The elephant in the energy room: establishing the nexus between housing poverty and fuel poverty

Andrew Burlinson[*], Monica Giulietti[†] and Giuliana Battisti[§]

Abstract

This paper contributes to the literature on fuel poverty by bringing together the 'housing-cost-induced-poverty' definition and the 'low-income-high-cost' indicator. Relying on the housing-cost-induced-poverty definition, this paper identifies three 'dimensions' of fuel poverty: 1) income-poverty-high-cost; 2) housing-cost-induced-poverty-high-cost; and, 3) fuel-cost-induced-poverty-high-cost. After breaking down the underlying structure of the low-income-high-cost framework, this paper proposes an alternative conceptual definition of fuel poverty and puts forward an empirical strategy which can help to identify the households most in need of financial and energy-related support. An application based on energy cost data in England allows us to identify several policy implications following from our proposed approach.

Keywords: Fuel poverty, housing poverty, energy efficiency, multinomial logit

JEL codes: Q4, I32, D1, C1

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* School of Business and Economics, University of Loughborough, Loughborough, UK, email: A.C.Burlinson@lboro.ac.uk
† School of Business and Economics, University of Loughborough, Loughborough, UK, email: M.Giulietti@lboro.ac.uk
§ Warwick Business School, University of Warwick, Coventry, UK, email: Giuliana.Battisti@wbs.ac.uk

1. Introduction

Over three decades, fuel poverty has been recognised as a distinct form of poverty, arising primarily from the interactions between energy prices, energy efficiency and low income (Moore, 2012). Previous research suggests that fuel poverty can have debilitating effects (Liddell and Morris, 2010), limit the life chances of children (Harker, 2006) and lead to excess winter mortality (Healy, 2003; Marmot Team Review, 2011). Age UK (2012) estimated that the National Health Service (NHS) incurs a cost in order of £1.3 billion per annum to provide services to elderly people suffering from conditions related to cold homes. It is estimated that around one tenth of English households are in fuel poverty (2.5 million in 2015/6), many of whom include vulnerable single parents, children and elderly people (BEIS, 2017). Although measures of fuel poverty vary across different European countries, estimates of the prevalence of fuel poverty for the EU27 range between less than 5% (e.g. Sweden and Finland) to over 40% (Bulgaria) [1] (Thomson et al., 2016). As several European countries are engaged in the fight against fuel poverty (e.g. France and Republic of Ireland), reliable and transparent indicators of fuel poverty are necessary to help policymakers address fuel poverty and the associated social issues.

While the measurement of fuel poverty has often relied on subjective approaches (Healy and Clinch, 2002; Waddams Price et al., 2012), objective measures, such as the Low-Income-High-Cost (LIHC) indicator (Hills 2011, 2012), are favoured by the United Kingdom's government and are gaining traction in EU-based research (Legendre and Ricci, 2015; Bouzarovski and Tirado Herrero, 2017). However, the LIHC indicator is an opaque instrument, which draws upon vast amounts of household and property information to construct 1) the poverty threshold (i.e. 60% of the national median equivalised after housing costs income[2], adjusted for required[3]

[1] Households are defined as fuel poor if they answer affirmatively to the question: are you able to keep your home adequately warm? Subjective measures have helped gauge the prevalence of fuel poverty in the EU in the absence of national (and uniform) objective indicators (Healy and Clinch, 2002; Thomson and Snell, 2013).

[2] Definitions of income, housing and energy costs and the household are provided in the Appendix, together with the equivalisation factors located in Table A1 and Table A2 respectively

[3] Importantly, required energy costs are calculated on the basis of household needs (e.g. minimum internal temperatures, adequate lighting, ample hot water) rather than actual energy expenditure, in order to circumvent the problem of energy rationing (BEIS, 2017). Note also that the reduction in

energy costs) and 2) the energy cost threshold (i.e. the national median of required equivalised energy costs).

A central pillar of the LIHC definition is the process of deducting housing costs from income to better reflect household disposable income (Hills, 2012). The public debate has been inflamed by the fact that households with below average incomes have seen a rise in housing expenditure of around £714 on average, compared to a fall of £217 for those with incomes above average, over the period since the financial crisis (2007/8 to 2015/6) (FT, 2017). Whereas, during the same period, the average fuel poverty gap in real terms has crept up from £324 to £353 (BEIS, 2017). This paper develops a framework that generates a clearer understanding of how the incidence of low income and high housing and energy costs affect the composition of fuel poverty.

In doing so, this paper attempts to move beyond the fall-back position that fuel poverty is best remedied by schemes primarily designed to improve energy efficiency, rather than by other means such as supporting income (Middlemiss, 2016). Utilising three key economic variables – income, housing costs, and energy costs – we put forward a conceptual and empirical framework that brings to the surface *three dimensions* of poverty underpinning the LIHC indicator: 1) income-poverty (IP); 2) housing-cost-induced-poverty (HIP); and, 3) fuel-cost-induced-poverty (FIP). In doing so, it becomes clear, *by construction*, that for households who find themselves below the poverty threshold – either due to low-income (i.e. IP) or to housing costs (i.e. HIP) (Kutty, 2005) – deducting the required amount of income to achieve acceptable levels of energy services pushes those households even further below the poverty threshold. Whereas, for the latter (FIP) group deducting the required energy costs from income (adjusted for housing costs) is the trigger that pushes the households below the poverty threshold, an issue that Legendre and Ricci (2015) (LAR hereafter) refer to as *fuel vulnerability*.

Our conceptual and empirical framework is distinct from the 'after-fuel-cost-poverty' approach, which assumes that *all* households below the poverty threshold are in fuel poverty after deducting fuel costs (Hills, 2011; LAR, 2015). Similarly, LAR (2015)

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required energy costs needed to bring a household below the threshold (the 'fuel-poverty-gap') can be used to estimate the aggregate or average depth of fuel poverty.

propose that households below the poverty threshold after deducting energy costs, but not before, are *fuel vulnerable* using the after-fuel-cost-poverty approach. Our proposed strategy departs from this approach by invoking the HIP definition and applying the energy cost threshold, which implies that all households within the LIHC group can be considered fuel vulnerable.

