ERGEG regional initiatives

CHAPTER

THREE

MERGERS AND THE SIZE DISTRIBUTION OF FIRMS AT THE AGGREGATE EU LEVEL

3.1 Introduction

Edith Penrose observed that many of the challenges faced by industrial economists with respect to economic policy, would fall away if firms grew roughly in proportion to the rate of growth in the industry (Penrose, 1959, p.198), and that "competition is at once the god and the devil" (*ibid.*, p.265) since it may lead to efficient firm growth but also to an industrial structure in which growth is dampened. The tension arises because competition provides firms with the motivation to improve efficiency and to innovate and expand, as well as the motivation to restrict competition in order to protect themselves against rivals. To put it another way, it is difficult to ascertain whether or not the dominance of an industry by a few large firms is the result of their superior efficiency, in which case consumers may expect welfare gains (assuming the efficiencies are passed on), or as a result of restrictions on competition.

Large corporations emerged at an increasing rate over the twentieth and early twenty first centuries, and concern about their social, political and economic power has been widespread and enduring; as long ago as 1887 the pricing of railroads in the USA was regulated by the Interstate Commerce Act

(White, 2002). This study is motivated by similar concerns. The problem identified by Penrose and which will be explored here can be mapped directly into the concept of aggregate concentration, or the ability of large firms to influence industrial structure, which increases as a consequence of the intensification of control of industrial assets, and therefore of output, sales and employment (Hannah and Kay, 1977, Clarke and Davies, 1983, p.41). Aggregate concentration matters in the present context because in order to evaluate progress towards the single market, it is important to know not only the structure of the sector today, but also the ways in which the sector has developed since the start of the liberalization process.

The key objectives of the chapter are (i) to trace out the changing structure of the industry post liberalization (ii) to investigate the direct causes of those changes (iii) to evaluate the role played by mergers, and (iv) tease out the policy implications.

The chapter proceeds as follows. To provide some context, the process of liberalization in EU power markets is outlined briefly in the next section, before the sample is described and basic data presented in section 3.3. Section 3.4 evaluates changes in aggregate concentration and section 3.5 relates the growth of firms to these observed changes. The contribution of mergers is assessed in section 3.7 and the implications of the study are discussed in the final section.

3.2 The liberalization of electricity markets in the European Union

The modern state, particularly as it developed following the Second World War, embraced the provision of essential services, for example, health care, education, prisons and utilites, in part because the values underlying modern states held their provision to be incompatible with the profit motive. State control and regulation became the norm. The intellectual shift that has taken place over the last thirty years reversed that trend, and as a consequence we have witnessed the transfer of responsibility for essential services away from the state and towards private firms.

The Single European Act of 1986 signaled the European Union's (EU) intention to pursue with renewed vigour its ambition to create a single internal market in which there is free movement of goods, people, services and capital. The ensuing legislative programme reflects the simultaneous withdrawl of the state and ascendency of the market in the supply of essential services. Legislative reform in the electric power sector was set in train by the First Electricity Directive in 1996 (Directive 96/92/EC) and embodied the belief that markets discipline participants.

Liberalization of a formerly monopolized sector may involve one or both of the following dimensions. First functional unbundling of the different segments in the production chain[1] and the introduction of competition where it is feasible, typically increasing the number of firms either through new entry or by splitting up the monopolist. The expectation of an inverse relationship between firm numbers and the intensity of competition is implicit. The second possibility is privatization, which results in the transfer of assets from state to private ownership. But the utility may already be in private ownership, or the state may not wish to relinquish its ownership, so privatization is not an essential step in the liberalization process.

In the case of utilities, privatization alone may be benign with respect to the structure of the industry since the 'control' element can be achieved through regulation, which is typically not sensitive to the ownership regime. On the other hand, liberalization, which subjects utilities to the discipline of the market, is likely to have important consequences for the industry structure. Indeed Newbery (2002, p.386) argues that the full benefits of privatizing former network monopolies are realized only when effective competition is established in the potentially competitive segments[2]. Importantly though, privatization presents opportunities for mergers and acquisitions (M&A), and of course this exerts capital market discipline even on monopolists. It will be shown that mergers drove firm growth and had a significant effect on

[1]For electricity, that is, generation, high voltage transmission, distribution and supply (or retail).

[2]Though the networks themselves remain natural monopolies.

aggregate concentration in the sector.

The introduction of effective competition in power generation has proved particularly challenging, and the progress towards a single internal market in power (and gas) has required an ongoing and increasingly sophisticated legislative programme and intervention by the EC's Directorate General for Competition (DG Competition). Nevertheless, the operating environment facing power generators has changed radically since the late 1990s, and they have adapted their corporate strategies accordingly. Firms have become larger, integrated both up and downstream, and are increasingly multinational.

3.3 Data

Detecting and explaining changes in aggregate concentration implies a focus on the largest firms in the sector because they have the largest impact on changes in concentration. In this section the sample firms and member states are described, the sample selection and data collection processes outlined and some preliminary analysis presented.

3.3.1 The sample firms

This study is concerned only with firms that own power generation assets. Power generators have diverse business models which include a range of organizational forms, and in some cases the scope of their operations has changed radically over the period; some have integrated vertically into inputs, for example the highly controversial merger of Eon and Ruhrgas in 2002 which brought a very substantial pan-European gas business into the Eon fold. While important, such changes in scope and their impact on the overall size of the firm are outside the remit of this work. References to 'the industry' and 'sector' therefore refer only to power generation.

Firm size is measured by installed capacity in gigawatts (GW), because changes over time in a firm's capacity act as a record of their strategic decisions conditional on a set of beliefs about the likely evolution of the industry and their place in that industry. More usual measures of firm size, for example, sales, revenue or production, necessarily reflect short-run market supply and demand conditions from which this study seeks to abstract. As Nilsson (2005) argues, if the issue of interest are long run changes, then capacity is the appropriate measure of size.

3.3.2 Sample selection

54 candidate firms were identified from the market share matrix introduced in chapter 2. Preliminary examination of distribution of matrix firms' size was highly positively skewed, reflecting the large number of small firms. The selection criterion for inclusion in the matrix was that a firm must be one of the largest five firms in at least one member state (which in fact was always their country of origin) but the large number of small countries included in the matrix meant that some matrix firms were, nevertheless, small. Because the focus on the largest firms, the analysis presented in this chapter is restricted to data on firms that were at some point, among the largest 30 generating firms in the EU and that originated in one of the 18 sample member states discussed above. The distribution was truncated so that only firms that were, in at least one year, among the largest 30 firms, were included. This resulted in a sample of 39 firms.

This approach to sample selection means that it is likely that the vast majority of large firms have been captured, though it is probable that a small number of generators at the lower end of the 'large firm distribution' have been omitted. There is no comprehensive, reliable and freely available listing of all generators based in the EU against which the database could be checked, and resource constraints prevented further data gathering. Nevertheless, it is shown in figure 3.1 that the sample covers approximately 80% of total capacity.

3.3.3 The sample member states

The sample firms originate in 18 countries[3] (17 EU–27 countries plus Norway), and the size of the generation assets of the i^{th} firm in country k is denoted s_{ik}. The system size of each member state is therefore given by $S_k = \sum s_{ik}$, and the total system size[4] of all member states calculated given by summing S over the 18 sample member states. Eurostat publish installed capacity equivalent to S_k for each member state, from which the total system size was calculated.

The top line in figure 3.1 shows that the total system size rose from 583 GW in 1998 to 703 GW in 2007[5], so over the ten year period, the total capacity, or system size, of all sample member states expanded by around 20%. This is consistent with consumption growth recorded by the European Network of Transmission System Operators for Electricity[6],[7] (ENTSOE) (UCTE, 2008, p.133).

3.3.4 Data collection and sources

Firm size

Data on the size of the sample firms for the period 1998 – 2007 were collected primarily from company annual reports which are in general available on their websites. Where this was not the case, the data were obtained either through direct communication with the firm concerned, or very occasionally, through other publicly available sources. The data includes shareholdings where possible. For example, in 2007 EdF had a shareholding of 45% in EnBW, so EdF's total capacity in 2007 includes 45% of EnBW's capacity.

Firm size was calculated in the following way. For each firm, annual

[3] Austria, Czech Republic, Germany, Denmark, Spain, Finland, France, Greece, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Sweden, Slovakia, UK.

[4] For the purposes of this study, system size is defined as the total net electrical capacity of all power plants in a given member state, as reported by Eurostat

[5] Because the data used is the aggregate of total system size for each sample member state rather than the EU total installed capacity, this measure is robust to changes in the size of the EU; in 2004 and 2007 two member states in this sample joined the EU.

[6] formerly UCTE

[7] Demand rose from 2,172 TWh in 1998 to 2,607TWh in 2007

reports were obtained and from them, the firm's capacity in each of the sample countries (if any) was extracted. These data were then summed to yield a measure of aggregate firm size which represents the total firm capacity in the 18 sample member states. This is not necessarily the same as the firm size in the EU or globally, though of course it may be. For example, the aggregate capacity of a firm active in only two member states both of which are included in the sample, will be the same irrespective of whether it is aggregated over the full EU 27 or just the sample member states. This exercise resulted in a unique panel of data on 39 of the largest firms spanning 10 years and which could be decomposed by country. To give an idea of the sizes of the very largest firms, the capacities of firms that ranked 1–10 in any given year are presented in table 3.1.

		Firm installed capacity in 18 member states (GW)									
Firm	Origin	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
EDF	France	102.1	102.1	105.5	110.6	112.4	114.6	115.0	121.8	122.8	123.4
Enel	Italy	57.0	56.0	56.0	44.8	44.8	45.3	45.3	50	48.9	68.7
Eon	Germany	10.9	11.2	29.0	40.8	45.1	44.7	44.4	45.6	46.1	60.25
RWE	Germany	30.2	30.2	35.1	35.1	43.7	43.5	43.0	42.9	43.2	43.5
Vattenfall	Sweden	18.2	18.2	19.1	19.1	30.7	33.9	33.3	35.2	35.9	35.9
Suez	France	1.5	22.2	26.2	26.2	26.3	26.8	26.8	27.7	30.5	31.3
Ibedrola	Spain	22.6	22.6	22.6	22.6	19.3	21.2	23.2	24.5	26.8	28.7
Cez	Czech Rep.	10.1	10.1	10.1	10.1	12.3	12.3	12.3	12.3	16.5	16.5
EDP	Portugal	7.5	7.5	7.6	7.6	10.8	10.5	11.0	12.0	12	13.3
Statkraft	Norway	11.5	11.5	11.6	12.2	12.2	12.2	12.1	12.1	12.1	13.1
Endesa	Spain	23.8	23.4	23.4	27.5	28.0	27.1	30.3	31.0	34.19	.
Edison	Italy	9.5	9.5	9.5	7.6	14.8	14.8	14.8	0	.	.
BE	UK	9.8	9.8	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7
Veba	Germany	17.8	17.8	.	.	.	.	.	.	.	.
NP/Innogy	UK	12.7	8.7	8.7	8.7	.	.	.	.	.	.

Source: Company annual reports, own calculations.
A firm that ceased to exist as an independent entity is denoted (.).
Firms that were at some point in the sample period, one of the largest 10 firms.

Table 3.1: Aggregate capacity of the very largest firms. 1998–2007.

Certain stylized facts about the changing structure of power generation in the EU can be drawn from table 3.1. First, there is one dominant firm that is larger than the combined size of the second and third firms in all years except the final year, when the ratio fell slightly. Second, the capacities of firms that exit are to a large extent, bought by other top ten firms and third, that the exiting firms had assets over 14.8 GW - that is to say, they were fairly large, even in this sample of large firms. These points will be investigated further below.

Merger data

To investigate the contribution of mergers to the increase in aggregate concentration, data on mergers was collected. The primary source of the merger data was a survey of M&A deals in EU power and gas between 1998 and 2007 (Lévêque, 2008). Where necessary other sources, for example company annual reports, coverage in the specialist press and the European Commission's merger database were consulted to augment the data.

3.3.5 Coverage of the sample

The sample firms' total capacity in the 18 member states grew from 451 GW to 584 GW over the period. Figure 3.1 shows the gap between the sample firms and the sample member states narrows slightly, and despite including only the largest 39 firms, the coverage of the sample is around 83% in 2007. Because the growth of the largest firms (by definition, the sample firms) was larger than growth in the total system size, the proportion of the total system accounted for by small firms excluded from the sample fell from 23% to 17% over the period: large firms controlled an increasing proportion of total capacity.

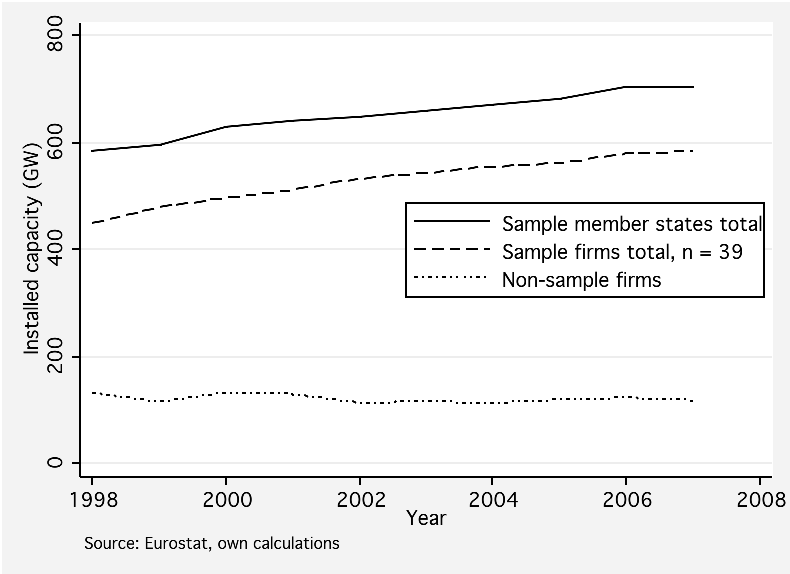


Figure 3.1: Coverage of the sample firms

3.4 Firm size and aggregate concentration

In this section data on the size distribution of sample firms at the start and end of the period are presented, and changes in firm size and thus aggregate concentration are traced out and discussed.

3.4.1 The firm size distribution

The mean size of firms increased from approximately 11.5 GW to 15 GW between 1998 and 2007. Kernel density distributions for 1998 and 2007 for the data described above were estimated and are shown in figure 3.2[8].

The kernel density estimate is bimodal, which is very interesting if unexpected. It suggests that the vast majority of the growth comes from the very largest firms which is not borne out by analysis later in this section or in table **??**. Two possible explanations rest on the shape of the underlying

[8]Kernel density estimation imposes no specific structure on the data and has two other advantages over histograms. First, it generates a smooth, not a step function, which is the result of connecting the midpoints of the histogram. Second, it assigns higher weights to data points closer to the evaluation point rather than the equal weight assigned to every entry in a histogram bin.

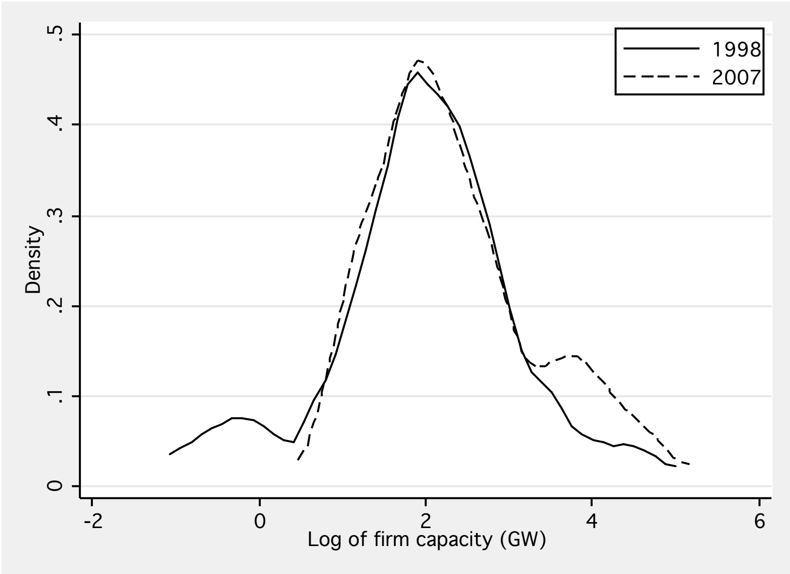


Figure 3.2: Kernel density estimate

population distribution. Kernel density estimation is based on the assumption that it is approximately log normal, and in accordance with the majority of the literature (e.g. Chesher, 1979) we have made this assumption. If the population is indeed log normal then the observed pattern may be an artefact of the particular sample that we have, i.e. the 39 largest firms, and may indicate the omission of a small number of largish firms.

An alternative and much more interesting explanation is the possibility that the underlying distribution is not log-normal throughout its whole range. Simon and Bonini (1958) show that if firms grow approximately in proportion to their size (the law of proportionate effect, see section **??**) and assuming that firms above some minimum size have constant costs, then the distribution of firms above the minimum size, i.e. those with constant costs, follows a Yule distribution. To put the same point another way, imagine splitting the existing sample into two parts, one sub-sample consisting of the firms with variable costs might be distributed log normally, while distribution of the firms with constant costs follows the Yule. The implications of this point are explored further in section 3.8.

3.4.2 Aggregate concentration and its measurement

Aggregate concentration has been defined as the degree of control over economic activity in the macro economy or at the sectoral level, that is held by the largest firms (Hannah and Kay, 1977, p.41). It is generally differentiated from market concentration, or the dominance of distinct markets by the largest firms operating in that market, though (Clarke and Davies, 1983) show aggregate concentration to be proportionate to a weighted sum of market concentration so the two concepts are formally linked. Recall that in chapter 1 we explained the intention to concentrate on the EC's single market vision. Accordingly in this study, aggregate concentration is defined as the extent of the influence over EU power generation exercised by the firms with the largest capacities, assuming that the EU is a single market.

No comprehensive study of aggregate concentration in EU power markets could be found in the peer-reviewed literature, and as discussed in section 3.2 the Sector Inquiry did not discuss the concept. A small number of studies fall somewhere in between; Domanico (2007) discusses the relationship between aggregate EU concentration and market concentration in selected member states in a multi-market contact framework, and Green (2006) takes a similar approach, highlighting the role of mergers.

For the purposes of this study, three different measures of aggregate concentration are calculated, each of which reveal a slightly different insight into the data[9]. A consequence of the absence of literature on aggregate concentration is a lack of consensus concerning the level of aggregate concentration at which concerns may be raised legitimately. While thresholds for various measures of market concentration are embodied in for example, the EC's Horizontal Merger Guidelines (EC, 2004), or the guidelines of individual competition authorities such as the German Bundeskartellampt, no such benchmarks exist with respect to aggregate concentration. To assist in evaluating our results, the quantitative estimates of aggregate concentration for this sample are evaluated with respect to those found in earlier studies of

[9]For a survey discussing the measurement of concentration, see Curry and George (1983).

other sectors. Furthermore, since the study is an attempt to evaluate firms' long run response to the changing competitive landscape, and thus implicitly to the policy framework, the *trend* in concentration is as important as its absolute level. As White (2002) notes, knowledge of trends (in levels) is at the very least, useful; a downward trend indicates that any problem related to aggregate concentration is not getting worse.

Concentration ratios

The concentration ratio is an *absolute* measure of concentration denoted CR_n, and expressing the share of total capacity controlled by the largest n firms. Despite or perhaps because of its simplicity, the CR_n is widely employed as a measure of concentration in academic studies (see Schmalensee, 1989) and by practitioners. In terms of macroeconomic level aggregate concentration, 50, 100, 150 and 200 firm concentration ratios were calculated and reported by White (2002), and the 5 firm concentration ratio in analysis of food retailing in the EU (Dobson et al., 2001). For this sample, the 3, 5 and 10 firm concentration ratios in power generation are calculated, and presented in figure 3.3.

Three features stand out. The CR_3 was fairly stable at approximately 30% until 2006, after which it increased sharply. Second, the CR_3 rose by 12.5% and both the CR_5 and CR_{10} rose by approximately 15% in ten years. Third, the gap between the CR_5 and the CR_{10} widened until 2006, after which its growth accelerated, mirroring the sharp rise in the CR_3, which suggests large changes in the size of one or more of the largest 3 firms. These findings are evidence of an upward trend in concentration.

Comparison with estimates of concentration in other industries suggests that aggregate concentration in EU power generation is high. Davies and Lyons (1996) found an average CR_5 of producer concentration for all manufacturing industries to be 26% and that the *twenty* largest firms in EU food retailing accounted for 43% of turnover. Dobson et al. (2001) record a CR_5 of over 40% for a very few sectors. Davies and Lyons (1996) find the mean CR_5 in EU manufacturing to be just 22.3%, less than half the mean CR_5 in this sample in 2007.

