A Multidimensional Approach to Measuring Fuel Poverty

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ABSTRACT

In this study we suggest that a more careful and systematic understanding of fuel poverty can be developed through a multidimensional approach to the relationship between monetary poverty, residential energy efficiency, and heating restriction. Our objective is to provide new ways to better identify those who suffer the most from fuel poverty to optimize policy. Thus, the purpose of this paper is to measure poverty in three steps following Sen (1979): (i) combining poverty characteristics into an aggregate measure involving a fuel poverty index (FPI), (ii) identification and comparison of poor people according to existing and new definitions and (iii) testing the robustness of the fuel poverty composite indicator. Our results show that the usual measures reveal a gap that does not consider all the dimensions of fuel poverty, excluding those who are at or above a certain threshold, but who are nevertheless vulnerable.

Keywords: Fuel poverty, Multidimensional approach, Heating restriction, Thermal discomfort

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1. INTRODUCTION

Fuel poverty occurs when a household is unable to afford the most basic amount of energy for adequate heating, cooking, lighting, and use of appliances in the home. In 2011, 9.8% of households in the EU27 countries and 15.8% of households in the 12 new member states could not afford to heat their homes adequately (European University Institute, 2011). Moreover, 8.8% of EU27 households and 17.1% of households in the 12 new member states were in arrears on their utility bills[1] (European University Institute, 2011), so between 50 million and 125 million people in Europe are estimated to be fuel poor which represents respectively between 10% and 25% of European population (Bird et al., 2010; European Fuel Poverty and Energy Efficiency, 2007, 2011). Thus, fuel

1. Information on the ability to keep one's home adequately warm and arrears on utility bills is from the Eurostat European Union Statistics on Income and Living Conditions (EU-SILC) Survey. The survey aims to collect timely and comparable cross-sectional and longitudinal multidimensional microdata on income, poverty, social exclusion and living conditions. This instrument is anchored in the European Statistical System (ESS). The inability to keep one's home adequately warm refers to the percentage of persons in the total population who are in a state of enforced inability to keep their home adequately warm. Arrears on utility bills refers to the percentage of persons in the total population who are in a state of arrears on utility bills, expressing the enforced inability to pay their utility bills on time due to financial difficulties.

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poverty is an increasingly serious problem across Europe[2] (Birol, 2007; Bouzarovski et al., 2012; Brunner et al., 2012) and requires the intervention of policymakers. Indeed, ONPE (2016) estimates the number of fuel-poor households in France to be 3.8 million (5,8% of population).

In particular, (i) corrective measures have been implemented which aim to help fuel-poor households pay their energy bills, and (ii) preventive policies have also been introduced, which focus more on improving residential energy efficiency. Debates about the effectiveness of these measures have ensued for several reasons; mainly because energy retrofit renovations have often been undertaken by wealthier households (Charlier et al., 2018; Vilches et al., 2017). Thus, despite these measures, given the expected increase in the cost of energy, some could find it difficult or even impossible to satisfy their energy needs. The relationship between subjective well-being and the affordability for households of electricity, heating oil and natural gas has been already demonstrated (Welsh and Bierman, 2017). As a prerequisite to discussions about the effectiveness of different measures to fight fuel poverty, debates have often focused on the need to reliably identify fuel-poor households and create a detailed profile of such households. In fact, the multidimensionality of fuel poverty makes it difficult to achieve this.

Fuel poverty has generally been treated as a monetary poverty problem. At European Union level, there is no common definition or standardized indicator for assessing fuel poverty. While there is a large body of literature on measuring poverty (Phradan and Ravallion, 1998; Ravallion, 1998; Ravallion and Bedani, 1994) consensus has not yet been reached on the related methodological and conceptual issues. Only four countries have defined the concept of poverty and energy poverty: The United Kingdom, Ireland, France and Slovakia (Host et al., 2014). However, households affected by fuel poverty are not always the same as those affected by monetary problems, even if the two phenomena are inextricably linked, representing an aspect of multidimensional poverty (Legendre and Ricci, 2015).

In this context, we suggest that a more careful and systematic understanding can be developed through a multidimensional approach to the relationship between monetary poverty, residential energy efficiency of buildings, and heating restrictions. Our objective in this paper is not to challenge existing measures of fuel poverty, but provide new ways to better identify those who suffer the most from fuel poverty in order to optimize policy. We argue this is needed to better identify the connection between energy use and well-being and therefore deepen understanding of energy poverty or energy precarity.