More specifically, within the LIHC group, income-poor and housing-cost-induced-poor households are vulnerable to relatively high energy costs albeit from a precarious position because they are already in poverty prior to deducting energy costs from their income (i.e., IP-HC and HIP-HC, respectively). Within the LIHC group, the fuel-cost-induced-poor group are vulnerable to relatively high energy costs albeit from a less precarious position because they are pushed into poverty exclusively after deducting energy costs (i.e. FIP-HC).

Applying a multinomial logit framework to data from the English Housing Survey, a nationally representative sample of households and housing stock, this paper reveals that the three dimensions of poverty contained within the LIHC are statistically differentiated. This finding has important policy implications, not only for the English definition of fuel poverty, but also for any (fuel) poverty measure which relies on the after-housing-cost (energy-cost) approach. By acknowledging the information underpinning the construction of the LIHC indicator, the present study not only adds to the existing literature in this area by proposing alternative definitions of fuel poverty (IP-HC, HIP-HC and FIP-HC), through the lens of 'housing-cost-induced-poverty' and LIHC indicators; but also develops a broader set of policy measures aimed at specific dimensions of fuel poverty.

The rest of the paper is structured as follows: Section 2 outlines our conceptual and empirical framework that brings to the surface three *dimensions* of fuel poverty. Section 3 describes our data, methodology and results, before providing concluding remarks and policy insights in Section 4.

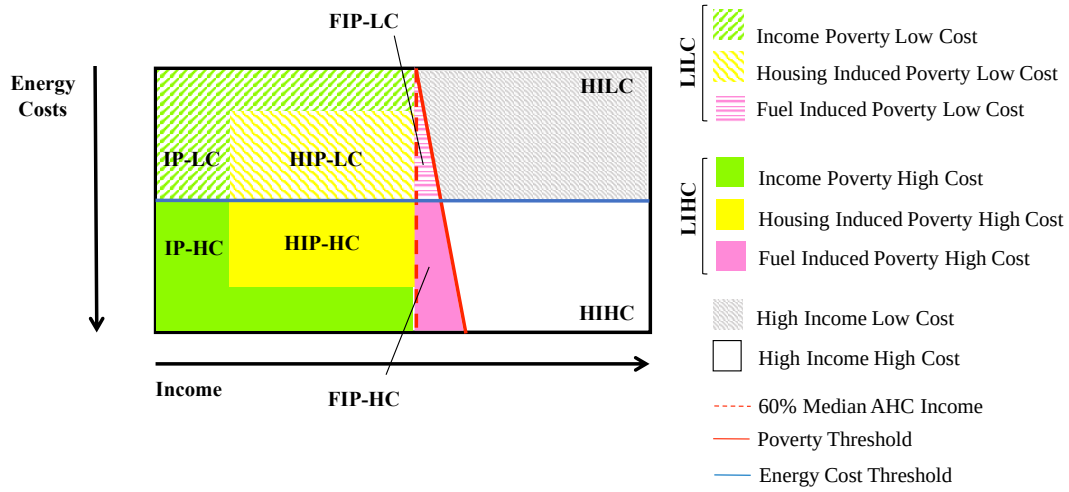
2. Conceptual framework

According to the LIHC indicator a household is defined as fuel poor, if they: 1) "have required fuel costs that are above the national median level"; and, 2) "were to spend that amount they would be left with a residual income below the official poverty line"

(Hills, 2012: 9). As illustrated in Figure 1, these thresholds create the quadrants of the LIHC framework.

The energy cost threshold equals the national median of equivalised required energy costs on the y-axis (Figure 1, solid blue line). And, the poverty threshold, calculated at 60% of the national median after-housing-cost (AHC) equivalised income (the vertical dashed red line), increases with energy costs on the x-axis (Figure 1, negatively sloped solid red line). The lower left-hand quadrant represents the LIHC group, as defined by Hill's indicator (Figure 1, solid green, yellow and pink area). Our conceptual framework identifies three dimensions of poverty underpinning Hills' approach, before separating the dimensions using the energy cost threshold.

Figure 1: Dimensions of poverty within the LIHC framework



Note: LIHC=Low-Income-High-Cost and LILC=Low-Income-Low-Cost. AHC =After housing costs. Poverty threshold=60% AHC equivalised income plus required energy costs. Energy Cost Threshold=Median required equivalised energy costs. Figure adapted from Hills (2011, 2012). This figure is an illustration of the distributions within each group but does not attempt to accurately represent the number of households within each group nor the spread of the distributions.

The first dimension, 'income-poverty' (IP), represents households whose earnings fall below the poverty threshold *before and after* deducting housing costs[4] (Figure 1,

[4] It is worth highlighting that some households, who find themselves below the poverty threshold before housing costs (BHC) are deducted from income, can 'escape' poverty after accounting for housing costs and upon recalculating the median AHC equivalised income. This can be the case for the households with relatively low (or zero) housing costs, such as small households (and homeowners).

green area). This group's earnings are generally below what is necessary to achieve a minimum standard of living regardless of the cost of essential goods and services.

Professor John Hills (2011, 2012) argues that measuring fuel poverty after deducting housing costs better represents the income left at the command of the household. Removing housing costs helps control for regional variation in affordability and relative quality of housing (DWP, 2012). In contrast to Hills, the UK Department for Work and Pensions (2012) presents both sets of poverty figures to avoid over (under) representing homeowners and retired (single) households, i.e. before (after) removing housing costs; whereas since 2016 the relevant UK Government departments have stopped reporting fuel poverty before-housing-costs (BHC) statistics (DECC, 2016; BEIS, 2017). The methodology applied herein exploits, rather than being constrained by, this trade-off.