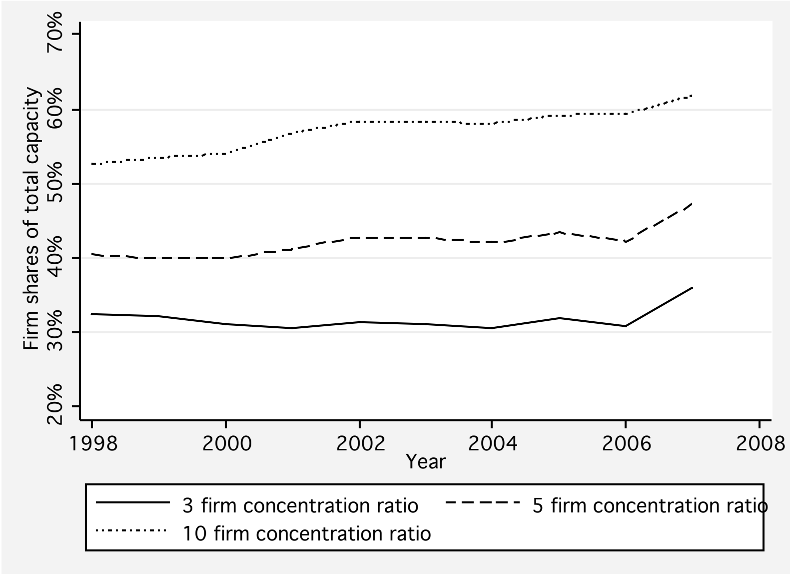


Figure 3.3: Three, five and ten firm concentration ratios

Gini coefficient

An alternative way measuring aggregate concentration is in terms of shares controlled by a given *proportion* of firms. It should be clear that aggregate concentration concerns both the number of firms and the (size) inequalities between them, and a useful tool for representing inequalities in distributions is the Gini coefficient. While more commonly applied to measures of income, it is equally well suited to analysis of size inequalities between firms (e.g. Hart and Prais, 1956).

The Gini coefficient, represented graphically by the Lorenz curves shown in figure 3.4, is the ratio of the area between the line of equality and the Lorenz curve, to the total area under the 45% line. The higher the Gini coefficient the greater the inequality, so a Lorenz curve that lies on the 45% line would have a Gini coefficient of 0, which implies that all firms are of equal size. By contrast, a Gini coefficient of 100[10] would imply that one firm

[10]The Gini coefficient generally lies between 0 and 1, but in this case has been multiplied by 100 to aid comparison with the CR_n

controls all capacity in the market.

Comparison of the coefficients calculated for the start and end of the period, 59.1, and 63.1 respectively, indicates that overall inequality has increased. However examination of the curves plotted in figure 3.4 reveals more detail about where in the size distribution the inequality has changed. For example, it shows that the share of the total capacity controlled by 80% of firms slipped from approximately 38% in 1998 to around 30% 2007, and that while the share of the largest 7% of firms has remained broadly constant over the period, that share was around 40% of capacity. Similarly, the share of the smallest 20% of firms remained fairly constant. More generally, figure 3.4 presents evidence that inequality has increased among firms that occupy the roughly the middle of the distribution. However, it is worth noting here that the sample by definition comprises only the largest firms.

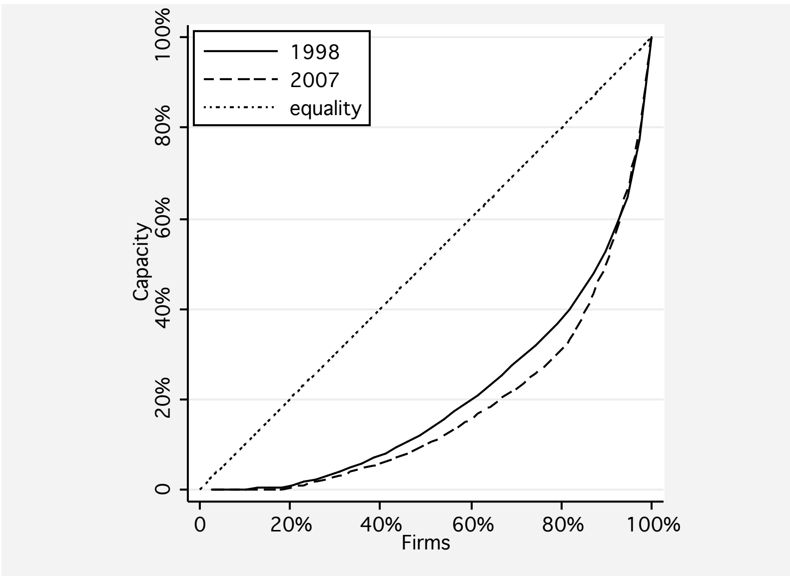


Figure 3.4: Lorenz curves. 1998 and 2007

Herfindahl Hirschman Index

The Herfindahl Hirschman index (HHI) is used by the Federal Trade Commission (FTC) and all competition authorities in the EU to measure market concentration during investigations into the potential abuse of market power and as a merger screen.

The HHI is also well suited to measuring aggregate concentration (Clarke and Davies, 1983) and is calculated by summing the squared share[11] of each market participant, so if s_i is the capacity share of the i^{th} firm of the industry of size S, aggregate HHI is calculated according to the following formula:

$$HHI = \sum_{i=1}^{n} s_i^2/S^2$$

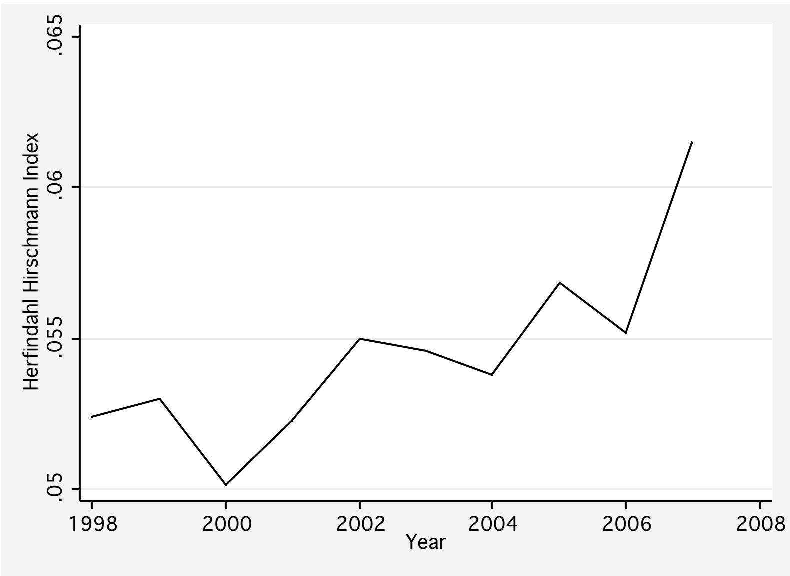


Figure 3.5: HHI, aggregate concentration

Figure 3.5 shows the HHI rose from 0.052 to 0.061, or about 17% over the period. The figure shows that the HHI took a sharp upward trend, though it is not continuously trending upwards. Rather, it follows a jagged path which may be an indicator of the associated large and sudden transfers of assets perhaps induced by mergers. The striking rise in the HHI between 2000 and 2002 and again between 2006 and 2007 reflects significant size increases among the very largest firms (see table 3.1). The decline in the HHI between

[11]More usually it is share of sales or revenue, but in this case, it is capacity share. See, e.g. Jans and Rosenbaum (1997) for a study of concentration in the cement industry based on kiln capacity as the measure of size.

1999 and 2000 reflects the fact that growth of the system size during these sub-periods was about twice that of the total sample size, and a similar story explains the fall towards the end of the period. To put this into context, Davies and Lyons (1996, p.53) report a mean HHI of 0.024 in their study of a wide range of EU industries, which places the HHI reported for this sector firmly towards the top end of the range.

Any Herfindahl type index may be defined in a number-equivalent form (Adelman, 1969), which is calculated by taking the reciprocal of the HHI, so

$$NHHI = 1/HHI$$

Conceptually, $NHHI$ is the number of (hypothetical) equal sized firms that would generate the corresponding HHI. For this sample, the number of equal sized firms required to generate the estimated values of HHI fell from 19 to 16. So in 2007, the estimated HHI is equivalent to 16 equal sized firms owning all the capacity of the 18 sample member states. There are in fact 32 unequal sized firms in the sample in 2007 (see table 3.4), but the device serves to emphasize the fact that the sector became more concentrated.

To summarize the evidence presented briefly; by three different measures, aggregate concentration in the sector was on an upward trend between 1998 and 2007. Comparison of the concentration ratios for this sample with existing studies reveals them to be high and that growth in the size of firms ranked 6–10 to be particularly strong. The path of the HHI suggests the possibility that mergers among the largest firms may be driving changes in its value, and the number of equal sized firms that would be required to generate the estimated HHI fell from 19 to 16. The Gini coefficient represented in figure 3.4 confirms that inequality has increased around the centre of the distribution of this sample of large firms, and that the share of capacity held by, for example the smallest 80% of firms, declined by over 20%.

3.4.3 Mobility among leading firms

While identifying long run trends in concentration may be a useful guide as to the likely future development of market structure, an increase in concentration may not *per se* constitute a cause for concern. If the identities of the largest firms change over time, that is to say if firms are mobile within the size distribution, even relatively high levels of concentration may not be inconsistent with a healthy level of competition. For example it may indicate an industry in which the most efficient firms thrive at the expense of less efficient rivals, and absent entry barriers, may encourage entry[12]. By contrast, a highly concentrated and rigid industrial structure may indicate monopolistic tendencies (Hart and Prais, 1956).

To investigate firm mobility, the ten largest firms in 2007 were identified and ranked by size. The rank of the top 10 in 2007 was then calculated for each of the preceding 9 years. In this way the path of each firm's rank was traced. Finally, firms that had appeared in the top 10 in any sample year were identified and treated in the same way. The results of the exercise are presented in table 3.2, which can be thought of as a companion table to table 3.1 and which shows the "churn" among the 15 firms that were in at least one year, among the 10 largest firms. Several points should be noted. First, the largest firm in the industry, EDF (France) remains in first place throughout, and the second largest firm Enel (Italy) retains that position with the exception of 2001, when it drops to third place. More generally, the largest 5 firms stay in the 5 five from 2001 to the end of the sample. Looking outside the largest 5 firms, there are some significant changes in the relative ranks of firms, for example Suez took the rank of 32 (of 35) in 1998 but by 1999 was in sixth place [13] CEZ moved up the ranking from 12 to 8 and and EDP from 19 to 10. Finally, 4 firms ceased to exist as independent entities.

[12]Which would *ceteris paribus* then reduce concentration again.

[13]Indeed in 2008 Suez moved into to second position, but that is outside the sample period.

		Rank									
Firm	Origin	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
EDF	France	1	1	1	1	1	1	1	1	1	1
Enel	Italy	2	2	2	2	3	2	2	2	2	2
Eon	Germany	10	10	4	3	2	3	3	3	3	3
RWE	Germany	3	3	3	4	4	4	4	4	4	4
Vattenfall	Sweden	6	7	8	5	5	5	5	5	5	5
Suez	France	32	6	5	7	7	7	7	7	7	6
Ibedrola	Spain	5	5	7	8	8	8	8	8	8	7
Cez	Czech Rep.	12	12	12	12	10	10	10	9	9	8
EDP	Portugal	19	20	19	16	13	14	13	11	11	9
Statkraft	Norway	9	9	10	9	11	11	11	10	10	10
Endesa	Spain	4	4	6	6	6	6	6	6	6	.
Edison	Italy	15	15	15	17	9	9	9	.	.	.
BE	UK	14	14	9	10	12	12	12	12	12	11
Veba	Germany	7	8	.	.	.	.	.	.	.	.
NP/Innogy	UK	8	17	16	14	.	.	.	.	.	.

Firms which were among the largest 10 in any year. A firm that ceased to exist is denoted (.)
Source: Company annual reports, own calculations.

Table 3.2: The largest 10 firms. 1998 - 2007

3.5 Patterns of firm growth

In this section the focus shifts from relative to absolute size. This is a necessary step in evaluating the importance of the largest firms in the EU.

The transition matrix in table 3.3 tracks the growth of the 39 sample firms between 1998–2007[14]. The table is essentially a frequency distribution of firms classified by their size at the start and the end of the period. The first step in the construction of the matrix is to classify firms by size class, the boundaries of which describe a geometric progression. There are nine classes ranging from 0, firms in the sample that are inactive[15], firms are classified as size 1 if their assets are less than 1 GW, and so on until firms with over 64 GW of installed capacity are captured in size class 8. In 2007 there were no firms in classes 1 or 2 which is a consequence of the sample selection procedure and the upward movement of firms through the classes.

To see how the matrix works, first examine the diagonal highlighted in bold face, which consists of firms that started and finished the period in the same size category. Firms above the diagonal have been 'promoted', while those below the diagonal have shrunk to a lower size class. So immediately we can see that only 1 active firm has been 'demoted', while 13 firms active throughout the period (i.e. excluding the 4 entrants shown in row 1) have moved up by at least 1 size class.

Now consider the fifth row, firms with 4–8 GW of capacity in 1998 (size class 4). Of the 8 firms in this category in 1998, by 2007 i has fallen into size class 3, 3 have between 8 and 16 GW capacity, and 4 firms have remained in class size 4. Looking now at the largest 2 class sizes, firms with more than 32 GW, we can see that membership has risen from 2 in 1998 to 5 in 2007. The transition matrix provides unambiguous evidence of an increase in the number of firms in the larger classes. Lastly, row 1 and column 1 (which capture firms that are inactive) show that there were 4 inactive firms in 1998 and 7 inactive firms in 2007, so the number of active firms must have fallen. *Ceteris paribus* this implies an increase in concentration.

[14]For other examples of the use of this type of matrix, see for example Prais (1976), Dunne and Hughes (1994).

[15]I.e., firms that either entered or exited the sector during the sample period.

		Size class 2007									
Size (GW)	Size class 1998	0	1	2	3	4	5	6	7	8	Firms 1998
0	0					4					4
< 1	1					1	1				2
$1 > 2$	2					1		1			2
$2 > 4$	3	2			**2**		1				5
$4 > 8$	4				1	**4**	3				8
$8 > 16$	5	3					**6**	1	1		11
$16 > 32$	6	2						**1**	2		5
$32 > 64$	7									1	1
> 64	8									**1**	1
	Firms 2007	7	0	0	3	10	11	3	3	2	39

Table 3.3: Leading power generators, by size class. 1998 - 2007

3.5.1 Entry, exit and survival

A useful characteristic of the transition matrix is that it allows the identification of firm entry and exit, which are examined in this section to give an idea of changes in the structure of the sector by type of firm.

Entry and exit

Entry

4 of the 32 firms active in 2007 entered the sector (captured in the first row of table 3.3, size class 0). All 4 entrants were in size class four by 2007. As might be expected the mean size and its variance of entrants in the period was smaller than other categories of firms, as shown in table 3.4.

Exit

7 or 20% of the 35 firms alive in 1998 exited in the interval (class size 0 in the first column of table 3.3)[16]. Firms that ceased to exist as independent entities were larger, by approximately 12%, than the mean size of all firms at the start of the period and the transition matrix establishes that in contrast with other studies (Hart and Prais, 1956, e.g.) firms that exited were not the smallest firms, but around the middle of the distribution in 1998. This is particularly interesting given that in this sample all firms exiting the market were acquired by other sample firms, and motivates the further analysis of the impact of mergers to changing industrial structure found in section 3.7.

Sample attrition

In section 3.3.2 it was noted that sample attrition may induce a downward bias in the growth rates of surviving firms (measured against opening size) since slow growing large firms have the option to slip down the size classes but they still survive (and therefore remain in the sample). By contrast, slow growing small firms may fall out of the sample. However, recall that the transition matrix, table 3.3, shows that only one firm shrank and firms that

[16] In their study of quoted and unquoted UK companies Dunne and Hughes (1994) find the same rate of attrition.

exited were in size class four in 1998, i.e firms exited from roughly the middle of the distribution, not the bottom. This suggests that sample attrition is not major problem for this sample.

Survivors

Summary statistics of surviving firms identified in table 3.3 are shown in table 3.4. There were 28 survivors and they were around 30% larger in 2007 than in 1998. However the variance in size fell by around 17% which suggests falling concentration; a paradox given data presented above that shows aggregate concentration among the full sample to have risen substantially.

	Number	Mean	S.D
Total 1998	35	1.97	1.11
Deaths in period	7	2.23	0.74
Survivors in 1998	28	1.91	1.19
Survivors in 2007	28	2.46	0.99
Births in period	4	1.30	0.57
Total in 2007	32	2.35	0.97

Survivors are firms that were alive throughout the 10 year period.

Table 3.4: Mean and variance of size, by category. 1998 and 2007

3.6 Firm growth, firm size and aggregate concentration

Having developed a quite detailed picture of the composition of the sample and how it changed over time, the next task is to investigate the relationship between firm size and firm growth. There is no unambiguous choice of theoretical framework since different frameworks imply different outcomes. Theories of the firm derived from traditional neoclassical economics for example, assume that firms face U-shaped long run average costs and the expectation of an inverse relationship between firm size and growth and hence an optimum size is implicit. By contrast theories drawn from managerial economics which emphasize the discretionary behavior of managers (e.g. Williamson, 1964), imply no optimum size and a positive relationship between growth and size. This expectation is driven by the assumption that managers (as distinct from owners) maximize growth rather than profits (or share price), and ownership and control are separated in large firms but not in small firms. Clearly both theories cannot simultaneously be correct.

An alternative to approaches derived from economic theory, is a framework grounded in statistical theory in which alterations in the shape of an industry in aggregate can be derived from the properties of the size distribution of firms. A stochastic framework exposes the links between firm size and growth and aggregate concentration, so is particularly suitable in the current context. The basic idea is this: there is a diverse range forces influencing changes in firm size, for example profitability, the ability of management and access to technology and inputs, as well as macroeconomic conditions. Taken together these forces drive changes in growth and thus the size distribution over time.

The critical assumption in the statistical approach is that firm growth follows a random walk, so there are no systemic influences on one particular type of firm, for example large firms. To understand the intuition, consider the following simple two period thought experiment. In period one all firms in a given population start out the same size, share the same probability of expansion or shrinkage and are subject to a random array of forces; some will grow while others shrink. Maintaining the assumption on growth and that influences are random, in period two dispersion will increase as the large firms get larger faster than the small firms get larger. And so on until a small number of firms become dominant. Thus in a constant sample of firms, rising concentration is consistent with the idea that firms grow in proportion to their size if:

$$s_{it}/s_{it-1} = \varepsilon_{it} \tag{3.1}$$

where s_{it} is the size of the ith firm at time t and ε_{it} is a random variable with mean 0 and is uncorrelated with s_{it-1}.

3.6.1 A simple model of firm growth

The law of proportional effect (LPE) is one of the simplest models of firm growth that has been developed in the stochastic framework. It holds that the probability of a firm growing by, e.g. 5% is the same for a firms with assets of 10 billion Euros and 100 million Euros, and from it three main hypotheses to be tested empirically in the next section are derived. If the LPE is valid then (i) firms experience growth in proportion to their size, and (ii) the dispersion of growth rates is invariant with respect to firm size. A further implication of equation (3.1) is that (iii) growth rates do not exhibit serial correlation, since the persistence of growth would imply a link between opening size and growth (Singh and Whittington, 1975).

First considering hypotheses (i) and (ii). If the LPE holds, then from equation (3.1) there will be a systematic relationship between the size in period one with size in period two which may be estimated by equation (3.2), the simplest form of the LPE, first proposed by Gibrat (1931).

$$logs_{it} = \alpha + \beta logs_{it-1} + U_{it-1} \tag{3.2}$$

where, $logs_{it}$ and $logs_{it-1}$ are the logs of firm size in years t and $t-1$ respectively, and U_{t-1} is a homoscedastic error term with mean zero. If $\beta = 1$, then no systematic influence on firm growth is implied, so firms grow in proportion to their size. This would support hypothesis (i). However, $\beta < 1$ implies systematic factors that result in small firms growing faster than large firms, and vice versa if $\beta > 1$.

One justification for adopting a stochastic framework was that it makes clear the link between changes in size/growth and concentration. To see why, note that from equation (3.2) it follows that:

$$Var(logs_{it}) = \beta^2 Var(logs_{it-1}) + Var(U_{it}) \quad (3.3)$$

and from hypothesis (ii) *ceteris paribus* concentration rises if:

$$\frac{Var(logs_{it})}{Var(logs_{it-1})} > 1 \quad (3.4)$$

and from (3.3), this suggests that:

$$Var(U_{it}) > (1 - \beta^2) Var(logs_{it-1}) \quad (3.5)$$

From hypotheses (i) and (ii) it follows that if $Var(U_{it-1}) = 0$ and $\beta = 1$ and in the absence of serial correlation of the dependent variable in (3.2), then there is no systematic influence that would cause concentration to rise over time. On the other hand, given that from (3.4) $VarU_{it-1} > 0$, concentration may be expected to rise over time if $\beta \geq 1$. If $VarU_{it}$ is large relative to $Var(s_{it})$ then it is possible that concentration increases even if $\beta < 1$ (see Kumar, 1985).

3.6.2 Empirical evidence on growth and firm size

Hypotheses (i) and (ii) the simple form of the LPE given in equation (3.2) were estimated by Ordinary Least Squares (OLS) and reported in the left column of table 3.5. Estimating autoregressive models such as equation (3.2) by OLS may generate estimators that are inconsistent due to serial correlation in the error term (Greene, 2000, p.533), so the results reported include robust standard errors.

Looking first at the overall fit of the model, the $R^2 = .93$ and the p value suggest that the model captures the vast majority of the influence on size. The coefficient of 0.94 on $\hat{\beta}$ is highly significant but is found not to be significantly different from 1. This result supports hypothesis (i), that firm growth is approximately proportionate to firm size.

Turning now to hypothesis (ii), that the dispersion of growth rates is invariant with respect to size. A Breusch and Pagan test rejected (at the 0.1% level) the hypothesis that the error term is homoscedastic. It was shown in table 3.4 that the variance of growth rates varies inversely with firm size so the intuition for this result is easy to see; large firms may be expected to have a 'smoother' rate of growth for the same reason that they are less likely to exit the market than small firms - diversification spreads the risk of low growth and thus reduces the variability of growth.