Current definitions of fuel poverty underscore the need to consider its multiple dimensions. Depending on the country, the definition of fuel poverty might include indoor temperature, cooling expenditures, damp walls and/or floors, lack of central heating, and rotted window frames.

Moreover, the literature has begun to highlight the need for a theoretical framework for fuel poverty similar to Sen's work on poverty (Sen, 1979). Over the past 20 years, many involved in energy issues have grappled with the concept of energy poverty (Foster et al., 2000; González-Eguino, 2015; Krugmann and Goldemberg, 1983; Pachauri and Spreng, 2003), and several approaches have been used to define and measure it (Department of International Development, 2002). These methods often define a minimum level of physical energy expenditures above which households can be considered non-poor. This level is based on a basket of goods and services for meeting direct energy

2. Fuel poverty is a major social problem which requires action across a range of policy issues and at all political levels. The number of fuel-poor households in Europe could multiply in the near future, as nearly one in seven households in Europe are at risk of poverty, the price of domestic gas increased by 18% on average from 2005 to 2007, and the price of domestic electricity increased by 14% on average over the same period..European Fuel Poverty and Energy Efficiency, 2011. Tackling Fuel Poverty in Europe - Recommandations guide for policy makers.

needs (e.g. heating, lighting and cooking) and the energy embodied in additional goods and services that households use. However, a problem arises in assessing the minimum level of energy required for basic needs, which can be different among countries and climates. Thus, consensus on a common definition and harmonizing the use of fuel poverty indicators is still needed in developed countries. Indeed, it is difficult to identify all the dimensions of fuel poverty, notably self-imposed heating restrictions, and the usual definitions result in an amalgamation of fuel poverty characteristics (Charlier et al., 2015), such that policymakers have difficulty identifying the fuel poor. Households around a certain threshold may be excluded from the definition of fuel poverty, yet still be vulnerable.

Within the same country, regional differences in climate, different socioeconomic characteristics (cost of living), and cultural factors necessarily influence the phenomenon of fuel poverty. Existing monetary indicators are not sufficient for a single, satisfactory conceptual framework that can make comparisons and capture inequalities from the local to the national to the global level to reveal more about variations between developed countries. On the other hand, assessing fuel poverty as a component of overall precarity and viewing it as connected to other forms of poverty appears essential to designing effective solutions. A convincing assessment of energy insecurity requires a broad and above all non-binary approach. The object of our research is to capture the phenomenon as a whole while retaining the elements to be considered, as well as the objectives created by binary measurement tools. We achieve this by controlling for specific regions. The results of our work will enable policymakers to adopt appropriate fuel poverty control strategies based on the distribution of the phenomenon in the population. Thus, the purpose of this paper is to measure poverty in three steps according to Sen's work (1979): (i) combining poverty characteristics into an aggregate measure involving a fuel poverty index (FPI), (ii) identification and comparison of poor people according to existing and new definitions and (iii) testing the robustness of the fuel poverty composite indicator. Our results show that the usual measures amalgamate the characteristics of fuel poverty, while the multidimensional approach enables us to consider all the components of fuel poverty: objective measures (monetary poverty, heating privation, and residential energy efficiency) as well as subjective measures such as thermal discomfort. Moreover, the fuel poverty composite indicator continues to be around 0.107 even when the robustness of the fuel poverty composite indicator is assessed in terms of the mechanism for calculating single indicators, the normalization scheme, and the removal of extreme value data. This new index provides a robust scale of energy precarity, and consequently a more precise way of capturing different degrees of fuel vulnerability. Thus, we contribute to the literature by proposing a global and quantified approach to energy poverty in a developed country by means of a multidimensional index.

The remainder of the paper is organized as follows. In section 2.1, a review of the literature on standard measures of fuel poverty is presented. Then, in section 2.2, we introduce our multidimensional approach and fuel poverty index. In section 3, we present the data. Household profiles are examined according to the different definitions of fuel poverty in section 4.1, and we demonstrate the robustness of the multidimensional approach in sections 4.2 and 4.3. Section 5 concludes.

2. MEASURING FUEL POVERTY IN FRANCE

2.1. Standard measures of fuel poverty

From a general point of view, a household is considered to be fuel poor when it occupies an energy-inefficient dwelling and is unable to pay the bills for heating the home at an appropriate level. Thus, fuel poverty refers to a multidimensional concept that includes three phenomena:

the socioeconomic situation of the household according to income level, the characteristics of the dwelling including energy efficiency, and the energy access conditions generally reflected in the price of energy (Devalière, 2007; European Fuel Poverty and Energy Efficiency, 2006; Palmer et al., 2008). One of the first measures of fuel poverty, the energy income ratio or the 10% approach, was proposed by Boardman (1991).