Clearly some households are more likely to fall below the poverty threshold after deducting housing costs (DWP, 2015):

"…in many cases, housing costs have the effect of pulling a subset of households just below the income threshold and into fuel poverty." (DECC, 2014)

Taking this issue into account, the second dimension of poverty invokes Kutty's (2005) 'housing-cost-induced-poverty' (HIP) approach, which defines householdsto be in HIP if they fall below the poverty threshold after deducting housing costs but not before. The HIP group is represented by the yellow area in Figure 1. To our knowledge the links between housing-cost-poverty and fuel poverty are yet to be drawn.

The concept of being 'pushed' (DECC, 2016) or 'tipping' (Imbert et al., 2016) into poverty after deducting energy costs clearly echoes the notion of housing-cost-induced-poverty. For example, LAR utilise the *after-fuel-cost poverty* approach in order to define *fuel-vulnerability*[5] as:

[5] In contrast, 'vulnerability in the energy market' broadly refers the ability of individual(s) to wholly represent their needs and/or access the necessary support to participate in the market (Ofgem, 2013).

"households who were not exposed to poverty prior to paying fuel bills...fuel vulnerable households [are] those who become fuel poor specifically and uniquely because of their domestic fuel expenses…" (p. 626)

LAR use this setup to estimate the key demographic, socio-economic and housing characteristics influencing the probability of households being fuel-vulnerable, using a Logit and complementary log-log model on a cross-section of households in France.

Our strategy deviates from LAR's approach for several key reasons. First, although the use of fuel-vulnerability in LAR's study is appropriate, we define the third dimension of poverty (i.e. falling below the poverty threshold once energy costs are deducted but not before) using the term fuel-cost-induced-poverty (FIP) in order to be consistent with the concept of housing-cost-induced-poverty (HIP)[6]. It is important to note that before implementing the energy cost threshold fuel vulnerability and fuel-cost-induced-poverty are conceptually equivalent.

Secondly, ignoring the energy cost threshold overlooks the relative nature of energy expenditure and needs. With this in mind, LAR's fuel-vulnerable group contains both low-income-low-cost *and* low-income-high-cost households, according to the LIHC approach (respectively, the checked and solid pink areas in Figure 1). As a result, the concept of fuel-vulnerability takes on a broader meaning, i.e. the likelihood of experiencing fuel poverty (Bouzarovski and Petrova, 2015), which can occur beyond the energy cost threshold *and* below the poverty threshold. This is because households above the energy cost threshold experience relatively high energy costs, albeit, in this case, from a precarious position as they are pushed into poverty subsequent to deducting energy costs.

The present paper therefore formally defines the third dimension of poverty *above the energy cost threshold* as fuel-cost-induced-poverty-high-cost (FIP-HC) (Figure 1, solid pink area). The FIP-HC definition indicates that fuel costs prevent households from reaching an acceptable standard of living if:

[6] Alternatively, we could use income-vulnerability, housing-vulnerability and fuel-vulnerability. However, given the fact that vulnerability has a myriad of definitions (see, e.g., Bouzarovski and Petrova, 2015; European Commission, 2017; Ofgem, 2013) we opt for Kutty's induced-poverty approach terminology. Induced-poverty also helps avoid further confusion with vulnerability related to the factors that push households above the energy cost threshold.

they avoid poverty prior to meeting required energy costs, but they would be pushed below the poverty threshold if they were to spend above the national median of the required amount of income on energy costs.

Lastly, upon applying the energy cost threshold, there is no objective reason to constrain the concept of energy vulnerability to households pushed below the income threshold 'uniquely' due to fuel costs. That is, income-poor (IP) and housing-cost-induced-poor (HIP) households are vulnerable to relatively high energy costs albeit from a precarious position because they are in poverty prior to deducting energy costs. Hence, we define households in income-poverty and housing-cost-induced-poverty, above the energy cost threshold, as IP-HC and HIP-HC, respectively as follows (Figure 1, solid green and solid yellow areas)[7]:

- *they are below the poverty threshold before and after deducting housing costs from income, and if they were to spend above the national median of the required amount of income on energy costs.*

- *they avoid poverty prior to meeting housing costs, but they would be pushed below the poverty threshold after deducting housing costs from income, and if they were to spend above the national median of the required amount of income on fuel costs.*

These dimensions of (fuel) poverty highlight the importance of distinguishing between households who are in traditional income-poverty and those who fall into poverty due to actual expenditures (under a positivist approach), or because of meeting their energy requirements (under a normative approach). This adjustment helps re-emphasise that fuel poverty is a distinct problem from general poverty, but, for some households, poverty is exacerbated by fuel costs (IP and HIP), and for other households, fuel costs may indeed push them into poverty (FIP).

[7] Likewise, below the energy cost threshold we also define income-poverty-low-cost, housing-cost-induced-poverty-low-cost and fuel-cost-induced-poverty-low-cost as IP-LC, HIP-LC and FIP-LC, respectively.

3. Data, methodology and results

We rely on data from the English Housing Survey (EHS) between fiscal years 2008/2009 and 2013/2014 in order to present an overall picture of fuel poverty. The EHS is a repeated cross section compiled from the general household survey and the housing stock survey[8]. The 70,222 observations from all the available surveys are pooled for the empirical analysis. The two-year EHS 'housing stock' weights are used throughout to preserve national representativeness.

Table 1 presents the weighted statistics for income, housing costs and energy costs[9]. On average, housing expenditure *and* required energy costs take up around 21% of household income. Moreover, required energy costs represent 4.6% (5.5%) of household income before (after) housing costs are deducted.

