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Fuel Poverty: Potentially Inconsistent Indicators and Where Next?

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Abstract: The measurement of fuel poverty is critical for judgements about the significance of the problem and the design of policies to address it. Reducing fuel poverty has been a government objective in the UK for many years, and is generally seen through the lens of the government's official fuel poverty statistics . We compare the households identified as fuel poor according to three metrics: (i) the 10% indicator; (ii) the Low Income High Consumption indicator; and (iii) whether households self-report an inability to afford to keep their home warm, using data from the British Household Panel Survey. We find substantial differences in the households identified according to each of these indicators; this highlights a lack of clarity about which households might be considered truly fuel poor. In particular, a surprisingly low proportion of those identified by the 10% and LIHC indicators report an inability to afford to keep their home warm. While this could raise concerns that current fuel poverty policies in the UK are misdirected, instead we emphasise the difficulties of drawing policy conclusions from the differences between the indicators, unless it can be combined with information on households' heating preferences and the in-home temperatures achieved.

1. Introduction

Fuel poverty (FP[3]) alleviation is a well-established policy objective, with the UK government producing annual statistics and the European Commission having established the European Energy Poverty Observatory[4]. The challenges of identifying households in FP and debates about different statistical definitions of FP are also well established. The current paper uses the British Household Panel Survey (BHPS) to compare expenditure-based and perception-based FP indicators[5] for around 10,000 households over a period of eight years. The analysis confirms a limited overlap between the two types of indicator and shows that each indicator identifies different types of households as fuel poor. Rather than arguing that one indicator is 'better' than others, the results are taken as illustrating a lack of precision regarding the measurement of the real-world problems faced by households that form the heart of FP. We argue that, if the core issue is identifying those living in the cold, records of household temperatures and temperature preferences need to be gathered on a large scale to supplement and reduce the uncertainties presented by existing statistics.

The paper builds on Waddams Price et al. (2012), but uses a much larger, richer and nationally representative multi-year dataset. The main indicators considered are: (i) reporting energy expenditures (ENEX) exceeding 10% of income; (ii) the Low Income-High Cost (LIHC) indicator; and (iii) reporting an inability to afford adequate warmth (IAAW). Indicators (i) and (ii) represent the two

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[2] Text has been revised to clarify the definition of household income used when generating the expenditure-based fuel poverty papers.

[3] The abbreviation FP is also used for 'fuel poor' in this paper.

[4] We make no distinction between energy and fuel poverty, but use the latter for consistency.

[5] We use the terms perception-based and expenditure-based to avoid terms that could be (mis-)interpreted as implying a judgement about the indicators' legitimacy. These correspond to the terms of 'subjective' or 'consensual' and 'objective' used elsewhere.

official indicators that have been used by government to assess FP in England[6], albeit with reported ENEX replacing 'required' (modelled[7]) ENEX and gross income (inclusive of benefits) replacing income net of taxes; while indicator (iii) provides an intuitive self-assessment of living in a cold home. The lack of overlap between these indicators is striking: no more than 6% of those identified as FP by the expenditure-based indicators report IAAW. Similarly, no more than 45% of those reporting IAAW were identified as FP according to the LIHC indicator[8]. This lack of overlap raises significant questions about the phenomena identified by the expenditure-based indicators. As discussed by Deller and Waddams Price (2018), a high energy expenditure share (ENEXShr) may indicate a low income rather than a specific energy issue.

Beyond descriptive statistics, pooled cross-section logit regressions identify the household characteristics associated with being classified as FP according to each of the indicators. First, this shows that any association between a households' ENEX and reporting IAAW exists only after controlling for household income level.

Second, and crucially for policy, older households are no more or less likely to be associated with FP according to the 10% indicator; they show a higher probability of being FP according to the LIHC indicator, but are less likely to report IAAW. Similarly, while a lack of central heating is positively associated with reporting IAAW, it shows no association with the expenditure-based metrics once a comprehensive range of other variables are controlled for. These differences highlight that the indicator chosen to represent FP not only affects the apparent prevalence of FP, but also the type of households which are targeted for policy support.

However, we recommend caution before concluding one indicator is 'better' than others: in particular, that the expenditure-based metrics significantly overstate the prevalence of households struggling to afford warmth; or concluding that the indicators pick up different aspects of FP. We urge caution because drawing these conclusions relies on additional assumptions. For example, older households may be less likely to report IAAW, not because they live in 'warm' homes, but because they define lower temperatures as adequate or feel less comfortable admitting 'problems' with their living conditions.

While using modelled ENEX, rather than reported ENEX, overcomes some of the above uncertainties by using a fixed target temperature, new issues arise in terms of householders' temperature preferences being ignored and results depending on the accuracy of the models estimating ENEX.[9]

These issues highlight the need for temperature measurements from within homes and temperature preference information from householders to be combined with survey data producing the FP indicators, in order to advance the empirical understanding of FP, and explain why different FP indicators present diverse pictures. Concern about cold homes was a key early motivation for the term FP[10] and has been associated with adverse health effects (for example, see Liddell and Morris, 2010), yet, as Hills (2012) notes, efforts to measure in-home temperatures in the UK since the mid-1990s have been limited. Temperature measurement is important to ensure that the significant resources associated with FP alleviation are allocated to maximise the benefits to householders in

[6] The UK government is consulting on changing the English FP definition to a 'Low Income Low Energy Efficiency' metric where being identified as FP is linked directly to the energy efficiency rating of a home. See BEIS (2019).

[7] The term modelled ENEX is used as a more accurate and neutral description of this form of data.

[8] The equivalent figure for the 10% indicator was 30%.

[9] For example, see Deller and Waddams Price (2017) and Summerfield et al. (2019).

[10] For example, the title of Boardman (1991) is 'Fuel Poverty: from cold homes to affordable warmth'.

most need. While the desirability of temperature measurements has long been recognised, it has been traditionally viewed as too difficult to obtain the required data on the necessary scale. The roll out of smart thermostats and other temperature recording devices, offer an important new route to obtain the desired data.

As this study utilises panel data, we also present descriptive statistics on the persistence of FP in Appendix 2. While not the paper's main focus, these statistics reinforce the evidence for a further policy point: even if persistence is identified econometrically, the magnitude of this persistence is important. While the first lag of the FP indicators is always significant in our main regressions, the magnitude of the persistence appears to be limited. For example, in all but one year, more than 50% of households identified as 10% or IAAW FP in period t were no longer identified as FP in period t+1. This compares to an exit probability from income poverty of no more than 35%. Moreover, of those reporting IAAW at least once in the eight years studied, around 60% reported being unable to afford warmth only once.

These findings are important for identifying the most cost-effective means to tackle FP.[11] Much attention has been given to using energy efficiency retrofits to tackle FP; however, if FP is mainly a short-term phenomenon, temporary interventions, such as income transfers, may be more appropriate.[12] For FP alleviation, energy efficiency investments become preferred to income transfers when the one-off cost of an energy efficiency upgrade is lower than the present value of providing an ongoing income transfer sufficient to allow the householder to achieve the same level of warmth.[13]

The paper proceeds as follows: Section 2 reviews the existing literature; Section 3 describes the data; Section 4 outlines the methodology; Section 5 provides descriptive statistics, before Section 6 reports the main regression results and Section 7 provides policy conclusions. Results relating to a lack of adequate heating facilities are reported in Appendix 1.

2. Existing Literature

The originality of the present study results from the richness of the BHPS dataset. This richness constitutes: (i) the number of FP indicators considered, (ii) data coming from multiple years, (iii) the comprehensive range of explanatory variables, and (iv) the large sample size. This breadth enables a more comprehensive and detailed assessment of how perception and expenditure-based FP indicators overlap, allowing nuances to be explored. Since data are collected over time, including periods when energy prices experienced notable fluctuations, we can confirm that the lack of overlap between the two types of FP indicators is a consistent feature, rather than an observation driven by temporary factors.

The main previous study considering the overlap of FP indicators in the UK is Waddams Price et al (2012). Waddams Price et al. consider a sample from 2000 which, unlike the present paper, deliberately over-represented low income and pre-payment meter users. Given this focus, it is unsurprising that the discrepancies between 10% FP and feeling unable to afford energy identified in Waddams Price et al. are somewhat smaller than in the present paper: 25.6% of the 10% FP felt

[11] By focusing on the most cost-effective tools, more households can be moved out of FP for a given quantity of resources.

[12] A similar point is made by Chaton and Lacroix (2018) and hinted at by Roberts et al. (2015).

[13] Energy efficiency retrofits can also lead to beneficial carbon emission reductions, but this is a separate objective to FP reduction.

unable to afford energy, while 44.1% of those feeling unable to afford energy were in 10% FP[14]. The present paper's main regressions involve around four times as many households as in Waddams Price et al. (2012) and over 20 times more observations, enabling increased confidence around the variables found to be statistically insignificant.

BEIS (2020) and DECC (2009) report descriptive statistics for England, which again show a limited overlap between FP measures. Using data from the English Housing Survey, BEIS (2020) finds that only 15.9% of LIHC FP households felt unable to keep their home comfortably warm, while only 19.3% of households who felt unable to keep their home comfortably warm were LIHC FP. Also, mirroring the results in this paper, only 46.7% of those reporting an inability to keep comfortably warm put the issue down to cost, with 47.0% viewing it as not possible to reach a comfortable heating level.[15] DECC (2009)'s findings of limited overlap again broadly mirror the results presented here, using similar data.

Beyond the UK, expenditure- and perception-based FP are compared in Spain by Phimister et al. (2015), in Greece by Papada and Kaliampakos (2016) and Ntaintasis et al. (2019), in Belgium by Meyer et al. (2018), in the US by Agbim et al. (2020), in France by Fizaine and Kahouli (2019) and in the Republic of Ireland by Scott et al. (2008). Direct comparison of the results is difficult due to the variations in the precise definitions of the expenditure-based indicators and different wording of the perception-based indicators, although all studies find a consistent lack of overlap between the two types of indicator.

The present paper improves on Phimister et al. (2015), Papada and Kaliampakos (2016), Meyer et al. (2018) and Ntaintasis et al. (2019) by including multivariate logit regressions identifying household characteristics associated with each type of FP. Scott et al. (2008) run logit regressions to identify factors associated with the 10% FP and a composite perception-based indicator, but their data depends on separate Irish surveys. Our analysis has the advantage that different FP indicators are available for the same households, hence the present analysis avoids the risk that differences in relationships across indicators result from differences in sampling, variable definitions and/or households' unobservable characteristics. Nevertheless, matching our results, Scott et al. find that a household head being over 65 is unrelated to the 10% FP and negatively associated with reporting heat affordability difficulties.

It is difficult to provide direct comparisons with the regression results in Agbim et al. (2020) and Fizaine and Kahouli (2019) because they use alternative FP definitions. Agbim et al. analyse Texan data and identify household spending above 8% of income on electricity (roughly twice the local median) as "objectively energy burdened", while also considering whether (i) households had difficulty paying their electricity bill, and (ii) their electricity bill was causing them stress or mental discomfort. The authors report that 34% of households reported (i), compared to 23% identified as objectively energy burdened. Thus, in contrast to the present study, the perception-based indicator gave a higher FP rate than the expenditure-based indicator.

Like the present paper, Fizaine and Kahouli (2019) show that different FP indicators are associated with different types of households. However, rather than directly identifying the household characteristics associated with each FP indicator, they first perform cluster analysis to identify profiles of households falling within each type of FP. Their analysis applies to only a single year, 2013. The precise definitions of FP in Fizaine and Kahouli follow those of the French Energy Poverty

[14] The greater overlap in Waddams Price et al. may result both from the focus on low income households and the 10% indicator relying on income data taken as the mid-point of bands.

[15] Households were able to report both reasons simultaneously.

Observatory (OPNE), in particular a restriction is applied to the perception-based indicator so that only households in the bottom three deciles of the income distribution are identified as experiencing thermal discomfort.

Looking across Europe, Healy and Clinch (2002) and Thomson and Snell (2013) use regressions to analyse the household characteristics associated with perception-based and/or proxy indicators of FP. Both studies include an 'inability to afford adequate heat' indicator and Healy and Clinch (2002) also consider a 'lack of adequate heating facilities' indicator. Healy and Clinch (2002) report evidence, consistent with the current paper, that younger households are more likely to report an inability to achieve adequate warmth.

These papers are also part of a longer debate about how to define and measure FP. Figure 1 of Deller (2018) provides an overview of how energy affordability (FP) measures can be split between: (i) ENEX indicators, (ii) self-reports of the lived experience, and (iii) proxy indicators. While Deller (2018) and Tirado Herrero (2017) caution against focusing excessively on a single FP metric/definition, Thomson et al. (2016) highlight the appeal of headline statistics to galvanise political action; while Thomson et al. (2017) and Tirado Herrero (2017) provide overviews of alternative FP measurement approaches in the European context.[16]

This broader debate has been influenced by changing official expenditure-based FP metrics in the UK, and the need to utilise perception-based metrics for pan-EU assessments of FP. In terms of expenditure-based metrics, the decision to change the English FP metric from a 10% to LIHC definition was driven by Hills (2012) and received comment from Moore (2012) and Liddell et al (2012).[17] Focussing on Germany, Heindl (2015) reviews different expenditure-based metrics and how their prevalence varies across households with different structures[18], while Heindl and Schuessler (2015) provides a more theoretical assessment of these metrics' statistical properties.

Assessing FP in the UK sits within a larger literature mapping variations in ENEX across households and identifying the determinants of these variations. Papers using data from the Living Costs and Food Survey and its precursors include Baker et al. (1989), Baker and Blundell (1991), Crawford et al. (1993), Advani et al. (2013) and Deller and Waddams Price (2018). Meier and Rehdanz (2010) and Meier et al. (2013) use BHPS data to investigate ENEX, while Longhi (2014) utilises the more recent Understanding Society dataset. The present study differs from these papers by focussing specifically on binary FP indicators, a deliberately narrower frame to focus on the FP indicators chosen by UK policymakers when assessing energy affordability issues.

As a secondary aim, the present paper uses the panel nature of the BHPS to provide descriptive statistics regarding FP persistence. The literature relating to FP dynamics is discussed in Appendix 2.3. Other FP studies utilising panel data to address different questions include: Awaworyi Churchill and Smyth (2020) who consider ethnicity as a determinant of FP in Australia; Awaworyi Churchill et al. (2020) who assess the impact of FP on overall life satisfaction in Australia; Bohr and McCreery (2020) who consider the impact of being FP on the dynamics of wider economic poverty in the US; Charlier and Kahouli (2019) who assess how income mediates responses to energy price fluctuations and find that the FP have a high demand elasticity; and Llorca et al. (2020) who consider the link between FP and self-reported health in Spain.

[16] See also Trinomics (2016).

[17] The UK government recently consulted on amending the official FP definition in England again, see BEIS (2019).

[18] Specifically, single person households, couples with children, lone parents, couples with children and other households.

3. Data

We use data from the British Household Panel Survey (BHPS)[19] from 2001-02 to 2008-09, providing 55,772 observations from 10,465 households in an unbalanced panel. The BHPS is used for three reasons: (a) the ability to compare perception- and expenditure-based FP indicators; (b) the re-interview of households in multiple time periods; and (c) the richness of household information. The more recent Understanding Society[20] dataset is not used as it does not contain a question specifically asking whether warmth was affordable.[21]

The BHPS is an annual survey administered between 1991 and 2009. The first survey wave aimed to be nationally representative of private households in Great Britain (GB) and sampled 5,500 households. To allow analysis of the devolved administrations, in 1999 two 'booster' samples of 1,500 households were added, covering Scotland and Wales respectively, while in 2001 a booster of 2,000 households was added covering Northern Ireland. In addition to households in the initial samples, households that evolved from the initial set of households[22] were also interviewed where possible. Our analysis begins in 2001-02 to coincide with the introduction of the Northern Ireland booster sample. Excluding the GB-only data prior to 2001-02 simplifies the interpretation of the results, especially regarding time trends and geographic identifiers.

Inclusion of the booster samples overrepresents households from the devolved administrations and increases the proportion of self-reports of FP/heat affordability difficulties, which are relatively rare in the sample as a whole. Households in the devolved administrations are likely to be at greater risk of FP due to lower average incomes, a less extensive gas grid and cooler temperatures than in England. We incorporate these booster samples in our study because we aim to understand the household characteristics associated with FP rather than to provide population estimates of the prevalence of FP.

To be included in the analysed sample a household must provide complete data for all the explanatory and control variables listed below in at least one survey wave. Households where annual ENEX as a proportion of annual household income was zero or exceeded 100% were dropped, due to the high probability of measurement error.[23]

The analysis considers two expenditure-based FP indicators and three perception-based indicators. The two expenditure-based indicators are:

1. 10% ENEXShr

2. Low Income – High Cost (LIHC) metric

while the three perception-based indicators are:

3. Inability to afford to keep home adequately warm (IAAW)

4. Inability to keep home adequately warm

5. Lack of adequate heating facilities

[19] See https://www.iser.essex.ac.uk/bhps/
[20] See https://www.understandingsociety.ac.uk/
[21] The closest question is: "In winter, are you able to keep this accommodation warm enough?", see: https://www.understandingsociety.ac.uk/documentation/mainstage/dataset-documentation/wave/1/datafile/a_hhresp/variable/a_hheat
[22] For example, when an adult child moved out or a relationship broke up.
[23] This also means households whose ENEX is included in their rent are dropped.

Our main regression results relate to indicators 1 to 3, while the results for indicator 5 are presented in Appendix 1. For the detailed definition of indicators 1 and 2, together with the relevant survey questions, see Appendix 3. The question for indicator 3 was structured so that the relevant affordability question was asked only of households that first reported an inability to keep their home adequately warm, which may influence why few households report unaffordable warmth.

Two key differences between indicators 1 and 2 and official FP statistics in England are that: (i) the official indicators use 'required' (or modelled) ENEX rather than reported ENEX, and (ii) the official indicators use income net of taxation rather than gross income (inclusive of benefits)[24]. Modelled ENEX represents the ENEX needed to achieve a given temperature (21°C in the primary living area) according to an engineering model. The BHPS does not include modelled ENEX as a variable, while the English Housing Survey's FP dataset does not include the necessary perception-based FP indicators.[25] Hence the current study compares reported ENEX FP indicators with perception-based indicators.