The 10% approach

The energy-income ratio is defined as a "household [being] in fuel poverty if it needs to spend more than 10% of its income on fuel to maintain a satisfactory heating regime and all other energy services" (De Quero and Lapostolet, 2009; Department of Energy and Climate Change, 2001). The energy-income ratio, representing this 10% indicator, is calculated as follows:

$$Energy\ income\ ratio = \frac{Theoretical\ fuel\ costs}{Income} \tag{1}$$

One main advantage of this ratio is that it considers theoretical rather than actual fuel costs. They are obtained by multiplying fuel requirements (theoretical consumption) by fuel prices. Considering theoretical fuel costs ensures that the household achieves an adequate level of warmth subject to a range of dwelling and household characteristics. However, this measure of fuel poverty has some limits. Although the energy-income ratio has the advantage of taking into account under-consumption by comparing theoretical and effective (or real) fuel consumption, it is not in fact intended to measure whether households are spending more than 10% of their income on domestic fuel. Rather, it measures whether households would need to do so to achieve an acceptable level of warmth in their dwelling on the basis of observed income and modeled physical data related to dwelling space and thermal efficiency (Fahmy, 2011; Legendre and Ricci, 2015). Fuel poverty is not only a cost-income function; households are also negatively affected by the poor condition of their housing in terms of noise (due to the absence of insulation) and humidity (European Fuel Poverty and Energy Efficiency, 2006; Phimister et al., 2015). Moreover, measuring theoretical needs and obtaining reliable physical data is complicated and controversial (Allibe, 2012). Results show that the ratio between observed consumption and theoretical consumption is always less than 1, meaning that theoretical consumption exceeds observed consumption. This can be mainly attributed to restrictions in thermal comfort. Consequently, the energy-income ratio does not take into account the restriction practices of some households, mainly with regard to heating needs, induced by high fuel costs (Dutreix et al., 2014). Furthermore, Hills (2011) and Moore (2012) argue that the energy-income ratio does not reliably take income level into account, especially for high-income households. Therefore, a significant number of households are found to be fuel poor, when in reality their large fuel expenditures are in line with their high income. Although the 10% indicator is still applied in different national contexts, it is definitely not suitable for policymaking because it was defined using an obsolete and country-specific threshold of energy expenditures. It could be revisited and made more suitable using specific national characteristics. Considering these limits, the After Fuel Cost Poverty (AFCP) indicator was developed by Hills (2011).

The AFCP indicator

This indicator is based on the comparison between the equivalized income of a given household and the standard threshold of 60% of equivalized national income, where income is considered after subtracting housing costs and domestic fuel costs. Under this approach, households whose equivalized income after housing costs and domestic fuel costs is below the threshold of 60% of the equivalized national median income net of housing and domestic fuel costs are classified as fuel poor.[3] According to this indicator, fuel poverty exists if:

$$\begin{cases} Equivalised\left(Income - Housing\,costs - Domestic\ fuel\,costs\right) < \\ 60\%\ Equivalised\left(Median\,income - Housing\,costs - Domestic\ fuel\,costs\right) \end{cases} \quad (2)$$

The main advantage of the AFCP indicator is that it considers housing costs. Even if housing costs represent only a part of constrained expenditures, the results become more reliable when they are included in calculations. On the other hand, it is possible some very low-income households will be classified as fuel poor regardless of their fuel requirements. As a consequence, confusion between fuel and monetary poverty is possible (Legendre and Ricci, 2015).

The Low Income-High Cost (LIHC) indicator

Defined by Hills (2011, 2012), the LIHC indicator is an alternative measurement framework that focuses on the overlap of high costs and low income. This indicator considers two thresholds for identifying fuel-poor households: The first threshold is the same income threshold as for the AFCP approach, and the second is an energy cost threshold based on the median spending of all households.

Therefore, according to this approach, a household is fuel poor in the following double condition:

$$\begin{cases} Equivalized\ disposal\ income \leq 0\%\left(Equivalized\ median\ disposal\ income\right) \\ Equivalized\ \ fuel\ expenditures \geq Required\ national\ median\ \ fuel\ expenditures \end{cases} \quad (3)$$

The advantage of the LIHC indicator is in clearly distinguishing between fuel and monetary poverty by defining two different thresholds. However, like the AFCP indicator, the LIHC is based on a calculation of net income and not on constrained income.