In summary, there is evidence that the LPE holds for this sample of 28 surviving firms - firms have grown more or less in proportion to their size.

The persistence of growth

The form of the LPE in equation (3.2) implies no serial correlation between growth rates; hypothesis (iii) was tested by estimating equation (3.6) by OLS:

$$log(s_{it}/s_{it-1}) = \alpha + \beta log s_{it-1} + \gamma log(s_{it-1}/s_{it-2}) + \epsilon_{it} \tag{3.6}$$

where t_{-1} and t_{-2} indicate lags of one and two years. The equation postulates that proportionate firm growth is a function of firm size at time t_{-1} and growth in the period $t_{-1} - t_{-2}$. Results are given in the right hand column of table 3.5. The coefficient on $\hat{\beta}$ is negative and very small, though significant at the 1% level. This shows that smaller firms grew slightly faster than larger firms. These results are strikingly similar in terms of the magnitude and sign of the coefficients to those found by Kumar (1985) though Singh and Whittington (1975) reported a weak positive relationship between growth and size.

The coefficient on $\hat{\gamma}$, the log of past growth, is weakly positive but not significant, which suggests that serial correlation in growth rates is not a problem in this sample and implies that OLS estimates will be consistent. Interestingly, the absence of serial correlation may indicate the prevalence of growth by merger rather than organic growth since it is likely that organic

	Dependent variable	
	$logs_{it}$ [a]	$log(s_{it}/s_{it-1})$ [b]
$\hat{\alpha}$	$0{\cdot}2**$	$0{\cdot}15***$
	(0·03)	(0·04)
$\hat{\beta}$	$0{\cdot}94***$	$-0{\cdot}04**$
	(0·03)	(0·01)
$\hat{\gamma}$	·	0·03
	·	(0·05)
R^2 within	0·54	0·07
R^2 between	0·99	0·13
R^2 overall	0·93	0·04
n	28	28
$Prob > chi$	0·000	0·01

a $logs_{it} = \alpha + \beta logs_{it-1} + \epsilon_{it}$
b $log(s_{it}/s_{it-1}) = \alpha + \beta logs_{it-1} + \gamma log(s_{it-1}/s_{it-2}) + \epsilon_{it}$
** indicates significance at 1% level.
*** indicates significance at 0.1% level.
Standard errors in parentheses.

Table 3.5: OLS Regression results, firm growth and persistence of growth. 1998-2007

growth is likely to be more persistent than growth by merger. Sustained organic growth is delivered by in-house managerial and technological ability and the building of human capital within the firm, which is a ongoing commitment. By contrast, growth by merger is by definition a discrete event. Although it may be argued that serial mergers also require specific expertise, the ubiquity of professional and financial services firms means that the required expertise, which may differ from deal to deal, can be bought in as required. It is to the role of mergers in growth that attention is now turned.

3.7 Mergers and firm growth

The preceding analysis has revealed several indicators that suggest mergers may have been important in the changing structure of the industry. The changes in the capacities of the largest firms presented in table 3.1 indicated large discrete changes in size which was supported by the step-wise path of the HHI shown in figure 3.5. The transition matrix table 3.3 showed that 7 firms exited the industry, and we know that all were taken over by other sample firms. It was shown in section 3.5.1 that firms exited from the middle of the distribution. Finally, the lack of evidence of the persistence of growth is a further hint. Together, these indicators motivate the final step of the analysis, the exploration of the impact of mergers on the observed increase in aggregate concentration.

3.7.1 The number of mergers

Lévêque (2008) surveys 247 mergers between power and gas firms between 1998 and 2007, of which 140 involved the power generation assets of firms in this sample. Figure 3.6 shows the number of such mergers by year.

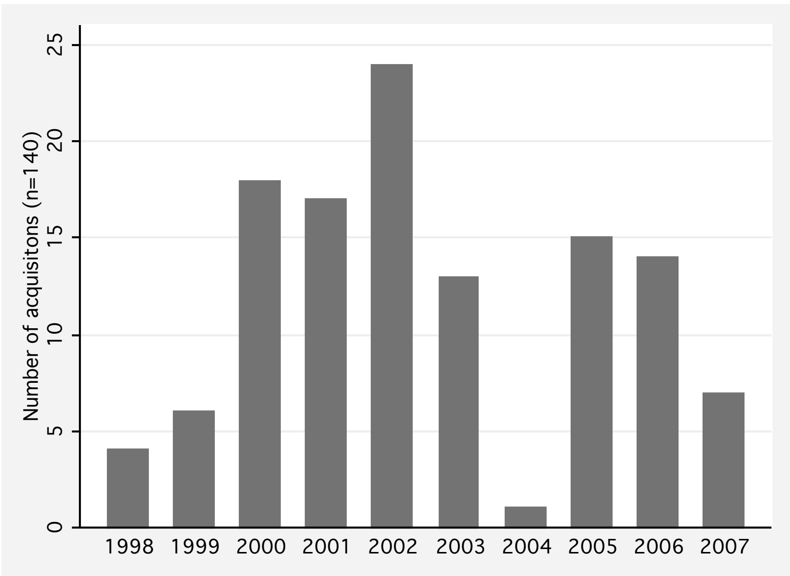


Figure 3.6: Mergers involving generation assets. 1998 – 2007

At first sight the fact that only one merger took place in 2004 seems puzzling, but it may be explained by the fact that in that year a new Commissioner for Competition, Ms. Neelie Kroes took office in DG Competition and the revised EC Merger Regulation (EC, 2004) incorporating new horizontal merger guidelines came into force[17]. Given the degree of influence of the EU merger guidelines and past EC decisions over firms' merger strategies (Ormosi, 2010) presumably the uncertainty associated with these changes induced firms to wait before launching merger bids.

3.7.2 The merger rate

The 'merger rate' gives an idea of the proportion of firms engaged in merger activity, but as (Hart, 1979) shows, the way in which the number of firms in the sample is defined has a powerful effect on the results of an assessment of the impact of mergers on concentration. No estimate of total merger activity among the population as a whole is available, so it is not possible to calculate the coverage of this merger data and hence the results must be interpreted with caution. In this study the probability of mergers in the total population is approximated by calculating the merger rate M is, as advocated by Hart (*ibid.*, p.222,), defined as:

$$M = \sum_{i=1}^{n} m_i/n \tag{3.7}$$

where m_i is the number of sample firms acquiring or selling generation assets in the ith year and n the number of firms in the sample.

Figure 3.7 shows how the 'merger rate' has changed over time based on the full sample of 39 firms. At its peak in 2005, over 30% of the sample firms were engaged in merger activity and the mean merger rate was 20%, though the possible omission of some mergers due to data restrictions mentioned above would bias this estimate downwards. This level of merger activity shows that mergers significantly influenced post liberalization industry structure.

[17] Thanks to participants at the CCP Seminar, UEA 23 April 2010 for this observation.

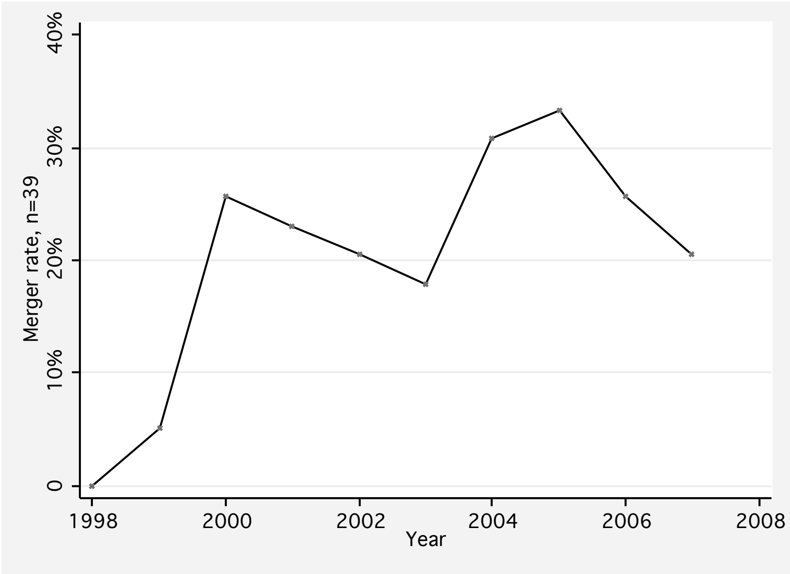


Figure 3.7: The merger rate. 1998 – 2007

3.7.3 The influence of mergers on firm growth

The empirical literature assessing the quantitative influence of mergers in explaining the upward trend in concentration provides no unambiguous conclusions, despite its large volume (see Curry and George, 1983). Following Hart and Prais (1956) and Hannah and Kay (1977), in this study the impact of mergers was evaluated using a counterfactual technique. The involved constructing an artificial or notional version of what would have happened *if* certain assumptions were true, and then comparing the results with what actually happened.

The counterfactual was generated as follows. First the net merger activity of each surviving firm that engaged in merger activity was calculated by subtracting divestitures by merger from growth by merger[18]. Then a notional 2007 distribution was created by adding the net merger activity for each firm to its 1998 size.

The real and notional 2007 distributions of the 19 surviving, merging firms had very similar means and variances though tests showed statistical

[18] To avoid incorporating organic growth in the acquired firm in merger growth of the acquiring firm, the size of acquired firms was evaluated in 1998, at the start of the period.

equivalence of neither the mean nor the variance. The mean size of surviving merging firms was considerable larger in 2007 than the mean size of the same 19 firms in 1998. Merging survivors also experienced stronger growth than the sample of surviving firms; approximately 34% as against 30% for all surviving firms.

	Actual		Notional
	1998	2007	2007
Number	19	19	19
Mean	2.09	2.81	2.77
Variance	1.34	0.99	1.02

Surviving firms are those that were alive throughout the period.
Size is log of firm size.

Table 3.6: Actual and notional firm size distributions.

Discussing an earlier study, (Weston, 1953), Stigler (1956) notes that the absolute growth of firms is irrelevant if the relationship between firm growth and changes in concentration is the object of interest, and argues that the unit of measurement must be firm shares of total industry size. Therefore, to assess the impact of mergers on aggregate concentration, the HHI implied by the notional 2007 distribution was calculated and is shown alongside the actual HHI in figure 3.8. It confirms that, using a measure which reflects firm shares, the increase in concentration observed over the period and discussed above can be accounted for by growth, due in very large measure to mergers. The notional HHI is slightly higher than the real HHI, which may be explained by ex-post portfolio rationalization and merger remedies.

To summarize, for the firms that survived the whole period and engaged in merger activity, mergers accounted for almost all growth. This result has several interesting implications and poses a number of questions. First, it implies that, on average, mergers were a substitute for greenfield expansion. Data collected by the European transmission systems operator UCTE, shows

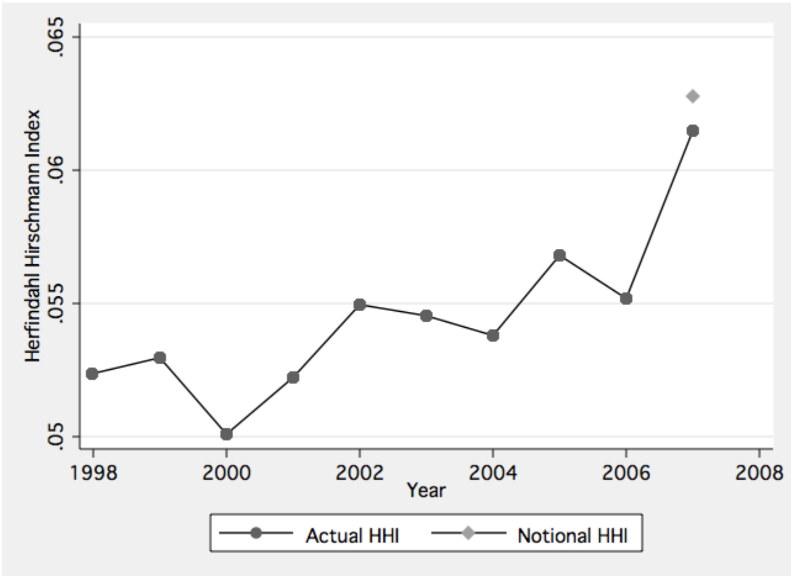


Figure 3.8: HHI and notional HHI

that minimum capacity margins across the UCTE control area as a whole exceeded the 5% lower threshold[19](UCTE, 2004). With installed capacity above the minimum required by the transmission systems operators, it is difficult to see where the incentive to build new capacity would come from. Nevertheless, some firms did implement an expansion strategy which which has been achieved by the relatively risky method of growth by merger, a result which raises questions about the motivation for mergers, which is discussed below.

3.8 Conclusion and discussion

The analysis of the size distribution and merger activity of the largest power generators which control over 80% of total installed capacity in their 18 European countries between 1998 –2007, has yielded the following stylized facts about the changing structure of the sector.

1. The mean size of firms operating in 2007 was 38% larger than the mean size of those operating in 1998, large firms controlled an increasing

[19]Except 2005 when it fell to 4.6%

proportion of total installed capacity and mobility among the ranks of the largest firms was very low.

2. For firms that were active throughout the period, the LPE appears to hold; that is to say, firms grew approximately in proportion to their size, though for the sample as a whole, proportionate growth was found to be weakly but inversely related to size.

3. Aggregate concentration was shown by three different measures to be unambiguously trending upwards, and the final period exhibited sharp upward growth. The level of aggregate concentration shown by both concentration ratios and the HHI was shown to be high by comparison with earlier studies on several industrial sectors. The number-equivalent HHI fell from 19 to 16, meaning that in 2007, 16 hypothetical equal sized firms would be required to generate the estimated HHI.

4. Twenty percent of firms operating in 1998 exited the sector, and all were acquired by other sample firms.

5. Mergers among firms operational throughout the period drove almost all the increase in concentration for the sample as a whole, 1998 to 2007.

The key objectives of this chapter, i.e. to expose the link between concentration and the evolution of firm size, and to examine the role of mergers in this evolutionary process, will now be discussed in turn. Concentration in the hypothetical EU single market has risen markedly since the start of sector liberalization, and this result is not sensitive to the measure of concentration. Overall growth in the sector was approximately 20%, so this strong upward trend was initially puzzling. The puzzle was resolved by recalling that the components of aggregate concentration include both firm size and firm numbers, and it was shown that on average the sample firms have become considerably larger over the period and firm numbers have fallen.

Analysis of concentration ratios showed that by 2007 the largest 3 and 5 firms owned respectively 36% and 47% of the total capacity owned by sample firms. The absolute value of the EU HHI was low by comparison with the thresholds set by competition authorities for the purpose of investigating potential abuse of market power, though it was shown to be high relative to aggregate concentration calculated for other industries in previous studies. However, market power is not the subject of this thesis. Rather it is about the introduction of competition into a formerly monopolized sector and with evaluating progress towards the hypothetical single market. So more relevant than the absolute value of the HHI is its trajectory. The numbers-equivalent HHI has an intuitive interpretation; it fell from 19 to 16 despite the best efforts of the EC to introduce competition and reduce concentration.

Evidence has been presented that the sample firms grew roughly proportionately to their size, though the literature is ambiguous in its predictions. Some studies find a systematic relationship (e.g. Aaronovitch and Sawyer, 1975, Kumar, 1985) while others do not (e.g. Hymer and Pashigian, 1962), or find them only for large firms Hall (1987). It is clear from both the results of this study and this existing literature that these results are sensitive to the sample chosen (Kumar, 1985). The result here that the growth of firms active throughout the period was more or less proportionate to their size carries the interesting implication that *ceteris paribus* concentration would have risen simply as a result of the statistical properties of the size distribution as discussed in section 3.6.1.

However section 3.7 showed that the majority of the growth in the sample as a whole was accounted for by the merger activity of the 19 firms that were both active throughout the period and which engaged in merger activity. Reserve margins[20] were generally well above the minimum required by the transmission system operators (UCTE, 2008) and since it is peak demand that drives capacity investments, motivation for greenfield expansion was low. In a standard neoclassical profit maximizing framework, firms on an expansionist path have a choice between expansion by merger and organic growth and will choose the cost minimizing option. In Cournot equilibrium, large firms have lower marginal costs so welfare may be improved by a merger that causes an increase in output of efficient firms at the expense of inefficient

[20] The excess of capacity over peak demand.

rivals (Farrell and Shapiro, 1990). From this perspective, mergers may be efficiency enhancing. Yet the literature on the efficiency effects of mergers is ambiguous both with respect to the existence of positive welfare effects and to their allocation between consumers, acquiring and target firms. A recent study of mergers in US electricity power distribution (Kwoka and Pollitt, 2007) find clear evidence that post merger cost performance is not enhanced, which leaves open the question of motivation: on the grounds of efficiency, the case for 'big[ger] business' is far from proven.

Alternative theories that might help to explain the motivation for merger are drawn from the managerialist perspective. Mitchell and Mulherin (1996) studied the merger wave of the 1980s and found strategic explanations for much of the merger activity in the 1980s, and show that merger activity is clustered within industries that have experienced a shock, for example from deregulation or rapid technological change. Gorton et al. (2009) develop and test empirically a theoretical model in which the size distribution of firms is a key determinant of merger activity. In industries exhibiting the structure revealed in the early part of this study, that is to say a dominant firm larger than the combined size of the second and third largest, it is shown that given low enough private benefits to managers, the net present value of acquisitions can be expected to be positive as firms use merger activity to position themselves to attract merger bids in the future.

The politicization of the sector is very high, in part due to the historical links between the state and the power industry that were discussed in section 3.2. Indeed Mez (2003) claims that in Germany the electricity supply sector has been a political and economic cartel for decades, and that it is a "state within a state" (*ibid.*, p.193). Whether or not that is the reality, there is at least a theoretical possibility that tacit collusion was a motive for the observed merger activity. Tacit collusion is defined as firm strategies that result in outcomes (in price or quantity terms for example) that may be similar to collusive outcomes resulting from a cartel or explicit collusion, although it does not imply that direct communication between the market participants is necessary (Ivaldi et al., 2003). The structural conditions for sustaining tacit collusion, such as the number of competitors, the presence of entry barriers, the frequency of interaction and the relatively low transparency in electricity markets[21] (Hooper et al., 2010) are present. Collusion is also easier to sustain if firms are more symmetric with respect to cost structure or production capacity (Ivaldi et al., 2003), and this study has shown that the very largest firms are becoming more symmetric in terms of capacities. Conversely, (Caves and Porter, 1978) show that instability in market shares impinges on the ability of oligopolists to strike and maintain implicit deals.

In his seminal paper Stigler (1964, p.45) states that "Collusion of firms can take many forms, of which the most comprehensive is outright merger". We have presented no evidence at all that tacit collusion has taken place in the power sector. Having said that, it is necessarily very difficult to detect and prove. Since mergers offer the opportunity for firms to take existing capacity off the system, and given the important contribution of mergers to the observed structural change, we merely seek vigilance on the part of competition authorities with respect to electricity mergers, and to suggest the explicit consideration of the long run evolution of the market. The results of this study for the first time sketch out temporal changes in structure at the EU level, which have taken place during a phase in which EU merger policy which has been described in the following way: "In contrast to the United States, mergers between energy companies have been subject to rather relaxed standards" (Newbery, 2007, p.2). On the basis of these findings, no comment may be made regarding the potential abuse of market power, but deliberately slightly mis-quoting White (2002), if aggregate concentration does pose concerns, then they seem to have got more serious since 1998.

[21] With the exception of the Nordic countries.

CHAPTER

FOUR

FIRM MULTINATIONALITY

4.1 Introduction

Strategic interactions between firms affect the competitive conditions within markets and may influence decisions with respect to multinationality. This chapter presents the results of a detailed empirical analysis of one specific aspect of firm strategy, the decision to locate production in more than one country, or horizontal multinationality[1]. Links between firm multinationality and industrial and regulatory structure are explored in an attempt to discover whether firms pursue similar or different strategies and to assess the influence of multinational corporate strategies on the integration of European power markets. Taking a slightly different perspective, the effect of firm 'nationality' on multinationality is investigated.

The remainder of the chapter is set out as follows: after outlining the context for the study in the next section, section 4.3 presents estimates of multinationality for the sample firms and discusses the nationality of multinationals. The spatial decomposition of firm size is presented in section 4.4 and the relative importance of country share and country size to aggregate firm size evaluated. Section 4.5 is the heart of the chapter. In it the empirical

[1]Throughout this chapter the term multinationality is used to mean horizontal multinationality only, i.e. a firm is multinational if it owns generation capacity in more than one country.

model is developed, the estimation procedure discussed and the econometric results reported. The conclusions and implications of the chapter are to be found in the final section.

4.2 Literature

In this section the academic literature relating to firm multinationality and multimarket contact are reviewed to provide some context for the study.

4.2.1 Multinational firms

Standard theories of the multinational enterprise or firm (MNE) are based on the notion of efficiency. Firms operating in multiple national markets can achieve cost savings, or economies of scope (Panzar and Willig, 1981) by sharing resources over markets (Penrose, 1959, Teece, 1980). The necessary conditions for the emergence of (horizontal) MNEs are uncontroversial; the efficiency of the dispersed i) location of production and ii) common ownership of production, and iii) the profitable application of the specific asset is achieved more efficiently within the MNE than by renting it out to another firm (Dunning, 1988).

Under these conditions, MNE's enjoy a net-revenue advantage derived either from minimizing production costs and/or non-production activities. Non-production advantages, or firm-specific assets (Caves, 2007, p.3) have the following properties i) the firm can use the asset or its services, but cannot necessarily sell or contract on it, ii) its productivity may differ from similar assets owned by rivals, iii) the asset or its productivity advantage is mobile across national borders and iv) its longevity is high relative to the firm's planning horizon, though it may be depreciable.