Table 1 Weighted summary statistics of equivalised income, housing and required equivalised energy costs (£)

Variable	N	Mean	Standard deviation	Min	Max
Income					
Full income BHC	70222	27614.16	17020.93	0	100000
Full income AHC	70222	23044.9	16037.39	-45671	100000
Housing and energy					
Required energy costs per annum	70222	1259.99	492.51	294.61	5000
Housing costs per annum	70222	4659.39	5235.01	0	52000

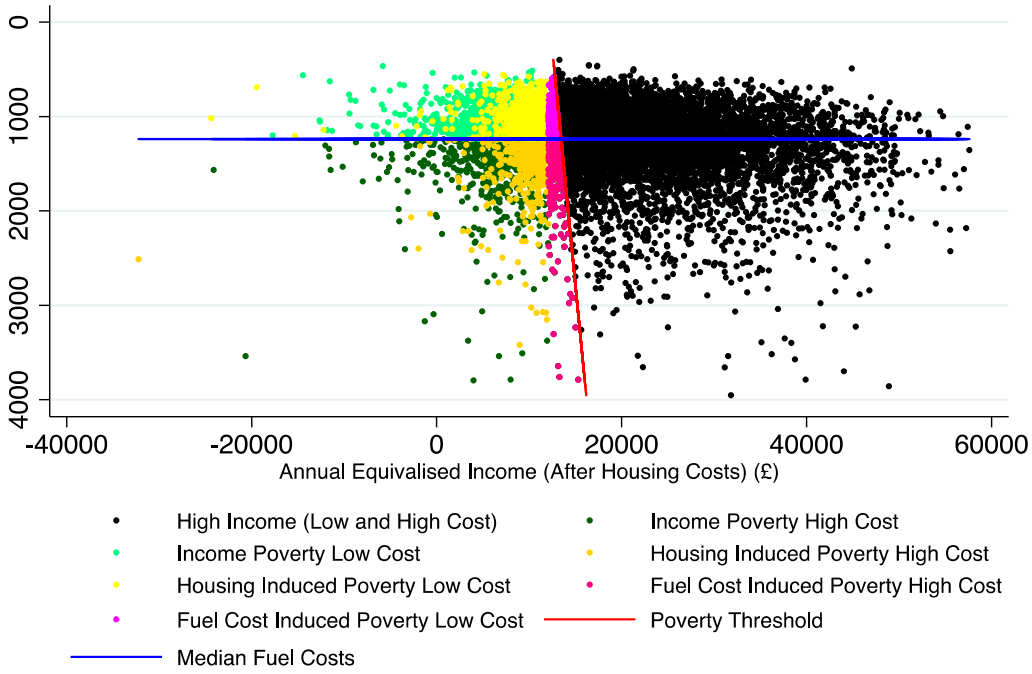
Figure 2 presents the proportion of households in each dimension of poverty, whereby the green dots represent households in IP; the yellow dots refer to those in HIP; the pink dots capture households in FIP; and, finally, the black dots represent high-income households. The (lighter) darker shade of each colour represents households located (below) above the energy cost threshold within each respective group. The y-axis decreases with fuel costs while the x-axis increases with income.

[8] A qualified surveyor collects the housing stock survey over two consecutive years. For example, the 2012 housing stock survey covers April 2011 to March 2013 (mid-point April 2012) with approximately 13,300 observations. The EHS' average (two-year) weights, created for households participating in both the interview and housing stock survey, counterbalance oversampling of less common demographics and non-response that varies across groups.

[9] The EHS data contains a ceiling for income and required fuel costs set at £100,000 and £5,000 respectively. Furthermore, housing costs exceed the income (and benefits) for some households.

According to the LIHC indicator, in 2013/2014, an estimated 10.2% (2.31 million) households in England were fuel poor. Within this group, about 5.4% (1.22 million) of households are IP-HC (Figure 2, dark green dots); while 3.4% (0.77 million) are in HIP-HC and 1.4% (0.32 million) are in FIP-HC (Figure 2, dark yellow and dark pink dots, respectively). Interestingly, the total FIP group (i.e. FIP-LC plus FIP-HC) is about 3.27% of households in England, similar to, but higher than the prevalence of FIP (or fuel-vulnerability) identified by LAR for France (2.76%)[10].

Figure 2: The dimensions of fuel poverty in England (2013/2014)



Note: Median equivalised fuel costs = £1239

The empirical analysis in this paper relies on a multinomial logit regression, rather than the binary logit regression adopted by LAR and DECC (2013). Our approach is flexible enough to explore the likelihood of a household moving away from the high-income (HI) group into one of the three dimensions of poverty (i.e. IP, HIP and FIP) within and outside of the LIHC quadrant, thus providing not only a consistent baseline

[10] Time series plots in the appendix show that, by and large, the proportions of the dimensions of poverty remain quite stable over time, while IP-HC has slightly fallen (Figure A.1).

with LAR but also new insights compared to their binary analysis. The probability of a household belonging to category *j* is defined as:

$$p_{(y=j \mid \boldsymbol{x})} = \frac{e^{(\boldsymbol{X}'_{i(t)}\boldsymbol{\beta}_{j|b})}}{\sum_{j=1}^{J} e^{(\boldsymbol{X}'_{i(t)}\boldsymbol{\beta}_{j|b})}}$$

Where, *i=1,…,70222* represents the individual households in a single cross-section *(t)* of the pooled sample at time period *t=2008/2009,…,2013/2014.* The categories *j=1,…,J* of the dependent variable are defined as follows:

$$j = \begin{cases} 1 \text{ if IP-HC} \\ 2 \text{ if IP-LC} \\ 3 \text{ if HIP-HC} \\ 4 \text{ if HIP-LC} \\ 5 \text{ if FIP-HC} \\ 6 \text{ if FIP-LC} \\ 7 \text{ if HIHC or HILC} \end{cases}$$

The baseline category *b* is set equal to high-income *(j=7)*. We use maximum likelihood to estimate the probability of a household belonging to a category *j=1,…,6*, relative to the baseline *b*, conditional on a vector of regressors $\boldsymbol{X}_{\mathbf{i(t)}}$. The vector of coefficients $\boldsymbol{\beta}$ is converted into relative risk ratios (RRRs) using an exponential transformation.

Figure 1 visually represents the different categories of households captured in the multinomial logit estimates with the high-income groups (i.e. HIHC and HILC represented by black dots in Figure 2) merged to form the baseline category (i.e. *b=j=7*).