Clearly, it is necessary to agree upon social measures (i.e. the absence of a central heating system in the home, damp walls and/or floors, rotten window frames, access to an electricity grid, indoor temperature) to capture the wider elements of fuel poverty, and focus on social exclusion and material deprivation, as opposed to approaches based solely on expenditure-based indicators. In the literature, we found cases where people can be fuel poor and not monetarily poor. Legendre and Ricci (2015), studied a sample of individuals above the monetary poverty line that fell into poverty after paying their energy bill. This sub-sample represents 2.76% of the non-poor before energy expenditures. Identifying these people is possible as the relative poverty rate in developed countries is calculated using disposable income per consumption unit before expenditures on food, clothes or energy. Consequently, creating the measure *house poor* appears particularly useful as it enables the identification of one particular source of precariousness. Knowing the source of precariousness makes it possible to design an appropriate policy to improve the standard of living and well-being of the population.

3. Legendre B, Ricci O. Measuring fuel poverty in France: Which households are the most fuel vulnerable? Energy Economics 2015;49; 620-628.. Households are fuel vulnerable when they are *a priori* non-poor (not below the 60% of the median adjusted income) when considering income net of housing costs but are poor when considering income net of housing costs and domestic fuel expenses.

Moreover, in some dwellings, real heating energy consumption is systematically lower than theoretical consumption (on average 30% lower), which is assumed to be explained by restriction behavior. This is the concept of the *prebound effect* (Galvin, 2014). The *prebound effect* suggests that policymakers who want to implement energy efficient initiatives may be over-estimating the benefits, and the rate of pay-back can be exaggerated due to restriction behavior and potential energy savings.

So, in the context of fuel poverty, being deprived of basic household utilities should be considered an indicator of fuel poverty in a unified social approach.

2.2 Construction of the Fuel Poverty Index (FPI)

Pioneering poverty specialists such as Sen (1979) recommended considering multiple dimensions to identify who the poor are. The report European Fuel Poverty and Energy Efficiency (2006) shows that fuel-poor households have several common characteristics: the inability to pay energy bills, cold and damp living conditions, debt, homes with low energy performance, and disconnection from energy supply. The consequences of these conditions are numerous, and sometimes the cost/income function approach is irrelevant: low-income households coping with financial constraints reduce their energy expenditures as a primary strategy. Spending on energy is usually reduced by cutting consumption (Anderson et al., 2012; Moore, 2012) especially by reducing the use of heating, which we will refer to as restricted heating. Overall, the notion of privation appears relevant to characterizing poverty, which is particularly consistent with the analysis of fuel poverty. Despite the recommendation of many European organizations to take restricted heating into account in ensuring basic needs are met, policymakers generally use monetary definitions to identify fuel-poor households. Thus, considering restriction behavior seems quite relevant in the study of fuel poverty.

The advantages of a composite indicator that compares fuel poverty level across households have been increasingly recognized in policy analysis (ONPE 2014). Such an indicator is a useful tool in identifying trends and drawing attention to particular issues. One of the main advantages of a composite indicator is its ability to capture multidimensional concepts that cannot be appraised by a single indicator, while being easier to interpret than a battery of many separate indicators. Thus, we propose a composite indicator that can allow for the three indicators from the EU SILC[4] but in a normative way. Instead of just analyzing answers to questions, as in the SILC survey, we devel-

4. Three indicators from the EU SILC dataset have been commonly used to capture aspects of EU fuel poverty: living in a damp home, inability to keep adequately warm, and being in arrears on utility bills: cf. Devalière I. Comment prévenir la précarité énergétique ? Les leviers possibles et les risques inhérents à la libéralisation du service de l'énergie. Les Annales de la Recherche Urbaine 2007;103; 137-143, European Fuel Poverty and Energy Efficiency, 2011. Tackling Fuel Poverty in Europe - Recommandations guide for policy makers, ONPE 2014. Définitions, indicateurs, premiers résultats et recommendations - Premier rapport de l'ONPE. ONPE, Waddams Price C, Brazier K, Wang W. Objective and subjective measures of fuel poverty. Energy Policy 2012;49; 33-39. These variables correspond to the fuel poverty dimensions we have identified: monetary constraints, energy inefficiency, and restricted heating. Unfortunately, often only low income/high costs and the energy-income ratio are used in fuel poverty analysis. We proceeded as follows in constructing the energy poverty index: First, the choice of dimensions in the indicator is micro-funded based on Welsch, H. and P. Biermann, 2017. Second, we drew from the handbook of composite indicators from the European Commission and OECD, 2008 in construction of the index. Finally, selection of a suitable method is not trivial and deserves special attention with respect to eventual scale adjustment Ebert U, Welsch H. Meaningful environmental indices: a social choice approach. Journal of Environmental Economics and Management 2004;47; 270-283.. For this reason we conducted some robustness tests in line with the recommendations of the European Comission, OECD, 2008. Handbook on Constructing Composite Indicators - METHODOLOGY AND USER GUIDE.."