However, sustained advantage is derived from non-production advantages, because production cost advantages are likely to be based on technological improvements which will eventually be available to all market participants (Porter, 1991). Selling or contracting on firm-specific assets that are not site-specific is strongly associated with market failure; for example, it is easy to see that the collective, interdependent skills of a highly specialized and experienced research team built up over years by firm A cannot be readily expected to enjoy the same efficiency if transfered to firm B. In this way a competitive advantage is confered on the 'owner' of specific assets, which is not easily appropriated or imitated.

Transaction costs theory is central to the specific asset theory of the MNE. Transaction costs[2] arise as a result of the inability to write complete contracts in the face of asymmetric information, bounded rationality and limited foresight. Firms will choose to undertake transactions outside the firm, i.e. in the market, if the cost of doing so is lower than the cost of transacting within the firm (Coase, 1937). If the cost of transacting in the market is too high relative to the cost within the firm then the market fails and the transaction takes place within the firm. The MNE emerges for the same reason - the cost of transacting in the market is too high relative to the cost of internalizing the cost of specific assets. Transaction costs will be higher if there is a possibility that the supplier of a key input has monopoly power or if inputs are site specific (Rose and Joskow, 1990), or if reputation is important.

Hymer (1960) developed an alternative theory of the MNE based on the notion that firms seek to increase profit over time by increasing their market power in the following way. Consider a firm that has either single or collective dominance and which may therefore set price above marginal cost. Having exhausted growth opportunities in their domestic market, the firm follows a horizontal growth strategy, which involves expanding production (in the presence of economies of scale), or acquiring smaller or less profitable firms through mergers and acquisitions.

Statistical tests of the theory of the horizontal MNE in a given industry have been dominated by studies that relate structural characteristics of the industry to the degree of multinationality. The usual dependent variables may be loosely termed 'outbound' and 'inbound' foreign direct investment and two key results emerge consistently. First, the positive influence of both firm-specific assets and the intensive use of skilled labour is confirmed (e.g.

[2]Costs defined as those costs not directly associated with production.

Lall, 1980, Giulietti et al., 2004). Second, the general coordinating capacity of the firm measured by, for example multiplant operations is strongly associated with multinationality. In the USA multiplant operations were found to be a significant predictor for expansion in to Canada (Caves, 1974) and similarly multiplant operations among German firms were related to higher multinationality (Juhl, 1985) but not for UK firms Caves (*ibid*).

The transactions-cost approach to explain MNEs motivates an obvious question; do MNE's behave differently from firms that compete only in a single market? This question may be understood with reference to the notion of *strategic groups* (Caves, 2007), or groups of similar firms that recognize their interdependency, share similar goals and tend to respond similarly to a particular shock, as well as by the theory of multimarket contact (see below). Industries characterized by complex strategic group structures are more likely to be highly competitive and conversely, firms in industries with a more symmetric strategic group structure may enjoy enhanced ability to sustain collusion. Evidence of the presence of strategic groups in a given industry may provide some insight into the likely direction in which competitive conditions may evolve in the future since, it is argued, differences in strategic groups are stable and significant features of industrial structure (Newman, 1978, p.417).

4.2.2 Multimarket contact

Multimarket contact refers to encounters between firms (including MNEs) in multiple markets[3]. The theory of multimarket contact proposes that mutual forebearance lessens the intensity of competition between two firms as the number of markets served by both firms increases, as a result of firm interdependence (Nickerson, 1997). In a seminal study which explicitly links industry structure and firm behaviour, Bernheim and Whinston (1990) show that under plausible assumptions, cooperative (collusive) outcomes are more easily sustained when rivals in a given industry meet in many markets than

[3]For the purpose of this chapter, markets are defined as the aggregate demand within a given country.

when they meet only in a single market. The building of long-term cooperative and reciprocal relationships between rivals results in 'mutual forebearance', where firms decline to compete aggressively. The argument is that collusive behaviour is maintained since as the number of overlapping markets increases, so does each firm's ability to punish rivals who deviate. However, as Bernheim and Whinston argue, this argument merely suggests that increased multimarket contact raises the costs and benefits of an optimal deviation proportionately. The key contribution of the Bernheim paper is that it clarifies that the mechanism for the maintenance of the optimal collusive equilibrium, which is different depending on whether the firms treat the markets separately or as one. In the latter case, firms will realise that punishment for deviation will be incurred in both markets. Then a firm deciding to deviate will deviate in both markets, effectively pooling the incentive constraints of both markets and possibly leading to a relaxation of binding incentive constraints and raising collusive profits.

Three key findings emerge from the paper. First, in a broad range of situations multimarket contact is shown to constrain the intensity of competition by relaxing incentive constraints. Second, the gains made by firms engaging in multimarket contact may result in real practical effects. Third, the real effects caused by multimarket contact are not necessarily socially undesirable. However if firms differ in technical expertise and capability, or in MNE parlance, specific assets, which allow them to develop 'spheres of influence', then simultaneous competition in several markets may lead to specialization and the maintenance of prices above the competitive level.

Empirical tests of the effect of multimarket contact typically consider the impact on prevailing prices or firm profitabilty, and tend to support the theory that multimarket contacts blunts competition. Increased contact has been shown to raise prices above the levels sustainable in a competitive market in mobile telecoms (Parker and Röller, 1997) and airline tickets (Evans and Kessides, 1994). Evans and Kessides in particular supports the inclusion in multimarket contact models, of a behavioural explanation of firm strategy in that in their paper it is fear of punitive retaliation by rivals encountered frequently in other city-market pairings that drives firms to set prices above the competitive level. In a study of the cement industry Jans and Rosenbaum (1997) find that the Lerner index is reduced by multimarket contact when using a simple measure of the frequency of contact, but when the measure accounts for concentration in the non-home market a postive relationship between the Lerner Index and multimarket contact is established. Similarly for the banking sector, (Pilloff, 1999) finds a positive correlation between profitability and contact in the group of firms most exposed to multimarket contact, and concludes that contact between firms becomes more of an issue as the industry becomes more concentrated.

Summary

Two questions amenable to empirical testing emerge from this overview of the overlapping concepts of firm multinationality and multimarket contact. Do MNE's have firm-specific assets and the ability to coordinate activities across separate markets? The market power theory of MNEs explains their presence as the outcome of firms' desire to expand profit over time by extending their market power, so what is the evidence on the link between monopoly power and MNE?

4.3 Multinationality in power generation

Little is know about firm multinationality among EU based power generators. Indeed no study of the sector explicitly evaluating multinationality at the firm level could be found, which is surprising given then importance attached by the EC to the creation of an effective single market in electricity. Therefore this section can be seen as a baseline. Analysis of sample statistics describes the multinationality of generators based in the EU which are examined in more depth using simple inferential statistics. MNE's or multinational firms are defined as those that own interests in a firm based in another country, or that have set up a subsidiary in another country (Markusen, 2004).

4.3.1 Measuring the multinationality of firms

Firm multinationality is measured in two ways. The initial decision to become an MNE is captured in a binary variable $MNAT$, which takes the value of 1 if a firm owns generation assets outside its member state of origin and zero otherwise. The second measure of multinationality is the M index which reflects the degree to which a firm is geographically diversified. The M score for each firm is a Hirschmann-Herfindahl based index equal to the weighted sum of their multinationality aggregated across all member states in which they own capacity. The index was first applied to spatial diversification in Davies and Lyons (1996) and is a variant on Berry's index of diversification (1974). If the capacity of firm i in member state k is denoted x_{ik} and the aggregate size of the firm is x_i, then M is calculated by summing their squared shares of capacity in each member state and then taking the complement:

$$M_i = 1 - \sum_k (x_{ik})^2/(x_i)^2 \tag{4.1}$$

A firm which controls no generation assets outside its member state of origin would have an M score of 0, and if $k = 25$, the theoretical maximum value of M is $1 - 25^{-1}$, which would indicate a firm with equal sized operations in each of the 25 equal sized member states.

A useful version of the index is the numbers equivalent of multinationality, NM_i which is the reciprocal of M. NM represents the number of equal sized firms that would be required to generate the equivalent M value (Adelman, 1969), and is given by:

$$NM_i = (1 - M_i)^{-1} \tag{4.2}$$

NM will fall into the range 1, where a firm holds no generation assets outside their member state of origin, to a theoretical maximum of 25, which would indicate the case where all firms own equal capacity in each equally sized member state i.e the situation corresponding with $M = 1 - 25^1$.

4.3.2 Data

The empirical analysis in this chapter is based on the market share matrix for power generation analyzed in Chapter 2. To recap, there are 54 firms on the matrix and firm size is measured by installed capacity (GW) in each of 25 member states. The analysis covers the years 1998 to 2007. Data on the level of experience of national independent energy regulators was gathered from their websites during late 2009.

4.3.3 The multinationality of firms

The number of MNEs[4] on the matrix rose from 8 in 1998 to 17 in 2007 and histograms for both years are shown in figure 4.1. As expected they are strongly positively skewed; the median is in all years less than the mean.

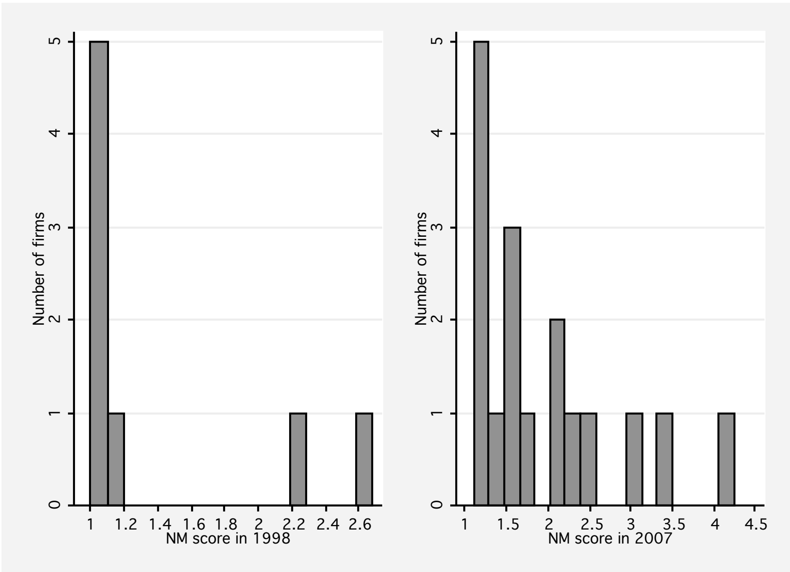


Figure 4.1: Distribution of multinational firms. 1998 and 2007

The distribution for 2007 suggests the existence of three multinational strategies that can be viewed as elements around which firms may coalesce into strategic groups. A $NM < 1.5$ describes a firm that may be termed minimally multinational, $1.5 < NM < 2$ a moderately multinational firm

[4] I.e. excluding firms with no generation assets outside their member state of origin.

and $NM > 2$ a highly multinational firm. Table 4.1 lists the set of multinational firms in 2007 according to multinational strategy. There may be a slight tendency for firms based in larger countries to be multinational, though Austria, the Netherlands and Portugal which are all fairly small, are also home to MNEs. It is interesting to note that the only former communist state that appears in the table the Czech Republic.

Minimal multinationality			Moderate multinationality			High multinationality		
Firm	Origin	NM	Firm	Origin	NM	Firm	Origin	NM
CEZ	CZ	1.30	EDP	PT	1.75	Suez	FR	4.24
Essent	NL	1.25	Iderdrola	ES	1.59	Vattenfall	SE	3.34
Centrica	UK	1.19	RWE	DE	1.56	EON	DE	3.06
Acciona	ES	1.15	EDF	FR	1.55	IP	UK	2.41
Verbund	AT	1.10				Enel	IT	2.21
Statkraft	NO	1.10				GDF	FR	2.16
						Fortum	FL	2.04

Highly multinational firms are those with $NM > 2$
Moderately multinational firms are those with $1.5 < NM < 2$
Minimally multinational firms are those with $NM < 1.5$

Table 4.1: Multinational strategies. 2007

4.3.4 The nationality of multinational firms

The relationship between firm nationality and its degree of multinationality is explored in this section. Power generation is an industry where there are real barriers to cross-border trade caused by a combination of a lack of inter-connector capacity, congestion on inter-connectors and poorly coordinated capacity allocation procedures. If it is assumed that, in accordance with European law, there is regulated third party access to inter-connectors, i.e. firms which own both inter-connectors and generation capacity are prevented from discriminating against rivals with respect to capacity allocation, firms wishing to serve markets outside their home market must own capacity in those markets if they are not to risk revenue volatility due to congestion. It is therefore likely that the growth strategy of a highly multinational firm, is related to conditions in its member state of origin.

Table 4.2 gives an overview of the extent of firm multinational tendencies by country of origin for 1998 and 2007. The table, which is is ordered by declining value of the mean of NM for all firms, is essentially a ranking of countries that seem to be the most conducive to multinationality. Sweden is the 'most multinational' country throughout the sample period and Germany has moved from rank 5 to rank 3, which signifies a change in strategy. It is interesting to note that with the exception of Norway and the Czech republic, all countries hosting multinationals are members of the EU15. It appears that firms based in the former Eastern European countries, which have historically had monopolistic incumbents, have in general not adopted a multinational strategy.

1998						2007					
Origin	Number of firms			Mean NM		Origin	Number of firms			Mean NM	
	Total	Mnat[a]	%	All firms	Mnat only		Total	Mnat[a]	%	All firms	Mnat only
SE	1	1	100	2.20	2.20	SE	1	1	100	3.37	3.37
FR	3	2	67	1.57	1.82	FR	3	3	100	2.65	2.65
FL	2	7	50	1.06	1.11	DE	2	2	100	2.31	2.31
ES	3	2	67	1.03	10.4	IT	3	1	33	1.40	2.21
DE	2	1	50	1.02	1.05	FL	2.	1	50	1.52	2.04
NO	2	1	50	1.02	1.05	UK	4	2	50	1.40	1.80
						PT	1	1	100	1.75	1.75
						ES	2	2	100	1.36	1.36
						CZ	1	1	100	1.30	1.30
						NL	2	1	50	1.12	1.24
						AT	5	1	20	1.02	1.10
						NO	2	1	50	1.05	1.10

[a] Number of multinational firms.

Table 4.2: Multinationality by country of origin. 1998 and 2007

Close examination of these estimates of multinationality suggests that the extent of multinationality may be related both to country level characteristics (in particular country size) and perhaps also to regional characteristics. Sweden, Norway and Finland were hosts to multinational firms in both 1998 and 2007, and Nordpool was the first functioning cross border power exchange, and remains the most liquid power exchange in the EU. This possibility is explored in section 4.6.

4.3.5 Decomposition of aggregate firm size in geographical space

A firm may be large because it has a substantial share of capacity in a large home member state or it may own production assets in several countries, or both. Within a given industry, patterns of multinationality may be based on regional, national and firm-specific factors. For example, assuming that firms operate only in their member state of origin, those that originate in small member states will reach the limits to growth sooner than those based in a large member state, which suggests an inverse relationship between the size of the member state of origin and the extent of multinationality. On the other hand, a monopolist has already reached the maximum size at home and must go multinational if their objective is to achieve growth.

The analysis that follows is based on what is essentially an accounting identity linking three dimensions of aggregate firm size; multinationality, typical share of country output and typical size of country first developed in Davies and Lyons (1996). To understand the idea more fully, imagine a firm of aggregate size 100. Several structures may produce such a firm; for example, it may have i) a 10% share in one country of size 1,000 or ii) a 20% share of one country of size 500 or iii) a 1% share in each of ten countries each of which is size 1,000. Firm size can then be decomposed according to the following identity:

$$FMSIZE \equiv CS \times NATS \times NM \tag{4.3}$$

Index	Symbol		Formula
Aggregate firm size	$FMSIZE$		x_i
Country size			x_k
Typical country share	CS		$\sum_k CS_{ik}(x_{ik}/x_i)$
		where	$CS_{ik} = x_{ik}/x_k$
Multinationality	M		$1 - \sum_k (x_{ik})^2/(x_i)^2$
Number equivalent	NM		$(1 - M_i)^-1$
Typical size member state	$NATS$		$\sum_k (u_{ik} x_k)$
		where	$u_{ik} = (x_{ik} CS_{ik})/\sum_k (x_{ik} CS_{ik})$

Table 4.3: Indices of firm structure

where the definitions of the indices are given in table 4.3.

The index for firm i's typical share of national capacity, termed *country share* (CS) is their weighted average share aggregated across countries in which they are active; the weight is the share of capacity in each country. $NATS$, or the *national size* is the weighted average size of all countries in which the firm owns capacity; the weight being firm i's size in country k multiplied by its share in that country. This method of weighting results in increased emphasis on asset holdings that are simultaneously of consequence within the firm itself and within the country.

4.4 Analysis of means and variances of multinational firms

An analysis of geometric means at the start and end of the period is reported in the top part of table 4.4. There was a 32% reduction in the mean size of multinational firms, which reflects the entry of smaller firms into the multinational group (see table 4.1). The typical country share has fallen dramatically from 48% to only 18% which is interpreted as a reflection of the ongoing tendency for countries of all sizes to privatize their power markets and may indicate some degree of fragmentation within national power markets. The typical size of the member state in which MNEs operate increased by 32% which may again reflect privatization programmes, but also forced divestiture to comply with competition policy remedies with respect to cross-border mergers. Finally, the mean extent of multinationality among MNEs increased by 36%.

To investigate the relative importance of each component of firm size in the total variation in $FMSIZE$, an analysis of variance is reported in the lower part of table 4.4, based on the logarithmic version of the decomposition in equation (4.3):

$$V(fmsize) \equiv V(ns)+V(cs)+V(nm)+2C(ns,cs)+2C(ns,nm)+2C(cs,nm)$$

where V denotes variance, C denotes covariance and lower case symbols ns, cs and nm denote logarithms of $NATS$, CS and NM respectively.

Analysis of geometric means

	$FMSIZE$		$NATS$		CS		NM
1998	21.35	$\equiv$	33.99	$\times$	0.48	$\times$	1.30
2007	14.57	$\equiv$	45.00	$\times$	0.18	$\times$	1.78

Analysis of variances

	$V(fmsize)$		$V(ns)$		$V(cs)$		$V(nm)$		$2C(ns, cs)$		$2C(ns, nm)$		$2C(cs, nm)$
1998	0.936	$\equiv$	0.711	+	0.388	+	0.154	-	0.118	-	0.424	+	0.226
	(100)	$\equiv$	(76)	+	(41)	+	(16)	-	(13)	-	(45)	+	(24)
2007	1.278	$\equiv$	0.567	+	1.367	+	0.171	-	0.694	+	0.087	-	0.220
	(100)	$\equiv$	(44)	+	(107)	+	(13)	-	(54)	+	(7)	-	(17)

V = variance, C = covariance
ns = log NATS, cs = log CS, nm = log NM
Numbers in parentheses represent share of total variation.
Multinational firms only.

Table 4.4: The spatial decomposition of aggregate firm size.

In 1998 the variance of national size $NATS$, accounted for 76% of the variance in the size of multinational firms and the typical country share (CS) and multinationality (NM) for 41% and 16% respectively. $NATS$ is highly correlated (correlation coefficient = 0.72) with the size of a firm's country of origin, so in 1998, just after the start of liberalization, the size of a firm's country of origin was an important influence on the variance in firm size, far more so than either CS or in particular, NM. The covariance terms reveal that multinationality and country share are positively correlated, so firms with large shares of installed capacity within individual countries were more likely to be multinational. Conversely, national size and multinationality are negatively correlated, so the strong effect of national size on overall variation is tempered by multinationality; firms in larger countries tend to be less multinational. Similarly, national size and country share are negatively correlated which means that firms in large countries tend to have a smaller share in those countries.

In 2007 the strongest component of variation in firm size is country share, followed by national size, and the contribution of multinationality has fallen from 16% to 13%. The negative correlation between national size and country share remains, but the sign on the other two covariance terms has changed. Firms in large countries are more likely to be multinational while those with large country shares are less likely to be multinational.

Comparing 2007 to 1998, it seems that corporate strategy has changed considerably, perhaps in response to the new operating environment brought about by liberalization. It is unsurprising that in an industry where an incumbent monopolist was historically the norm, that national size *appears* to exercise a strong influence on firm size, and this observation is explored in the next sections.

4.5 Empirical model

Recall that from section 4.3, there are two measures of multinationality $MNAT$, the decision to become an MNE, and NM, a measure of the extent of the multinationality of multinational firms. These are the dependent variables in the model. In this section the hypotheses and explanatory variables are discussed and the empirical model presented. Variables relate to the firm, country and regional level factors which the literature has shown to affect multinationality. Since the analysis is of a specific sector, firms are assumed to share similar characteristics such as minimum efficient scale, research and development ratios and transport costs etc., so no industry level variables are included.

4.5.1 Firm size

The effect of firm-specific assets would be tested directly on variables that have been shown to be robust predictors of multinationality, in particular firm R&D and advertising ratios (Caves, 2007). However, these measure are not really appropriate in the context in which this study is set. First, it has been shown that R&D ratios have been severely negatively affected by deregulation (Jamasb and Pollitt, 2008). Second, advertising spending is not likely to be indicative of the kind of firm-specific assets that might produce a competitive advantage in power generation. Given the high levels of merger and acquisition activity in the sector, is is probable that unsuccessful generators i.e. those that have failed to develop a sufficiently distinct specific-asset portfolio to give them a long-run competitive advantage will have ceased to exist as independent entities. A positive relationship between firm size and the extent of a firm's specific assets is likely.