Following a systematic review of the academic and policy literature, a comprehensive list of likely determinants of fuel poverty was identified. Table 2 provides the summary statistics for the variables[11] used in the analysis after testing down (i.e. removing statistically insignificant and highly collinear variables). The explanatory variables used in the analysis include the economic activity of the household

[11] Variable labels and acronyms are listed in the appendix (Table A.3).

representative and the household's socio-economic classification. As the prevalence of fuel poverty in England is generally lower for elderly households, the age of the household representative is also included. Education, marital status and ethnicity are also controlled for. Heating requirements are captured by the number of adults and children in the household (Harker, 2006; Waddams Price et al., 2012). Housing tenure (and length of residency) is included as a higher rate of energy efficient technologies has been observed in owner-occupied compared to privately rented properties (Leicester and Stoye, 2013). The age of the property is included to control for the difference in housing quality (DECC, 2014; Walker et al., 2014), as have the main source of fuel, heating system age, the lack of insulation systems, property type and size. Finally, a set of indicators are included to control for regional and time effects.

Table 2: Summary statistics of control variables

Variables	N	Mean	Median	S.D.	Min	Max
Household characteristics						
FEMALE	70222	0.39	0	0.49	0	1
AGE	70222	52	51	17.14	16	95
DEGREE	70222	0.27	0	0.44	0	1
MARRIED	70222	0.43	0	0.49	0	1
NON-WHITE	70222	0.10	0	0.30	0	1
ADULTS	70222	1.83	2	0.79	1	11
CHILDREN	70222	0.55	0	0.96	0	9
DISABILITY	70222	0.09	0	0.28	0	1
SEMI-ROUTINE & ROUTINE	70222	0.42	0	0.49	0	1
ACTIVITY-HRP: Baseline=FT-work						
PT-WORK	70222	0.09	0	0.28	0	1
RETIRED	70222	0.28	0	0.45	0	1
UNEMPLOYED	70222	0.04	0	0.19	0	1
FT EDUCATION/OTHER	70222	0.10	0	0.30	0	1
TENURE: Baseline=Owner-occupier						
PRS	70222	0.17	0	0.37	0	1
LA	70222	0.08	0	0.27	0	1
RSL	70222	0.09	0	0.29	0	1
Housing characteristics						
TIME	70222	0.26	0	0.44	0	1
PROPERTY-AGE	70222	0.43	0	0.49	0	1
PROPERTY-SIZE	70222	0.65	1	0.48	0	1
FLAT/OTHER	70222	0.20	0	0.40	0	1
CAVITY	70222	0.39	0	0.43	0	1
CAVITY-OTHER	70222	0.31	0	0.49	0	1
LOFT	70222	0.31	0	0.46	0	1
FUEL TYPE: Baseline=Gas						
ELECTRICITY	70222	0.09	0	0.28	0	1
OIL, SOLID or COMMUNAL	70222	0.06	0	0.24	0	1
HEATING-AGE	70222	0.27	0	0.44	0	1
Regional characteristics						
RURAL	70222	0.18	0	0.38	0	1
LONDON & SOUTH-EAST	70222	0.30	0	0.46	0	1

Table 3 presents the relative risk ratios (RRRs) of being in the following groups as opposed to the baseline high-income group: 1) IP-HC, 2) IP-LC, 3) HIP-HC, 4) HIP-LC, 5) FIP-HC and 6) FIP-LC. The colours in the second and third row of Table 3 map onto the groups represented in Figures 1 and 2.

Similar to LAR's findings for the fuel-vulnerable group (i.e. FIP-HC and FIP-LC combined), the results presented in Table 3 (Column 5) suggest that retired households, without degree qualifications, private tenants, living in older properties, with poor insulation, and those who use solid fuels are more likely to belong to the FIP-HC group, compared to high income households. Interestingly, these similarities exist despite the fact that we are using an English sample, and required energy costs (rather than actual expenditure) and that we have introduced the energy cost threshold. In contrast with LAR's findings, whereby single households and those using boilers were more likely to be in their 'fuel-vulnerability' group, our results suggest that it is large households and households using electric heating who are more likely to be in the FIP-HC group.

It is possible to test whether the significant RRRs are equal for the FIP-HC and HIP-HC groups using a likelihood-ratio (LR) test. For example, a test of equality (based on the Chi-square statistics) on the variable 'electricity' suggests that households in the FIP-HC group are more likely to heat their homes with expensive electric systems relative to those in either the IP-HC group or HIP-HC group. Hence it could be argued that income support or energy-related schemes could be targeted towards households who are just below the poverty threshold and are using electric systems.

Moreover, the equality tests imply that the RRR for the variable 'disability' is significantly larger in the FIP-HC group. This implies that households whose representative is either disabled or has a long-term illness are more likely to be located in the FIP-HC group than HIP-HC or IP-HC. What is more, since the RRR for disability is below 1 for all dimensions of poverty, these results suggest that, on average, disability and illness related benefits could be sufficient to provide the goods and services required for an acceptable standard of living. However, for households just below the poverty threshold, Government payments appear insufficient for the purchase of *all* goods and services necessary for an acceptable standard of living, such as food, clothing etc., after paying for housing *and* energy costs. Hence, ensuring that

vulnerable households have access to support that meets both housing and energy needs is essential.

Table 3: Multinomial logit estimates for poverty dimensions within a LIHC framework.