oped a multidimensional numeric index, the fuel poverty index (FPI), to capture these three aspects of fuel poverty. This index is based on geometric means and considers differences in achievement across dimensions. Moreover, weights can have a significant effect on the overall composite indicator. Most composite indicators rely on equal weighting (EW), which implies that all variables are equally considered in the indicator. This assumption seems justified in the absence of proof of an alternative. The composite fuel poverty index (FPI) is expressed as:

$$FPI\left(P.C.R\right) = \sqrt[3]{I_p \times I_c \times I_R} \tag{4}$$

where I_p is an indicator of standard of living, I_c an indicator of the housing energy inefficiency and I_R captures the potential heating restriction by providing information about housing temperature. I_P, I_c, I_R allow comparisons of household attributes to objective references in the three dimensions.

Equation [4] enables us to consider the complementarity between the three dimensions across a geometric aggregation: The elasticity of the FPI in each dimension cannot be separated from the other two. Indeed, an objectionable consequence of additive aggregations is that poor performance in one dimension can be compensated with high values in other dimensions. The geometric mean reduces the level of substitutability between dimensions and at the same time ensures that a 1% decline in the index of restricted heating has the same impact on the FPI as a 1% decline in the income index. Thus, as a basis for comparison of achievement, this method is also more sensitive to the intrinsic differences across the dimensions than a simple average. If multi-criteria analysis entails full non-compensability, the use of a geometric aggregation is a solution (European Comission and OECD, 2008). Moreover, in this study, a Min-Max normalized indicator is retained by subtracting the minimum value and dividing by the range of the indicator values. While there are several possible normalization methods (Freudenberg, 2003; Jacobs et al., 2004), they should be chosen based on data properties as well as the objectives of the composite indicator. Thus, sensitivity analyses are provided in part 4.3 to ensure the robustness of the indicator and the choice of the Min-Max normalization.

First, monetary poverty is captured through I_p:

$$I_p = \frac{P - Min\left(P\right)}{Max(P) - Min\left(P\right)} \tag{5}$$

where P is the ratio between the poverty threshold, set at 60% of the median per consumption unit (PCU)[5] disposable income, and the household PCU disposable income.

Energy per square meter consumption (*C*) is used to calculate I_c :

$$I_C = \frac{C - Min\left(C\right)}{Max(C) - Min\left(C\right)} \tag{6}$$

Finally, we measure heating restriction. The restriction behavior measure stands out from other previous monetary approaches but still belongs to the group of objective measures. It is often based on the calculation of both the actual and theoretical fuel consumption needed to reach an appropriate level of warmth in a dwelling. As mentioned previously, considering theoretical measures of consumption does not seem appropriate for France (Allibe, 2012). One issue is the quality of the energy performance diagnoses made by professionals, who do not necessarily have the skills to perform accurate diagnoses. Moreover, there is no regulation of the professionals who prescribe

5. Consumption per household member.

and install equipment. Not all information is available and therefore assumptions must be made about certain aspects of energy efficiency, such as the quality of wall insulation. Finally, theoretical energy consumption does not consider the number of persons or the number of appliances in the dwelling. The strengths of a composite fuel poverty indicator largely derive from the quality of its underlying variables (European Comission and OECD, 2008). Thus, one difficulty lies in the objective measurement of privation. The concept of restricted heating can be very subjective and relative if it is not rigorously observed. Several indicators of residential thermal standards are found to be significantly related to variations in relative excess winter mortality at the 5% level (Healy, 2003). The World Health Organization WHO (1987) recommends an indoor temperature of 21 degrees Celsius in living areas and has demonstrated the consequences of insufficient temperatures on health (Lacroix and Chaton, 2015; Ormandy and Ezratty, 2012). Considering these findings, we propose indoor temperature as an objective measure of restricted heating. One solution to measure heating privation is to compare effective indoor temperatures to those recommended. The calculation of the last indicator is based on this recommendation:

$$I_R = \frac{R - Min(R)}{Max(R) - Min(R)} \tag{7}$$

where

$$R = \frac{21}{Housing\ mean\ temperature} \tag{8}$$

In order to demonstrate that indoor temperature is a good proxy for heating privation, we provide some evidence in supplementary materials A using an econometric analysis involving matching methods. Some proofs of the quality estimate are also provided.