The FP literature[26] has suggested that modelled ENEX is preferable to reported ENEX because the latter is likely to under-record FP, as the poorest households may 'restrict' their ENEX due to affordability constraints. However, Deller and Waddams Price (2017) indicate[27] it is simplistic to assume that reported ENEX always under-records FP. They find that the relationship between FP rates calculated using reported and modelled ENEX is complex: for some groups and time periods FP rates based on reported ENEX appear higher. Furthermore FP statistics based on modelled ENEX can only be as good as the underlying ENEX model, for example, Summerfield et al. (2019) notes systematic discrepancies between the actual gas consumption of larger older dwelling in the UK and that predicted by standard models. Summerfield et al. suggest a range of possible explanations for this discrepancy, including householders' heating patterns differing to those in other dwellings, the thermal properties of solid walls being different than expected and the potential use of fuels other than gas or electricity for heating.

A potential issue with the current data is seasonality due to the variability in external temperatures and internal heating needs. This may be particularly significant for perception-based indicators, if responses are influenced by household experiences immediately before interview.[28] To deal with seasonality, interview month dummies are included in the main regressions.

A further known issue with the BHPS ENEX data, which may affect the results regarding persistence in Appendix 2, is the potential for the data to be bunched at 'round' amounts, e.g. multiples of £25. Pudney (2008) notes this can mean over reporting of the year-to-year changes in ENEX as households move between different rounding points. While this might contribute to the limited persistence of ENEX-based FP, it does not explain the limited persistence of perception-based FP.

The explanatory variables in the main regressions are split into two groups: (i) Policymaking variables, and (ii) Best Predictor variables. The 'Policymaking' variables include the main demographic, socio-economic and housing indicators that are available to policymakers to co-ordinate/target large scale policies. The Best Predictor variables include factors, such as housing

[24] Gross income is used as it is an official variable in the BHPS, whereas only an 'unofficial' net income variable can be obtained.
[25] See the variable list in BEIS (2017).
[26] See Hills (2012), Liddell et al. (2012) and Thomson et al (2017).
[27] See Section 7 and Appendix 2.
[28] While reported ENEX involves an annual figure, seasonality could affect it, if households receive multiple bills a year and base their annual estimate on their most recent payment/bill.

condition indicators, which are less likely to be available for all households. Also, many of the Best Predictor variables refer to different aspects of poverty, hence, while highly correlated with FP they may provide limited additional insight for understanding FP beyond confirming that a 'poor' household is likely to suffer deprivation across several dimensions.

The Policymaking variables are: UK nation (devolved administration), dwelling ownership, dwelling type, whether dwelling has central heating, whether dwelling has a gas connection, whether the household head is aged under 65, 65-75 or over 75[29], whether the household head is unemployed, whether the household receives income from investments, whether incapacity benefit or housing benefit or income support is received by the household (3 variables), whether the household head is a single parent, whether the household contains children, the number of household members and the number of cars owned.

The Best Predictor variables are: number of rooms in dwelling[30], whether a household has problems with loan repayments or housing payments (2 variables), whether a household states it cannot afford a holiday or to replace furniture or new clothes or to eat meat on alternate days or to invite visitors for food/drink (5 variables)[31], whether a household has a satellite dish or cable TV or colour TV or VCR or freezer or washing machine or tumble dryer or dishwasher or microwave or CD player or home computer (11 variables), whether a household states its dwelling suffers from condensation or a leaky roof or damp walls/floors or rot in windows/floors (4 variables) and whether a household states there is crime in the local area.

In some regressions, perception-based FP indicators are also related to additional explanatory variables, namely gross annual household income, annual reported ENEX and annual net housing costs.[32] All monetary amounts are converted to 2008 prices using the Consumer Price Index. As a control, survey wave dummies are included in all regressions.

4. Methodology

To identify the household characteristics associated with each FP indicator logit models are used. The dependent variable, y_{it}, takes a value of 1 when household *i* is FP in period *t* and a value of 0 when a household is not FP. For each household the probability, p_{it}, of being FP in period *t* can be expressed as:

$$y_{it} = \begin{cases} 1 & with\ probability \quad p_{it} \\ 0 & with\ probability \quad 1 - p_{it} \end{cases}$$

where the probability of being FP, p_{it}, is modelled as:

$$p_{it} = Prob(y_{it} = 1 | \boldsymbol{x_{it}}) = F(\boldsymbol{x_{it}}' \boldsymbol{\gamma})$$

[29] To ease interpretation we did not include a separate variable for retirement status. As such, the effect of the age variable will also be capturing the fact that most of these older household heads will also be retired.

[30] The BHPS's number of rooms excludes kitchens, bathrooms and any rooms let to individuals who are not a household member.

[31] Prior to a household reporting an inability to afford an item they had expressed their desire to consume the item.

[32] Housing costs less any housing benefit received. If a dwelling is owned outright or rent free, net housing costs are zero.

Here p_{it} is the probability that household *i* is FP in period *t* given the vector of potentially time varying explanatory variables for household *i*, $\boldsymbol{x_{it}}$. This probability can be expressed as a function of $\boldsymbol{x_{it}}$ multiplied by the regression coefficients, $\boldsymbol{\gamma}$. The logit model assumes the error process for the latent variable behind the model is logistically distributed and $F(.)$ is the logistic cumulative distribution function. The model is estimated using maximum likelihood estimation following a pooled cross-section approach. As the error terms for each household, *i*, are likely correlated through time, cluster robust standard errors are used where each household, *i*, is treated as a separate cluster.

Average marginal effects (AMEs) are reported, which are the average percentage point increase in the probability of a household being FP associated with a change in a particular explanatory variable. For each FP indicator a range of regression specifications is used to highlight points relevant to the policy discussion. For all the FP indicators, separate regressions were run using: (i) the Policymaking variables only, and (ii) the Policymaking plus Best Predictor variables. For policy discussions, the regressions only using the Policymaking variables are most relevant.

Since the 10% and LIHC indicators are calculated directly from household income, ENEX and (for the LIHC indicator) housing costs, these three variables are not included as explanatory variables in the regressions for the expenditure-based indicators. However, for the perception-based indicators, their relationship with ENEX, income and housing costs are of central importance. Hence, before the main regressions for indicators 3 and 5 are reported, additional regressions are run to assess how the perception-based indicators relate to the component parts of the expenditure-based FP indicators. For the perception-based indicators, two separate types of main regressions are run: (a) including ENEX, income and housing cost as explanatory variables; and (b) excluding these variables to enable a direct comparison of the socio-economic groups associated with FP across the perception- and expenditure-based indicators.

As a secondary question in the current paper is FP's persistence, the main regressions are also repeated including a one-period lag of the dependent variable as an explanatory variable. Alternatively, the lag can be interpreted as controlling for unobservable household characteristics associated with FP. When a lag is included, the sample is restricted to those households that additionally have data for the four analysed FP indicators in the previous survey wave.

5. Descriptive Statistics

5.1 The frequency of different fuel poverty indicators

Figure 1 presents the unweighted percentage of households reporting each FP indicator by year.

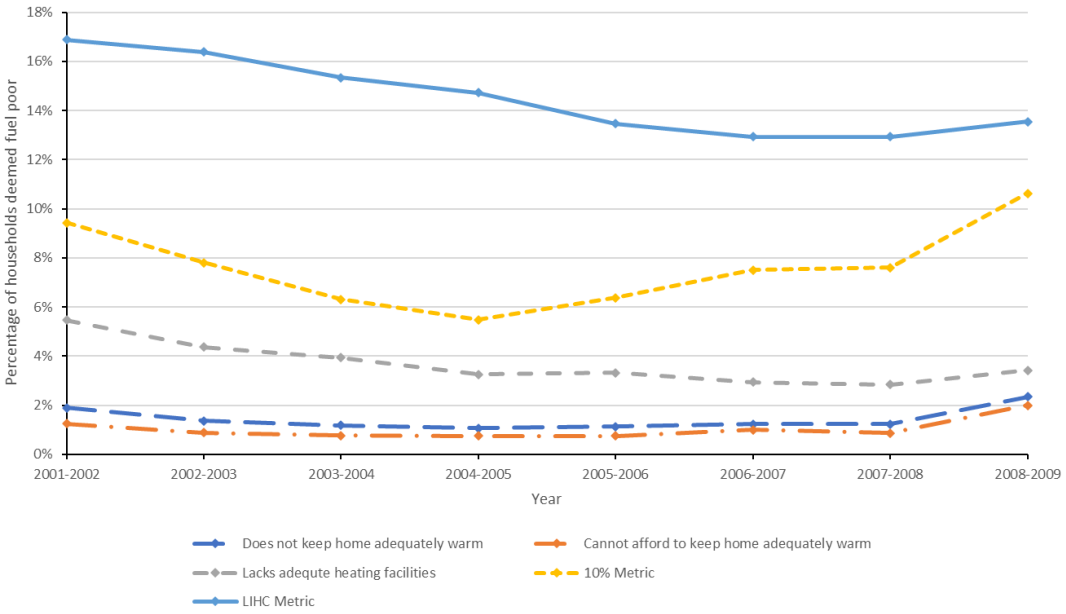

Figure 1 : Rates of alternative fuel poverty indicators in the analysed sample (unweighted), 2001-02 to 2008-09

Figure 1 shows a fundamental gap between the proportion of the households identified as IAAW FP and those identified as 10% or LIHC FP. The percentage of households reporting IAAW FP is 2% or below, while the percentage of FP households according to the 10% indicator is always above 5% and for the LIHC indicator is always above 13%.[33]

The dip in 10% FP around 2004-05 and its subsequent increase likely relate to the changing price of energy over the period.[34] In contrast, both the LIHC and lack of adequate heating facilities indicators show a general decline across the time period. Between 2001-02 and 2008-09 the percentage of households reporting a lack of adequate heating facilities fell by 2.0 percentage points and the rate of LIHC FP fell by 3.3 percentage points. The trend in LIHC FP may be linked to the oversampling of households in the devolved administrations where incomes of the sampled households grew faster. Between 2001-02 and 2008-09 the unweighted median gross household income in England rose in real terms by 10.6%, while in Wales it rose by 20.1%, in Scotland by 26.1% and in Northern Ireland by 23.9%

The last point to note regarding Figure 1 is the increase in 10% FP and the proportion of households reporting IAAW FP between 2007-08 and 2008-09. The percentage of households in 10% FP rose by 3.0 percentage points, while the percentage of households reporting IAAW more than doubled, rising by 1.2 percentage points. These increases coincide with a growth in ENEX that exceeded the growth in gross household incomes. Between 2007-08 and 2008-09 the median gross income of all households rose 1.8% in real terms, while median ENEX rose by 9.7% in real terms.

[33] Figure 8 in Appendix 4 repeats Figure 1 with weights applied to provide UK population estimates. Applying weights does not alter the finding that the rates of perception-based FP are much lower than expenditure-based FP.

[34] The time path of 10% FP broadly corresponds to that in Figure 15, Deller and Waddams Price (2017), based on data for England from the Living Costs and Food Survey.

5.2 The overlap between FP indicators

The very different FP rates in Figure 1 are associated with the limited overlap between the different FP indicators. Figure 2 illustrates the extent of overlap between the three perception-based FP indicators when data is pooled across the time period. Of all the observations[35] of households reporting either an inability to keep their home warm or a lack of adequate heating facilities, a clear majority, 68.5%, only report a lack of adequate heating facilities. Only 20.7% of those reporting a lack of adequate heating facilities reported an inability to keep adequately warm.

The majority of households who felt unable to keep their home adequately warm, 71.6%, were unable to do so because they felt it was unaffordable. Nevertheless, this implies that for almost a third of households who were unable to keep their home adequately warm, this was caused by something other than affordability. Of these, 53.5% reported a lack of adequate heating facilities.

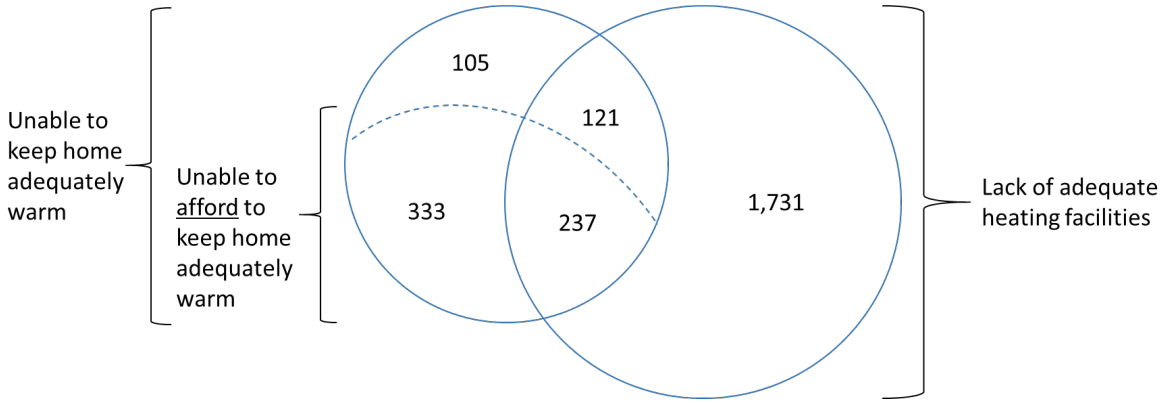

Figure 2: The overlap of the perception-based fuel poverty indicators, pooled data 2001-02 to 2008-09 (number of observations, areas not to scale)

Figure 3 shows the overlap between our main FP indicators of interest: reporting IAAW, the 10% metric and the LIHC metric. Figure 3 emphasises the limited overlap between the main FP indicators. Of all the observations where a household reported at least one of the FP indicators, in only 1.1% of cases were all three FP indicators reported simultaneously by a household. Figure 3 also shows the asymmetric overlap between the 10% and LIHC indicators. While 77.5% of observations that were 10% FP were also LIHC FP, only 40.4% of observations that were LIHC FP were 10% FP. More generally, Table 11 in Appendix 4 reports the Pearson correlation coefficients between the five FP indicators. All of the correlation coefficients are significantly different from zero at the 1% level, but the magnitudes of the correlation coefficients vary considerably. For example, the correlation coefficient between the 10% and LIHC indicators is 0.511, while the correlation coefficient between the 10% indicator and reporting IAAW is 0.059.

[35] An observation is a particular household in a particular year.

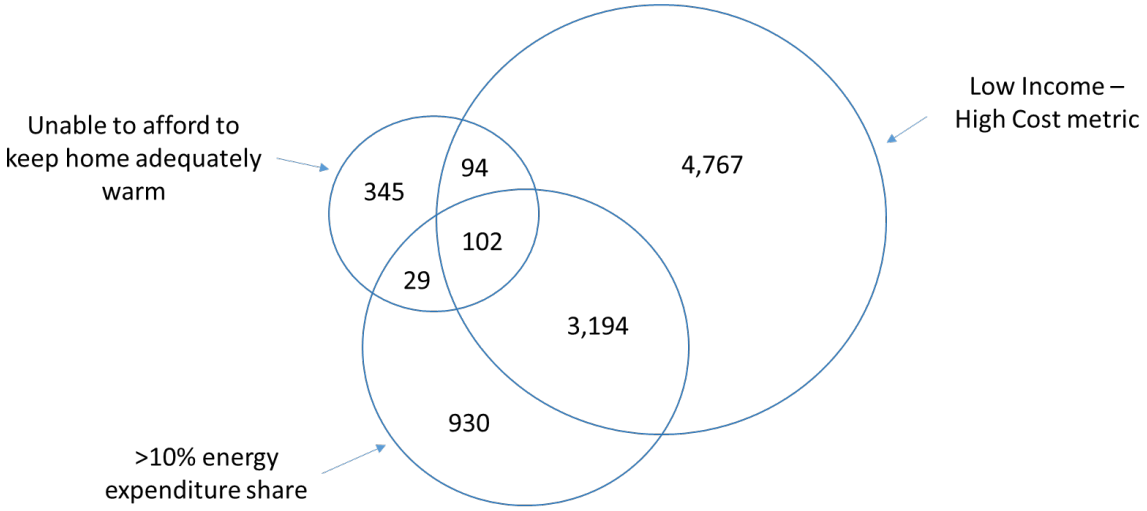

Figure 3: The overlap of the three analysed fuel poverty indicators, pooled data 2001-02 to 2008-09 (number of observations, areas not to scale)[36]

The panel nature of the BHPS confirms that the lack of overlap between 10% FP or LIHC FP and households reporting IAAW occurs in multiple time periods. Figure 4 shows that only a small proportion of households identified as 10% or LIHC FP in each survey wave also report IAAW. In none of the years studied does the proportion of 10% or LIHC FP households reporting IAAW exceed 5%. While the overlap remains low, Figure 4 shows an uptick in the overlap between 2007-2008 and 2008-2009.[37]

Despite the limited overlap, the rate of perception-based FP is higher among expenditure FP households than in the general sample. For example, across the time period, the percentage of 10% FP households reporting IAAW is 2.3-3.7 times the percentage in the general sample.[38]

Overall, Figure 3 and Figure 4 raise fundamental questions about the phenomena identified by the expenditure-based FP indicators, and whether they effectively identify households living in the cold. Palmer et al. (2008) also find a limited overlap between 10% FP, based on modelled ENEX, and being unable to afford warmth. Using data from the 2005 English Housing Condition Survey, they find that only 6% of those identified as 10% FP stated that their living room was not kept comfortably warm in winter and that the reason for this was cost.[39]

[36] Note that only the indicator 'Unable to afford to keep home adequately' is common to both Figures 2 and 3. In both Figures there were a total of 570 observations of this FP indicator being reported.
[37] The increase in the overlap with 'Lacks adequate heating facilities' begins a year earlier in 2006-2007
[38] The percentage of LIHC FP households reporting IAAW is 2.1-2.8 times the percentage in the general sample.
[39] See pg16. Also, Palmer et al. (2008) find that, of those households reporting that their living room was not kept comfortably warm in winter due to cost, only 20% were identified as 10% FP.