	Poverty Dimensions					
Baseline group: HI	IP		HIP		FIP	
Fuel Costs	HC	LC	HC	LC	HC	LC
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Household characteristics						
FEMALE	0.781***	0.725***	1.019	1.107***	0.904	0.930
	(-6.355)	(-9.712)	(0.385)	(2.709)	(-1.497)	(-1.268)
AGE	0.994***	0.981***	0.996	0.984***	0.996	0.987***
	(-3.542)	(-12.723)	(-1.557)	(-9.253)	(-1.179)	(-4.805)
DEGREE	0.588***	0.693***	0.646***	0.731***	0.655***	0.605***
	(-10.848)	(-8.629)	(-7.817)	(-6.929)	(-5.152)	(-6.465)
MARRIED	1.035	1.416***	0.917	1.247***	0.906	1.013
	(0.779)	(8.612)	(-1.481)	(4.582)	(-1.300)	(0.189)
NON-WHITE	2.194***	2.190***	1.753***	1.715***	1.002	1.167*
	(14.667)	(17.496)	(8.761)	(10.990)	(0.018)	(1.824)
ADULTS	1.228***	1.241***	1.000	0.904***	1.089**	1.132***
	(9.355)	(9.990)	(-0.005)	(-3.578)	(2.062)	(3.127)
CHILDREN	1.352***	1.326***	1.420***	1.430***	1.649***	1.662***
	(16.687)	(17.077)	(16.565)	(19.599)	(18.429)	(20.251)
DISABILITY	0.514***	0.400***	0.600***	0.490***	0.793**	0.607***
	(-10.931)	(-18.754)	(-5.775)	(-11.814)	(-2.265)	(-5.997)
SEMI/ROUTINE	1.437***	1.423***	1.440***	1.411***	1.424***	1.207***
	(10.500)	(11.871)	(8.194)	(10.074)	(5.945)	(3.693)
HRP-PT	4.541***	4.427***	1.894***	2.100***	1.481***	1.486***
	(25.741)	(28.467)	(8.714)	(12.948)	(3.907)	(4.482)
HRP-RETIRED	3.116***	3.615***	1.355***	2.005***	1.499***	1.859***
	(16.906)	(20.900)	(3.168)	(9.570)	(3.414)	(5.876)
HRP-UNEMPLOYED	47.385***	38.574***	12.379***	9.942***	2.680***	4.148***
	(52.009)	(55.188)	(27.426)	(30.370)	(5.367)	(11.507)
HRP-FT EDUCATION	13.585***	12.309***	5.409***	4.801***	2.920***	2.564***
	(47.388)	(53.818)	(26.172)	(31.037)	(11.805)	(12.171)
PRS	1.980***	1.852***	6.310***	6.629***	3.580***	3.290***
	(13.259)	(11.814)	(30.061)	(32.077)	(14.991)	(12.796)
LA	1.892***	3.600***	2.380***	4.043***	4.755***	5.857***
	(11.509)	(27.288)	(10.571)	(21.939)	(16.711)	(20.544)
RSL	1.506***	3.074***	2.418***	5.390***	3.529***	5.988***
	(7.353)	(24.214)	(11.261)	(28.205)	(13.450)	(21.468)
Property characteristics						
TIME	1.136***	0.845***	0.651***	0.763***	0.957	0.860*
	(2.676)	(-3.642)	(-5.509)	(-4.292)	(-0.496)	(-1.810)
PROPERTY-AGE	0.438***	1.091***	0.528***	1.417***	0.504***	1.008
	(-19.512)	(2.687)	(-11.535)	(9.198)	(-9.524)	(0.140)
PROPERTY-SIZE	2.186***	0.540***	2.503***	0.575***	2.229***	0.587***
	(17.425)	(-17.080)	(16.403)	(-13.352)	(10.448)	(-8.644)
FLAT/OTHER	0.628***	1.460***	0.511***	1.300***	0.504***	1.201***
	(-7.864)	(9.176)	(-9.533)	(5.800)	(-6.624)	(2.595)
CAVITY-INSULATED	0.549***	1.470***	0.544***	1.310***	0.421***	1.280***
	(-13.306)	(10.616)	(-9.477)	(6.609)	(-10.758)	(4.028)
WALL-OTHER	1.047	0.956	1.354***	0.927	1.030	0.862*
	(1.055)	(-1.026)	(5.516)	(-1.541)	(0.406)	(-1.937)
LOFT	0.871***	1.165***	0.816***	1.117***	0.874**	1.200***
	(-3.522)	(4.495)	(-3.766)	(2.700)	(-1.974)	(3.144)

ELECTRICITY	2.585***	0.581***	2.464***	0.599***	3.355***	0.631***
	(16.412)	(-9.513)	(12.232)	(-8.507)	(13.069)	(-4.533)
OIL/SOLID/COMMUNAL	1.155**	0.616***	1.112	0.650***	1.407***	0.638***
	(2.010)	(-6.730)	(1.074)	(-5.341)	(2.917)	(-3.589)
HEATING-AGE	0.546***	1.102***	0.535***	1.151***	0.460***	1.032
	(-13.923)	(3.060)	(-10.962)	(3.857)	(-9.528)	(0.582)
Regional indicators						
RURAL	1.068	0.735***	0.915	0.834***	1.055	0.855*
	(1.309)	(-5.858)	(-1.287)	(-3.067)	(0.630)	(-1.828)
LONDON & SE	0.479***	0.702***	1.029	1.587***	0.608***	1.033
	(-16.156)	(-9.662)	(0.573)	(12.291)	(-6.535)	(0.538)
Annual indicators included	Y					
Observations	70222					
LR X^2	33136.81***					
McFadden's R^2	0.210					

*Notes: * p<0.1, ** p<0.05, *** p<0.01. t-statistics in parentheses. Exponentiated coefficients (Relative Risk Ratios).*

Table 3 identifies several additional household characteristics which increase the probability of being in the FIP-HC group relative to the HI group, including: households with more children; the household representative working part-time, being unemployed or in full-time education; and households living in social housing. In terms of property characteristics, we identify properties over 70sqm and properties with a heating system aged over 3 years as being associated with being in FIP-HC. Finally, households living outside London and in the South-East of England are less likely to be in the FIP-HC group relative to the HI group.

Our empirical approach also allows us to explore the drivers of the housing-cost-induced dimension of fuel poverty. Almost all variables which are significantly associated with FIP-HC are also linked to HIP-HC, but non-white ethnicity and properties with solid or other types of walls are positively and *uniquely* related to HIP-HC (relative to the HI group), compared to the FIP-HC group.