If multinationality is the result of a strategy to achieve growth by a firm with constrained growth opportunites in their domestic market, either as a result of an existing large share of domestic capacity or because their country of origin is small, then multinationality and firm size are likely to be correlated. Some evidence to support this hypothesis was presented in section 4.3 However, given that equation (4.3) shows NM to be a component of $FMSIZE$ there is a problem of two way causality since *ceteris paribus*, an increased in NM will lead to an increase in $FMSIZE$. Fortunately this problem may be resolved by including not $FMSIZE$ itself as an explanatory variable, but rather its components $NATS$ and CS. A firm that faces domestic constraints to growth due to a large share of capacity in its home market may have no option but to pursue a multinational growth strategy, so a positive relationship between the probability of multinationality and CS is expected. This is likely to be emphasised if the country size $NATS$ is small. The sign on $NATS$ is rather more difficult to predict since firms from small countries may not have the specific assets that are prerequisites for making the multinational choice even if they have a large share of domestic capacity, for example the ability to coordinate across markets.

4.5.2 Country level variables

The regulation of the energy sector in Europe can be loosely divided into three phases. The first phase was 1989–1997 when regulators formally began co-operation as the advantages of taking a European perspective on energy regulation became apparent. The second phase was 1998 and 2003; during this time the regulatory framework of EU energy policy was established. Finally, the period since 2004 can be characterised as a period of consolidation and perhaps the "re-invention" of European energy regulation (Vasconcelos, 2009, p.4) as a new political approach to energy regulation emerges. Though many member states had already adopted independent regulation voluntarily, legislation was approved in 2003 that institutionalized independent regulation at the member state level.

It is highly likely that the presence of a sector specific regulator will affect firms' strategic choices. Furthermore, given the technical nature of the power sector and the extent to which the sector is politicized (Mez, 2003) or at the very least the extent to which it has been subject to high levels of state involvement (Pollitt, 1999), the level of experience of the regulator is likely to be related to their effectiveness at constraining limitless domestic growth. $REGYEARS$ captures both the existence of an independent regulator and the extent of their experience. However it is difficult to sign *a priori* because countering the hypothesis that more experienced regulators are more effective, is the notion of regulatory capture. That is to say, the possibility that after some years building relationships and experience of working with the regulator, firms become more adept at manipulating the regulatory system. This then suggests a negative relationship between multinationality and regulation.

While sector level influences are irrelevant since this is a sector specific study, characteristics specific to countries like natural resource endowment and terrain as well as the availability (or otherwise) of inter-connector capacity to facilitate cross-border trade may influence costs and firm strategy. A set of country dummies was included in an early version of the model to test the effect of these and other country-specific factors on multinationality. However collinearity afflicted 5 of the 24 country dummies in step one, and 18 in step two, and parameter estimates are not reported.

4.5.3 Regional level variables

Finally, the analysis in section 4.3 suggested that characteristics of the region may influence multinationality. The European Regulators Group for Electricity and Gas (ERGEG) Regional Initiatives (RI) were launched in 2006 with the objective of speeding up integration between markets. The definition of the seven regions[5] was based on shared characteristics, physical flows, the compatibility of for example, rules pertaining to the allocation of inter-connector capacity and participation in power exchanges like NordPool and the European Energy Exchange (EEX). In order to capture regionally derived influences on multinationality, a set of dummy variables was created that capture all firms which own capacity in a given RI. It was not possible to predict the sign on the regional dummies. The full model is therefore given by:

Multinationality = f(NATS, CS, REGYEARS, REGIONAL DUMMIES)

[5] *Baltic*: Estonia, Latvia, Lithuania; *Central East*: Austria, Czech Republic, Germany, Hungary, Poland, Slovakia, Slovenia; *Central West*: Belgium, Germany, France, Netherlands; *Central South*: Austria, Germany, France, Greece, Italy, Slovenia; *Northern*: Germany, Denmark, Finland, Norway, Poland, Sweden; *South West*: Spain, France, Portugal.

4.6 Estimation procedure and results

Several econometric approaches were considered and experimented with. A natural choice would be a two-part or hurdle model in which part one generates the probability of an event occurring, usually using a probit or logit model, and part two uses linear regression to estimate the effect of the covariates on the size of the dependent variable. Hurdle models allow covariates to have a different effects in each part of the model and for that reason are attractive. However, a potential restriction on the model is that the two parts of the model are assumed to be independent. If in fact firms that are multinational are not randomly selected from the population, then the second stage results will suffer from selection bias.

To overcome this potential problem, a Heckman bivariate sample-selection model which allows for the possibility that the two parts of the model are not independent was chosen.

4.6.1 Econometric model structure and assumptions[6]

Let y_2^* denote the outcome of interest[7]. A second latent variable is denoted by y_1^* and the outcome y_2^* is observed if $y_1^* > 0$. In this case, y_1^* determines whether or not the firm is multinational, and y_2^* determines the extent of multinationality and $y_1^* \neq y_2^*$.

The two-equation model consists of a selection equation for y_1, where

$$y_1 = \begin{matrix} 1 & \text{if} & y_1^* > 0 \\ 0 & \text{if} & y_1^* \leq 0 \end{matrix}$$

and the outcome equation for y_2, where

$$y_2 = \begin{matrix} y_2^* & \text{if} & y_1^* > 0 \\ - & \text{if} & y_1^* \leq 0 \end{matrix}$$

[6]This section draws extensively on StataCorp (2007, p.561-563) and Cameron and Trivedi (2009, p.545-546)

[7]Throughout this section an asterisk denotes a latent variable.

In this set up, y_2 is observed only when $y_1^* > 0$.

Regression estimates using the inverse Mills' ratio, or nonselection hazard (Heckman, 1979) give initial values for maximum likelihood estimation. The regression equation is

$$y = \mathbf{x_j}\beta + \mathbf{u_{1j}} \tag{4.4}$$

and the selection equation is

$$\mathbf{z_j}\gamma + \mathbf{u_{2j}} > \mathbf{0} \tag{4.5}$$

where $u_1 \sim N(0, \sigma)$, $u_2 \sim N(0, 1)$ and $corr(u_1, u_2) = \rho$.

The log likelihood for observation j, $\ln L_j = l_j$ is

$$l_j = \begin{cases} w_j \ln\Phi\{\frac{\mathbf{z}\gamma + (y_j - \mathbf{x}_j\beta)\rho/\sigma)}{\sqrt{1-\rho^2}}\} - w_j \ln(\sqrt{2}\pi\sigma) & y_j \text{ observed} \\ w_j \ln\Phi(-\mathbf{z}_j\gamma) & y_j \text{ not observed} \end{cases}$$

where $\Phi()$ is the standard cumulative normal and w_j is an optional weight for observation j.

Two-step estmitates are computed using Heckman's (1979) procedure as follows. First, probit estimates of the selection equation (4.5) are obtained:

$$\Pr(y_j \text{ observed} \quad | \quad \mathbf{z}_j) = \Phi(\mathbf{z}_j\gamma)$$

Next Heckman's inverse Mills' ratio m_j, also know as the nonselection hazard, is computed for each observation as:

$$m_j = \frac{\phi(\mathbf{z}_j\hat{\gamma})}{\Phi(\mathbf{z}_j\hat{\gamma})}$$

where ϕ is the normal density. Also define

$$\delta_j = m_j(m_j + \hat{\gamma}\mathbf{z}_j)$$

Following Heckman, the two-step parameter estimates of β are obtained by augmenting the regression equation with the inverse Mills' ratio $\mathbf{m}$. Therefore the regressors become $[\mathbf{Xm}]$ and an additional parameter β_m on the variable containing the inverse Mills' ratio is obtained.

A consistent estimate of the regression disturbance variance is obtained using the residuals from the augmented regression and the parameter estimate on the inverse Mills' ratio,

$$\hat{\sigma}^2 = \frac{\mathbf{e\prime e} + \beta^{\mathbf{2}}_{\mathbf{m}} \sum_{\mathbf{j=1}}^{\mathbf{N}} \delta_{\mathbf{j}}}{N}$$

The two-step estimate of ρ is then

$$\hat{\rho} = \frac{\beta_m}{\hat{\sigma}}$$

Heckman derived consistent estimates of the coefficient covariance matrix on the basis of the augmented regression.

Let $\mathbf{W} = [\mathbf{Xm}]$ and $\mathbf{R}$ be a square diagonal matrix of dimension N, with $(1 - r\hat{ho}^2\delta_j)$ as the diagonal elements. The conventional VCE is

$$\mathbf{V_{twostep}} = \hat{\sigma}^{\mathbf{2}}(\mathbf{W\prime W})^{-\mathbf{1}}(\mathbf{W\prime RW} + \mathbf{Q})(\mathbf{W\prime W})^{-\mathbf{1}})$$

where

$$\mathbf{Q} = \hat{\rho}^{\mathbf{2}}(\mathbf{W\prime |bfDZ})\mathbf{V_p}(\mathbf{Z\prime DW})$$

where $\mathbf{D}$ is the square diagonal matrix of dimension N with δ_j as the diagonal elements, $\mathbf{Z}$ is the data matrix of selection equation covariates, and $\mathbf{V_p}$ is the variance-covariance estimate from the probit estimate of the selection equation.

4.6.2 Econometric results

For ease of reference and clarity of presentation, results from fitting the model have been split into two tables. Table 4.5 reports estimates from stage one of the model with the binary dependent variable $MNAT$. Estimates of the extent of firm multinationality, NM conditional on $MNAT = 1$ in the first stage are presented in table 4.6. The full data set was a panel covering the 54 firms in 25 countries, over 10 years. After delection of observations due to missing values, step one of the model was estimated on 517 observations, and step two on the remaining 125 uncensored observations. Four equations were estimated. The first two identify the effect of decomposing $FMSIZE$ into its components parts $NATS$ and CS. The third equation introduces the variable $REGYEARS$ to test for the effect not just of the presence of an independent regulator, but of the level of experience of the regulator, on multinationality. Finally, equation 4 includes a set of dummy variables to capture potential regional effects. Test statistics are reported at the bottom of table 4.6.

It is possible that NM and CS are jointly determined. Imagine a firm with a high CS in its domestic market and that has under utilized resources so seeks a growth opportunity. The firm goes multinational and initially their CS will fall because it is firm share weighted by all the countries in which it is active. However, if the firm expands into an increasing number of markets causing NM to rise *and* shares in each active country rise, CS may again increase. Potential joint determination of NM and CS was tested for by substituting CS for $SHAREHOME$, the proportion of domestic capacity owned by the firm in the selection and regression equations. The estimated coefficients on the explanatory variables were barely affected. Therefore CS was retained as the preferred measure of country share: not only does breaking firm size into its component parts overcome the problem of correlation between $FMSIZE$ and NM discussed in section 4.5 but that it is amenable to the decomposition is also attractive.

Decomposing $FMSIZE$ into its constituent parts yields interesting insights. Firms from larger countries ($NATS$) are more likely to go multinational and markedly less likely to be extensively multinational than firms with a large typical country share (CS), though the latter effect becomes significant only in the final equation in which regional dummies are included. Typical country size is therefore quantitatively more important than typical country share as a determinant of both the decision to go multinational and the extent of multinationality. This is not inconsistent with the evidence presented in section 4.3 that firms from large member states develop a general co-ordinating capacity that make multinationality more likely, though a large national size in itself does not seem to equip or incentivise firms to be highly multinational. Conversely, monopolists and firms with a large country share seem to suffer from inertia, which is perhaps surprising given the large number of profitable opportunities that have occurred over the period as many countries have privatized their generation sectors either totally or partially. On the other hand, it is possibly that in contrast to firms from large member states, those with large shares are not required to develop coordination skills. Or perhaps Hicks (1935, p.8) was indeed correct in his conjecture "The best of all monopoly profits is a quiet life", which presumably precludes going to the effort of profit maximizing.

Firms originating in countries where the years of experience of the independent regulator $REGYEARS$ is high are slightly more likely to be multinational and similarly firms from these countries are also somewhat more likely to be intensively multinational. These results provide some weak evidence against the notion of regulatory capture. Strict regulation by a national regulator is likely to influence the direction of firm growth. It is plausible that the combination of an experienced regulator and a large country share might have a positive effect on multinationality. An interaction term for $REGYEARS$ and CS was generated, but it was not significant and added little to the model so is not reported here. Similarly an equation which included a set of dummy variables intended to capture country specific effects was estimated, but the dummies were seriously affected by collinearity so the results are not reported.

Finally, data on multinationality by country of origin that was presented and discussed in section 4.3 suggested that there may be some regional effects operating and to control for this possibility regional dummies were included in the model. The most striking effect of the inclusion of the regional dummies is on the overall fit of the model[8]. The Wald chi^2 statistic and the associated p values for equations 1 – 3 means that hypothesis that the coefficient on each of the variables is equal to zero, cannot be rejected. The explanatory power of the model is very limited indeed. By contrast for equation 4, the Wald chi^2 statistic with $p = 0.000$ leads to an emphatic rejection of this hypothesis.

The individual coefficients on the regional dummies refer to comparisons with Baltic, the region omitted from the analysis. In the selection stage, firms operating in Central East were less likely than those operating in Baltic to be multinational, while those owning capacity in Central West, Northern and South West were significantly more likely to be multinational and those operating in Central South shared a similar propensity to be multinational with Baltic. Concerning the extent of multinationality, only firms owning capacity in Central South and Northern are significantly more likely to be more intensely multinational than those owning capacity in Baltic.

There appear to be important factors operating at the regional level but that are not explained by differences in the sizes of countries, the share of firms in domestic systems or the level of experience of the regulator. Potential factors include ease of communication, and common dispatch and trading rules. But another candidate is derived from the literature. In defining their RIs, ERGEG took note of shared practices, physical flows and trading platforms among other things, which suggests, unsurprisingly, that there is greater homogeneity among firms within regions than within the EU taken as a whole. It was shown above that firms with multiplant operations in the USA were more likely to expand into Canada (Caves, 1974) and the

[8]Interestingly, this large effect of the inclusion of dummies on the fit of the model is also found in earlier work of this type (Davies and Lyons, 1996) though in their case the effect was produced by country dummies.

situation seems analogous. RIs might serve to facilitate the formation of effective strategic groups, which are associated with more easily sustained collusion.

	Estimated coefficients and standard errors			
Variable	(1)	(2)	(3)	(4)
Constant	−2·234 ∗ ∗∗	−2·731 ∗ ∗∗	2·874 ∗ ∗∗	−3·084 ∗ ∗∗
	(0·15)	(0·28)	(0·30)	(0·44)
FMSIZE	0·844 ∗ ∗∗			
	(0·172)			
NATS		0·888 ∗ ∗∗	0·909 ∗ ∗∗	0·796 ∗ ∗∗
		(0·09)	(0·093)	(0·14)
CS		0·550 ∗ ∗∗	0·559 ∗ ∗∗	0·568 ∗ ∗∗
		(0·07)	(0·07)	(0·09)
REGYEARS			0·028	0·048∗
			(0·02)	(0·024)
CENTRALEAST				−0·579∗
				(0·25)
CENTRALWEST				1·392 ∗ ∗∗
				(0·24)
CENTRALSOUTH				−0·202
				(0·24)
NORTHERN				0·684 ∗ ∗∗
				(0·19)
SOUTHWEST				1·839 ∗ ∗∗
				(0·25)

Heckman two-step selection model, stage one: selection equation.
Dependent variable $MNAT = 1$ if firm is multinational, 0 otherwise. Variables $FMSIZE$, $NATS$ and CS were estimated in log form.
Total number of observations = 517, censored observations = 392, uncensored observations = 125

Table 4.5: Results of stage one: the multinational decision.

	Estimated coefficients and standard errors			
	(1)	(2)	(3)	(4)
Constant	0·796	2·286	2·092	0·621∗
	(0·77)	(1·51)	(1·43)	(0·31)
FMSIZE	−0·063			
	(0·156)			
NATS		−0·433	−0·391	−0·195 ∗ ∗∗
		(0·33)	(0·31)	(0·06)
CS		−0·276	−0·253	−0·124 ∗ ∗
		(0·22)	(0·21)	(0·04)
REGYEARS			0·005	0·031 ∗ ∗
			(0·01)	(0·01)
CENTRALEAST				−0·080
				(0·25)
CENTRALWEST				0·086
				(0·11)
CENTRALSOUTH				0·355 ∗ ∗∗
				(0·10)
NORTHERN				0·333 ∗ ∗
				(0·10)
SOUTHWEST				0·129
				(0·14)
Mills	−0·193	−0·605	−0·553	−0·049
	(0·29)	(0·58)	(0·54)	(0·11)
Test statistics				
Wald χ^2	0·16	1·70	3·71	63·26
P value	0·685	0·428	0·294	0·00

Heckman two-step selection model, stage two: regression equation.
Dependent variable log NM. Variables $FMSIZE$, $NATS$ and CS estimated in log form.
Total observations = 517, censored = 392, uncensored = 125

Table 4.6: Results of stage two: the extent of firm multinationality.

4.7 Conclusion and discussion

The focus of this chapter has been the detailed analysis of one particular element of firm strategy, firm multinationality. Two separate questions are addressed: is the firm multinational? if so, how multinational are they? Preliminary descriptive statistical analysis suggested broad associations. On the face of it, large firms appear to follow a more multinational strategy than small ones. Firm nationality appears to be important to some extent – Swedish and French firms are the 'most multinational' throughout the period, and German firms rise from almost the bottom of the 'multinationality ranking' of countries in 1998 to third position in 2007. Evidence that firms from the larger member states tend to be more intensively multinational is rather mixed, though there is some suggestion that regional influences on multinationality may be important. Formerly communist states have a particularly low incidence of multinationality. However none of these findings is particularly surprising given the historical context of the sector.

However by decomposing firm size into its constituent components, typical country share and typical national size, and by controlling for the regulatory regime and possible regional effects, a more comprehensive and telling story about how firms have responded to market liberalization has been developed. Considering first the decision to go multinational. The typical size of member state in which the firm operates has a stronger influence than the typical share of national capacity owned by the firm on the multinational decision. As suggested by specific-assets theories of the MNE, a general ability to organize operations across markets is important. For example, a firm based in Germany, which has a relatively fragmented market structure, may be forced develop this ability in order to operate successfully at home, which puts them at an advantage relative to a monopolist when it comes to international expansion. The market power theory of the MNE predicts that firms dominant in their home market but that have reached the limits to domestic expansion seek to increase profit by extending market power across countries. If this were the case, then we would expect typical market share to dominate typical country size. The specific assets theory then seems to be more consistent with the present analysis. However an alternative interpretation drawn from multimarket contact theory recognises the likelihood that firms operating within a (large) national market are likely to meet rivals more often in domestic markets and to recognize the interdependency which is critical to the maintenance of collusive behaviour (Bernheim and Whinston, 1990).

Typical national size does not appear to confer the kind of advantage that leads to the intensification of multinationality, indeed the two are negatively correlated. Firms operating in large countries are less likely to be highly multinational than those operating in small countries. In a market power framework, this result is consistent with a multimarket contact story that since firms operating in large countries are in regular contact with rivals, they have an enhanced ability to sustain collusive behaviour without having to resort to intensive multinationality. Typical country share is also negatively correlated with intense multinationality, so monopolists are not highly multinational. This is not consistent with the market power theory of the MNE, though it is consistent with the theory that firms are influenced by the behaviour of their rivals and the membership of strategic groups. A monopolist does not have rivals.

These results may also suggest that the two decisions are independent, which takes us back to the motive for going multinational in the first place. Why would a firm go multinational but then halt the process? Perhaps the influence of the firms that they see as their rivals is important? If that is the case, then as discussed above, this may be evidence of the formation of relatively symmetric strategic groups which can be expected to 'improve' the conditions for collusive strategies.

Evidence has been presented showing that since market liberalization, the multinational strategies adopted by generators have changed. That is to say, the behaviour of the firms has materially altered the structure of the market. The new conditions may be more conducive to an increased likelihood of collusive behaviour, though this study presents no evidence at all that collusive behaviour has taken place, it suggests one possible explanation of the observed change in strategy.

CHAPTER

FIVE

INTER-FIRM AND INTRA-FIRM DIFFUSION OF CLEAN GENERATION TECHNOLOGIES: THE CASE OF WIND

5.1 Introduction

This chapter is concerned with the adoption process and patterns of use of a particular clean power generation technology, wind turbine generators (WTG). Technological change [1] in large measure determines the development path of industrial societies (Grashof et al., 1999). There is therefore a direct link between technological change and social welfare. Despite a longstanding recognition that social benefits are fully realized only when new technologies are widely adopted or diffused throughout the economy (Fudenberg and Tirole, 1985) the vast majority of academic research has focussed on one of two themes. First, the analysis of innovation in which the distinction between the different stages of technological change[2] is not drawn (e.g. Geroski, 2000, Gilbert, 2006). The second major theme concerns R&D – the invention of

[1] Throughout this chapter the terms technological change and innovation are synonymous.

[2] *Invention*, the creation of new ideas and knowledge, *R&D*, the introduction of new methods or knowledge, and finally *diffusion* when the new technology is adopted on a widespread basis (Schumpeter, 1942)

new ideas (e.g. Braun et al., 2010). Despite its clear importance, the analysis of diffusion is under developed (Hall, 2004).

There are two aspects of diffusion; the number of firms using the technology, or inter-firm diffusion, and the share of the firm's capacity (or equivalently, production) accounted for by the new technology, or intra-firm diffusion. The limited research effort devoted to diffusion has concentrated on inter-firm diffusion where much progress has been made through both theoretical and empirical analysis since the seminal early work of Griliches (1957) and Mansfield (1963b). Mansfield (1963a) was the first to explore intra-firm diffusion empirically, and proposed the possibility that the same factors may determine both types of diffusion. Until recently intra-firm diffusion has remained a largely neglected topic.