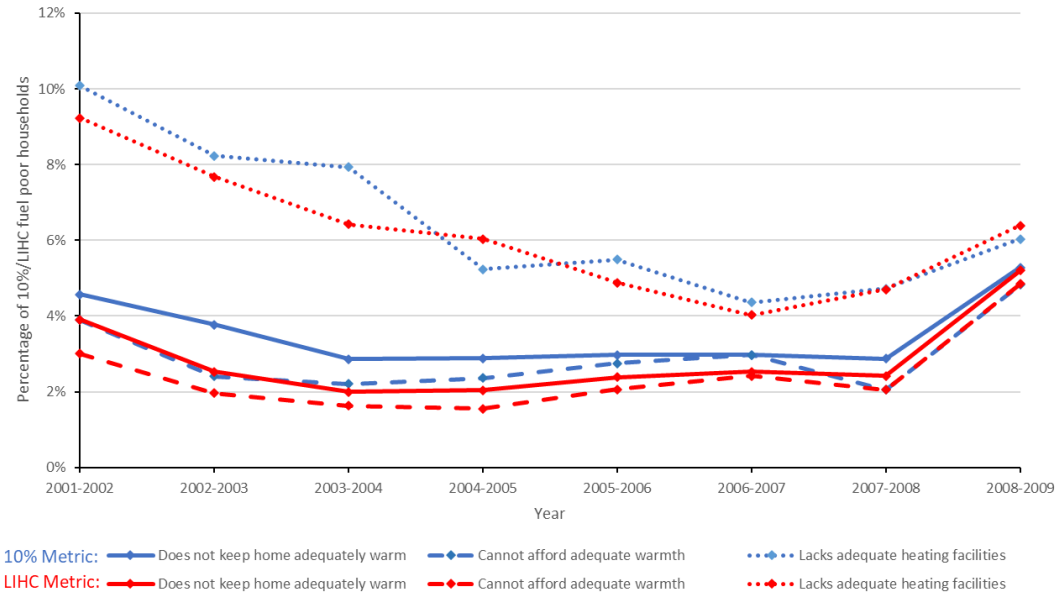

Figure 4: Percentage of 10%/LIHC fuel poor households reporting perception-based fuel poverty in the analysed sample, 2001-02 to 2008-09

Dubois (2012), Boardman (2011) and Tirado Herrero (2017) suggest that the low rates of perception-based FP compared to expenditure-based FP results from households being unable or unwilling to self-identify as FP. This suggests that there is a need to further investigate and understand the discrepancies between indicators to gain additional insights about FP. In particular, the discrepancies suggest that there are benefits from turning FP from a high-level intuitive or statistical concept into a set of observable circumstances/behaviours which are closer to household's experience and which can be robustly measured and addressed.

Beyond an unwillingness to self-identify, there are a range of possible explanations for the discrepancy between the expenditure- and perception-based FP indicators. For example, the thresholds of the expenditure-based FP metrics could be a poor reflection of the boundary where the majority of householders consider energy to become unaffordable. This is possible since the origins of the expenditure-based indicators did not explicitly consider householders' opinions of the level of income devoted to ENEX which might be considered unaffordable.[40] Alternatively, householders may view energy as a necessity and so choose to spend a high proportion of their income on energy to ensure adequate warmth. Here the main impact of high energy costs is restricting consumption of other goods. It is difficult to move beyond intuitive explanations for the discrepancies without collecting temperature data for individual households.

It seems unlikely that the lack of overlap is due to the data coming from a period of relatively low energy prices and easy energy affordability. While Deller and Waddams Price (2018)[41] show that the period 2001-02 to 2008-09 corresponded with a long-term low for the median proportion of household expenditures devoted to energy in the UK, they also show that this median had largely returned to its long-term level by 2009. Although the proportion of 10% FP households reporting IAAW rose from 2.1% to 4.8% between 2007-08 and 2008-09, the overlap remains low.

[40] Boardman (1991) chose the 10% indicator as in the 1988 UK Food and Expenditure Survey devoting 10% of expenditure to energy corresponded to the average ENEXShr of the 30% of households with the lowest incomes and was twice the average ENEXShr for the population as a whole.
[41] See Figure 5 and Figure A2.3.

In terms of the BHPS dataset, one factor that may contribute to the lack of overlap is that IAAW is the result of a binary Yes/No question, whereas householders may view energy affordability as a spectrum. This may be compounded by the question structure which first requires households to state they were unable to achieve adequate warmth in their home, before asking whether this was due to it being unaffordable.

Figure 5 depicts the converse overlap to that shown in Figure 4, i.e. the percentage of households reporting perception-based FP who are also identified as being expenditure FP. A higher proportion of those reporting perception-based FP are also FP by expenditure-based measures than vice versa. Among the perception-based FP indicators, Figure 5 shows those reporting IAAW have the highest rates of expenditure FP, with a noticeably higher overlap with LIHC FP than with 10% FP: among those reporting IAAW, the rate of LIHC FP is between 7.3 and 15.2 percentage points higher than the rate of 10% FP. The higher rate of overlap with LIHC FP is unsurprising given that Figure 1 shows that a greater proportion of households are in LIHC FP than 10% FP.

It seems likely that a household reporting IAAW, but devoting a low proportion of income to ENEX, will be restricting their energy consumption for affordability reasons. However, as the temperature deemed adequate by these households is unknown, one cannot be certain of appropriate policy interventions across the households in this situation. Some of the discrepancy could result from relatively well-off households seeking particularly high temperatures.

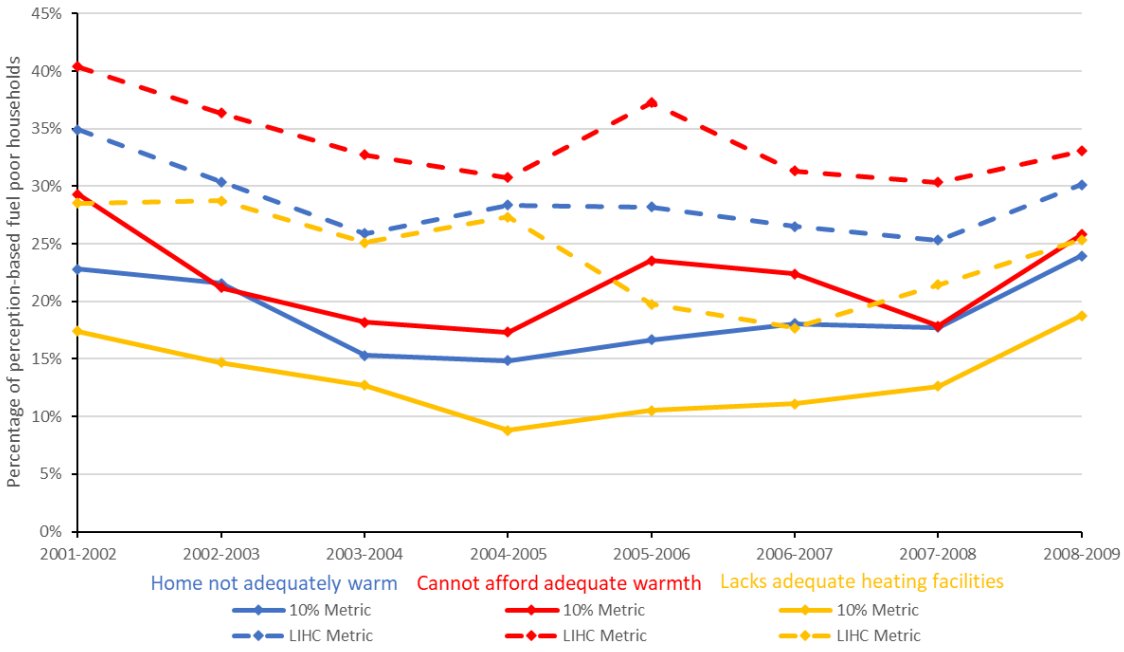

Figure 5: Percentage of perception-based fuel poor households identified as 10% or LIHC fuel poor in the analysed sample, 2001-02 to 2008-09

5.3 Characteristics of Households by Fuel Poverty Indicator

Table 1 details the substantial differences in the characteristics of households identified as FP according to each of the indicators. As expected, FP households have lower average gross incomes than the whole sample regardless of indicator, although the 10% metric is associated with a particularly low median income of £7,483, only 55% of the median income of IAAW households.

Households in 10% FP also have the highest median ENEX and ENEXShr.[42] Perhaps more surprising is that the median ENEX for IAAW households is close to the whole sample average (£776 vs £797) and the median ENEXShr for this group is above that of the whole sample (5.9% vs 3.2%), providing little direct evidence of any 'rationing' of energy consumption among IAWW households. However, IAAW households may still be failing to achieve an adequate home temperature if their dwelling characteristics and/or unit energy price mean this expenditure translates into less heat than for other households.

Household Characteristic	Whole sample	Inability to afford warmth	Lack of adequate heating facilities	10% Metric	LIHC Metric
Median gross household income (£, 2008 prices)	25,499	13,714	18,967	7,483	11,550
Median energy expenditure (£, 2008 prices)	797	776	767	1,124	1,033
Median energy expenditure share (%)	3.2	5.9	4.0	13.6	8.9
Median net housing cost (£, 2008 prices)	2,042	678	2,246	0	173
% in Northern Ireland	18.6	27.2	21.5	43.1	33.6
% renting from local authority/housing association	17.8	40.4	36.1	28.5	35.6
% with household head aged over 65	25.4	17.2	16.2	37.1	29.7
% containing children	31.6	27.5	35.4	23.1	39.3
% with no central heating	5.8	22.8	34.2	9.2	7.5
% with no gas connection	25.1	42.6	49.9	42.4	35.9
Mean number of household members	2.5	2.1	2.5	1.9	2.6
Mean number of rooms	4.6	4.0	3.9	4.5	4.4
% stating can't afford holiday	13.9	68.6	38.0	29.5	31.2
% stating can't afford to replace furniture	7.3	58.1	21.4	15.2	15.8
% stating can't afford visitors for food/drink	4.3	32.5	14.1	10.1	10.4
% reporting a leaky roof	3.3	13.7	16.0	5.0	4.4
% reporting damp walls/floors	7.0	31.6	33.8	9.4	10.3
% reporting rot in windows/floors	5.1	21.9	24.7	7.5	7.6
Number of observations	55,772	570	2,089	4,255	8,157
Number of households	10,465	380	1,293	2,192	3,547

Table 1: Characteristics of those classified as fuel poor according to each indicator

6. Results

The main regression results, incorporating the full set of explanatory variables, are provided in Table 4 and Table 6. Table 4 is the first analysis of IAAW FP using the BHPS.[43] In Table 6 results for the 10% and LIHC indicators are presented. **Error! Reference source not found.**Appendix 1 reports equivalent regression results for households reporting a lack of adequate heating facilities. When discussing Table 6 we focus on the differences to the household characteristics associated with reporting IAAW.

Prior to these main regression tables, univariate regressions are reported between the different FP indicators and, for the perception-based indicators, simplified multivariate regressions indicate the associations with ENEX, income and ENEXShr.

6.1 Self-Reports of Unaffordable Warmth

Table 2 indicates that all three alternative FP indicators, in univariate regressions, are positively associated with reporting IAAW at the 1% level. However, the magnitude of the association is stronger between the two perception-based indicators: on average reporting a lack of adequate

[42] These households could be paying for their high ENEX by drawing down assets or borrowing money.
[43] Roberts et al. (2015) use the same dataset to consider the dynamics of 10% FP.

heating facilities is associated with a 10.7 percentage point increase in the probability of reporting IAAW, whereas being LIHC FP is only associated with a 1.6 percentage point increase. Table 2 also indicates persistence, as reporting IAAW in period *t-1* increases the probability of reporting IAAW in period *t* by 32.7 percentage points. The argument made in Appendix 2 is that, if persistence is identified, its magnitude may influence the appropriateness of alternative FP remedies.

	Inability to afford adequate warmth indicator			
Explanatory Variable	**(1)**	**(2)**	**(3)**	**(4)**
1. 10% fuel poor	0.022***			
2. LIHC fuel poor		0.016***		
3. Reports a lack of adequate heating facilities			0.107***	
4. Reports an inability to afford adequate warmth, period t-1				0.327***
Log likelihood	-3,113.96	-3,109.59	-2,763.33	-2,183.16
P-value, likelihood ratio test of joint significance	0.000	0.000	0.000	0.000
Policymaking variables	No	No	No	No
Best predictor variables	No	No	No	No
Number of observations	55,772	55,772	55,772	47,493
Number of households	10,465	10,465	10,465	9,400

Notes: * indicates statistical significance at the 10% level, ** indicates significance at the 5% level and *** indicates significance at the 1% level. The table reports average marginal effects on the probability of a household reporting an inability to afford to keep their home adequately warm. A blank space indicates a variable was not included in the regression. In column (4) 8,279 observations were dropped as the sample is restricted to observations where the four analysed fuel poverty indicators are available in period t-1.

Table 2: Average marginal effects of alternative fuel poverty indicators on the probability of reporting an inability to afford to keep one's home adequately warm, univariate regressions

The 10% and LIHC indicators are binary indicators which are formed from income and ENEX, and regressions exploring the relationship of IAAW to these underlying variables are reported in Table 3.

	Inability to afford adequate warmth indicator									
Explanatory Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
1. Energy expenditure share (%) - linear	0.000***									
2. Energy expenditure share (%) - quadratic[1]		0.001***								
3. Annual energy expenditure (£ hundreds, 2008) - linear			-0.000				0.000***			
4. Annual energy expenditure (£ hundreds, 2008) - quadratic				-0.000				0.000***	0.000***	0.000***
5. Annual gross household income (£ thousands, 2008) - linear					-0.001***		-0.001***			
6. Annual gross household income (£ thousands, 2008) - quadratic						-0.001***		-0.001***	-0.000***	-0.000***
7. Annual net housing costs (£ hundreds, 2008) - quadratic									0.000***	0.000***
8. Reports an inability to afford adequate warmth, period t-1									0.231***	0.201***
9. No central heating										0.011***
10. No gas connection										0.003***
Log likelihood	-3,136.51	-3,067.88	-3,179.30	-3,179.29	-3,020.21	-3,018.51	-3,013.75	-3,009.61	-2,103.10	-2,074.73
P-value, likelihood ratio test of joint significance	0.000	0.000	0.555	0.678	0.000	0.000	0.000	0.000	0.000	0.000
Policymaking variables	No	No	No	No	No	No	No	No	No	No
Best predictor variables	No	No	No	No	No	No	No	No	No	No
Number of observations	55,772	55,772	55,772	55,772	55,772	55,772	55,772	55,772	47,973	47,973
Number of households	10,465	10,465	10,465	10,465	10,465	10,465	10,465	10,465	9,400	9,400

Notes: * indicates statistical significance at the 10% level, ** indicates significance at the 5% level and *** indicates significance at the 1% level. The table reports average marginal effects on the probability of a household reporting an inability to afford to keep their home adequately warm. A blank space indicates the variable was not included in the regression. In columns (9) and (10) 8,279 observations were dropped as the sample is restricted to cases where the lags of the four analysed fuel poverty indicators are available. In many of the regressions some observations where households reported they could afford adequate warmth were completely determined. In column (5) 29 obervations were completely determined, in (6) it was 10 observations, in (7) it was 31 observations, in (8) it was 12 observations, in (9) it was 22 observations and in (10) it was 16 observations.

[1] Where a variable is labelled as quadratic the regression included both a linear and squared term of the variable; the reported average marginal effect for such variables is the combined change in probability associated with the linear and squared terms.

Table 3: Average marginal effects of income and energy expenditure on the probability of reporting an inability to afford to keep one's home adequately warm, alternative specifications

In Table 3 columns 1 to 6 report univariate regressions when ENEXShr, ENEX and income are treated separately as linear relationships (columns 1, 3 and 5) and quadratic relationships (columns 2, 4 and 6). First, in columns 3 and 4 the relationship between ENEX and IAAW is insignificant. Second, there is a positive relationship between ENEXShr and IAAW, and a negative relationship between gross household income and IAAW. Third, while both quadratic and linear relationships between ENEXShr, income and IAAW are statistically significant at the 1% level, Figure 11 and Figure 12 in Appendix 4 show that the actual relationships are non-linear.

Furthermore, using ENEXShr as an explanatory variable places a restriction on the relationship between ENEX, income and IAAW; ENEXShr implies the coefficient on income is the inverse of the coefficient on ENEX. In columns 8 to 10 this restriction is relaxed, with ENEX and household income included separately both as linear and squared terms. Statistical tests reject the equality of the coefficients on income and ENEX (used separately as absolute values in column 8) confirming that they should be included as separate variables. Columns 8-10 indicate that, once household income is controlled for, there is a statistically significant relationship between ENEX and IAAW. Table 3 also shows that the magnitude of the relationship between ENEX, income and IAAW is low. For example, equation 8 implies that a £1,000 increase in gross household income is associated with a 0.1 percentage point drop in the probability of reporting IAAW; while a £100 increase in ENEX is associated with less than a 0.05 percentage point increase in the probability of IAAW. The U-shaped relationship between ENEX and IAAW in Figure 10 in Appendix 4 is consistent with both particularly high and particularly low ENEX levels being associated with FP.

In columns 9 and 10, annual net housing costs are included, since housing costs are the third component of the LIHC indicator, while the first lag of IAAW is introduced as a control. A positive non-linear relationship is found between net housing costs and IAAW. In column 10 indicator variables for lacking central heating or a gas connection are included; that both variables are significant at the 1% level indicates that reporting these heating system characteristics increases the probability of reporting IAAW, even after controlling for how these characteristics can increase ENEX.

Table 4 reports a further 8 regressions; columns 1, 2, 5 and 6 include income, ENEX and net housing costs, while columns 3, 4, 7 and 8 exclude these variables to enable a direct comparison with the regression results for the 10% and LIHC indicators in Table 6. In columns 2, 4, 6, and 8 the first lag of IAAW is included. Columns 1 to 4 consider the 'Policymaking' explanatory variables, while columns 5 to 8 also include the 'Best Predictor' variables. Wald tests indicate that in all four regression specifications, the inclusion of the Best Predictor variables improves the specification, i.e. the coefficients of these additional variables are jointly different from zero at the 1% significance level.

Compared to the simpler regressions in Table 3, one difference in Table 4 is that both ENEX and net housing costs are statistically insignificant. The insignificance of at ENEX is partly linked to the inclusion of survey wave dummies which likely control for most of the intertemporal variation in ENEX. In a regression using the Policymaking variables but without the lag of IAAW or the wave dummies, ENEX is statistically significant at the 1% level. That net housing costs is insignificant likely results from the detailed housing characteristic variables included in the Table 4 regressions being better predictors of IAAW than the more general housing costs variable.