The Chi-square (1) statistics suggest that the RRR for the HIP-HC group is significantly larger if the household representative person is working part-time, unemployed or in full-time education and living in the privately rented housing with an uninsulated roof, compared to the FIP-HC group. These findings suggest that income, housing or other energy related support, could be directed towards households who are less active (or inactive) in the labour market and living in the privately rented sector. This could help households located in the HIP-HC group advance across the poverty threshold. Indeed, these methods of support could be

issued nationwide since the regional indicators are insignificant for the HIP-HC group, unlike the IP-HC and FIP-HC counterparts.

The results in Table 3 (Column 1) further suggest that young and/or male respondents are *uniquely* more likely to be located in IP-HC group (relative to the high-income group), compared to the HIP-HC and FIP-HC groups. We also find that the RRRs for the labour market variables are significantly greater for IP-HC relative to *all* other poverty dimensions, particularly unemployment. Moreover, non-white households, households with a greater number of adults and children and households living in large and ageing properties are significantly more likely to be located in IP-HC.

An important consideration for policy purposes relates to housing tenure. To unravel the story behind tenure we conducted three sets of the equality tests on the tenure RRRs (Private rental sector, local authority housing and registered social landlords): between groups on either side of the energy cost threshold (e.g. IP-HC vs. IP-LC); within the LIHC quadrant (e.g. IP-HC vs. HIP-HC); and for each dimension of poverty. The tests suggest that households living in social housing are more likely to fall below the energy cost threshold[12]. This implies that, if policymakers aim to help households to move across the *energy cost threshold* and out of fuel poverty, then they should focus their energy-related schemes either on private tenants or homeowners for *all dimensions of poverty*. If policymakers want to focus instead on the *poverty threshold* the picture becomes more complex. The tests imply that for the IP-HC and HIP-HC groups, targeting the private rental sector is crucial since the private rental sector's relative risk ratio is significantly larger (than for local authority housing and registered social landlords). The local authority housing's relative-risk-ratio is significantly larger (than for the private rental sector and registered social landlords) for the FIP-HC group. In this case targeting local authority owned housing

[12] Notice that for each poverty dimension pair in Table 3, e.g. IP-HC and IP-LC, the RRRs for PRS are similar, statistically equal in fact across the groups, but significantly larger for LA and RSL for the respective low-cost group. This implies that, for each pair, households living in local authority or registered social housing are more likely to fall below the energy cost threshold, due to the relatively energy efficient housing provided by these sectors.

could help households located in the FIP-HC group who are just below the poverty threshold[13].

The policy recommendations identified for the HIP-HC group can largely be extended to the IP-HC group. Nevertheless, there are some important socio-demographic considerations that could improve the policymaker's ability to target those most in need. Firstly, the equality tests and magnitude of the RRRs suggest that income, housing or energy-related support can focus on households whose primary earner is unemployed or in full-time education, followed by households in part-time work or retired households. Secondly, national and local government programmes could be targeted towards households whose primary earner is young, male and residing in precarious living conditions, particularly old properties in need of retrofitting. Thirdly, such schemes could be directed to regions outside of London and the South East.

4.2 Diagnostic checks

Several restrictions must be satisfied to justify collapsing the dimensions of poverty, as it is done in the standard LIHC approach, or like the fuel-vulnerability group implemented by LAR (which combines FIP-LC and FIP-HC). Using the results presented in Table 3, a Wald test is used to test whether the RRRs are significantly different across the dimensions of poverty. There are 21 restrictions, equivalent to the number of pairwise outcomes which can be generated between $j=7$ categories (counting a single pair only once and excluding homogenous pairs). The Wald test rejects the null hypothesis that the difference in the coefficients estimated for each pair are jointly equal to zero at the 1% level (p-values=0.000). Since the equality of all pairwise combinations of the groups is statistically rejected, this paper fundamentally highlights the fact that the current LIHC grouping overshadows important dimensions of fuel-poverty and suggests that the groupings used in previous research, such as LAR's, can be usefully extended.

[13] This finding supports the previous observation that, within the LIHC indicator, households whose representatives have a disability or long-term illness are more likely to be located in the FIP-HC group.

4. Concluding remarks

This paper subsumes the housing-cost-induced-poverty definition within the LIHC indicator. Compared to the existing literature this approach provides additional clarity about the makeup of the fuel poor households by identifying three distinct dimensions of poverty: income-poverty, housing-cost-induced-poverty, and fuel-cost-induced-poverty. Within our conceptual framework these dimensions indicate that spending the required amount of income on energy pushes those households who find themselves in the income-poverty group and housing-cost-induced-poverty group *deeper into poverty*. Breaking down the low-income-high-cost (LIHC) group in this way highlights potential limitations in the grouping implemented in the UK Government policy and in previous research.

Compared to previous research, the findings in this paper demonstrate that an alternative modelling strategy can be applied to better understand the various dimensions of poverty within the LIHC fuel poverty quadrant, rather than treating these dimensions as one. More specifically, in contrast with LAR (2015), who overlook these additional dimensions of poverty, this paper suggests that the poverty dimensions contained within the LIHC are each associated with a specific set of socio-demographic and housing characteristics. Our findings suggest that the income-poor and housing-cost-induced-poor groups are less active in the labour market and tend to be of non-white ethnicity, relative to the fuel-cost-induced-poverty group. The household representative person is more likely to be young, male and a homeowner or tenant in the income-poor group, whereas, households in the housing-cost-induced-poverty group are concentrated in the private rental sector. This paper uncovers three unique dimensions of poverty dormant beneath the structure of the UK's official fuel poverty indicator, providing information previously hidden as a result of aggregation.