Public support for potentially costly policy interventions that support technological change is at least implicitly based on the perception that it is driven by scientific discoveries. However, if as Schmookler argued, new technologies emerge in response to "the recognition of a costly problem to be solved or a potentially profitable opportunity to be seized" (Schmookler, 1966, p.199), then the adoption of new process technologies can be considered as a consequence of dynamic competition (Sidak and Teece, 2009). Indeed Schmookler's recognition of the strategic importance of innovation to firms appears to be consistent with the prevailing opinion in at least one important industrial sector. In a recent survey, the leaders of global utility firms report the view that "technology will be central to future growth and competitive advantage" (PricewaterhouseCoopers, 2009, p.3).

Power generation is the largest single contributor to greenhouse gas emissions (Solomon, 2007) so the sector has a responsibility to make large emissions reductions. Furthermore, clean technologies are a major emerging global business (Pew, 2010) that presents opportunities for growth. Prior to the 2008 economic downturn, the EU experienced an extended period in which investment in generation capacity was low while demand for electricity increased. This has proved an uncomfortable combination given the planned plant retirements due to, for example the Large Plant Directive. The emergence of supply gaps in EU member states is a real prospect, and accordingly, 83% of respondents to the PricewaterhouseCoopers survey claim that their competitive strategy includes making large or medium investments in generation capacity.

However, it is not clear which technologies the utilities will invest in. Aghion et al. (2009) has recently argued that public interventions in the market are needed to mobilize the private investment that can ensure that today's investment decisions result in a future technology portfolio consistent with a sustainable economy. Such interventions must be made on the basis of a sound body of evidence, but unfortunately the academic analysis of innovation in power generation reflects the dominant approaches outlined above. In particular, the literature focusing on the diffusion of low carbon technologies for power generation is very limited though there are two recent examples: Diaz-Rainey (2010) considers the diffusion of wind turbines across EU member states when diffusion is induced by interventions such as support mechanisms or targets, and a recent empirical study of the diffusion of environment related technologies based on patent data finds that the absorptive capacity of recipient countries is a deterministic factor in technology transfer (Glachant et al., 2009). In common with the remainder of the literature, these two studies deal with patterns of aggregate diffusion among countries.

The absence of empirical research on the diffusion of low-carbon technologies at the firm level is important for at least four reasons. First, aggregate diffusion and the implied emissions reductions associated with substituting conventional generation technologies for low carbon technologies is a function of both the number of firms that adopt the technology *and* the intensity with which they use it. Second, these outcomes are primarily the result of investment decisions made by firms not governments. Third, existing research suggests that the decision to adopt a new technology is independent of the decision to intensify use of it (Battisti and Stoneman, 2003, Hollenstein and Woerter, 2008), which means that interventions which have the effect of increasing the number of users may have little impact on the overall use of the technology. Finally, costly interventions intended to increase the penetration of clean technologies should be precisely targeted if they are to meet their objectives and command public support. Grubb (1997) showed that diffusion can be induced by policy: a refined analysis that considers individual firm behaviour would make a solid basis for policy formation.

The objectives of this study are three fold. First, to find out if we can map certain firm specific characteristics to a particular intensity of use of WTG. Given the growing evidence base regarding the anthropogenic nature of climate change, and the emphasis on innovation as a major part of the solution (Pew, 2010), this may have important policy implications. Second, to demonstrate the importance of decomposing aggregate diffusion into its constituent parts based on an application to the diffusion of wind turbine generators (WTG) among leading generators based in the EU. The third objective is methodological. The volume of literature on intra-firm diffusion, and particularly on the joint modelling of inter-firm and intra-firm diffusion is miniscule, and there remain a number of methodological challenges to overcome.

The remainder of the study is structured as follows. The discussion above suggests that public policy is a driver of investment in low carbon technologies. The purpose of this chapter is to examine firm level factors affecting diffusion, therefore a brief discussion of policy which provides some context is covered in the following section. An overview of the relevant literature is discussed in section 5.3, then in sections 5.4 and 5.5 the data is described and patterns of adoption of wind turbines across and within firms and the industry are analyzed. In section 5.6 a model of diffusion is developed and the econometric methodology specified. Results are presented and discussed in section 5.7. Section 5.8 concludes the chapter with a discussion of potential policy implications and the next steps for the research.

5.2 Policy options for the diffusion of low carbon technologies

Potential market failures which affect technology diffusion are numerous, and include imperfect information, market structure in both the supplying and adopting industries, and externalities which may lead to, for example, first mover advantages (see Stoneman and Diederen, 1994). The uncertainty and risk implied by all these factors change the relative costs and benefits of adoption in a complex and interrelated way, and mean that the market alone is likely to underinvest in low carbon technologies relative to the social optimum, and potentially justify the provision of subsidies. Diffusion policy is, therefore far from straightforward, and this is not the place for a detailed analysis.

However, to get a feel for the kind of instruments currently in use and which influence the diffusion of low carbon technologies, we briefly discuss and contrast two alternative policy choices intended to reduce risk and uncertainty through subsidies. There is an inherent risk associated with new and unproven technologies - how much are the costs likely to fall and over what period? what is the option value of waiting? how will the technology fit with my existing portfolio? Will the supplying firm provide effective after sales service? A second problem for investors relates to policy uncertainty when the asset life of generation technologies varies, between say 20 and 60 years. Even taking the lower end of the spectrum, this is significantly shorter than the political cycle. If policy makers are unable to credibly commit to long term policies, policy risk is introduced. How does a potential investor in a project know whether or not after say, 5 years, a policy offering a subsidy that makes a specific project commercially viable today, will in years to come be altered and render the project unprofitable? The high capital intensity of renewable energy projects only serves to enhance downside risks.

Subsidies are implemented in either a quantity or price setting framework. For example, the policy may mandate generators to produce a certain proportion of their output from renewable sources, the so-called portfolio standards approach that is becoming dominant in the USA. These quantity based systems generally rely on tradeable certificates, and their key advantage is that firms enjoy flexibility with respect to decisions on how to meet the target. However, the success of these schemes depends critically on the credibility of the punishment mechanism if firms fail to meet the targets.

By contrast, price setting frameworks are typified by the feed-in-tariff systems which are prevalent in the EU, e.g. Germany and Spain. In this framework, investor risk is reduced by a per-unit subsidy paid to renewable generation, in addition to the standard power price. Feed-in-tariff systems are considered to be both predictable and flexible: they can be tapered to reflect expected falls in the cost of the technology, and can be specified for the lifespan of the project. However, critics argue that they can be more expensive than quantity based systems, and force policy makers to make decisions regarding which technologies to support, and at what level.

EU member states have adopted a patchwork of policies with respect to investment in low carbon technologies, and since e.g, Grubb (1997) has shown that policy may induce diffusion, it follows that the different policy regimes among member states in part drive different adoption patterns. However, since the focus of this chapter is the adoption behaviour at the aggregate firm level, the effect of policy differences between member states is diminished. To see why, consider two member states, A and B. Given member state based policies, all firms wishing to invest in renewables in member state A will face the same policy environment, and the same for those wishing to invest in member state B. Therefore the firm level approach is well suited to analysis that seeks to abstract from country level variables, for example policy regime, in order to build up a picture of firm behaviour.

5.3 Literature

It is striking that with few exceptions, diffusion has been studied from either the perspective of inter-firm diffusion, *or* intra-firm diffusion. This may not matter if the new technology instantly displaces the old technology, but the reality is often different. In these cases a deeper understanding may be gained by decomposing overall or aggregate diffusion into its component parts. In this section the related literatures on inter-firm and intra-firm diffusion are discussed, and the nascent literature that concerns the simultaneous analysis of inter-firm and intra-firm diffusion considered.

5.3.1 Disequilibrium models of inter-firm diffusion

The models discussed in this section are disequilibrium models in the sense that the diffusion path reflects a series of disequilibrium positions as the level of diffusion adjusts to an equilibrium some time in the future. Griliches (1957) was the pioneer of the basic disequilibrium model[3] in which the observed variation in rates of diffusion among firms is driven by the spread of information. Griliches' (*ibid.*) key finding was that the profitability of the innovation is the main driver of the 'rate of acceptance'. Another early study based on a disequilibrium model Mansfield (1963b) explores the effect of firm size and the ex-post profitability of adoption on inter-firm diffusion. Larger firms adopted faster than smaller firms, and a positive relationship between speed of adoption and expected increases in profit (due to the innovation) was found.

Epidemic models are capable of generating the logistic diffusion curve that appears to describe the diffusion of new technologies well, but crucial enabling assumptions are not necessarily justifiable (Davies, 1979, p.11-12). In particular, the assumptions that potential adopters are homogenous and that the pace of adoption is constant seem highly unrealistic, and Davies argues that the superficially impressive correlation coefficients generated by these models conceal underlying econometric problems, making them less convincing than they first appear. Furthermore, they are unable to explain the emergence of new technologies. This is an important limitation if, for example, we are relying on technological change as a key component of the fight against climate change. A consensus has developed: epidemic models of diffusion have generated important insights into the diffusion process and a framework for ongoing research, but on their own cannot provide a detailed picture of the drivers of the diffusion process.

5.3.2 Equilibrium models of inter-firm diffusion

In equilibrium models the diffusion path is traced out between shifting equilibria. Theoretical advances have yielded three analytical approaches to the

[3] Also known as epidemic models.

study of diffusion that rely on less restrictive assumptions than those of disequilibrium models. By contrast to disequilibrium models where diffusion is a self-propagating process, the diffusion path in equilibrium models is driven by variation in the costs and payoffs to adoption among firms.

The first set of models assume a heterogenous population of potential adopters, and that the cost of the technology falls over time. Firm heterogeneity generates a ranking of potential adopters, and the diffusion path is determined as costs fall and firms expecting high returns invest before rivals with lower expectations.

The first models capable of explaining the role of firm-specific factors in the speed of diffusion were David (1969) and Davies (1979). Potential adopters are assumed to have full information regarding the existence of the technology, which is assumed to experience falling costs as a result of learning. Firms differ in their attitude to risk and in their ability to 'absorb' the innovation, and have divergent expectations regarding the profitability of the technology. Davies (1979) finds diffusion to be faster when the innovation is more profitable, the adopting firm has a small number of rivals and size inequalities between firms are small.

An alternative approach rests on two additional assumptions which affect the balance of costs and benefits accruing to the adopter (e.g. Reinganum, 1981, Quirmbach, 1986). First, the profitability of adoption is positively related to increased use of the technology by rival firms. There are positive spillovers. Second, as the accumulated stock of the technology rises, so production costs fall, which in turn drives adoption. Firm heterogeneity does not enter these models so they are not capable of predicting which types of firms will be early adopters. However they do imply an inverse relationship between the number of adopters and the benefits from adoption, and so point to the possibility of first mover advantages.

Closely related are models where the ordering of the payoffs to adoption causes competition for first mover advantages and thus the diffusion path up to the point where the marginal firm is indifferent. Diffusion only continues past this point if the costs of adoption decline (e.g. Fudenberg and Tirole, 1985).

5.3.3 Intra-firm diffusion

There is very little literature concerning intra-firm diffusion although it is at least as important to understand diffusion processes within the firm as it is to understand how diffusion spreads among firms. The first intra-firm study was Mansfield's seminal paper which explored the possibility that factors found to influence the speed of adoption, may also determine the speed of substitution between the old and new technologies within the firm (Mansfield, 1963a). The time interval since the appearance of the technique was found to be positively correlated with the speed with which firms intensified their use of the new technology. Mansfield's analysis of intra-firm diffusion was important for the development of more nuanced models in two respects. It was the first attempt to apply the inter-firm model to intra-firm diffusion, and second, by identifying firm liquidity and the expected profitability of the invention, it was the forerunner of models that recognize the role of firm heterogeneity as a driver of differential rates of adoption. However, Mansfield's intra-firm study is a disequilibrium model, so suffers from the deficiencies outlined in the preceding section.

There was then a long period during which intra-firm diffusion was apparently totally neglected by academic researchers. But more recently empirical analysis examining the determinants of diffusion within the firm have begun to emerge (e.g. Arvanitis and Hollenstein, 2001, Fuentelsaz et al., 2003, Åstebro, 2004) though empirical evidence remains thin.

5.3.4 Joint modelling of inter-firm and intra-firm diffusion

Even rarer are studies which jointly analyze inter-firm and intra firm diffusion. Battisti et al. (2004) develop an encompassing model which hypothesizes that effects that have been shown to determine diffusion patterns in inter-firm models, also drive diffusion within the firm. Battisti et al. (2007) apply the encompassing model to the diffusion of information technology within and across countries, and find that the first adoption decision is not a direct determinant of the current intensity of use. Furthermore, the epidemic-type effects incorporated in Mansfield's studies (1963a, 1963b) were not found to be valuable in explaining differences in intra-firm diffusion patterns.

5.4 Definitions and data

For the sake of clarity, four terms used throughout the chapter to denote specific aspects of diffusion at a given time t are defined as follows:

5.4.1 Defining diffusion

Inter-firm diffusion is the cumulative number of adopters as a proportion of the number of firms in the sample.

Intra-firm diffusion for is the proportion of each firm's total global installed capacity accounted for by wind turbines.

Aggregate diffusion is the product of inter and intra-firm diffusion, and measures diffusion across the industry.

An **Adopter** is a firm which reports generating electric power from wind turbines.

5.4.2 Data

There is no compelling reason for firms in most industries to report their technology mix[4] so the availability of data that could be used to measure inter-firm and intra-firm diffusion is low. However firms take corporate social responsibility very seriously and corporations operating in a variety of sectors have responded to heightened public and political concerns over climate change by publicizing their green credentials, e.g. in 2007 Marks and Spencer launched their 'Plan A' aimed at combatting global climate change, and have advertised it extensively. Figure 5.1 shows that in 2010 energy

[4]The technology mix, or equivalently in this study, the capacity mix, is the combination of plant types used in production. For example, 50% nuclear reactors, 30% coal fired power stations and 20% hydro.

industries account for approximately one third of total greenhouse gas emissions (GHG) emissions of the EU-27, the bulk of which comes from power generation. Therefore generators have a particularly strong motive to publish information about how 'green' their generation mix is.

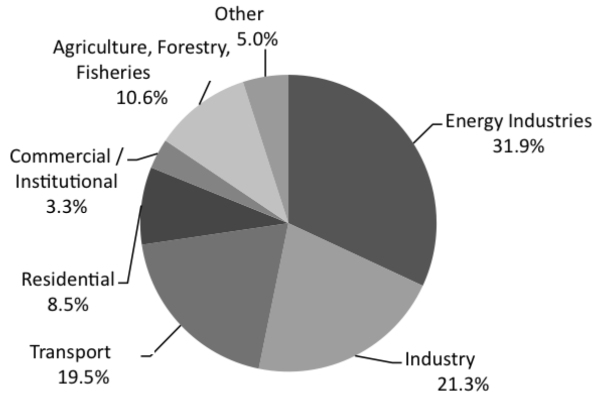


Figure 5.1: GHG emissions by sector, EU–27. 2010
Source:Eurostat

Inter-firm diffusion curves are generated by the time path of the date of first adoption. The date of first adoption for each firm was inferred from the technology mix reported in company reports. So for example, if company A reported generating power using coal, oil and gas in year 1, but in year 2 the mix included WTG, then they would be classified as having adopted WTG in year 2. Archives of company reports lodged on websites are generally limited to a maximum of 10 – 12 years, so the adoption date of early adopters, for example Nuon (Netherlands) and DEI (Greece) was obtained by direct communication with the firm concerned.

Estimates of intra-firm diffusion of WTG are based on detailed knowledge of the proportion of the capacity mix accounted for by each technology. While for recent years most (but not) all generators report this information in their annual or environmental reports, the data was very patchy prior to about 2005. Since firm heterogeneity has been shown to be an important driver of diffusion, data on specific firm characteristics was required. However obtaining detailed data over several years would have entailed sending out a questionnaire to each firm, and resources for large scale data collection were unavailable. Therefore data on firm specific characteristics for a single year, 2008, was collected from firm annual reports. Diffusion is an inherently dynamic process so while not ideal, this is the approach adopted in most other studies of intra-firm diffusion (Battisti et al., 2007, Hollenstein and Woerter, 2008, e.g.), with the notable exception of Fuentelsaz et al. (2003).

5.4.3 The sample firms

The sample firms are all generators that are leading firms in their country of origin as presented in the market share matrix for power generation presented in chapter 2[5]. Of the 54 matrix firms, 15 failed to supply data despite repeated requests, so the sample consists of 39 firms.

5.5 Patterns of diffusion of WTG

In this section observed patterns of inter-firm diffusion and intra-firm diffusion among adopting firms are evaluated.

5.5.1 Inter-firm diffusion

As the 'California wind rush' took off in the 1970s, the first European power generators began to take an interest in the new technology and to build demonstration plants. It seems likely that among firms that did eventually adopt, the time-lag between the firm installing the prototype and first reporting generation using the technology would vary between firms. Anecdotal evidence bore out this suspicion. For example, under the auspices of their R&D department, Vattenfall committed funding and installed a 70kW

[5] The unit size of WTG is small relative to more traditional generating technologies, which means that total wind farm size may be small. There is a multitude of small organizations such as farms and communities that own their own small wind farm consisting of a few turbines. The sample does not include such installations since it is the strategy of large firms that is of interest.

prototype in 1976, followed by a larger 2MW unit in 1984[6]. But it was only in 1995 that the first 20 WTG formed part of the Vattenfall capacity mix, i.e. generated power which was sold commercially. To avoid ambiguity and imprecision, sample firms were classified as having adopted the technology only when they first reported generating power from the technology, which is not necessarily the coincident with the year of first installation.

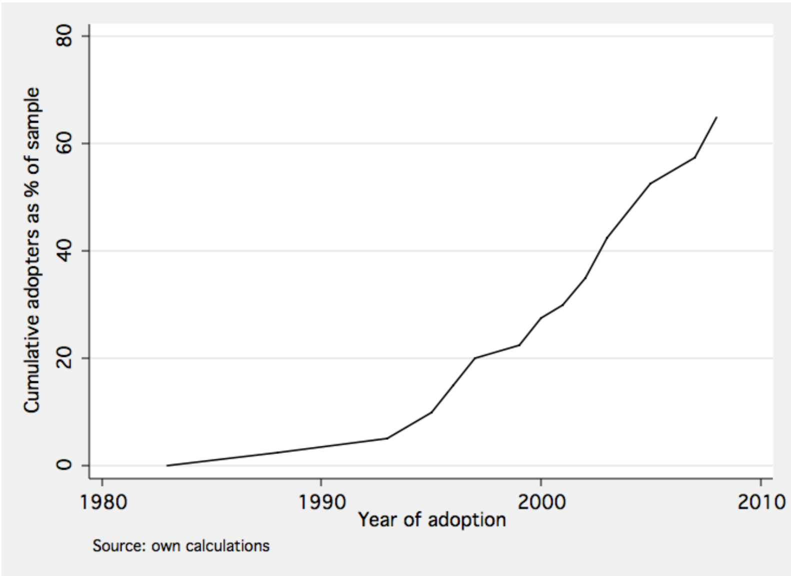


Figure 5.2: Inter-firm diffusion of WTG

Figure 5.2 traces out the time path of WTG adoption between the first commercial adoption of the technology (1982) and 2008. By the end of 2008, 26 years after the pioneering firm Nuon (then called PEN) of the Netherlands had adopted WTG, 70% of firms in the sample had reported producing power with the new technology. Just less than half of the firms in the sample had also adopted WTG after 18 years. By comparison, Battisti and Stoneman (2003) find that 82% of firms in the sample had adopted computer numerically controlled machine tools (CNC) 22 years after the first firm adopted. Based on data for the USA, table 5.1 provides similar information for a variety of process technologies. WTG is a complex, expensive technology and while none of the technologies mentioned is particularly similar to WTG,

[6]Source: correspondence with Anders Sjogren at Vattenfall

Technology	Years for half potential adopters to acquire
Industrial robots	12
Numerically controlled machine tools	5
Diesel locomotives	9
Centralised traffic control	14
Car retarders	13
Continuous wide strip mill	8
By-product coke oven	15
Continuous annealing	13
Shuttle car	5
Trackless mobile loader	6
Continuous mining machine	3
Tin container	1
High speed bottle filler	6
Pallet loading machine	5

Source: Mansfield (1989)

Table 5.1: Inter-firm diffusion of selected technologies.

many are also high cost and complex. The time taken for inter-firm diffusion of WTG to reach 50%, about 18 years, is longer than all the comparators.

Another way to look at the delay in introducing a new technology is with reference to the number of years that adopting firms wait, measured as the interval between commercialization[7] of the product and adoption. The mean number of years waited before adoption is 17, and the median 19, so the data has a slight negative skew. 33% of adopting firms waited between 19 and 22 years to do so, as shown in table 5.2. Overall, the data suggest that the inter-firm adoption of WTG has taken place at an unusually slow pace relative to other technologies, though unfortunately comparators from the power sector are not available because of the dearth of firm-level analysis.

Several factors may have contributed to this lengthy delay (see Kemp and Volpi, 2008). Technical factors include the complexity of the technology and hence the scope for post introduction refinements and declining prices,

[7] Defined here as the first year that a sample firm reported producing power from WTG, 1982.