	Inability to afford adequate warmth indicator							
	Policymaking Explanatory Variables				Policymaking plus Best Predictor Explanatory Variables			
Explanatory Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
1. Unable to afford adequate warmth in the home, period t-1		0.148***		0.159***		0.062***		0.063***
2. Annual gross household income (£ thousands, 2008) - quadratic	-0.000***	-0.000***			-0.000***	-0.000**		
3. Annual energy expenditure (£ hundreds, 2008) - quadratic	0.000	0.000			-0.000	-0.000		
4. Annual net housing costs (£ hundreds, 2008) - quadratic	0.000	0.000			0.000	0.000		
5. 2001-02 wave	0.003**	0.003*	0.003**	0.003*	0.003**	0.004**	0.003***	0.004**
6. 2003-04 wave	-0.001	0.000	-0.001	0.000	0.001	0.001	0.001	0.001
7. 2004-05 wave	-0.000	0.001	-0.000	0.001	0.001	0.002	0.001	0.002
8. 2005-06 wave	-0.000	0.001	-0.000	0.001	0.001	0.002	0.001	0.002
9. 2006-07 wave	0.002	0.004**	0.002	0.004**	0.004***	0.005***	0.004***	0.005***
10. 2007-08 wave	0.002	0.001	0.002	0.001	0.004**	0.003*	0.003**	0.002
11. 2008-09 wave	0.014***	0.014***	0.014***	0.014***	0.014***	0.014***	0.014***	0.013***
12. Wales	0.003	0.002	0.003*	0.003*	0.003*	0.003*	0.003*	0.003**
13. Scotland	0.001	0.001	0.002	0.001	0.004**	0.004***	0.004**	0.004***
14. Northern Ireland	-0.001	0.000	0.000	0.001	0.003	0.004**	0.003	0.004*
15. Owned with mortgage	0.000	-0.000	-0.001	-0.000	0.000	0.000	0.001	0.001
16. Social housing	0.004	0.002	0.004*	0.003	-0.000	0.000	0.001	0.001
17. Private rented	0.006**	0.005*	0.007***	0.006***	0.001	0.001	0.002	0.002
18. Semi-detached house/bungalow	-0.000	-0.000	0.000	0.000	0.001	0.001	0.001	0.001
19. End terraced house	-0.002	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.001
20. Terraced house	-0.000	-0.001	-0.000	-0.000	-0.001	-0.001	-0.001	-0.001
21. Purpose built flat	-0.002	-0.002	-0.003	-0.002	-0.003	-0.002	-0.003	-0.002
22. Converted flat	0.004	0.004	0.003	0.003	0.001	0.001	0.001	0.001
23. Bedsit	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24. No central heating	0.021***	0.012***	0.022***	0.012***	0.013***	0.009***	0.014***	0.009***
25. No gas connection	0.005**	0.003	0.005**	0.003*	0.005***	0.003*	0.005***	0.003**
26. Household head aged 65 to 75	-0.005***	-0.002	-0.004**	-0.002	-0.000	0.001	-0.000	0.001
27. Household head aged 75+	-0.008***	-0.005***	-0.007***	-0.005***	-0.004**	-0.002	-0.003*	-0.002
28. Household head unemployed	0.009***	0.008***	0.012***	0.010***	0.004*	0.004**	0.004**	0.004**
29. Has investment income	-0.004***	-0.002**	-0.005***	-0.003***	-0.000	0.000	-0.001	0.000
30. Receives incapacity benefit	0.007***	0.006***	0.009***	0.007***	0.002	0.002	0.002	0.001
31. Receives housing benefit	0.003*	0.002	0.003*	0.001	0.000	-0.000	-0.000	-0.001
32. Receives income support	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000
33. Contains single parent(s)	0.004	0.004*	0.005*	0.005**	0.000	0.001	0.001	0.001
34. Contains children	-0.005***	-0.005***	-0.004**	-0.003**	-0.003**	-0.003*	-0.003*	-0.002
35. Number of household members: 2	-0.003	-0.001	-0.005***	-0.003**	-0.003*	-0.001	-0.004**	-0.002
36. Number of household members: 3	0.002	0.003	-0.002	-0.000	0.000	0.001	-0.002	-0.000
37. Number of household members: 4	-0.000	0.001	-0.005*	-0.003	-0.002	-0.001	-0.004*	-0.003
38. Number of household members: 5	0.005	0.006	-0.001	0.001	-0.000	0.003	-0.002	0.000
39. Number of household members: 6	0.001	0.004	-0.005	-0.002	-0.004	-0.001	-0.006**	-0.004
40. Number of household members: 7+	-0.000	0.003	-0.006	-0.003	-0.005	-0.002	-0.008**	-0.004
41. Has home computer					0.002	0.001	0.002	0.001
42. Number of rooms: 1					-0.009***	0.000	-0.009***	0.000
43. Number of rooms: 3					0.002	-0.000	0.002	-0.000
44. Number of rooms: 4					0.001	-0.000	0.001	-0.001
45. Number of rooms: 5					-0.000	-0.000	-0.000	-0.001
46. Number of rooms: 6					0.003	0.002	0.002	0.001
47. Number of rooms: 7+					0.004	0.004	0.003	0.003

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	Policymaking Explanatory Variables				Policymaking plus Best Predictor Explanatory Variables			
Explanatory Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
48. Loan/hire payments somewhat of a burden					-0.000	-0.001	-0.000	-0.001
49. Loan/hire payments a heavy burden					0.003	0.004**	0.002	0.004**
50. Problems paying for housing					0.001	0.002	0.002	0.002*
51. Cannot afford holiday					0.010***	0.008***	0.011***	0.008***
52. Cannot afford to replace furniture					0.016***	0.014***	0.017***	0.014***
53. Cannot afford new clothes					0.007***	0.005***	0.007***	0.005***
54. Cannot afford to eat meat on alternate days					0.009***	0.006***	0.009***	0.006***
55. Cannot afford visitors for food/drink					0.003**	0.003**	0.003**	0.003**
56. Has condensation					0.002	0.001	0.002	0.001
57. Has a leaky roof					0.006**	0.006**	0.006**	0.006**
58. Has damp wall/floors					0.006***	0.005***	0.006***	0.005***
59. Has rot in windows/floors					0.007***	0.005**	0.008***	0.005**
60. Has crime in the local area					0.003***	0.003**	0.003***	0.003**
Log likelihood	-2,702.39	-1,942.31	-2,734.80	-1,961.54	-2,163.27	-1,610.77	-2,170.26	-1,615.66
P-value, likelihood ratio test of joint significance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Policymaking variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Best predictor variables	No	No	No	No	Yes	Yes	Yes	Yes
Number of observations	55,708	47,849	55,708	47849	55,708	47,673	55,708	47,673
Number of households	10,461	9,388	10,461	9,388	10,461	9,367	10,461	9,367

Notes: * indicates statistical significance at the 10% level, ** indicates significance at the 5% level and *** indicates significance at the 10% level. The table reports average marginal effects on the probability of a household reporting an inability to afford to keep their home adequately warm. A blank space indicates a variable was not included in the regression. Where a variable is labelled as quadratic the regression included both a linear and squared term of the variable; the reported average marginal effect for such variables is the combined change in probability associated with the linear and squared terms. In columns (2), (4), (6), (7) and (8) 8,279 observations were dropped as the sample is restricted to cases where the first lag of the four analysed fuel poverty indicators are available. Selected base categories: rows 5-11 = 2002-03 wave; rows 12-14 = England; rows 15-17 = owned outright; rows 18-23 = detached house/bungalow; rows 26 and 27 = Household head aged less than 65; rows 35-40 = household contains 1 person; rows 42-47 = dwelling has 2 rooms; rows 28-34 and 50-60 are all binary variables where the base category is the opposite of the variable statement. Columns (3), (4) and (7) and (8) exclude the energy expenditure, income and housing cost variables to allow comparison with the expenditure-based fuel poverty indicators. In columns (1), (3), (5) and (7) 5 observations were dropped for May perfectly predicting being able to afford warmth and for the same reason 59 observations were dropped for living in a bed sit. In columns (2), (4), (6) and (8) 82 observations were dropped for April perfectly predicting being able to afford warmth and for the same reason 4 observations were dropped for May and 38 observations were dropped for living in a bedsit. In columns (6) and (8) 176 observations were dropped for living in a single room perfectly predicting being able to afford warmth. In column (1) 10 observations of being able to afford warmth were completely determined and the same is true of 9 observations in columns (2) and (6), and 13 observations in column (5). Variables/categories frequently significant at the 10% level or above (direction in brackets) but not reported are: interview month - April (negative), has two or more cars (negative), has a satellite dish (negative), has a colour TV (negative) and has a tumble dryer (negative).

Table 4: Average marginal effects on the probability of reporting an inability to afford to keep one's home adequately warm (Policymaking and/or Best Predictor variables included)

The most notable results in Table 4 relate to age. In columns 5 to 8, where the full set of housing and deprivation variables are included, households with a head aged 65 to 75 show no statistically significant difference in reporting IAAW from households with a head aged below 65. In the Best Predictor regressions a household head aged over 75 only has a statistically significant difference at the 5% level to a household head aged below 65 when income and expenditure are included but the lag of IAAW is excluded (column 5). However, in column 5, as in the Policymaking regressions (columns 1 to 4), a household with a head over 75 years old is less likely to report IAAW than one headed by an under 65 year old. This negative relationship also holds for households with a head aged 65-75 in the regressions with policymaking variables when the lag of the dependent variable is

excluded (columns 1 and 3). This result is consistent with the descriptive statistics reported in Figure 9 and Healy and Clinch (2002)[44].

Why are older households associated with a lower probability of reporting IAAW? The key factor appears to be that whether older households report IAAW is correlated with their reporting of other forms of deprivation or problems with their home, since a head of household over 65 has a strong negative association with reporting IAAW only when the deprivation and housing condition variables are excluded.[45] The unanswered question is whether the deprivation and housing condition variables are controlling for households' substantive characteristics or a reporting bias, where older households are less willing to disclose any form of deprivation.

Regarding the possibility of a reporting bias, in the current dataset all of the deprivation and poor housing condition indicators show a lower incidence rate among households headed by someone over 65 than for households with a younger head.[46] Dominy and Kempson (2006) report that research has shown that, for a given level of income, older households are less likely to report material deprivation than younger households. More specifically, Berthoud et al. (2009) indicate that while older cohorts are less likely to report material deprivation compared to more recent cohorts, this is offset by individuals tending to become relatively poorer as they age. This highlights the extra value that data on in-home temperatures and householders' temperature preferences could add, to help tease out which households are living in 'low' temperatures and whether they would appreciate interventions to achieve higher temperatures.

Reporting IAWW is also positively associated with the head of household being unemployed across all the equations, unsurprisingly with a more significant and numerically greater effect when deprivation and housing condition indicators are omitted. It is noticeable that this relationship exists even after controlling for household income.

Regarding the deprivation and housing condition indicators, there is a strong association between them and reporting IAAW (columns 5 to 8). The highest increase in the probability of reporting IAAW is associated with being unable to afford to replace furniture, with an increase of 1.4-1.7 percentage points. Among the housing condition indicators, reporting condensation does not show a statistically significant association with IAAW. When the deprivation and housing condition indicators are removed, i.e. only the policymaking variables are included, other variables, which are likely proxies for these issues, become significant. For example, in columns 1-4, investment income is negatively associated with reporting IAAW, while receiving incapacity benefit is positively associated with IAAW.

When the housing and deprivation indicators are removed, private renting, compared to owning one's home outright, is positively associated with IAAW. However, renting from a social housing provider does not show a statistically significant relationship with IAAW at the 5% level, compared to owning a home outright. When policymaking variables are included, the presence of children in a household is associated with a reduced probability of reporting IAAW, though this relationship is weaker when controlling for housing and deprivation factors.

[44] See Tables 15 and 16.

[45] This is seen by comparing columns 1-4 with 5-8. More specifically, when the regressions in columns 5-8 are repeated without the other 'cannot afford' indicators (rows 51-55) and housing deprivation indicators (rows 56-59), a household head over 75 is negatively associated with reporting IAAW at the 1% level in all the regressions and a household head aged 65-75 has a negative association significant at the 5% level in the regressions where the lag of IAAW is not included.

[46] In all instances the difference was statistically significant at the 1% level.

Columns 2, 4, 6 and 8 indicate some persistence in reporting IAAW, since reporting IAAW in one period is associated with a higher probability of that household having reporting IAAW in the previous period. While the magnitude of the AMEs for the lag of IAAW are large relative to those of the other explanatory variables in Table 4, they are noticeably smaller than in Table 3 after controlling for the full set of housing condition and deprivation indicators.

This apparent persistence might be explained by households reporting IAAW having particular 'unobservable' characteristics. For example, the lagged variable could be picking up that some households have a greater predilection to *report* fuel poverty. The lag of IAAW also reflects some characteristics which change little over time, and which are otherwise associated with FP. For example, comparing columns 1 and 2 (and 5 and 6), introducing the lag of IAAW reduces the statistical significance of not having a gas connection. Similarly, the magnitude of the AME associated with the presence of central heating falls when the lagged dependent variable is included.

6.2 Expenditure-based Indicators

In Table 5 AMEs from univariate regressions for the associations between different FP indicators and at different times are reported. Without controlling for other factors, reporting IAAW is associated with an increase in the probability of being 10% FP of 15.5 percentage points and an increase in the probability of being LIHC FP of 20.0 percentage points. As in the case of IAAW discussed above, there is evidence of persistence, since the one period lags of the two expenditure-based FP indicators are statistically significant at the 1% level. One striking correlation is that being 10% FP is associated with a 68 percentage point increase in the probability of being LIHC FP, reflecting the large proportion of 10% FP observations in Figure 3.

	10% Indicator				LIHC Indicator			
Explanatory Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
1. Unable to afford adequate warmth in the home	0.155***				0.200***			
2. Lack of adequate heating facilities		0.064***				0.108***		
3. LIHC fuel poor, period t			0.384***					
4. 10% fuel poor, period t							0.680***	
5. 10% fuel poor, period t-1				0.417***				
6.LIHC fuel poor, period t-1								0.452***
Log likelihood	-14,971.61	-14,988.89	-10,197.12	-9,833.07	-23,140.04	-23,129.01	-18,369.92	-15,681.40
P-value, likelihood ratio test of joint significance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Policymaking variables	No	No	No	No	No	No	No	No
Best predictor variables	No	No	No	No	No	No	No	No
Number of observations	55,772	55,772	55,772	47,973	55,772	55,772	55,772	47,973
Number of households	10,465	10,465	10,465	9,400	10,465	10,465	10,465	9,400

Notes: * indicates statistical significance at the 10% level, ** indicates significance at the 5% level and *** indicates significance at the 1% level. The table reports average marginal effects on the probabilities of: (i) being 10% fuel poor, columns (1)-(4); and (ii) being LIHC fuel poor, columns (5)-(8). In columns (4) and (8) 8,279 observations are dropped as the sample is restricted tocases where the first lags of the analysed fuel poverty indicators are available. A blank space indicates a variable was not included in the regression.

Table 5: Average marginal effects of alternative fuel poverty indicators on the probabilities of being identified as 10% fuel poor or LIHC fuel poor, univariate regressions

The present study's focus is to highlight differences between the characteristics of households reporting IAAW and those identified as 10% FP and LIHC FP. To do this the regressions in Table 6 are compared with columns 3, 4, 7 and 8 of Table 4. Wald tests show that, for both the 10% and LIHC indicators, the coefficients of the additional variables in the Best Predictor regressions (columns 3, 4, 7 and 8) are significantly different to zero at the 1% level, indicating that the Best Predictor specifications offer an improvement over the Policymaking specifications. In columns 2, 4, 6 and 8 of

Table 6 the first lag of the dependent variable is included. In general, the AMEs' magnitudes in Table 6 are noticeably larger than in Table 4, probably reflecting the higher proportion of households classified as 10% FP or LIHC FP rather than unable to afford adequate warmth.

From a policy perspective, the most interesting difference between Tables 4 and 6 are the associations between older households and each FP indicator. As noted above, for the IAAW indicator, in the Best Predictor regressions (columns 7 and 8) there is little association with the household head being aged 65 or over; while in the Policymaking regressions (columns 3 and 4) the household head being aged over 75 is associated with a reduction in the probability of reporting IAAW at the 1% level. In contrast, columns 1-4 of Table 6 show no association between older household heads and 10% FP, while older household heads are positively associated with LIHC FP (columns 5-8). A household head aged 65-75, on average, is associated with 3.4-4.2 percentage points increase in the probability of LIHC FP compared to a household head under 65, with a similar but wider range for a household head over 75.

These associations for IAAW and 10% FP reflect the patterns in Figure 9 in Appendix 4. However, Figure 9 shows that the rate of 10% FP is noticeably higher among households with a head aged 65 or over than for households with a younger head (11.2% vs 6.4%). That the age variables are insignificant for 10% FP in Table 6 suggest that the pattern for 10% FP in Figure 9 is driven by household characteristics positively correlated with age, rather than by age itself. The contrast in the relationship between age and, respectively, the 10% indicator and reporting an IAAW, is consistent with descriptive statistics in DECC (2009)[47].

[47] See Chart 38, pg42, comparing the figures for "one person under 60" with those for "one person aged 60 or over".