It is clear that poor energy efficiency in housing does not have the same consequences for low-income households as it does for rich ones, since wealthy households have the means to undertake energy-efficiency renovations. The advantage of the FPI index is to provide a scale rather than simply defining households as fuel-poor or not. While the problem of using an index is that the values generated have little intrinsic meaning, it is still a better way to classify who suffers the most from fuel poverty in France. It is then up to the policymaker to decide which population at which ranges of the FPI index needs to be targeted with specific policies.

The FPI index can also be applicable to other countries, and depending on the extent of its use, an international scale of fuel poverty might emerge to compare these phenomena worldwide. However, to be able to compare countries, homogenization measures of the surveys are necessary. For the moment, though, we will use this micro-foundation to categorize the population and estimate the intensity of the phenomena for each household.

Finally, while several decisions must be made when a composite indicator is constructed (on the selection of indicators, data normalization, weights, and aggregation methods), the sensitivity analyses provided in section 4.3 confirm the robustness of the FPI.

3. DATA

This study uses French data based on the PHEBUS (survey on housing performance, equipment, needs, and uses of energy) database. This new periodic survey consists of two parts administered separately: a face-to-face interview with the occupants of the home about their energy consumption expenditures and attitude, and an energy performance diagnosis of the housing.[6] The survey aims to provide information about the energy performance of the housing stock, allowing for analysis according to household characteristics and appliances, as well as energy use and energy consumption. It was implemented to understand the drivers of energy consumption in France for the purpose of adapting public policy.

This survey is very interesting because it provides highly detailed information on energy consumption by type of fuel, energy costs and energy rates. Information is also available on the renovations undertaken by households, incentives to renovate (energy savings or improved comfort), and public policies. Moreover, a large part of the survey is devoted to the behavior of households and their satisfaction with their heating system, so it is possible to know if households restrict their energy use and what their preferences are. We know whether households prefer to achieve energy savings or comfort in their homes by end-uses, namely, by making a distinction between consumption of hot water, electricity, and heating. A part of the survey is also dedicated to indoor temperature in winter and in summer. Detailed questions are asked about the rate of occupancy. We also know whether households restrict their consumption by reducing the temperature or by choosing not to heat some rooms. Finally, we know if households have a sense of discomfort and what the source of this feeling is.

Considering all these factors, we can therefore conduct a thorough analysis of fuel poverty taking into account not only monetary variables but also household and building characteristics as well as heating restriction. More subjective questions on satisfaction in terms of heating are also available. This study also makes it possible to study fuel poverty with information not only on disposable income but also on energy expenditures and attitude towards energy consumption (through temperature). To our knowledge, such an interesting and detailed database is rare in France. Our sample contains 2,318 households and is representative of the population (the sample is weighted to ensure representativeness).

Some descriptive statistics are presented in Table 1. In general, energy consumption is higher in old buildings and in the coldest climate zone, which is not surprising. One interesting result has been obtained for the fuel poor according to the AFCP definition: their energy consumption is lower than the average and they have a low indoor temperature, which highlights restriction behavior. This group is also poorer than those in other fuel-poor categories.

To measure fuel poverty, we examined the multiple aspects of fuel poverty in France using three different measurement approaches: the 10% ratio approach (energy-income ratio), the LIHC approach and the AFCP approach. Descriptive statistics are also presented in Table 2.

We found the energy-income ratio to be equal to 0.0516,[7] while the same ratio calculated between energy expenditures and disposable income after housing costs and domestic fuel costs increased to 0.0571. The three definitions of fuel poverty identify quite different fuel poverty rates in France: 9.16% of the population are fuel poor according to the 10% ratio approach, 8.54% according to the LIHC approach, and 18.57% according to the AFCP approach.