Years waited	Number of firms	% adopting firms
up to 10	3	11
11-14	6	22
15-18	4	15
19-22	9	33
22-26	5	19
Total	27	100

Time elapsed from the year the pioneering firm adopted.

Table 5.2: Time firms waited before adopting WTG.

may induce firms to wait in the expectation of lower prices and 'learning by doing'. Institutional factors, including support mechanisms such as feed in tariffs and green certificate schemes change the relative costs and benefits of adoption, and are intended to induce adoption. But equally, they may delay adoption in countries that have not implemented support schemes. Therefore while institutional arrangements cannot explain differences in the speed of adoption among firms, given that schemes vary considerably across member states, firms that do not (or cannot) pursue a multinational strategy, may be constrained by arrangements in their domestic market. In the presence of uncertainty about for example, the future cost or level of technology specific subsidy, waiting may carry an option value (Dixit et al., 1994). Similarly, resource availability may be important if for example the wind resource in a given member state is low and domestic generating firms do not follow a multinational strategy.

The pattern observed in figure 5.2 is consistent with the predictions from the literature which suggest that inter-firm diffusion follows a logistic curve (Hall, 2004, p.16), and further that typically complex and expensive process technologies tend to exhibit a cumulative normal curve (Davies, 1979, p.50). A recent study suggests that diffusion induced through policy instruments may sometimes follow a different diffusion path, though does not provide conclusive evidence of its shape (Diaz-Rainey, 2010). Learning affects the expected cost of adoption, which varies between firms, so the post invention period for a complex, expensive technology is characterized by a fairly slow

Category	WTG %	Number of firms	% of firms
Intensive	Over 20%	3	11
Low	1 – 20%	17	63
Basic	0.1 – 1%	7	26
Total		27	100

Table 5.3: Intra-firm diffusion of WTG, by category.

rate of learning during which suppliers improve and refine the technology over time which leads to cost reductions. This is represented by the fairly flat portion of the curve up to about 11 years, after which it starts to increase more rapidly and interestingly, the rate of growth continues to rise, though there are possibly the first signs of a decline in the *rate* of growth at 25 years.

5.5.2 Intra-firm diffusion

27 sample firms had adopted WTG by 2008. Following earlier studies, (e.g Battisti et al., 2007), adopters were categorized according to the proportion of WTG in their capacity mix; basic adopters for whom WTG remained a tiny share of their capacity, low level adopters who had between 1% and 20% WTG and intensive adopters with a WTG share of over 20%. The cut points dividing the categories, 1% and 20% were derived from visual inspection of the data, so there is a possibility that a bias is introduced by this ad hoc classification, however the purpose of proceeding in this way is simply to offer an approximate characterization of the types of strategy that firms adopted[8].

Table 5.3 shows that among adopting firms, 63% firms had a low WTG share in 2008, and for only 11% firms was WTG an intensive part of their capacity mix. The mean level of intra-firm diffusion is only 5.4%, compared with, for example, 27% for CNC 22 years after its introduction (Battisti and Stoneman, 2003). Given that the WTG was first adopted in 1982, the low proportion of firms using the technology intensively some 26 years later may have important policy implications, which are addressed in section 5.8.

Two of the three intense adopters, Acciona and Ibedrola, are based in

[8]The econometric model was estimated on the continuous variable.

Spain and the third, EDP, in Portugal, and all are multinational. None was an early adopter, waiting 13, 17 and 19 years respectively as compared to a mean of 17 years, which confirms that Mansfield's (1963a) prediction that the intensity of use of a new technology increases with experience, may not hold in this case.

Figure 5.3 shows the relationship between intra-firm diffusion and the number of years experience the firm has with the technology. Two features stand out: first, it shows that the for the majority of firms, WTG remains a very small proportion of the capacity mix; second, for the majority of firms, the decision to intensify the share of wind in total capacity appears to be independent of the decision to adopt in the first place, i.e. the wind share of capacity remains very small many years after the firm adopted the technology.

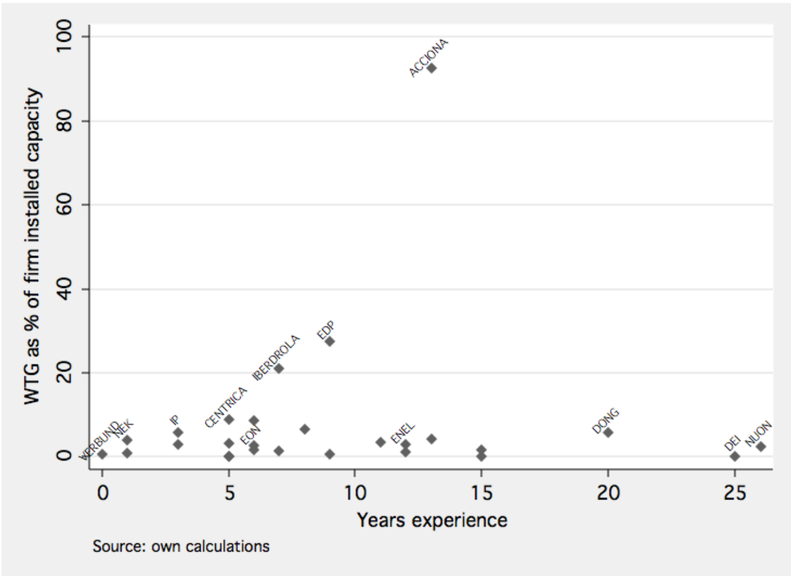


Figure 5.3: Intra-firm diffusion of WTG, proportionate measure. 2008

Figure 5.4[9] shows the relationship between the absolute size of WTG capacity for each firm and their years experience, i.e., it is not weighted by firm size. Ibedrola (Spain) is the clear leader in terms of installed capacity

[9]Data points in figures 5.4 and 5.3 are in general labelled if they lie at the extremes of the plot. Labelling all data points resulted in a figure that is difficult to read.

with 9 GW. This is an impressive achievement, particularly when it is noted that Ibedrola was a fairly late adopter. Fellow Iberians EDP (Portugal) and Acciona (Spain) also have large WTG capacities, and it is tempting to speculate that the generous renewables support schemes on the Iberian peninsular may be part of the explanation. This may reflect reality, but recall that the data is global installed capacity for each firm and only the capacity installed in domestic markets would attract the relatively high level of subsidy. At the other extreme lie the early adopters Nuon (Netherlands), DEI (Greece) and Dong (Denmark) but who by 2008 still had a very small WTG share.

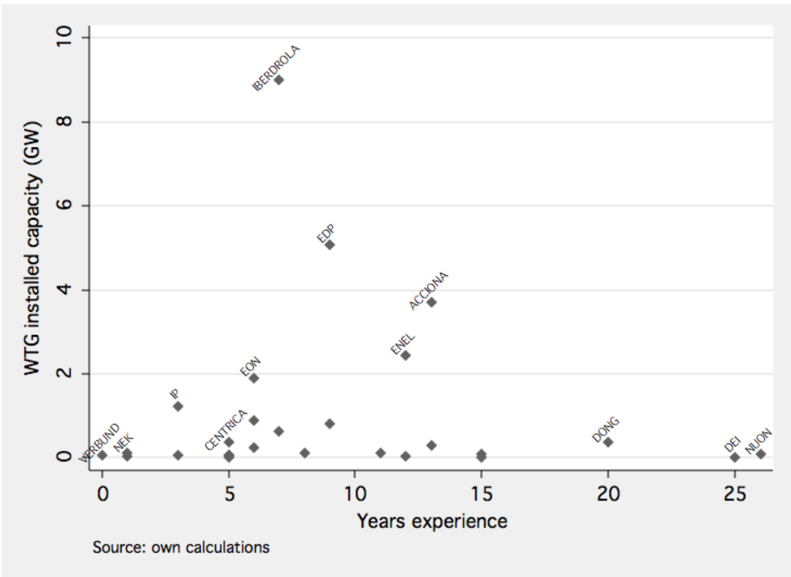


Figure 5.4: Intra-firm diffusion of WTG, absolute measure. 2008

Comparing the two figures is instructive. First, both share similar patterns and there appears to be an upper bound (bottom left to top centre) which exhibits the expected logistic shape - firms on or close to this upper bound have invested relatively late and intensified the share of wind in their total capacity fast relative to other firms. However, the ranking of firms changes, particularly among those with the higher WTG share. Though EDP and Ibedrola have a considerably larger WTG share than the remaining firms, Acciona's share is of a different order of magnitude. It is interesting to note that while, for example, Enel (Italy) has the fourth largest capacity in absolute terms, the proportion WTG in their overall capacity mix is among the lowest in the sample. These findings suggest very different corporate strategies with respect to wind, and supports the characterization of firms as basic, low and intense adopters. Finally, both figures imply that first mover advantages do not exist - the first three adopters have among the lowest WTG share by either measure.

5.5.3 Aggregate diffusion across the industry

To determine whether or not the behaviour of the sample firms was consistent with that implied by studies examining diffusion at the country level[10], data was obtained for the share of wind in overall net electrical capacity by OECD region for the period 1992 – 2008. Figure 5.5 shows OECD Europe to have around 7.5% WTG in total capacity, however recall that although sample firms are all based in the EU, sample capacities are global, so the correct comparator is OECD total.

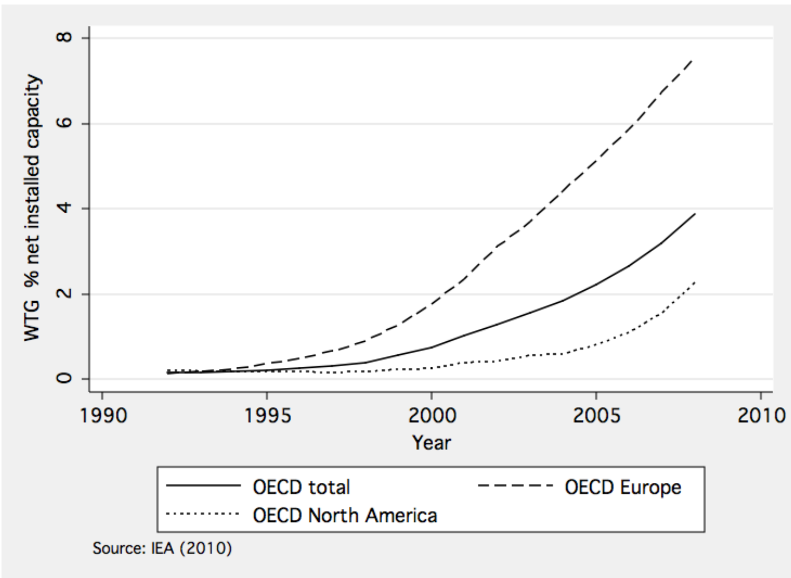


Figure 5.5: WTG share of total capacity, OECD regions. 1992–2008

[10] As discussed above, such studies comprise the vast proportion of literature. (see, for example Diaz-Rainey, 2010)

To calculate overall diffusion D_t for the sample firms at time t let:

$$D_t = \frac{K_t}{Y_t} \tag{5.1}$$

where $K_t = \sum_{i=1}^{M} k_{new}$ is the sum of firms' installed capacity of the new technology, and $Y_t = \sum_{i=1}^{N} k_{new} + k_{old}$ is the sum of firms' total installed capacity and where M is the number of adopters and N is the number of potential adopters.

Average intra-firm diffusion is defined as $(K_t/M_t)/(Y_t/N_t)$, the average proportion of the new technology in the installed capacity of adopters, as a proportion of the average industry installed capacity per firm. Then equation (5.1) is equivalent to equation (5.2)

$$D_t = \left(\frac{M_t}{N_t}\right)\left(\frac{K_t/M_t}{Y_t/N_t}\right) \tag{5.2}$$

From section 5.4 we know that inter-firm diffusion, or the proportion of firms that had adopted the technology in 2008 was 70%, and calculate average intra-firm diffusion to be 5.4%. Thus using equation (5.2), D_{2008} is $0.70 \times 0.054 = 0.038$. So 26 years after the technology first appeared, overall diffusion among leading electricity generators is less than 4%.

The sample estimate is therefore consistent with the WTG share in the OECD data shown in figure 5.5 and the sample appears to be representative of the industry as a whole. Further, the extent of inter-firm diffusion and intra-firm diffusion are vastly different, so decomposing overall diffusion into inter and intra-firm diffusion is justified.

5.6 Modelling inter-firm and inter-firm diffusion

The modelling of intra-firm diffusion is based on the more developed inter-firm models (see section 5.3). Encompassing models jointly analyze inter-firm and intra-firm diffusion and following Battisti et al. (2004, e.g.) and Hollenstein and Woerter (2008), is the route taken here.

5.6.1 Empirical model specification

In this section the estimating equation is derived based on the theoretical and empirical literature.

5.6.2 Dependent variables

Aggregate diffusion is the product of two distinct steps. First the firm adopts the technology, and conditional on that initial adoption, may intensify the proportion of the technology in their capacity mix. Therefore since we wish to decompose aggregate diffusion into its component parts, two dependent variables are estimated. The initial decision to adopt the technology is captured by the variable $ADOPT_{it}$, which is a binary variable that takes the value 1 if firm i has adopted the technology at time t, and 0 otherwise. The proportion of firm i's capacity accounted for by WTG is captured by $INTRA_{it}$. Because $INTRA_{it}$ is a fractional response variable, it was transformed as follows. The variable was assumed to be described by the model:

$$INTRA_{it} = \frac{1}{1 + \exp(-XB)}$$

where X is the vector of independent variables. Application of the logit transformation yields:

$$ln(INTRA_{it}/(1 - INTRA_{it})) = XB$$

and the original variable which had been bounded by 0 and 1, is now mapped to the real line and may be estimated by Least Squares (see Papke and Wooldridge, 1996).

5.6.3 Independent variables

The set of independent variables included in the estimating equation were derived from the literature discussed in section 5.3 and below, and in particular Battisti et al. (2007) and Hollenstein and Woerter (2008).

Firm level variables

Firm size, measured by the firm's total global installed capacity in gigawatts (GW), $SIZE$. Existing empirical research has shown that larger firms are more likely to adopt new technologies (e.g. Davies, 1979, Karshenas and Stoneman, 1993) though evidence concerning the influence of size on the intensity of use of new technologies is mixed. Mansfield (1963a) and Battisti et al. (2004) find the intensification of use of a new technology to be faster in small firms, but by contrast Battisti and Iona (2009) show that large firms are more likely to use a set of complementary management practices more intensively than small firms. Accordingly, it is not possible to predict the sign of the coefficient *ex ante*. Preliminary analysis showed firm size to be strongly positively skewed, therefore a Box-Cox transformation was performed. Details of the procedure are given in the Appendix.

Firm multinationality. The variable $MNAT$ is the M index that captures the extent of mulitnationality of multinational firms that was developed in chapter 4. If the firm's country of origin is for example, relatively resource poor and opportunities for trade are limited, then multinationality may offer a firm the opportunity to exploit superior resources. For example, in the present context the UK has a high wind resource relative to France, so *ceteris paribus* it might be expected that a firm which owned capacity in both countries to use WTG more intensively than a firm restricted to France. In a sector that was until at least the mid 1990s characterized by vertically integrated monopolies that were either owned by the state or over which the state took a proprietorial interest, multinationality might also proxy institutional flexibility. The dataset used in that chapter ended in 2007, so the M index used here relates to 2007. This seems safe given the fact that no multinational firm made the decision to give up their multinational status during the ten year period covered by the multinationality database.

Absorptive capacity is represented by $R\&D$, which captures the proposition that firms which devote resources to innovative activity have an enhanced ability to evaluate, assimilate and apply new information (Cohen and Levin, 1989, Zahra and George, 2002). Absorptive capacity is expected to have a positive relationship with diffusion. Numerous empirical studies support this expectation, including in the context of intra-firm diffusion (Battisti et al., 2007) and for WTG, Klaassen et al. (2005). Since there are a number of missing values for the share of R&D in total revenue and the sample size is already rather small $R\&D$ is included as a dummy variable that takes the value 1 if the firm conducts in house R&D in 2007, and 0 otherwise. Previous studies have followed the same strategy. Arguably it is the fact that the firm conducts the innovative activity not the absolute spend that is important.

Concentration in the domestic market, represented by the two-firm concentration ratio, CR_2. Concentration is widely employed as a measure of competitive pressure, though this tendency is explicitly avoided throughout the thesis. Nevertheless, market structure, e.g. measured by concentration, is an *indicator* of the possible level of competitive pressure. Bresnahan and Reiss (1991) show that even without information on prices or costs, it is possible to infer the competitive effect of entry in oligopolistic markets, and that the greatest effect on competition is by the entry of the second and third firms. The voluminous literature relating market structure and innovation is ambiguous in its predictions (Gilbert, 2006) though Sidak and Teece (2009) argue that competitive markets may not generate strong enough signals to deliver the socially optimum level of innovation. In the absence of a measure of competition, the effect of concentration in the firm's domestic market was captured by the two firm concentration ratio.

Intra-firm learning which is captured by $RENEWABLES$ which takes the value of 1 if the firm reports power generation from other renewable technologies (excluding hydro) and 0 otherwise. Given the special market rules for renewables, it is possible that a firm that has developed experience in operating under the distinct renewables rules has lower costs of adopting other renewables. Evidence from other studies supports this prediction (e.g Hollenstein and Woerter, 2008, Colombo and Mosconi, 1995), though neither concerns clean technologies and no empirical study of the intra-firm diffusion of a clean technology could be found. A positive impact on adoption and intensification is expected.

Industry level variables

Inter-firm learning is captured by $ADOPTEARLIER$, the number of firms that had adopted earlier[11]. A classical barrier to innovation is the inability of firms to fully internalize the benefits of innovation which then becomes a positive externality for rival firms, known as spillover effects (Griliches, 1992). An alternative way of thinking about spillovers is as inter-firm learning. A very recent study that examines learning and spillovers in wind power provides preliminary evidence that inter-firm learning was positive but small (Nemet, 2010), but that it was highly activity specific and not generalized.

[11]Two variants on the variable were tested, the number of firms which had adopted earlier, and earlier adopters as a proportion of potential adopters, but the parameter estimates differed little so the count variant was included in the final model.

Type	Variable	Description	Expected sign
Firm			
	$SIZE$	Firm size (GW)	+/-
	$MNAT$	Index of firm multinationality	+
	$R\&D$	Absorptive capacity	+
	CR_2	Competitive pressure	+/-
	$RENEWABLES$	Inter-firm knowledge base	+
Industry			
	$ADOPTEARLIER$	Spillovers	+/-

Dependent variable adoption equation: $ADOPT = 1$ if yes, 0 otherwise.
Dependent variable intensification equation: $INTRA_i$ (logit transformation.)

Table 5.4: Independent variables

5.7 Estimation procedure and empirical results

An encompassing model was used to jointly estimate inter-firm and intra-firm diffusion of WTG. The Heckman (1979) maximum likelihood selection procedure was adopted because it permits testing the hypothesis that the two decisions are independent. This is important because if a firm's decision to adopt a new technology, and the decision to increase the proportion of the technology in their capacity mix are motivated by different factors, potentially effective policy mechanisms designed to induce diffusion may also differ.

5.7.1 Econometric model structure and assumptions[12]

Let y_2^* denote the outcome of interest[13]. A second latent variable is denoted by y_1^* and the outcome y_2^* is observed if $y_1^* > 0$. In this case, y_1^* determines whether or not the firm adopts, and y_2^* determines the share of WTG in their

[12]This section draws extensively on StataCorp (2007, p.561-563) and Cameron and Trivedi (2009, p.542-543)

[13]Throughout this section an asterisk denotes a latent variable.

capacity mix and $y_1^* \neq y_2^*$.

The two-equation model consists of a selection equation for y_1, where

$$y_1 = \begin{matrix} 1 & \text{if} & y_1^* > 0 \\ 0 & \text{if} & y_1^* \leq 0 \end{matrix}$$

and the outcome equation for y_2, where

$$y_2 = \begin{matrix} y_2^* & \text{if} & y_1^* > 0 \\ - & \text{if} & y_1^* \leq 0 \end{matrix}$$

In this set up, y_2 is observed only when $y_1^* > 0$. The model is linear with additive errors so:

$$y_1^* = x_1'\beta_1 + \varepsilon_1 y_2^* = x_2'\beta_2 + \varepsilon_2 \tag{5.3}$$

and ε_1 and ε_2 may be correlated. The likelihood function for the model is:

$$\mathrm{L} = \prod_{i-1}^{n} \Pr(y_{1i}^* \leq 0)^{1-y_{1i}} f(y_{2i} \mid y_{1i}^* > 0) \times \Pr(y_{1i}^* > 0)^{y_{1i}}$$

The first term is the contribution if $y_{1i}^* \leq 0$ since then $y_{1i} = 0$ and the second term is the contribution when $y_{1i}^* > 0$.

5.7.2 Results and discussion

Empirical results are presented in table 5.5. The Heckman ML selection model jointly estimates adoption and intensification; results for each step are discussed in turn.

General assessment

The logic of applying an encompassing model is supported by the empirical results. Firm specific and industry level characteristics are important determinants of the extent of inter-firm and intra-firm diffusion in 2008. The Wald test statistic provides evidence that the coefficients on the variables are significantly different from zero at the 5% level. The likelihood ratio test has a p-value of 0.003, therefore the estimated correlation between the errors is significantly different from zero. This means that the hypothesis that the two parts of the model are independent is rejected, so the decision to intensify WTG in the capacity mix is not independent of the decision to adopt WTG.

Inter-firm diffusion

Multinational firms were more likely to have WTG in their 2008 generation mix than non-multinationals (significant at the 1% level). In general clean technologies[14] typically flow across borders only if the recipient country has 'better' incentives to invest (Popp, 2008), which suggests that MNE's may have a role in transferring clean technologies from developed to less developed and transition economies.