Explanatory Variable	10% Indicator (1)	(2)	(3)	(4)	LIHC Indicator (5)	(6)	(7)	(8)
1. 10% fuel poor, period t-1		0.213***		0.201***				
2. LIHC fuel poor, period t-1						0.303***		0.290***
3. 2001-02 wave	0.010***	0.007	0.009***	0.007*	0.000	-0.006	-0.002	-0.006
4. 2003-04 wave	-0.008**	-0.003	-0.007**	-0.003	-0.006	-0.003	-0.003	-0.002
5. 2004-05 wave	-0.014***	-0.007**	-0.012***	-0.007**	-0.007	-0.005	-0.003	-0.003
6. 2005-06 wave	-0.002	0.007*	-0.000	0.007*	-0.016***	-0.013**	-0.012**	-0.011**
7. 2006-07 wave	0.010**	0.015***	0.012***	0.015***	-0.023***	-0.016***	-0.018***	-0.014***
8. 2007-08 wave	0.013***	0.015***	0.015***	0.015***	-0.019***	-0.009*	-0.013**	-0.007
9. 2008-09 wave	0.044***	0.045***	0.046***	0.044***	-0.013**	-0.002	-0.009	-0.002
10. Wales	0.013***	0.007**	0.011***	0.006**	0.031***	0.017***	0.028***	0.016***
11. Scotland	0.026***	0.016***	0.030***	0.019***	0.050***	0.026***	0.055***	0.031***
12. Northern Ireland	0.072***	0.038***	0.068***	0.038***	0.091***	0.050***	0.084***	0.049***
13. Owned with mortgage	-0.066***	-0.043***	-0.060***	-0.041***	-0.048***	-0.026***	-0.041***	-0.024***
14. Social Housing	-0.027***	-0.021***	-0.023***	-0.017***	0.037***	0.020***	0.032***	0.017***
15. Private rented	-0.024***	-0.019***	-0.022***	-0.018***	0.043***	0.030***	0.038***	0.025***
16. Semi-detached house/bungalow	-0.042***	-0.026***	-0.031***	-0.021***	-0.027***	-0.015***	-0.020***	-0.011**
17. End terraced house	-0.040***	-0.025***	-0.028***	-0.019***	-0.025***	-0.016**	-0.017**	-0.010
18. Terraced house	-0.037***	-0.022***	-0.025***	-0.016***	-0.026***	-0.014**	-0.018**	-0.008
19. Purpose built flat	-0.067***	-0.043***	-0.044***	-0.030***	-0.079***	-0.048***	-0.051***	-0.030***
20. Converted flat	-0.056***	-0.034***	-0.031***	-0.020**	-0.059***	-0.034***	-0.026*	-0.015
21. Bedsit	-0.086***	-0.053**	-0.056**	-0.033	-0.096***	-0.009	-0.034	0.043
22. No central heating	0.007	0.005	0.001	0.003	0.006	0.000	-0.001	-0.003
23. No gas connection	0.005	0.007**	0.007*	0.008***	0.009	0.006	0.013**	0.008*
24. Household head aged 65 to 75	-0.004	0.001	-0.004	0.001	0.042***	0.035***	0.042***	0.036***
25. Household head aged 75+	-0.001	-0.000	0.001	0.002	0.048***	0.032***	0.050***	0.036***
26. Household head unemployed	0.097***	0.054***	0.085***	0.050***	0.086***	0.057***	0.069***	0.047***
27. Has investment income	-0.043***	-0.029***	-0.042***	-0.029***	-0.078***	-0.051***	-0.072***	-0.047***
28. Receives incapacity benefit	0.035***	0.028***	0.028***	0.024***	0.078***	0.055***	0.065***	0.047***
29. Receives housing benefit	-0.014***	-0.008**	-0.019***	-0.009**	0.019***	0.010*	0.008	0.004
30. Receives income support	0.035***	0.015***	0.028***	0.013***	0.051***	0.026***	0.034***	0.017***
31. Contains single parent(s)	0.047***	0.031***	0.039***	0.026***	0.062***	0.040***	0.051***	0.033***
32. Contains children	0.029***	0.023***	0.030***	0.024***	0.021***	0.018***	0.023***	0.020***
33. Number of household members: 2	-0.079***	-0.051***	-0.085***	-0.056***	-0.001	0.000	-0.006	-0.003
34. Number of household members: 3	-0.103***	-0.074***	-0.111***	-0.082***	0.007	0.000	-0.003	-0.007
35. Number of household members: 4	-0.108***	-0.078***	-0.117***	-0.086***	0.030***	0.015*	0.017*	0.006
36. Number of household members: 5	-0.108***	-0.075***	-0.119***	-0.085***	0.057***	0.025***	0.037***	0.013
37. Number of household members: 6	-0.128***	-0.094***	-0.139***	-0.103***	0.109***	0.057***	0.081***	0.042***
38. Number of household members: 7+	-0.114***	-0.077***	-0.128***	-0.090***	0.218***	0.110***	0.168***	0.082***
39. Has home computer			-0.010***	-0.004			-0.013***	-0.007*
40. Number of rooms: 1			0.010	-0.008			-0.018	-0.016
41. Number of rooms: 3			0.027***	0.018***			0.046***	0.029***
42. Number of rooms: 4			0.040***	0.026***			0.068***	0.042***
43. Number of rooms: 5			0.047***	0.031***			0.081***	0.051***
44. Number of rooms: 6			0.057***	0.033***			0.088***	0.057***
45. Number of rooms: 7+			0.073***	0.040***			0.088***	0.053***

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Explanatory Variable	10% Indicator (1)	(2)	(3)	(4)	LIHC Indicator (5)	(6)	(7)	(8)
46. Loan/hire payments somewhat of a burden			-0.015***	-0.012***			-0.008	-0.005
47. Loan/hire payments a heavy burden			-0.007	-0.004			-0.012	-0.011
48. Problems paying for housing			0.015**	0.014**			0.047***	0.046***
49. Cannot afford holiday			0.030***	0.019***			0.042***	0.026***
50. Cannot afford to replace furniture			0.011**	0.007*			0.026***	0.020***
51. Cannot afford new clothes			0.012*	0.007			0.015*	0.011
52. Cannot afford to eat meat on alternate days			0.012	0.008			0.002	0.002
53. Cannot afford visitors for food/drink			0.007	0.004			0.015**	0.008
54. Has condensation			0.003	-0.000			-0.004	-0.005
55. Has a leaky roof			0.027***	0.015**			0.016*	0.010
56. Has damp wall/floors			-0.002	-0.003			0.005	0.001
57. Has rot in windows/floors			0.014**	0.009*			0.023***	0.021***
58. Has crime in the local area			0.003	-0.001			0.002	-0.004
Log likelihood	-12,146.62	-8,703.75	-11,902.67	-8,607.90	-19,769.21	-14,551.73	-19,420.24	-14,392.24
P-value, likelihood ratio test of joint significance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Policymaking variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Best predictor variables	No	No	Yes	Yes	No	No	Yes	Yes
Number of observations	55,767	47,969	55,767	47,969	55,767	47,969	55,767	47,969
Number of households	10,465	9,400	10,465	9,400	10,465	9,400	10,465	9,400

Notes: * indicates statistical significance at the 10% level, ** indicates significance at the 5% level and *** indicates significance at the 1% level. The table reports average marginal effects on the probabilities of: (i) being 10% fuel poor, columns (1)-(4); and (ii) being Low Income - High Cost fuel poor, columns (5)-(8). In columns (2), (4), (6) and (8) 8,279 observations are dropped as the sample is restricted to cases where the first lags of the four analysed fuel poverty indicators are available. A blank space indicates a variable was not included in the regression. Selected base categories: rows 3-9 = 2002-03 wave; rows 10-12 = England; rows 13-15 = owned outright; rows 16-21 = detached house/bungalow; rows 24 and 25 = Household head aged less than 65; rows 33-38 = household contains 1 person; rows 40-45 = dwelling has 2 rooms; rows 26-32 and 48-58 are all binary variables where the base category is the opposite of the variable statement. In columns (1), (3), (5) and (7) 5 observations are dropped as May perfectly predicts not being fuel poor, while in columns (2), (4), (6) and (8) 4 observations are dropped for the same reason. Variables/categories consistently significant at the 10% level or above (direction in brackets) in the 10% FP regressions, but not reported, are: interview months - November, December, January, February, March, April (positive), has one car (negative), has two or more cars (negative), has a dishwasher (positive) and has a CD player (negative). Variables/categories consistently significant at the 10% level or above (direction in brackets) in the LIHC indicator regressions, but not reported, are: has one car (negative), has two or more cars (negative), has a washing machine (positive) and has a CD player (negative).

Table 6: **Average marginal effects on the probability of a household being identified as Fuel Poor according to: (i) the 10% indicator and (ii) the LIHC indicator**

Another policy point is that while tenure and dwelling type show limited association with the probability of IAAW, they show considerable association with the expenditure-based indicators. For the 10% indicator all tenure types are associated with a lower probability of being FP than households owning their property outright; and all dwelling types are associated with a lower probability of being FP than households living in a detached house/bungalow.

The pattern of association between tenure and the LIHC FP indicator is more complex, though unsurprising given its direct relationship with low income, with households in social housing and private rented accommodation being associated with a *higher* probability of LIHC FP than households who are owner occupiers, though as with the 10% indicator, owning a property with a mortgage is negatively associated with being LIHC FP. The signs of these AMEs appear to be driven by variations in incomes between tenure types rather than by variations in ENEX. For example, households with a mortgage had a median gross household income of £37,242 compared to £19,392

for households owning their property outright.[48] The importance of income in the relation between LIHC FP and social housing/ private renting is emphasised by their relative low ENEX median values, £699.99 and £687.07 respectively, compared with £789.07 for households owning their property outright.

Another difference between the expenditure-based indicators and reporting IAAW is the influence of children in a household. While the presence of children is negatively associated with reporting IAAW, it is positively associated with both 10% and LIHC FP. Again, temperature data would be valuable to understand whether these differences are due to households with children choosing to allocate a higher proportion of their income to ENEX to achieve comfortable temperatures for a longer part of the day, or due to households with children being unwilling to admit IAAW.

Neither is any association found between lacking central heating and 10% or LIHC FP in Table 6, unlike the positive association between IAAW FP and lacking central heating. Moreover descriptive statistics indicate a higher rate of expenditure based FP among those without central heating (10% FP: 12.1% vs 7.4%; LIHC FP: 19.0% vs 14.4%), differences which are significant at the 1% level. Factors correlated with a lack of central heating rather than the absence of central heating itself seem to be driving the descriptive statistics. This conclusion is reinforced for the LIHC indicator since median ENEX (although not ENEXShr) is higher among households *with* central heating, namely £799.73 compared with £712.35 for the sample as a whole.

Another difference across the indicators are the associations with the number of household members: there is limited association with IAAW, a negative association with 10% FP and a positive association with LIHC FP for households with 4 or more members. The negative association with the 10% indicator may be because larger households, after controlling for factors such as dwelling size, contain more potential income earners and so, on average, have higher gross incomes. For example, the mean unequivalised gross income for a 1-person household is £15,274 compared to £39,330 for a 7-person household. In contrast, the positive association between large households and LIHC FP is likely to be a mechanical consequence of equivalising income and deducting housing costs; the equivalised after housing costs gross income for a 1-person household is £23,640 compared to £13,431 for a seven person household.

Furthermore, the expenditure-based indicators in Table 6 show stronger associations with some of the low income proxies and less association with the self-assessed affordability indicators, than for IAAW in Table 4. Within the Best Predictor regressions (columns 5 to 8 in Table 4 and columns 3, 4, 7 and 8 in Table 6), having an investment income, receiving incapacity benefit and receiving income support all have associations with the 10% and LIHC FP indicators significant at the 1% level, but lack statistically significant associations with IAAW.[49] In contrast, in Table 4 reporting an inability to afford new clothes or to eat meat on alternate days or to invite visitors for food/drink are positively associated with IAAW at the 5% significance level or above, while in Table 6 they show limited significance. The housing problem indicators also show a reduction in their significance for 10% and LIHC FP compared to IAAW. Dwellings reported as suffering from damp or being in areas suffering crime, were significant at the 5% level or above in Table 4, but are not statistically associated with 10% and LIHC FP.

[48] The lower income of those owning properties outright is explained by the greater proportion of these households who had a head aged over 65, i.e. likely to be retired, compared to households who were still paying off a mortgage. 2.9% of households owning with a mortgage had head aged over 65, compared to 43.5% of households owning their property outright.

[49] The significance of a household head being unemployed also increases in Table 6.

Dummies representing the devolved administrations have a more consistent pattern of high statistical significance in Table 6 than Table 4. In Table 4 only living in Scotland (compared to England) has statistically significant association with IAAW at the 1% level, and this is only when the first lag of IAAW and the Best Predictor variables are included; i.e. living in Scotland is only positively associated with IAAW after controlling for affordability/housing condition problems. In contrast, living in any devolved administration, compared to England, is positively associated with 10% and LIHC FP in all the regressions in Table 6.

We note that the variations in the significance and signs of the survey wave dummies across the different FP indicators broadly follow the time trends for each FP indicator in Figure 1.

7. Policy Discussion and Conclusions

7.1 The implications of using different FP indicators

First, using expenditure-based FP indicators, especially the LIHC indicator, implies a higher prevalence of FP being identified than if perception-based indicators are used. Second, the present analysis confirms earlier studies in demonstrating limited overlap between perception-based and expenditure-based indicators. This limited overlap holds regardless of whether the 10% or LIHC indicator is used.

This limited overlap means the choice of FP indicator has a material impact on the type of households which would receive support under policies targeted using the different indicators. Most significantly, given the prominence of the age-related Winter Fuel Payment (WFP) in the UK, which involves £2 billion of expenditure per annum[50], the indicators show noticeably different associations with households headed by someone aged 65 or older. While no association is found between older households and 10% FP, reporting IAAW is negatively associated with older households, while LIHC FP is positively associated with older households.

While the positive association between older households and LIHC FP may be used to justify WFP[51], this association does not make LIHC FP a 'better' FP indicator, unless the efficacy of support for older households has been pre-determined. Similarly, the positive association between LIHC FP and larger households is a mechanical result of equivalising income, and so is linked to the metric's design rather than an independent empirical result. It is also interesting to consider whether the 'labelling' of WFP itself has influenced older households' perception of the affordability of energy and warmth.[52]

One way to explain the lack of overlap between the indicators is to suggest they are measuring different aspects of FP. The expenditure-based indicators, by identifying households with high ENEXShr/ENEX, may pinpoint households who achieve a reasonable heating standard only by restricting other forms of consumption; conversely reporting IAAW might identify situations when heating expenditure is being limited to enable other forms of consumption. Evidence to confirm such an intuitive interpretation depends on observing the temperatures achieved by the households identified by each indicator.

[50] See Table 4.17, pg 100, Office for Budget Responsibility (2019).
[51] WFP is available to those of pensionable age.
[52] Beatty et al. (2014) find evidence that, despite the WFP being a cash transfer, households spend a disproportionate amount of the transfer on fuel compared to a simple income increase suggesting the WFP 'label' is influencing their behaviour.

7.2 The importance of directly assessing in-home temperatures and heating preferences

Rather than identifying a 'best' FP indicator or confirming that different indicators are useful for different purposes, the results above suggest a lack of precision in moving from an intuitive understanding of FP to its practical identification. Rather than forming a composite FP indicator, which would sacrifice the information contained by the differences between the indicators, we propose adding an additional crucial piece of information which is currently unrecorded.

Current FP indicators do not assess either the temperatures achieved within homes or householders' preferences around the temperatures to be achieved. Ultimately householders' welfare depends on the services that energy provides, i.e. heat and light, for which energy consumption and energy expenditure provide only proxies. Without direct assessments of temperatures current FP indicators risk significant errors of both inclusion and exclusion, leading to a distorted picture regarding the prevalence and nature of cold homes. These errors will likely reduce the effectiveness of interventions designed to reduce the number of households living in the cold. In order to advance the research and policy agenda, datasets which combine temperatures, temperature preferences and the data to construct both perception-based and expenditure-based FP indicators are needed.

A householder self-reporting IAAW is indicating dissatisfaction with the temperature in their home, but does not necessarily identify the appropriate policy response. It could be that the householder prefers a particularly high temperature, where it is unclear that a policy intervention is justified. Equally, householders may report that warmth is affordable because they view a relatively low temperature as adequate; if this low temperature is associated with poor health, particularly in older respondents, policy intervention may nevertheless be justified.

High ENEX may again result from a household preferring a particularly high temperature, leading to an indication of FP. Moreover, a household might be identified as FP because they have a low income rather than elevated ENEX, where justification for an energy-specific intervention, rather than income support, may not be clear. Using modelled ENEX raises other issues. For example, if a household prefers low temperatures they may be wrongly identified as FP since modelled ENEX incorporates a standard the temperature to be achieved.

While the challenge of identifying FP/cold homes is not new, and the desirability of in-home temperatures is widely appreciated, much of the FP literature takes as given the unavailability of large datasets on in-home temperatures.[53] We argue that if is both possible and important to address this gap. First, as expenditure on FP alleviation increases the economic case for additional expenditure on FP measurement also increases: inadequate FP measurement now risks a greater misallocation of public money. Second, devices such as smart thermostats mean that in-home temperature and temperature preference data are already being collected on a large scale.

Given the political prominence of FP and the billions of pounds devoted by UK governments to alleviate FP/energy affordability, there is a strong case to gather temperature data and link it to FP statistics on a routine basis, say at 5 year intervals. The analysis of this paper and recommendations support the second Technical Recommendation in Hills' (2012) official FP review, which states "The Government should reinstate a component to its surveys that allows an up-to-date assessment of contemporary behaviour in terms of the temperatures of people's homes." Yet this change has not been implemented.

Some data on household temperatures had previously been collected. Hughes et al. (2019) note that the last very large scale collection of nationally representative (English) temperature data was in

[53] For example, see Thomson et al. (2017) and Tirado Herrero (2017).

1996 when the English Housing Condition Survey recorded indoor spot temperatures for 17,511 households.[54] Huebner et al. (2019) note that as a follow-up to the English Housing Survey in 2011-12 temperature data for 823 households, intended to be broadly nationally representative, was collected[55], while Oreszczyn et al. (2006) report data from 1,604 households in urban areas which received Warm Front interventions in the winters of 2001-02 and 2002-03.

These studies contain results which speak to the present analysis, but they do not allow a comparison of temperatures for the households reporting both perception- and expenditure-based FP indicators. Huebner et al. (2019) finds that LIHC FP is negatively associated with the number of hours households had a temperature above 18°C in the bedroom. Hamilton et al. (2017) report descriptive statistics showing that households in 10% FP had lower temperatures in their living room and bedroom than non-FP households.[56] Turning to perception-based indicators, Oreszcyzn et al. (2006) find that households reporting it was fairly or very difficult to pay bills had lower temperatures in their living room and bedroom, while lower temperatures were also recorded for those who were fairly or very dissatisfied with their heating, compared to those who were fairly or very satisfied. Last, looking at the effectiveness of FP interventions, Angelini et al. (2019) consider the impact of WFP on indoor temperatures as recorded by nurse visits for around 12,000 individuals. Using a regression discontinuity design they conclude that WFP eligibility did not result in an increase in home temperatures.