6. The energy performance diagnosis is a document that provides an estimate of energy consumption and greenhouse gas emissions of a dwelling. It is part of the technical diagnostics record, along with asbestos diagnostics, termites, lead, and status of indoor facilities for electricity and gas. This diagnosis has been mandatory since November 1, 2006 in case of sale of a dwelling and since July 1, 2007 for leasing. The display of the energy performance of real estate in the real estate agencies has been mandatory since January 1, 2011. The diagnosis is provided free to the respondent at the end of the investigation and has a 10-year validity period.

7. This means that energy expenditures represent 5.16% of a household's disposable income.

Table 1: Main descriptive statistics 1

	Effective Energy Consumption (kWh/m²/year)	Temperature	Disposable income
Individual housing units	186.02	19.90	40,962
Collective building	120.37	20.13	32,280
Dwelling constructed before 1919	196.06	19.63	35,068
Dwelling constructed between 1919 and 1945	184.64	19.80	36,288
Dwelling constructed between 1946 and 1970	161.97	20.07	36,032
Dwelling constructed between 1971 and 1990	150.57	20.15	38,090
Dwelling constructed between 1991 and 2005	157.74	20.01	43,092
Dwelling constructed after 2005	139.24	19.95	42,764
Dwelling located in climate zone H1 (coldest zone)	172.88	20.12	39,493
Dwelling located in climate zone H2 (middle zone)	160.10	19.66	35,744
Dwelling located in climate zone H3 (Mediterranean zone)	121.77	20.21	37,281
Possible to change the indoor temperature in the dwelling	168.86	19.89	39,269
Not possible to change the indoor temperature in the dwelling	144.50	20.35	33,085
Boiler system installed before 1986	223.28	19.99	36,323
Boiler system installed between 1987 and 1991	223.76	19.92	40,600
Boiler system installed between 1992and 1996	222.21	20.04	41,104
Boiler system installed between 1997 and 2001	198.28	19.90	39,869
Boiler system installed between 2002 and 2006	213.41	19.94	43,450
Boiler system installed between 2007 and 2012	188.16	19.81	40,362
Dwelling with a cooling system	218.59	20.02	31,883
Dwelling without a cooling system	166.20	19.94	37,673
Dwelling occupied by fuel poor (energy income ratio)	278.3	19.82	18,760
Dwelling occupied by fuel poor (AFCP)	162.05	19.79	16,979
Dwelling occupied by fuel poor (LIHC)	203.68	19.91	18,531
Means	164.12	19.98	38,066

Table 2: Main descriptive statistics 2

Variables	Means (with weight) in Euros
Disposable income	38,066
Disposable income by PCU	23,589
Annual housing costs for tenants or rent-free occupants	5,839
Housing costs for homeowners or first-time buyers	3,724
Total housing costs	4,229
Household disposable income - housing costs	35,005
Household disposable income - housing costs in PCU	21,534
Effective (or real) energy expenditures for electricity	769
Effective energy (or real) expenditures for gas	968
Effective energy (or real) expenditures for oil	1,633
Effective energy expenditures for coal	974
Total effective (or real) energy expenditures	1,464
Total effective energy (or real) expenditures by PCU	949
Disposable income – housing costs and energy expenditures by PCU	33,526
60% poverty threshold of the median (using disposable income – housing costs and energy expenditures by PCU)	10,288

4. RESULTS

4.1 Fuel poverty and household profile

We conducted *t*-tests (Table B-1 in supplementary materials B) to identify household profiles according to the definition of fuel poverty. For continuous variables, particularly FPI, indoor temperature, and energy consumption, we conducted correlation tests. There is a strong correlation (significant at 1%) between FPI, low indoor temperature, and high energy consumption.

Standard measures of fuel poverty miss households who are at around a certain threshold, but who are not necessarily fuel poor (Charlier et al., 2015): When we combine definitions, different households are included. Only 2.26% of households are fuel poor if we combine the three usual measures. Indeed, according to the definition, the profile of the fuel-poor households is different. In the 10% approach, low indoor temperature and thermal discomfort are not included. The AFCP also