Firms that reported generating power from other renewable technologies (excluding hydro) were also more likely than those who used only conventional technologies to have WTG in 2008. Power generated from renewable energy sources (RES) is treated in a different way from other power, which implies that generators familiar with and set-up to deal with one RES are more likely to invest in others. There is essentially a sunk cost associated with the first RES technology, so subsequent investments become less costly and less risky. This implies that reducing the complexity of the interactions between the RES and standard power regimes may have a positive effect on the number of firms that adopt WTG.

A statistically significant relationship between firm size and inter-firm diffusion was not found, in contrast to earlier studies which found that larger firms were more likely to adopt a new technology (e.g. Davies, 1979, Karshenas and Stoneman, 1993). The prior expectation was that R&D as a proxy for absorptive capacity would be found to be positively related to inter-firm diffusion in 2008 was confirmed, but the result was not significant.

[14] Other than some energy efficiency technologies.

Data limitations required R&D to be included as a dummy variable, so it is possible that a better measure of absorptive capacity may have generated the expected result. Finally, the two-firm concentration ratio in the firm's domestic market again carried a positive but insignificant coefficient.

Intra-firm diffusion

The two-firm concentration ratio in the member state of origin is strongly negatively correlated with intra-firm diffusion (at the 0.1% level of significance). To put it another way, firms based in countries where the share of the two largest firms is low are much more likely to have a high proportion of WTG in their generation mix in 2008. This might be taken to support theories that suggest that competition is good for innovation, however that would be to equate market structure with the intensity of competition, which we have explicitly avoided. We can only say that the absence of monopoly seems to stimulate intensive investment in WTG.

Smaller firms are more likely to have a high share of WTG in their capacity mix (significant at the 10% level). The (limited) evidence on the effect of firm size on intra-firm diffusion is mixed, but this result is consistent with Hollenstein and Woerter (2008). The mixed evidence may mean that we do not yet understand the effect of size on diffusion very well, but Battisti (2008) argued that effective intra-firm information flows stimulate intra-firm diffusion. In which case, we might infer the relationship to be due to less formal and restrictive practices and greater flexibility found in small firms.

Aggregate diffusion

Considering aggregate diffusion, a story of intra-firm learning being a crucial driver of the diffusion process seems to emerge. It is apparent that effective within firm learning and information flows are characteristics of both MNEs and firms that have more than one RES in their capacity mix. It is also likely that small firms have fewer barriers to information flows than large firms.

Explanatory variable	Adoption		Intensity	
	Coefficient	Standard error	Coefficient	Standard error
$FIRMSIZE^1$	$-0{\cdot}399$	$0{\cdot}686$	$-2{\cdot}046*$	$1{\cdot}122$
$MULTINATIONALITY$	$3{\cdot}767**$	$1{\cdot}383$	$0{\cdot}410$	$2{\cdot}138$
$R\&D$	$0{\cdot}205$	$0{\cdot}708$	$1{\cdot}386$	$1{\cdot}025$
CR_2	$0{\cdot}244$	$0{\cdot}885$	$-5{\cdot}257***$	$1{\cdot}518$
$ADOPTEARLIER$	$\cdot$	$\cdot$	$-1{\cdot}782$	$1{\cdot}782$
$RENEWABLES$	$1{\cdot}686**$	$0{\cdot}628$	$-1{\cdot}067$	$0{\cdot}858$
Test statistics				
N	38			
Censored	12			
Uncensored	26			
Wald test	$\chi^2(6) = 19.40(\text{Prob} > \chi^2 = 0.003)$*			
Log likelihood	-60.88			
LR test $rho = 0$	$\chi^2(1) = 8.53(\text{Prob} > \chi^2 = 0.003)$*			

Heckman selection ML model.
Dependent variable adoption equation: *ADOPT*
Dependent variable intensification equation: *WTGSHARE*
1. Box-Cox transformation.
* indicates significance at 10% level.
** indicates significance at 1% level.
*** indicates significance at 0.1% level.
Standard errors in parentheses.

Table 5.5: Results: Inter-firm and intra-firm diffusion of WTG.

5.8 Conclusion and discussion

Aggregate diffusion is a function of the proportion of firms using the technology (inter-firm diffusion) and the proportion of the total capacity mix (or production) accounted for by the technology (intra-firm diffusion). The evidence presented in this chapter shows that inter-firm diffusion was particularly slow for the first 11 years after the first firm adopted and that in 2008, 26 years after their first commercial use, aggregate diffusion of WTG remained very low at less than 4%. The overall level of diffusion was due to an inter-firm diffusion level of 70% and average intra-firm diffusion of only 5.4%. It was shown that for only 11% of sample firms was the WTG capacity share over 20%.

Policy interventions are justified when the actual outcome diverges from the social optimum, but unfortunately there is no consensus on the social optimum level of diffusion of WTG. However, the broad dimensions of the requirement for RES technologies can be inferred from, e.g. the EU's commitments under the Kyoto Protocol. Current installed capacity is very substantially below the levels required to meet those commitments. While some analysts may argue that the market will deliver the optimum level of WTG or any other new technology, it has been shown that the inter-firm of WTG was very slow, and there is a pressing need to avert dangerous climate change (Stern et al., 2006). Evidence that waiting will be very costly (e.g. McKinsey, 2009), argues for immediate intervention.

There are two key instruments of diffusion policy (Stoneman and David, 1986). The first is intended to speed up the rate of initial adoption by spreading information. Unfortunately the present analysis is silent on the importance of information in the adoption decision because the variable capturing the spread of information dropped out due to collinearity. However existing literature does provide some support for the theory that information has a positive effect on initial adoption (Mansfield, 1963b), though design of the policy mechanism must be undertaken with care if public provision of information is not to crowd out private information provision. The second set of policies is intended to subsidize the cost of adoption, but again caution must be exercised since capital goods suppliers with market power, may be able to appropriate the subsidy by pricing above marginal cost.

Intra-firm diffusion is largely neglected in both theoretical and empirical literature: diffusion analysis generally focuses only on the date of first adoption, or inter-firm diffusion. This would not matter if the two aspects of diffusion were generated by similar processes, but the substantial difference between the inter-firm and intra-firm rates identified in this study, suggests this not to be the case. There are a number of implications. First, the relative neglect of intra-firm diffusion in the literature should be redressed in order that a fuller understanding of processes that govern intra-firm diffusion can be generated. Second, the joint modelling of inter-firm and intra-firm diffusion has been successful and the approach should be replicated for other technologies. For example, this approach revealed that the initial decision to adopt and the decision to increase the WTG share were not independent, therefore subsidy aimed at inter-firm diffusion is likely to have an effect on intra-firm diffusion and vice versa. Since diffusion was shown to be largely a story of intra-firm learning, this suggests that diffusion policy should focus on improving information flows within firms and their abilities to put the information to good use.

However, these policy implications should be treated with caution because there are three main shortcomings of the study. First, the data available was limited to a cross section, though it is obvious that a much fuller understanding of the inherently dynamic nature of the diffusion process would be permitted using panel data. This would also alleviate the problems associated with the small sample size. The second concerns the econometric methodology. As discussed, econometric studies of intra-firm diffusion are rare, and the joint modelling of inter-firm and intra-firm diffusion even rarer, so no consensus on the most appropriate methodology has yet emerged. While the overall fit and results of the econometric approach adopted here are satisfactory, there remains plenty of scope for experimentation with different econometric strategies. In addition to developing further models of intra-firm diffusion, it would be interesting to conduct a 'model comparison' study in the vein of Neuhoff et al. (2005), though the body of empirical evidence available may be too small for this to be of practical use at the present time. The final shortcoming is that the paper does not account for policy differences in the member states. While we argued in section 5.2 that the effect of differences between individual member state policies is diminished because our measures of diffusion are at the aggregate firm level, it would nevertheless be an interesting extension to introduce into the model policy variables capturing member state policies.

5.9 Appendix

5.9.1 Box-Cox transformation

The variable is assumed to take the following form:

$$y = \alpha + \beta(x) + \varepsilon$$

then is it linear only if $\lambda = 1$ in equation (5.4):

$$x^{\lambda} = \frac{x^{\lambda} - 1}{\lambda} \tag{5.4}$$

If the variable y is skewed, then $\neq 1$. The Box-Cox transformation finds a value for λ such that x^{λ} has approximately 0 skewness and the efficiency of Ordinary Least Squares estimates are not compromised.

CHAPTER

SIX

CONCLUSIONS AND FUTURE RESEARCH

6.1 Introduction

The EC has a vision of a single internal market in electricity, and has taken steps to attain that goal by introducing competition into what in most member states was a monopolized industry with high levels of state involvement. Ten years after the EC's liberalization process began, progress towards the single market objective was deemed sufficiently slow to merit a Sector Inquiry, which found that concentration to be high in many member states. On this basis of this finding, the EC concluded that competition was insufficiently intense. Equating competitive pressure and industrial structure is pervasive in industrial economics, but in reality structure is about more than concentration; it is determined by both the size distribution of firms and their number. And competitive pressure is about more than structure; it is about barriers to entry as well. This thesis has identified and evaluated the changing nature of the industrial structure of power generation in the EU in the context of radical sectoral restructuring.

6.2 The market share matrix

It is surprising that the EC's single electricity market vision has not stimulated a body of research examining the dimensions of the hypothetical EU market. The EC themselves seem to have suffered a failure of imagination; the specification of the data to be collected from firms under the Sector Inquiry omitted data that would have enabled the EC to evaluate market structure at the EU level. There is no publicly and freely available data that would permit such an analysis, therefore the market share matrix for EU power generation was compiled from scratch. The database records the capacity of 54 leading firms based in the EU over the period 1998 – 2007, and is highly representative of the EU; matrix firms covered 74% of total EU installed capacity in 2007.

The matrix is a remarkably flexible and powerful tool for the analysis of sectoral structure that can be disaggregated at the member state or regional level. Statistical analysis based on the matrix revealed the dimensions of the hypothetical EU single market that were to guide the more sophisticated analysis pursued in later chapters. For example regarding concentration, it showed that by the end of the period, 3 firms owned 36% of total EU installed capacity, that concentration at the aggregate EU level had risen over the period and that the dynamic path of concentration varied very substantially between ERGEG regions. Examination of the behaviour of individual firms showed that mean firm size increased, while the number of competitors declined. Further, the large discrete changes in firms size that were observed pointed towards the possibility that mergers were important.

6.3 Mergers and the size distribution of firms at the aggregate EU level

The purpose of this chapter was to examine in detail the rise in aggregate concentration identified in the matrix chapter, and in particular, the increase in size of the very largest 39 firms which owned over 80% of total installed capacity in their countries of origin. It was shown that the mean size of firms operating in 2007 was 38% greater than the mean size of those operating in 1998, and using a transition matrix approach, it was shown that firms moved up the size classes. 20% of firms active in 1998 exited the sector, and all were acquired by other sample firms.

The relationship between firm size and firm growth was explored in a stochastic growth model derived from statistical theory, the law of proportionate effect (LPE). This kind of model exposes the links between firm size and growth and aggregate concentration, so was particularly apposite given the objectives of the study. Assuming that firm growth follows a random walk, on average firms grow proportionately to their size and the dispersion of size increases as a result of random influences. Then concentration increases purely as a function of properties of the distribution. Our results show that the LPE held for firms that were active throughout the period, i.e. firms grew roughly in proportion to their size. Therefore some of the increase in concentration was caused by the properties of the distribution.

However, the temporal path of the HHI was jagged, and statistical analysis showed that there were large, discrete changes in firm size, which suggested that mergers may be important. The effect of mergers on firm growth was estimated using a counterfactual technique and for firms operational throughout the period, it was shown that the majority of growth was accounted for by merger activity. Mergers therefore played an important role in the observed increase in aggregate concentration.

The main messages of this chapter are that mergers drove almost all the increase in firm size and reduced the number of large firms, which lead to an increase in aggregate concentration. It was shown that mobility among the very largest firms was very low, and that the same firms occupied the top 5 slots in a ranking of firm size. Taken together, these findings have implications for competition policy.

Newbery (2007) argues that proposed horizontal mergers in electricity should be evaluated with respect to both the likely market power effects, and the possible effect on the structure of sector in the future. This study is set in the context of the hypothetical single market, and has shown that the trend in aggregate concentration has been rising and that mergers exerted an important influence on the trend. Our results therefore support Newbery's argument and emphasize the need for vigilant enforcement of existing competition law, and for the explicit evaluation of the potential dynamic effects of merger on future sectoral structure. The high degree of politicization in the sector only serves to reinforce these conclusions.

6.4 Firm multinationality

The focus of this chapter was the detailed analysis of one particular element of firm strategy, firm multinationality. Two separate questions were addressed: is the firm multinational? if so, how multinational are they? There are clear links between firm size and multinationality; firms are large because they have a large share of capacity in a large home member state, or because they own assets in other member states, or both. Aggregate firm size was decomposed in geographical space into its three dimensions: typical share of country capacity they own, typical size of country in which they operate, and the extent of multinationality. The use of this analytical device enabled us to conduct a more refined analysis than would have been possible otherwise. Two theoretical reasons for firms to 'go multinational' were considered; the specific-asset theory (Caves, 2007) and the market power theory (Hymer, 1960) of which multi-market contact is a variant (Bernheim and Whinston, 1990).

On the initial decision to hold assets in another member state, we found that both the typical size of the member state in which the firm operates and the typical share of capacity owned by the firm had a positive influence on the multinational decision, and that the typical share effect was dominated by the typical country size effect. As suggested by specific-assets theories of the MNE, a general ability to organize operations across markets is important. For example, a firm based in Germany, which has a relatively fragmented market structure, may be forced develop this ability in order to operate successfully at home, which puts them at an advantage relative to a monopolist when it comes to international expansion. However this reasoning also suggests that multimarket contact, which facilitates the maintenance of collusive outcomes, may be a part of the story.

High levels of multinationality are negatively correlated with both typical country share and typical country size; firms operating in large countries are less likely to be highly multinational than those operating in small countries, and monopolists are typically not multinational. A multimarket contact story again emerges - firms operating in large countries are in regular contact with rivals, so theoretically may have an enhanced ability to sustain collusive behaviour without having to resort to intensive multinationality.

Finally, we found that the multinational strategies adopted by generators have changed since market liberalization. This observation may be explained by the profit maximizing theory of the firm, whereby the most efficient firms prosper at the expense of their less efficient competitors. Assuming cost savings are passed on to consumers, this would enhance social welfare. On the other hand, the altered the structure of the market may lead to the increased likelihood of collusive behaviour in the future.

6.5 Inter-firm and intra-firm diffusion of clean generation technologies: the case of wind.

Tomorrow's capital stock is the product of decisions made in earlier periods, and this final substantive chapter concerns a specific element of firm strategy, the decision to invest in a particular clean generation technology, wind turbine generators (WTG). Our understanding of diffusion processes is poor, and in particular our knowledge of the ways in which new technologies diffuse within firms is very limited. This is at the very least unfortunate given the pressing need to avert dangerous climate change (Stern et al., 2006).

Patterns of inter-firm and inter-firm diffusion were evaluated, and the analysis revealed that in 2008 approximately 70% of firms had adopted the technology, though the mean level of intra-firm diffusion was only 5.4%. This disparity is an important finding because our understanding of the diffusion of low carbon technologies is as yet poor, and here we have shown that the diffusion within the firm is a key barrier to more intense use. This result is supported by the fact that only 11% of firms were found to have more than 20% of WTG in their capacity mix.

An encompassing model of inter-firm and intra-firm diffusion was estimated using a Heckman two-step econometric procedure. Results showed that the first adoption and intensification decisions were not independent, herefore policy interventions intended to speed up inter-firm diffusion can be expected to have a positive effect on intra-firm diffusion. Multinationals and firms which were using another renewable generation technology were found to be more likely to have adopted WTG by 2008, and a high WTG share in 2008 was associated with small firms and with those originating in a member state where the structure was not monopoly. On the basis of these findings, it was argued that intra-firm learning is a critical driver of the diffusion process, and policy interventions should focus on improving the ability of firms to use information effectively.

6.6 Conclusion

Given the importance of electricity supply to well functioning modern economies, it is unsurprising that the sector has been subjected to considerable attention by the EC. Furthermore, the reliance on fossil fuel technologies means that the sector is responsible for approximately one third of total EU GHG emissions. The Directorate General for Energy is of the view that "Energy is what makes Europe tick"[1], and together with the Directorate General for Competition, have driven a far-reaching liberalization agenda intended to reduce concentration by introducing competition into the generation sector. For all these reasons, energy policy is at the heart of the EU project, indeed a leading analyst has declared it to be "a litmus test for the usefulness of the European Union as an institution" (Roller et al., 2007).

The analysis conducted in the course of this research project does not suggest sectoral reform to have been a resounding success, but rather presents

[1]Source: DG Energy website homepage, accessed 12/09/2010

a mixed picture. Leading generators have responded to liberalization by pursuing growth strategies that have altered the structure of the sector significantly. Firm strategies have lead to a sector which has fewer, larger players which are increasingly multinational. These changes may have enhanced welfare relative to the status quo if it is the most efficient firms that have prospered and if cost savings have been passed on to consumers. On the other hand, given the objective of the liberalization programme to introduce competition though increasing the number of players, observed firm behaviour has undermined this objective, and may have increased the likelihood of tacit collusion in the future. The penetration of WTG is less than 4%, although multinationality is strongly associated with intense use of WTG, which suggests that firm response to liberalization has had a positive effect on technology transfer across borders. While WTG is only one RES technology, it is nevertheless the most widespread low carbon generation technology (other than hydro) so penetration is higher for WTG than other RES. Taken together, installed capacity of RES technologies is far below the level required if the EU is to meet its commitments under the Kyoto Protocol.

This study has for the first time generated a comprehensive picture of the structure and evolution of the hypothetical single market for power generation across the EU, and has identified key strategies adopted by the leading generators in response to the liberalization agenda pursued by the EC. On the basis of this research, it is not possible to form a judgement on the likelihood of the successful formation of a single market in electricity. Such a judgement would need to be informed by studies of the performance of the leading firms that have been identified and explored in the course of this research. However, the knowledge and understanding embodied in the thesis is fundamental to a fuller understanding of an industrial sector that is of critical importance to the continued prosperity of the citizens of the EU. Furthermore it suggests a potential analytical framework for analysis of other sectors which share similar characteristics, and for which the ultimate goal is also a single market, for example telecoms and water.

6.7 Limitations and future research

The dynamic nature of the research process means that results generated in any given study motivate questions that cannot be immediately addressed, perhaps in the interests of retaining focus, or due to resource constraints. The implication is that most academic research carries limitations, but at the same time forms the basis for an ongoing research agenda. This thesis is no exception. The limitations of each chapter were discussed as the thesis progressed, but in this final section, those that present the most promising avenues for future research are discussed.

In chapter 3 it was shown that mergers drove almost all the observed growth in firm size and the reduction in firm numbers, and the results indicated the possibility of the formation of strategic groups. However, pursuing questions such as how the composition of the groups changed over the sample period, and exploring for example, the barriers to jumping from one group to another, was outside the scope of the chapter both because the main focus of the chapter was to explore firm growth and to evaluate the role of mergers, and as a result of resource constraints.

The data contained in the market share matrix is sufficiently rich to support a more detailed analysis of the sample firms than has already been achieved. Strategic groups may be explored using cluster analysis, which is the analysis of groups of observations, where the groups reflect their similarities over several variables. Cluster methods are frequently used as to explore data and are capable of developing robust typologies which can then form the basis of further more sophisticated empirical analysis.

The kernel density plot of the size distribution of firms presented in figure 3.2 was intriguing, and as noted, suggested the possibility that a dual structure may be emerging in the industry, with a subset of very large firms breaking away from the rest. This hypothesis could be tested in a stochastic framework as advocated by Simon and Bonini (1958).

It was shown in chapters 2 and 3 that aggregate concentration within the hypothetical single market had risen unambiguously over the period. While preliminary analysis in chapter 2 showed that there was considerable variation in concentration at the regional level, no attempt has been made to estimate the importance to EU concentration, of concentration at the national level. Clarke and Davies (1983) showed that aggregate concentration (e.g. at the EU level) may be decomposed into the weighted average of national concentration and multinationality. It would be interesting to explore further the identified rise in EU concentration and the relative contributions of both factors, based on this accounting identity, which is similar to that employed in chapter 4.

There are many ways in which chapter 5 may be extended, but three in particular deserve serious consideration. First, in common with the majority of other studies of diffusion, the model was estimated on cross sectional data. Given the dynamic nature of the diffusion process, this is clearly sub-optimal and so the most obvious next step is to collect data to form a panel. Second, the research showed that disaggregating the overall level of diffusion of a new technology revealed very substantial differences between inter-firm (70%) and mean intra-firm diffusion (5%). This is a new finding which has implications for policy formation, notably that both components of technology diffusion respond to different policy initiatives. The dissagregated approach therefore appears to be a step forward in improving our currently poor level of understanding of the diffusion process, and may be particularly valuable where there is substantial public support for new technologies, for example renewable energy or energy saving technologies.

The third avenue for research in this area is methodological. The empirical modelling of intra-firm diffusion is in its infancy, and while the the Heckman two-step procedure implemented in this study has revealed new insights, there remain many methodological challenges. In particular, while the nature of the supplying industry is clearly an important influence on the process of a technological diffusion, it has so far proved very difficult to introduce supply side factors into current models of diffusion. However, we have started work on a study in which we hope to map the supply side into diffusion models through the use of patent data.

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