New technologies seem likely to lower the cost of obtaining large scale in-home temperature measurements. In particular, smart thermostats, as a by-product of their core function, seem to be gathering home temperature data at scale. For example, British Gas indicates that over 1.5 million households have its Hive system installed[57] and its privacy policy indicates that data on "rooms' temperatures, temperature settings, heating schedules"[58] is likely to be collected. Although the early adopters of smart thermostats may be on relatively high incomes, and so at low risk of FP, there are systems specifically targeted at social landlords, such as Switchee, used by over 45 housing associations.[59] In the long-term, widespread adoption of smart technologies may enable the direct identification of households living in the 'cold' who may warrant FP assistance, assuming privacy and data protection issues can be overcome.[60]

A number of papers already harness these new technologies in areas related to FP. For example, Huchuk et al. (2018) analyse data from over 10,000 Ecobee thermostats in North America to understand how households change their temperature settings according to season, climate and energy prices. Indeed, Ecobee runs a specific 'Donate your Data' programme[61] to encourage its users to provide anonymised data for scientific research, with Meier et al. (2019) providing further detail on this dataset. Turning to a different source of data, looking at older households in the UK, Kennard

[54] Hills (2012) implies the data collection actually took place in 1991. Vadodaria et al. (2014) suggests that 1991 analysis involved 25,000 households, while there was separate analysis in 1996.
[55] This data is used in Hamilton et al. (2017) and Huebner et al. (2018).
[56] A similar result is found for LIHC FP, although, the living room temperature difference is only significant at the 10% level.
[57] See https://www.britishgas.co.uk/smart-home/hive-heating.html (accessed on 30 July 2020).
[58] See the bullet "How you use Hive products" under "Personal information we collect", https://www.hivehome.com/privacy (accessed on 30 July 2020).
[59] See 'Affordable housing industry switching on to Switchee's innovative data tools', CITY A.M., Tuesday 21 April 2020, available at: https://www.cityam.com/affordable-housing-industry-switching-on-to-switchees-innovative-data-tools/ (accessed on 30 July 2020).
[60] Fergus and Chalmers (2020) move in this direction, but focus on appliance use rather than heat.
[61] See https://www.ecobee.com/donate-your-data/

et al. (2020) consider data from 77,743 UK Biobank participants who wore an activity tracker that took temperature readings of their environment. They consider how temperatures vary according to socio-economic variables and home heating type.

Of course such technologies do not offer a panacea to FP measurement issues and will present their own methodological issues regarding the precise way temperatures are captured etc. Furthermore, at least initially, smart thermostats are likely to be distributed unevenly across households so that some groups, such as private renters, may be under-represented. Another fundamental challenge will be for researchers to obtain permission to access to the temperature datastreams being captured. Another complication is that since smart thermostats are designed to reduce the cost of achieving a particular temperature, the temperatures achieved in smart thermostat homes will likely be higher than in other homes. Nevertheless they do offer a potential step change in understanding heating preferences and the prevalence of 'cold' homes.

7.3 Why the magnitude of FP's persistence matters

Appendix 2 presents descriptive statistics on the magnitude of FP's persistence. Whether households remain consistently FP for long periods of time has clear implications for the design of FP alleviation policies. A key observation of this paper, confirming Phimister et al.'s 2015 finding, is that households have a noticeably higher exit probability from FP than from income poverty. While there are reasons to be cautious about this observation, it is worth considering its implications. FP alleviation policies in the UK generally focus on permanent interventions, either energy efficiency improvements to dwellings or WFP which is available to older households on an annual basis. This contrasts to the most prominent income poverty interventions which are temporary and contingent on having a low income.

Both WFP and energy efficiency improvements should improve the welfare of recipient households. The policy question we highlight, but leave open, is whether non-permanent interventions, quite possibly income transfers, offer a more effective means to minimise the number of households living in the cold/FP. Shifting resources to time limited income transfers may enable a greater number of households temporarily living in the cold to be helped, or an increase in the size of assistance per household. While overall investments in home energy efficiency may be justified by their ability to reduce carbon emissions, this is a different policy objective to minimising FP. If the main objective is minimising the duration for which households live in FP, other interventions beyond energy efficiency interventions may be more appropriate.

8. Appendices

Appendix 1 – Lack of Adequate Heating Facilities

Error! Reference source not found. The discussion here follows the format of the equivalent discussion for IAAW in section 6.1. In Table 7 univariate regressions showing relationships with the other FP indicators are reported, before in Table 8 basic regressions are shown identifying associations with ENEX and household income, while in Table 9 the main regressions are reported.

Table 7 shows positive associations between the other FP indicators and reporting a lack of adequate heating facilities significant at the 1% level. The magnitude of the AME for the other perception-based indicator, IAAW, is more than ten times higher for IAAW than for the two expenditure-based indicators.

Explanatory Variable	Lack of adequate heating facilities indicator (1)	(2)	(3)	(4)
1. 10% fuel poor	0.033***			
2. LIHC fuel poor		0.031***		
3. Reports an inability to afford adequate warmth			0.382***	
4. Reports a lack of adequate heating facilities, period t-1				0.372***
Log likelihood	-8,862.50	-8,829.83	-8,494.60	-5,662.82
P-value, likelihood ratio test of joint significance	0.000	0.000	0.000	0.000
Policymaking variables	No	No	No	No
Best predictor variables	No	No	No	No
Number of observations	55,772	55,772	55,772	47,493
Number of households	10,465	10,465	10,465	9,400

Notes: * indicates statistical significance at the 10% level, ** indicates significance at the 5% level and *** indicates significance at the 1% level. The table reports average marginal effects on the probability of a household reporting a lack of adequate heating facilities in their home. A blank space indicates a variable was not included in the regression. In column (4) 8,279 observations were dropped as the sample is restricted to those cases where the lags of the four analysed fuel poverty indicators are available.

Table 7: Average marginal effects of alternative fuel poverty indicators on the probability of reporting a lack of adequate heating facilities in one's home, univariate regressions

An interesting feature of the regressions reported in Table 8 and Table 9 is the changing sign and significance of ENEX. The univariate regressions in columns 1 and 2 of Table 8 show a positive association between ENEXShr and reporting a lack of adequate heating facilities, however, the univariate regressions in columns 3 to 6 indicate that *both* ENEX and gross household income have a negative relationship with reporting a lack of adequate heating facilities. However, as discussed in section 6.1, treating income and ENEX as separate variables is the more appropriate specification. Column 8 of Table 8 indicates that the positive relationship between ENEXShr and reporting a lack of adequate heating facilities is driven by the dependent variable's negative relationship with gross household income. After controlling for household income, column 8 shows an insignificant relationship between ENEX and reporting a lack of adequate heating facilities. However, Table 9 indicates that when a larger number of control variables are included there is a statistically significant positive association with ENEX.

	Lack of adequate heating facilities indicator									
Explanatory Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
1. Energy expenditure share (%) - linear	0.001***									
2. Energy expenditure share (%) - quadratic		0.002***								
3. Annual energy expenditure (£ hundreds, 2008) - linear			-0.001**				0.000			
4. Annual energy expenditure (£ hundreds, 2008) - quadratic				-0.001***				0.000	0.000	0.000
5. Annual gross household income (£ thousands, 2008) - linear					-0.001***		-0.001***			
6. Annual gross household income (£ thousands, 2008) - quadratic						-0.001***		-0.001***	-0.000***	-0.000***
7. Annual net housing costs (£ hundreds, 2008) - quadratic									0.000***	0.000***
8. Reports a lack of adequate heating facilities, period t-1									0.348***	0.233***
9. No central heating										0.075***
10. No gas connection										0.023***
Log likelihood	-8,871.79	-8,835.31	-8,905.42	-8,904.31	-8,784.43	-8,773.63	-8,784.08	-8,773.07	-5,608.59	-5,238.54
P-value, likelihood ratio test of joint significance	0.000	0.000	0.019	0.016	0.000	0.000	0.000	0.000	0.000	0.000
Policymaking variables	No	No	No	No	No	No	No	No	No	No
Best predictor variables	No	No	No	No	No	No	No	No	No	No
Number of observations	55,772	55,772	55,772	55,772	55,772	55,772	55,772	55,772	47,973	47,973
Number of households	10,465	10,465	10,465	10,465	10,465	10,465	10,465	10,465	9,400	9,400

Notes: * indicates statistical significance at the 10% level, ** indicates significance at the 5% level and *** indicates significance at the 1% level. The table reports average marginal effects on the probability of a household reporting a lack of adequate heating facilities in the home. A blank space indicates a variable was not included in the regression. In columns (9) and (10) 8,279 observations were dropped as the sample is restricted to cases where the lags of the four analysed fuel poverty indicators are available. In regressions (5) and (7) 1 obervation was completely determined, in regressions (9) it was 9 observations and (10) it was 8 observations.

Table 8: Average marginal effects of income and energy expenditure on the probability of reporting a lack of adequate heating facilities in one's home, alternative specifications

The positive association between ENEX and a lack of adequate heating facilities in Table 9 contrasts with the lack of statistical association between ENEX and IAAW in Table 4. Another interesting feature of Table 9 is that once the Best Predictor variables are added, a lack of adequate heating facilities no longer has a statistically significant association with gross household income.

Compared to the IAAW regressions, any positive association between living in Wales and Scotland and reporting inadequate heating facilities disappears. However, in Table 9 there is a consistent negative association between living in Northern Ireland and reporting inadequate heating facilities which is statistically significant at the 1% level. One might think this is surprising since Northern Ireland has higher than average heating costs due to a limited gas grid and a reliance on heating oil. However, in Table 9 not having a gas connection is controlled for directly, so the negative relationship with being located in Northern Ireland is after the impact of the limited gas grid is accounted for. This may indicate that Northern Irish households view what constitutes 'adequate heating facilities' in a differently to English households.

Another difference with the IAAW results is that renting one's home, compared to owning it outright, is consistently associated with a higher probability of reporting inadequate heating facilities. That the AMEs' magnitudes for tenure type roughly double when only the Policymaking explanatory variables are used suggests a correlation between tenure type and perceived housing condition issues. Similarly, while no association is found between dwelling type and IAAW, those living in terraced houses or flats have a greater likelihood of reporting inadequate heating facilities than those living in detached properties. That the flat indicators have reduced statistical significance when the Best Predictor variables are added suggests a correlation between flats and perceived housing condition problems. Wald tests on the regressions coefficients confirm that including the Best Predictor variables offers an improvement in specification over the Policymaking regressions.

	Lack of adequate heating facilities indicator							
	Policymaking Explanatory Variables				Policymaking plus Best Predictor Explanatory Variables			
Explanatory Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
1. Lack of adequate heating facilities, period t-1		0.170***		0.172***		0.120***		0.120***
2. Annual gross household income (£ thousands, 2008) - quadratic	-0.000**	-0.000***			-0.000	-0.000		
3. Annual energy expenditure (£ hundreds, 2008) - quadratic	0.001***	0.001***			0.001**	0.001**		
4. Annual net housing costs (£ hundreds, 2008) - quadratic	-0.000	0.000			0.000	0.000		
5. 2001-02 wave	0.005**	-0.002	0.006**	-0.002	0.005**	-0.001	0.005**	-0.001
6. 2003-04 wave	-0.000	0.000	-0.000	0.000	0.004	0.003	0.004	0.004
7. 2004-05 wave	-0.005*	-0.004	-0.005*	-0.004	-0.000	0.000	-0.000	0.000
8. 2005-06 wave	-0.003	-0.003	-0.003	-0.003	0.002	-0.000	0.002	0.000
9. 2006-07 wave	-0.008***	-0.006**	-0.007**	-0.005*	-0.002	-0.001	-0.001	-0.000
10. 2007-08 wave	-0.007**	-0.005	-0.006**	-0.004	-0.003	-0.001	-0.002	-0.000
11. 2008-09 wave	-0.000	0.001	0.002	0.003	0.003	0.003	0.005	0.005
12. Wales	0.003	0.002	0.005	0.002	0.002	-0.000	0.002	-0.000
13. Scotland	-0.005	-0.003	-0.002	-0.002	0.000	-0.001	0.001	0.000
14. Northern Ireland	-0.023***	-0.018***	-0.020***	-0.015***	-0.017***	-0.014***	-0.015***	-0.013***
15. Owned with mortgage	0.003	0.003	-0.000	0.001	0.004	0.004	0.005*	0.005**
16. Social housing	0.028***	0.016***	0.027***	0.016***	0.014***	0.008***	0.015***	0.010***
17. Private rented	0.036***	0.019***	0.033***	0.018***	0.017***	0.009**	0.018***	0.010***
18. Semi-detached house/bungalow	0.004	0.004*	0.003	0.003	0.002	0.002	0.002	0.001
19. End terraced house	0.021***	0.013***	0.020***	0.012***	0.014***	0.010***	0.014***	0.009***
20. Terraced house	0.016***	0.012***	0.015***	0.011***	0.009**	0.006**	0.008**	0.006*
21. Purpose built flat	0.019***	0.016***	0.016***	0.013***	0.006	0.006*	0.005	0.005
22. Converted flat	0.039***	0.031***	0.035***	0.028***	0.015**	0.012**	0.014**	0.012**
23. Bedsit	0.048	0.030	0.045	0.029	0.056*	0.040	0.056*	0.040
24. No central heating	0.142***	0.078***	0.143***	0.078***	0.107***	0.062***	0.107***	0.062***
25. No gas connection	0.041***	0.028***	0.041***	0.028***	0.038***	0.027***	0.038***	0.028***
26. Household head aged 65 to 75	-0.016***	-0.007***	-0.015***	-0.007***	-0.007**	-0.002	-0.007**	-0.002
27. Household head aged 75+	-0.019***	-0.010***	-0.018***	-0.010***	-0.008**	-0.003	-0.008**	-0.003
28. Household head unemployed	0.010**	0.004	0.012**	0.005	0.003	-0.001	0.003	-0.001
29. Has investment income	-0.003	-0.001	-0.004**	-0.002	0.000	0.001	-0.000	0.001
30. Receives incapacity benefit	0.002	0.006	0.004	0.007*	-0.003	0.001	-0.003	0.002
31. Receives housing benefit	0.003	0.005	0.004	0.005*	-0.001	0.001	-0.001	0.001
32. Receives income support	0.004	0.002	0.006*	0.003	0.001	-0.000	0.002	0.000
33. Contains single parent(s)	-0.000	0.002	0.001	0.003	-0.003	-0.000	-0.003	-0.000
34. Contains children	0.001	0.000	0.002	0.001	-0.000	0.001	-0.000	0.001
35. Number of household members: 2	0.005*	0.003	0.005*	0.003	0.001	0.001	0.002	0.001
36. Number of household members: 3	0.011**	0.007**	0.011***	0.007**	0.005	0.003	0.006	0.004
37. Number of household members: 4	0.005	0.002	0.006	0.003	-0.001	-0.002	0.000	-0.001
38. Number of household members: 5	0.011*	0.006	0.011*	0.007	0.002	0.000	0.004	0.001
39. Number of household members: 6	0.008	0.008	0.009	0.010	0.001	0.003	0.002	0.005
40. Number of household members: 7+	0.001	-0.002	0.003	0.000	-0.010	-0.010	-0.008	-0.008
41. Has home computer					0.004*	0.002	0.004*	0.002
42. Number of rooms: 1					-0.014**	-0.013**	-0.014**	-0.012**
43. Number of rooms: 3					0.005	0.001	0.006	0.001
44. Number of rooms: 4					-0.003	-0.004	-0.002	-0.003
45. Number of rooms: 5					-0.005	-0.004	-0.003	-0.003
46. Number of rooms: 6					-0.007	-0.010**	-0.006	-0.008*
47. Number of rooms: 7+					-0.010	-0.010**	-0.008	-0.008*

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	Policymaking Explanatory Variables				Policymaking plus Best Predictor Explanatory Variables			
Explanatory Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
48. Loan/hire payments somewhat of a burden					0.008***	0.008***	0.008***	0.008***
49. Loan/hire payments a heavy burden					0.002	-0.002	0.002	-0.002
50. Problems paying for housing					0.009***	0.007**	0.009***	0.007**
51. Cannot afford holiday					0.014***	0.009***	0.014***	0.009***
52. Cannot afford to replace furniture					0.007**	0.005**	0.007**	0.005**
53. Cannot afford new clothes					0.003	0.003	0.003	0.003
54. Cannot afford to eat meat on alternate days					0.000	0.002	0.000	0.001
55. Cannot afford visitors for food/drink					0.007**	0.003	0.007**	0.003
56. Has condensation					0.036***	0.025***	0.036***	0.025***
57. Has a leaky roof					0.037***	0.037***	0.037***	0.038***
58. Has damp wall/floors					0.023***	0.017***	0.023***	0.017***
59. Has rot in windows/floors					0.027***	0.019***	0.028***	0.019***
60. Has crime in the local area					0.016***	0.013***	0.016***	0.013***
Log likelihood	-7,228.25	-4,996.21	-7,247.72	-5,011.10	-6,336.22	-4,460.87	-6,341.54	-4,466.56
P-value, likelihood ratio test of joint significance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Policymaking variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Best predictor variables	No	No	No	No	Yes	Yes	Yes	Yes
Number of observations	55,767	47,969	55,767	47,969	55,767	47,969	55,767	47,969
Number of households	10,465	9,400	10,465	9,400	10,465	9,400	10,465	9,400

Notes: * indicates statistical significance at the 10% level, ** indicates significance at the 5% level and *** indicates significance at the 1% level. The table reports average marginal effects on the probability of a household reporting that their dwelling lacks adequate heating facilities. A blank space indicates a variable was not included in the regression. Where a variable is labelled as quadratic the regression included both a linear and squared term of the variable, the reported average marginal effect for such variables is the combined change in probability associated with the linear and squared terms. In columns (2), (4), (6) and (8) 8,279 observations were dropped as the sample is restricted to cases where the lags of all four fuel poverty indicators. Selected base categories: rows 5-11 = 2002-03 wave; rows 12-14 = England; rows 15-17 = owned outright; rows 18-23 = detached house/bungalow; rows 26 and 27 = Household head aged under 65; rows 35-40 = household contains 1 person; rows 42-47 = dwelling has 2 rooms; rows 28-34 and 50-60 are all binary variables where the base category is the opposite of the variable statement. Columns (3), (4), (7) and (8) exclude the expenditure, income and housing cost variables to allow comparison with the energy expenditure based fuel poverty indicators. In columns (1), (3), (5) and (7) 5 observations were dropped for May perfectly predicting adequate heating facilities, while in columns (2), (4), (6) and (8) 4 observations were dropped for the same reason. In columns (5) and (6) 4 observations of having adequate heating facilities were completely determined. Variables/categories frequently significant at the 10% level or above (direction in brackets) but not reported are: interview month - October, November, December and January (positive), has two or more cars (negative), has a dishwasher (negative).