As a result, this paper provides an important tool for policy makers on two distinct fronts. First, the three dimensions of poverty we identify could be considered by Governmental departments in the UK, to complement the current income after-housing cost approach. Indeed their current adoption of a binary poverty indicator ignores the fact that some households fall below the poverty threshold before *and* after housing and energy costs are considered. This is an important group to consider, not least because households within this group have the lowest average income

compared to households in the other two dimensions of poverty, i.e. those who fall below the poverty threshold upon deducting housing or energy costs, but not before. In doing so, the UK Government could evaluate the efficacy of income and energy-related schemes by assessing the impact of such measures on households who are unable to afford essential goods and services required for a socially acceptable standard of living.

Second, and just as importantly, policy could be designed by focusing on the threshold of interest. For example, our results suggest that, from the policymaker's perspective, *energy-related schemes* could be targeted specifically to the private rented sector *and/or* homeowners in order to bring these sectors in-line with the greater level of energy efficiency offered by the social sector. Our tests also suggest that this approach could be applied across *all* the dimensions of fuel poverty. In contrast, the policymakers could design income, housing *and* energy-related schemes that target specific types of house tenures for each dimension of poverty above the energy cost threshold. This could be a more efficient method to allocate funds aimed at alleviating the burden of relatively high energy costs.

As fuel-cost-induced poverty is far less widespread than housing-cost-induced-poverty and income-poverty, the primary responsibility of Government regarding fuel poverty should be the alleviation of the impact of high energy costs for the households below the poverty threshold before accounting for their energy costs. However, targeting only the largest groups would miss out another important group of vulnerable households, who might not be effectively supported by measures aimed at households with different socio-economic characteristics.

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Appendix

A1 Household and other definitions

A household is defined as a group of individuals living in the same building and share at least some of the utilities and main living space within the building.

Full income, as defined in the EHS, is the annual net income of the whole household from any source, including benefit sources such as housing benefits (net council tax payments) and winter fuel payments, as well as savings, investments, mortgage interest and mortgage payment protection insurance.

Housing costs are defined as the total annualised mortgage payments and annualised rent payments, excluding service charges (in British pounds per year). The former applies to households who are purchasing a property with a mortgage either solely or via shared ownership. The latter concerns households who live in either rented accommodation or shared owners' housing. Furthermore, households who own their homes outright or live rent-free have zero housing costs.

Energy costs per year (£) comprise of the total gas and electricity (or solid fuel) expenditure that is required to meet the basic needs of the household including the cost of space heating, water, cooking and lighting.

A2 Equivalisation Factors

Income equivalisation factors work to balance household annual income and energy costs in order to reflect differences in household size and composition. The baseline household of comparison typically used when computing equivalisation factors is a couple with no children, and receives a factor equal to one. In contrast, a single household receives a smaller factor (i.e. less than one), while the factor attributed to larger households is greater than one. Hence the income of a larger household, who earns the same as a smaller household, is reduced to reflect a lower income per capita.

Table A.1: Income equivalisation factors

Variable and relevant weighting	Factor
Income – before housing costs	
Household structure	
First adult in the household	0.67
Subsequent adults (including partners and children > 15 years of age)	0.33
Children aged 14 or under	0.20
Income – after housing costs	
Household structure	
First adult in the household	0.58
Subsequent adults (including partners and children > 15 years of age)	0.42
Children under 14 years of age	0.20

Source: DECC (2014)

Table A.2: Fuel cost equivalisation factors

Variable and relevant weighting	Factor
Household structure	
1 person	0.82
2 people	1.00
3 people	1.07
4 people	1.21
5 or more people	1.32

Source: DECC (2014)

Table A.3: Variable definitions and labels

Variable name	Description
Household characteristics	
FEMALE	Gender of the household representative person (HRP).
AGE	Age (years) of the HRP.
EDUCATION	Highest qualification attained by the household.
MARRIED	Marital status of the HRP.
NON-WHITE	Ethnicity of the HRP.
ADULTS	Number of adult residents.
CHILDREN	Number of child residents.
DISABILITY	Either HRP or partner registered as disabled.
SEMI-ROUTINE-ROUTINE	The National-Statistics Socio-Economic-Classification of the HRP's position of work.
HRP-ACTIVITY	Economic activity classification of the HRP: full-time (FT) employed; part-time (PT) employed; retired; unemployed; or FT-education.
TENURE-TYPE	Tenure status of household: owner occupier; private rented sector (PRS); local authority (LA); or registered social landlord (RSL).
Housing characteristics	
TIME	Time spent at current address >20yrs.
PROPERTY-AGE	Property built post-1964.
PROPERTY- FLAT/OTHER	Resides in flat/maisonette/apartment/other.
PROPERTY-SIZE	Property size >70sqm.
CAVITY	Cavity wall insulation installed.
LOFT	Loft insulation installed.
FUEL-TYPE	Main fuel type.
HEATING-AGE	Heating system age >3yrs.
Regional indicators	
RURAL	Property in rural location.
LONDON & SOUTH-EAST	Resides in London or South-East (SE).
Time indicators	
YEAR	EHS survey year.

Table A.4: Mean BHC/AHC equivalised income, equivalised housing costs and equivalised required energy costs by the three dimensions of poverty (above and below the energy cost threshold)

Variable	Mean full BHC equivalised income	Mean full AHC equivalised income	Mean equivalised housing costs	Mean equivalised required energy costs
Income poverty (IP)				
High cost (HC)	11766.86	7877.99	3888.87	1571.90
Low cost (LC)	11317.01	7313.13	4003.88	978.2191
Housing-cost-induced-poverty (HIP)				
High cost (HC)	20479.91	10770.55	9709.36	1583.35
Low cost (LC)	17469.26	9763.861	7705.40	966.04
Fuel-cost-induced-poverty (HIP)				
High cost (HC)	22565.25	15869.28	6695.97	1724.83
Low cost (LC)	19498.55	14016.5	5482.06	1037.49

Figure A.1: Time series plots of the income-poverty, housing-cost-induced-poverty and fuel-cost-induced-poverty in England during 2009-2013