Table 9: Average marginal effects on the probability of a household reporting a lack of adequate heating facilities

Comparing the lack of adequate heating facilities results with the expenditure-based FP indicators, while being in a flat or terraced house is frequently associated with a higher probability of reporting inadequate heating facilities, Table 6 shows these types of dwelling are generally associated with a lower probability of expenditure-based FP. Similarly, for the 10% indicator, having a housing tenure other than outright ownership is associated with a lower probability of FP, however, in Table 9 being in a rented property is positively associated with reporting inadequate heating facilities **Error! Reference source not found.**.

As one might expect, there is a positive relationship between lacking central heating and/or a gas connection and reporting inadequate heating facilities. The AMEs for the absence of central heating are particularly large, with this issue being associated with around a 14 percentage point increase in the probability of reporting a lack of adequate heating facilities in the Policymaking regressions

when the lag of the dependent variable is excluded. In the same two regressions, lacking a gas connection is associated with a 4.1 percentage point increase in the probability of reporting a lack of adequate heating facilities.

As with reporting IAAW, reporting a lack of adequate heating facilities has a negative association with households headed by those over 65. Compared to the IAAW regressions, the Best Predictor regressions in Table 9**Error! Reference source not found.** show an increase in the statistical significance of the household head age variables when the lagged dependent variable is not included. This is particularly true for households with a head aged 65 to 75. In contrast to the other FP indicators, the receipt of benefits and a household containing children have almost no statistically significant associations with reporting a lack of adequate heating facilities.

Further differences to the IAAW regressions include that reporting an inability to afford clothes or to afford to eat meat on alternate days do not have statistically significant associations with reporting inadequate heating facilities. This pattern is more in keeping with the expenditure-based FP indicators, however, unlike the expenditure-based FP indicators, all the housing condition problem indicators are positively associated with reporting a lack of adequate heating facilities at the 1% level.

Appendix 2 – Evidence on the persistence of fuel poverty

The BHPS' panel nature enables an assessment of FP's persistence. The magnitude of persistence is important as there has been an emphasis on tackling FP through energy efficiency interventions which are 'permanent', i.e. they increase heat affordability over a large number of time periods. If households are only in FP for limited time, one may question whether other 'temporary' interventions, such as time limited income transfers, may be a more cost-effective.

Here we only report descriptive statistics rather than conducting a full panel data analysis. However, these descriptives fit with our questioning of some of the foundations of FP policy in the UK.

A2.1 Persistence Descriptive Statistics

Figure 6 reports the percentage of households who were FP in period *t* that were not FP in period *t+1*.[62] To provide context to the FP exit probabilities, the probability of exiting income poverty[63] is also reported. Figure 6**Error! Reference source not found.** shows that: (i) the exit probabilities for all FP types are noticeably higher than for income poverty; and (ii) in all years, except 2007-08, a majority of households who lived in IAAW or 10% FP in one year had exited FP by the following year. Both observations question whether permanent energy efficiency interventions are the lowest cost method of alleviating FP, when income poverty, which is more persistent, is primarily alleviated through temporary income related cash transfers. As one might expect, given that it is a 'relative' metric[64], in all years, apart from 2007-08, the LIHC indicator had the lowest exit probability of the FP indicators. The differences between the FP and income poverty exit probabilities are all significant in

[62] This graph**Error! Reference source not found.** uses a dataset of 42,241 observations (9,011 households) where households were required to have sufficient data to be in the analysed sample for at least two consecutive waves. The results are very similar if one restricts analysis to households who did not move house between waves, or uses a larger dataset where households simply need to report the FP indicators (and not explanatory variables) in adjacent waves.

[63] We follow the UK definition of income poverty: the income poor are those with an income below 60% of median (gross) income, where income is equivalised.

[64] A movement in a household's relative position in the income or ENEX distributions over time is less likely than an absolute movement in income or ENEX, as relative movements exclude movements that are common to all households.

all years at the 1% level, with the exception of the comparison with IAAW FP in 2007-08 where the difference is significant at the 5% level.

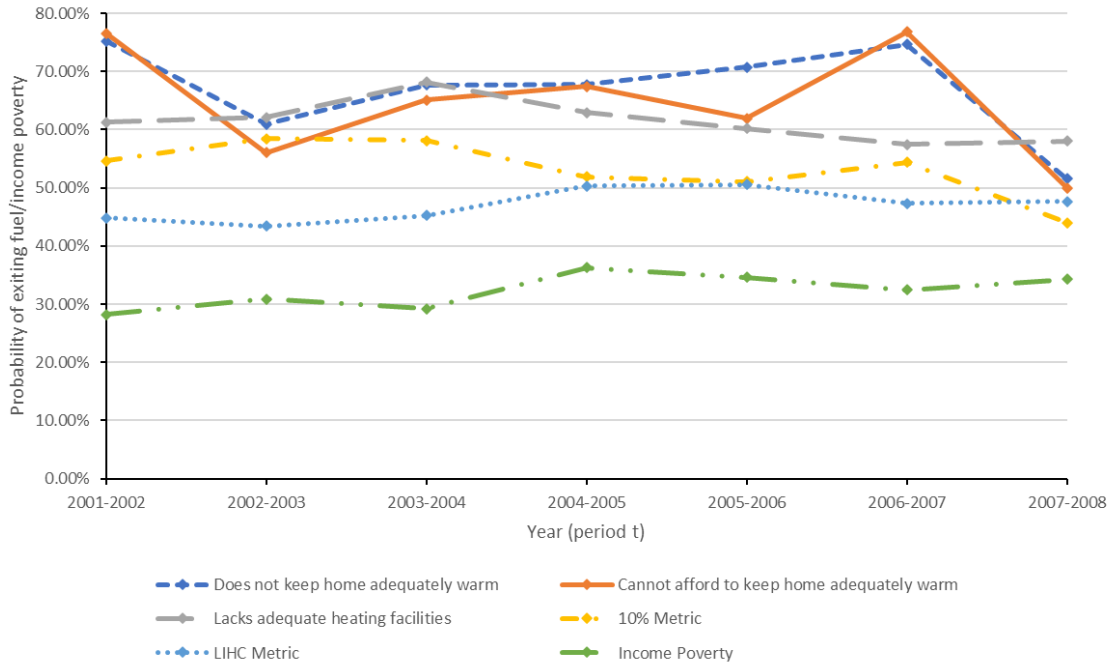

Figure 6: **Percentage of fuel/income poor households in period t that were not fuel/income poor in period *t+1* in the analysed sample, 2001-02 to 2007-08**

Figure 7 reports the number of time periods in which a particular household identified themselves as FP conditional on being identified as FP at least once. To be considered for inclusion Figure 7 a household had to provide sufficient data to be included in the analysed sample in all eight waves.[65] Of the households with sufficient data, 3.75% reported IAAW in at least one year, 22.8% were 10% FP in at least one year and 37.3% were LIHC FP in at least one year.

Figure 7 again shows comparatively low persistence in the perception-based FP indicators. 61.3% of those who reported IAAW at least once reported that they faced this problem only once, while 85.7% reported this issue in no more than two waves. There also appears to be limited persistence with 10% FP since 69.4% of households in this type of FP at least once experienced it in no more than two periods. However, LIHC FP is noticeably more persistent: only 33.2% of those LIHC FP at least once were LIHC FP only once and 22.7% of households in LIHC FP at least once were in FP for between 5 and 8 waves.

[65] 3,197 households met this condition.

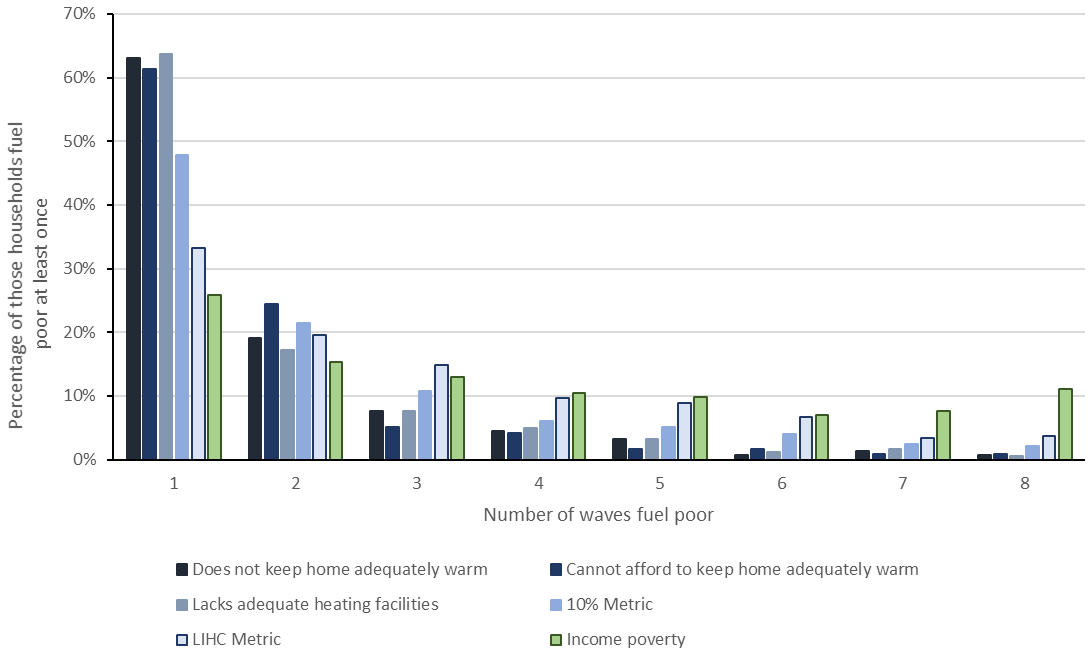

Figure 7: Number of waves in which a household was identified as fuel poor, conditional on being identified as fuel poor at least once and present in all waves 2001-02 to 2008-09

A2.2 Robustness of the persistence statistics

It is important to consider whether the persistence results above are robust. In broad terms the finding that FP is less persistent than income poverty seems reasonably solid.

First, the BHPS does not indicate whether households received interventions that reduced the persistence of their FP spell. Overall, the results show the persistence of FP *after* FP alleviation policies have been applied to households. However, for the comparison with income poverty it is important to note that the persistence of income poverty is also shown after policy interventions. For policy interventions to explain the gap in persistence, it must be that FP interventions are noticeably more effective than income poverty interventions. However, this seems unlikely given the FP literature's conclusion that it is hard to effectively target FP households[66].

Another concern is that FP persistence is reduced by attrition, i.e. households dropping out of the survey. Again, differences in attrition across the poverty indicators matter, rather than the absolute level of attrition. Table 10 reports the average rate of attrition per period for households reporting each poverty indicator. The table also reports the differences in attrition rates between the various types of FP and income poverty. One can adjust the exit probabilities in Figure 6 by assuming all those who drop out after being identified as FP/income poverty in period t, would have remained in FP/income poverty, if they had remained in the survey. After this adjustment it is still possible to state that, at the 1% significance level, in each survey wave the FP indicators have a higher exit probability than income poverty significant.

[66] For example, see Walker et al. (2013).

Group of respondents	Percentage of those identified as fuel poor at period t recorded as missing in period t+1	Difference to attrition rate for income poverty
All respondents	14.7	-2.7
Does not keep home adequately warm	18.2	0.8
Cannot afford adequate warmth in the home	18.6	1.2
Lacks adequate heating facilities	20.5	3.0
10% Metric	18.0	0.6
LIHC Metric	16.3	-1.2
Income poverty	17.4	-

Data is pooled across all analysed time periods. The last period t is 2007-2008 and the number of observations is 49,535. To be included in period t a household had to have all the data required for the main regressions. A household is classed as missing in period t+1 if it did not provide all the data required for the main regressions.

Table 10: Percentage of respondents identified as fuel poor according to different fuel poverty indicators in period t that lacked the required data to be part of the analysis in period t+1

One might think the persistence results could be affected by the trajectory of energy prices and, therefore, ENEX over the sampled period. As noted previously, Deller and Waddams Price (2018) indicate that the period 2001-02 to 2004-05 was a period when median ENEXShr was unusually low and, hence, was a time of particularly easy energy affordability. It seems likely that this relative affordability does affect the results above. Between 2006-07 and 2007-08 (a period of rising energy prices) the FP exit probabilities fell by 10.4 percentage points for the 10% indicator and by 26.8 percentage points for the IAAW indicator. However, Deller and Waddams Price indicate that, by 2009, median ENEXShr was roughly back to its long-run level. Significantly, the exit probabilities for the FP indicators in 2007-08[67] in Figure 6 remain noticeably above the exit probability for income poverty.

The lower persistence of perception-based FP relative to expenditure-based FP/income poverty may be elevated by two factors. First, the perception-based indicators may be particularly context dependent. A report of IAAW may be disproportionately influenced by the conditions at, or in the days immediately prior to, interview. If so, differences in reports of IAAW may be influenced by, for example, variations in weather conditions between interview days rather than by a change in the fundamental position of a household. Second, it is not certain that the same household member answered the questions for the perception-based indicators in all years. This highlights a further complexity in identifying FP in multi-person households: views about what constitutes adequate warmth and affordability may vary between household members. However, the expenditure-based FP indicators (and income poverty) may themselves have inflated exit probabilities, due to the tendency to round ENEX, as discussed in section 3.

Last, statistics from our sample might overstate income poverty persistence. This is because median gross income is weighted to represent the median gross income for the UK as a whole. The analysed data significantly oversamples devolved administrations which have lower household incomes than England, hence, that a small proportion of households exit income poverty between periods may be structural. However, using unweighted median incomes, i.e. removing the structural element, indicates the impact of this issue is small. Averaged across all time periods, an unweighted median income increases the income poverty exit rate by only 1.0 percentage points. Similarly, using unweighted medians increases the percentage of households in Figure 6 that were income poor in only one period by only 1.8 percentage points.

[67] In this year the t+1 period is 2008-09.

A2.3 Existing Literature on Fuel Poverty Persistence

A number of existing papers consider FP dynamics. While these papers often provide full econometric models of FP dynamics, the descriptive statistics nevertheless highlight that for policymaking the magnitude, as well as the existence of persistence, is important. Compared to some of the papers the analysis benefits from analysing a greater number of time periods.

Roberts et al. (2015) use BHPS data between 1997 and 2008 to consider persistence in expenditure-based FP with a discrete hazard model. Compared to Roberts et al., we consider perception-based indicators and use a 10% FP metric that matches the official English FP definition.[68] The exit probabilities for our 10% metric are similar to Roberts et al. In their regressions, Roberts et al. find greater persistence among urban than rural households. The authors note that, depending on the extent of persistence, different households may require different FP interventions.

The other assessment of FP persistence in the UK is BEIS (2018). However, as BEIS acknowledges their analysis is weakened by the fact that it does not actually track individual households through time. Instead, they predict 'churn' in FP households by running their model projecting headline rates of LIHC FP multiple times. This methodology may explain why they predict only 16% LIHC FP households moved out of FP between 2016 and 2017.

Turning to studies in other countries, Phimister et al. (2015) look at persistence in expenditure-based FP and a composite perception-based indicator[69], using Spanish panel data covering 4 years. Again, Phimister et al. find the exit probability from 10% FP is higher than for income poverty (55.9% vs 30.6%). That Phimister et al. report a noticeably lower exit probability from perception-based FP than the present paper data probably reflects the broader definition of Phimister et al.'s composite indicator.

Chaton and Lacroix (2018) consider FP dynamics in France using perception-based FP indicators. They find that households further up the income distribution have higher odds of moving out of FP/severe FP, although, their analysis uses only three years of data. In a similar vein to ourselves, they suggest direct subsidies for energy costs may be most appropriate if FP is transitory whereas energy efficiency improvements are more suitable where FP is a chronic phenomenon.

Extending the study of FP dynamics to less developed economies and a different set of indicators, Alem and Demeke (2020) find persistence in FP for Ethiopian households in a dynamic probit model. Last, Poggi and Florio (2010) consider the dynamics of households reporting arrears on their utility bills using pan-European data between 1994 and 2001. Using a dynamic probit model, they identify a positive relationship between the first lag of utility bill arrears and reporting utility bill arrears in the current period.[70]

[68] Unlike the official 10% indicator, Roberts et al.'s indicator uses equivalised after housing costs income as the denominator.

[69] The composite indicator classifies a household as FP if they cannot afford an appropriate temperature in winter or their dwelling suffers from leaks, damp or rot or the household has been late with their water, energy or community cost bill in the last year.

[70] A positive relationship is also found between utility bill arrears in 1994 and utility bill arrears in the present period.

Appendix 3 - Fuel poverty indicators

A3.1 Official fuel poverty definitions

DECC/BRE (2016) describes the official English FP statistics' methodology.

10% metric A household is FP if the value of the following ratio exceeds 0.1:

$$FP\ Ratio = \frac{Required\ Fuel\ Costs}{Income}$$

Income is net of tax and benefits.

LIHC metric This definition involves two thresholds, a household is FP if both:

1. Required fuel costs are above the national median

AND

2. Income remaining *after* the deduction of required fuel costs is below the official poverty line.

Income is net income after the deduction of housing costs and equivalisation[71], where housing costs are restricted to mortgage and rent payments (net of housing benefit). The official poverty line is defined as 60% of median equivalised disposable income[72]. When calculating the LIHC metric required fuel costs are also equivalised using a different equivalisation factor.

The official annual FP statistics are based on English Housing Survey (EHS) data from two consecutive waves which combines a household interview with a physical survey for around 6,000 households. Required energy use is based on the EHS's physical survey and aggregates four estimates reflecting: space heating, water heating, lights and appliances, and cooking. Each of these estimates is calculated based on an engineering model and a set of assumptions, such as, that all households aim to heat their main living space to the same temperature. In contrast, the present analysis is based on households' self-reports of their ENEX, which will vary according to households' differing preferences etc.

A3.2 BHPS data for the expenditure-based indicators

The ENEX used to calculate the 10% and LIHC indicators in our analysis refers to the 12 months prior to a household's interview. Four questions separately record expenditures on electricity, gas, oil and coal/other fuels. For example, for electricity, the question was:

"In the last year, since September 1st 1999, approximately how much has your household spent on domestic fuel starting with…Electricity"[73]

The expenditures on each fuel are then summed to give total ENEX.

The 10% indicator is calculated from total ENEX divided by annual gross household income (inclusive of benefits). Calculating the LIHC indicator is more involved as median ENEX and the income poverty line need to be estimated for each year. Since the booster samples mean the devolved administrations are oversampled, household weights supplied with the BHPS are applied to make the median estimates representative of the population of UK households. Also, to ensure

[71] For after housing costs equivalisation factors see Table 10, pg 50, DECC/BRE (2016).
[72] Equivalised after housing costs net income.
[73] The reference year changed with each survey wave. If an interview occurred in a month other than September, it is unclear how this question was adjusted.

representativeness, the medians are calculated using all households that answer the questions required to produce the LIHC indicator. This is a less restrictive requirement than for the main analysed sample where a household must provide answers for all the variables detailed in Section 3.

A3.3 Perception-based survey questions

The 'Inability to keep home adequately warm' indicator comes from the question:

"Here is a list of things which people might have or do. Please look at this card and tell me which things you (and your household) have or do? Keep your home adequately warm"

A household responding *No* to this question, is marked as being unable to keep their home adequately warm. If a household answered *No* to the question above, they were then asked the following question:

"Would you like to be able to keep your home adequately warm, but must do without because you cannot afford it?"

If a household responded *Yes* to this second question, they have been marked as IAAW FP.

A household was marked as lacking adequate heating facilities if they answered *Yes* to the following question:

"Does your accommodation have any of the following problems? Lack of adequate heating facilities"

Appendix 4 – Additional Materials

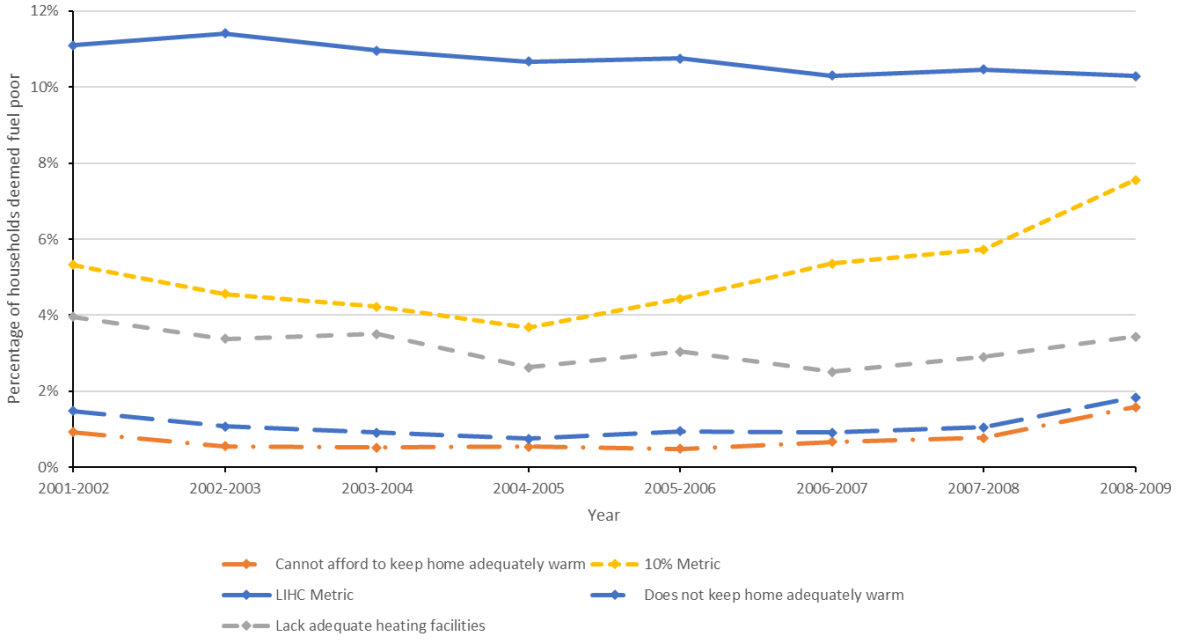

Figure 8: UK population estimates of rates of alternative fuel poverty indicators, 2001-02 to 2008-09

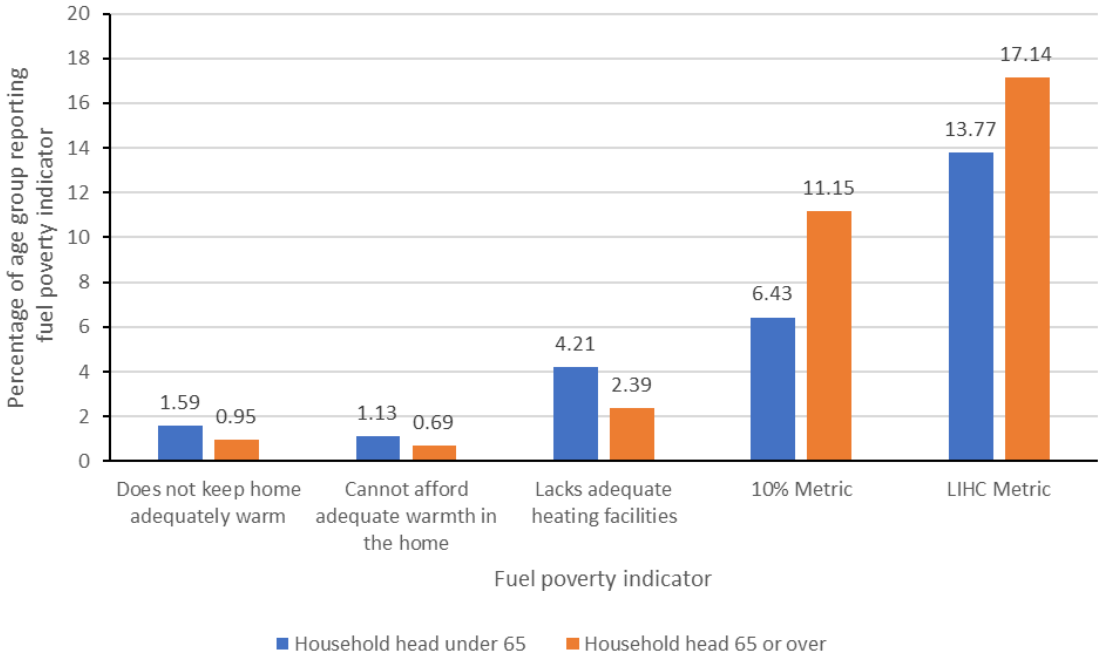

Figure 9: **The percentage of households in fuel poverty by age of household head, pooled data 2001-02 to 2008-09**[74]

	Does not keep home adequately warm	Cannot afford to keep home adequately warm	Lacks adequate heating facilities	10% Metric	LIHC Metric
Does not keep home adequately warm	1.000				
Cannot afford to keep home adequately warm	0.845***	1.000			
Lacks adequate heating facilities	0.261***	0.203***	1.000		
10% Metric	0.055***	0.059***	0.046***	1.000	
LIHC Metric	0.050***	0.057***	0.058***	0.511***	1.000

Notes: The table reports Pearson's correlation co-efficients for each pair of fuel poverty indicators. *** indicates the correlation is significantly different from zero at the 1% level. The high correlation co-efficient between 'Does not keep home adequately warm' and 'Cannot afford to keep home adequately' results from the survey's question structure . The data covers 55,772 observations from 10,465 households.

Table 11: Pearson's correlation coefficients between pairs of fuel poverty indicators, pooled data 2001-02 to 2008-09

[74] The equality of the fuel poverty rates between households with a head aged under 65 and those aged 65 and over is rejected at the 1% significance level for all five indicators.

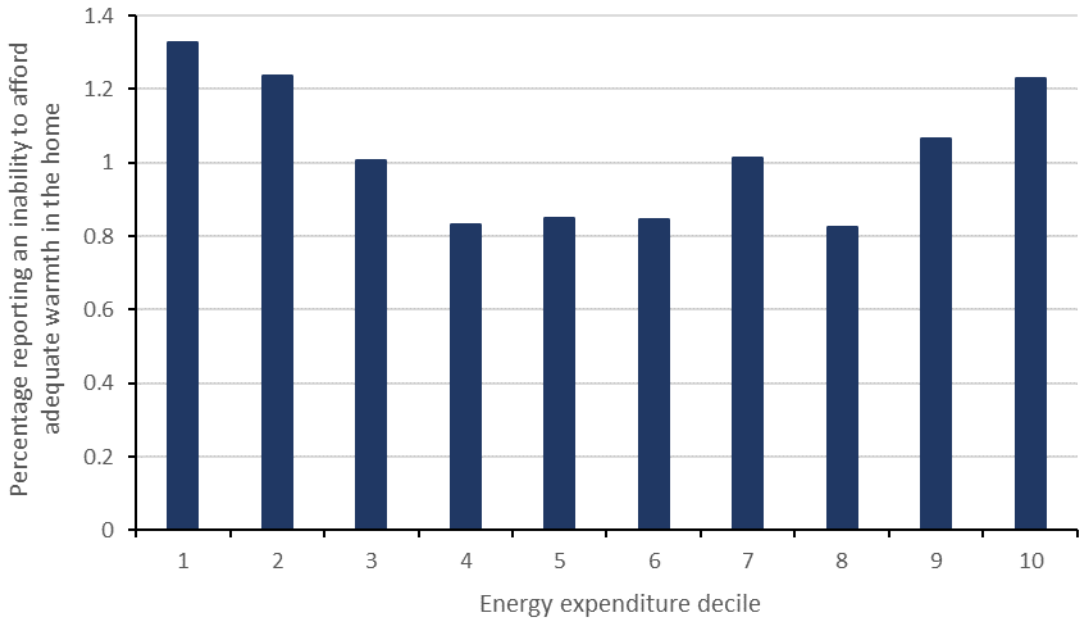

Figure 10: Percentage of observations where an inability to afford adequate warmth in the home is reported by energy expenditure decile, pooled data 2001-02 to 2008-09

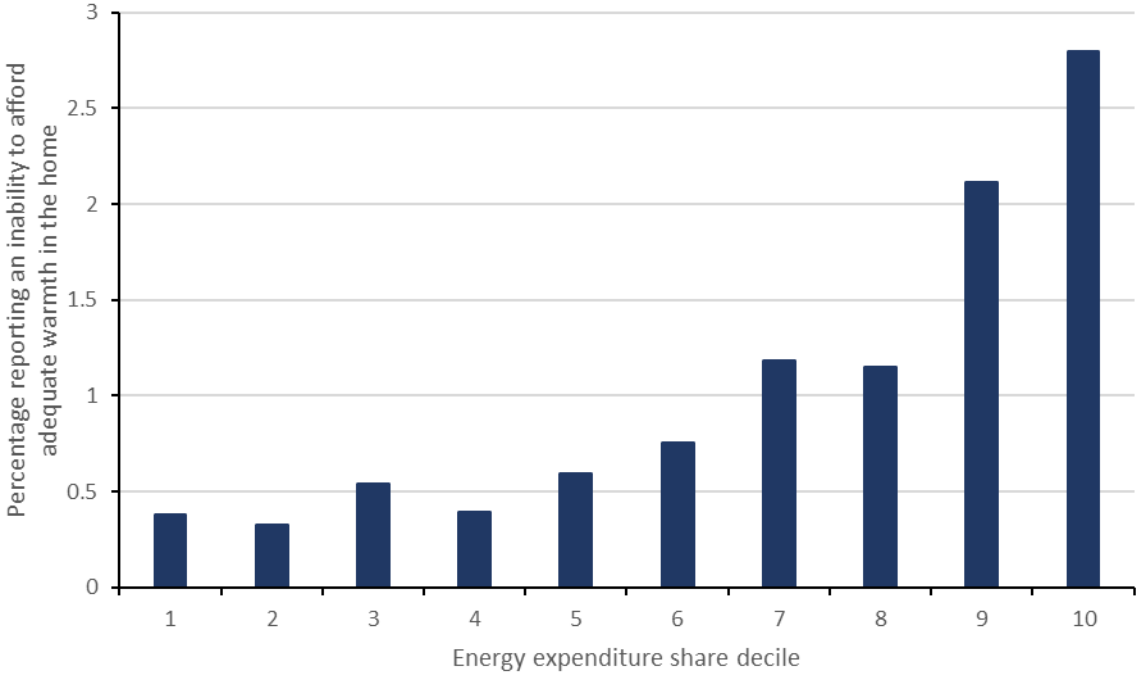

Figure 11: Percentage of observations where an inability to afford adequate warmth in the home is reported by energy expenditure share decile, pooled data 2001-02 to 2008-09

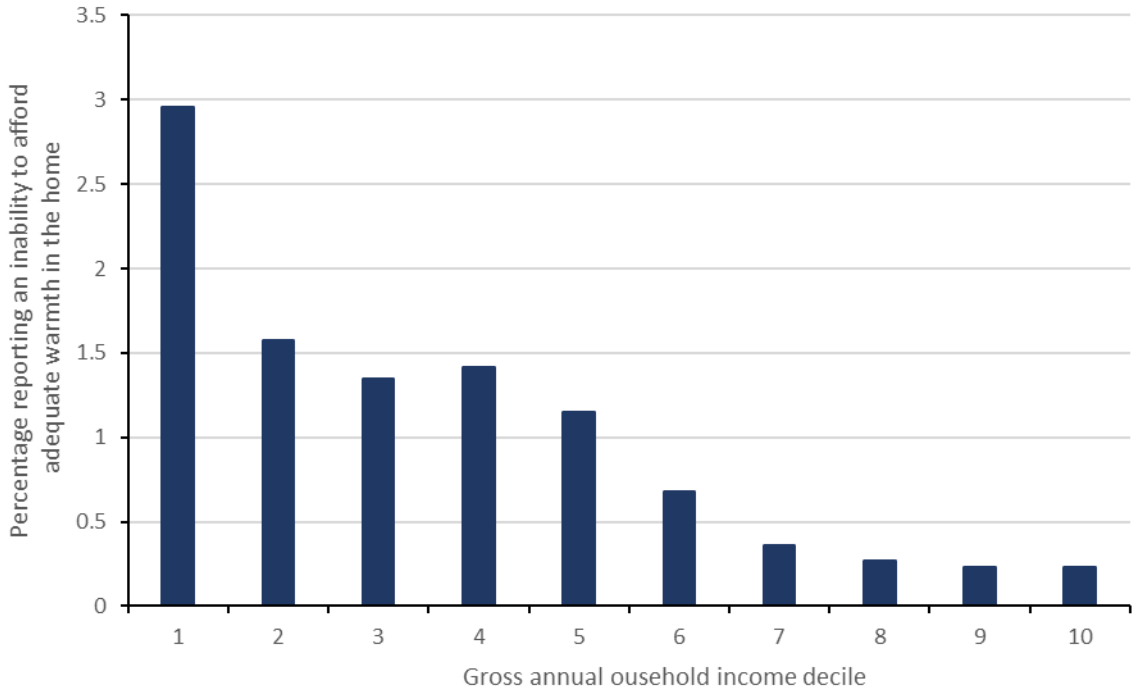

Figure 12: Percentage of observations where an inability to afford adequate warmth in the home is reported by gross annual household income decile, pooled data 2001-02 to 2008-09

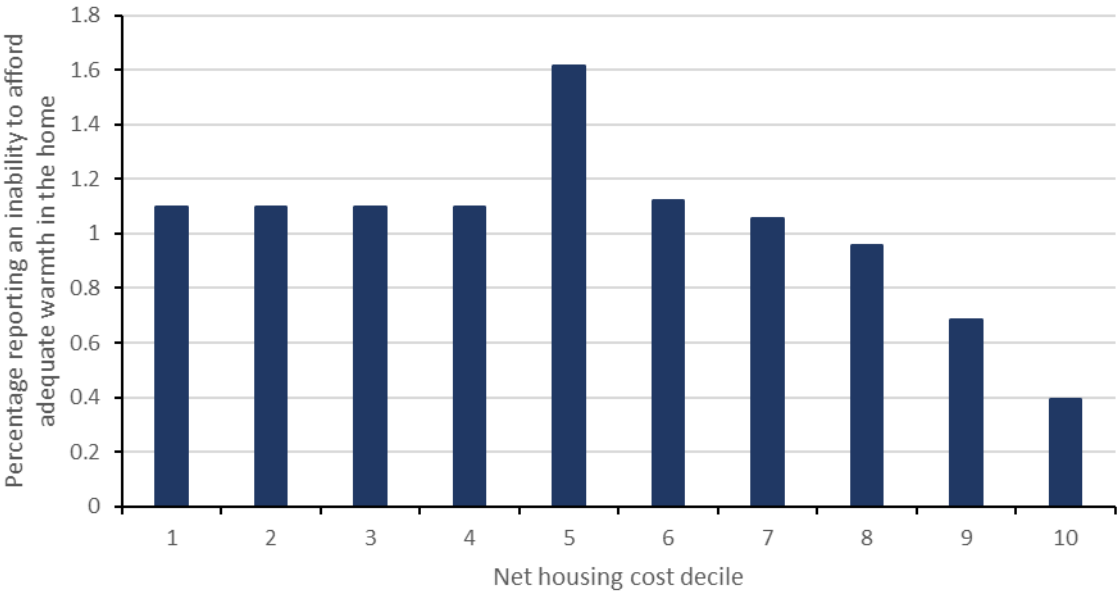

Figure 13: Percentage of observations where an inability to afford adequate warmth in the home is reported by net housing cost decile, pooled data 2001-02 to 2008-09[75]

[75] In the first three deciles the net housing costs of all households is zero, while in the fourth decile all but 12 observations involve net housing costs of zero.

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