Table 3: Profiles of the fuel poor by indicator

10%	AFCP	LIHC	FPI
	Household characteristics		
Low income Tenant Possible to adjust the heating Preference for heating comfort	Low income Tenant Possible to adjust the heating Preference for heating comfort	Low income Tenant Possible to adjust the heating Preference for heating comfort	Low income Tenant Possible to adjust the heating Preference for heating comfort
	Building characteristics		
High energy consumption Old building	High energy consumption Old building	Old building	High energy consumption Old building
	Location		
Coldest climate zone		Coldest climate zone	Coldest climate zone
	Heating restriction		
Report restricting heating consumption by cutting or sharply reducing heating	Low temperature Report restricting heating consumption by —cutting or sharply reducing heating —limiting the number of heating weeks in the year —limiting the heating time during the day —not heating some rooms —using auxiliary heater instead of main heater	Report restricting heating consumption by —cutting or sharply reducing heating —limiting the number of heating weeks in the year —limiting the heating time during the day —not heating some rooms —using auxiliary heater instead of main heater	Low temperature Report restricting heating consumption by: —cutting or sharply reducing heating —limiting the number of heating weeks in the year —limiting the heating time during the day —not heating some rooms —using auxiliary heater instead of main heater
	Subjective measure of fuel poverty		
			Cold discomfort due to: —Financial reasons —Insufficient heating installation —Bad insulation —Unpaid power provider —Power supply shutdown —Wrong setting —Harsh winter

Figure 1: Fuel poverty as captured by standard measures

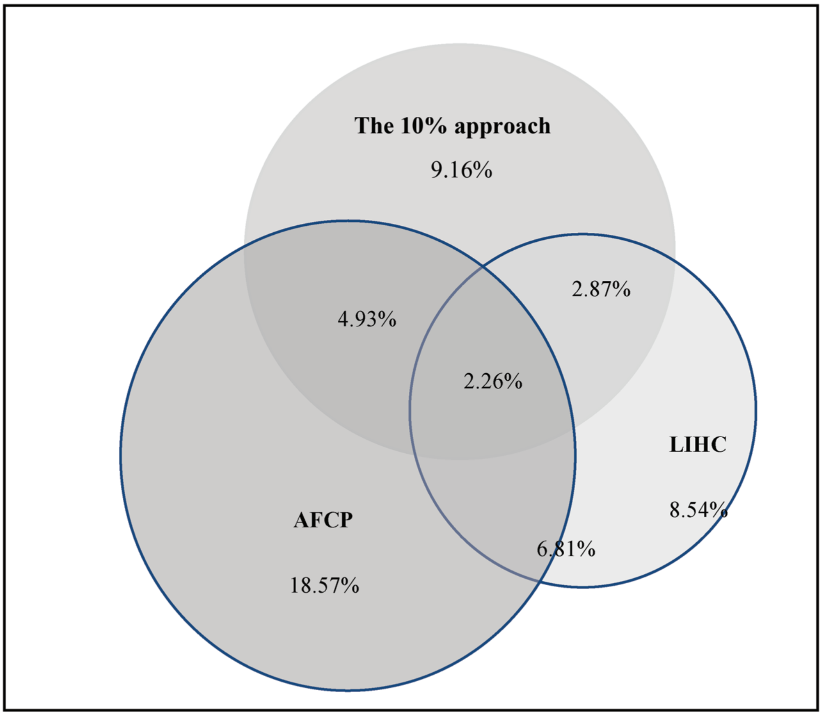


Table 4: FPI index and its three dimensional indicators

	(weighted) Mean	Min	Max
P	0.69	0.05	3.93
C	164.1	0.00	3126.94
R	1.06	0.165	2.63
Ip	0.186	0.00	1.00
Ic	0.052	0.00	1.00
Ir	0.107	0.00	1.00
FPI	0.13	0.00	0.44

includes these subjective measures and location (a proxy for energy needs). The LIHC, on the other hand, does not include poor energy efficiency of dwellings, measured by high energy consumption (and confirmed by the absence of a low indoor temperature), or subjective measures of fuel poverty.

These results show that one advantage of the FPI is that it considers all dimensions of fuel poverty, especially heating restriction and subjective measures such as thermal discomfort.

4.2 Comparison of FPI to other measures (10%, LIHC, AFCP)

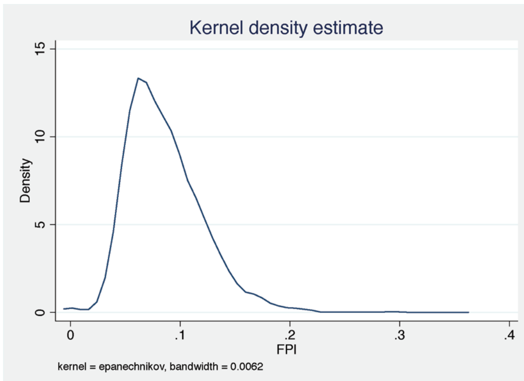
We found that 75% of the population has an FPI value lower than 0.126 and 99% has a value lower than 0.206. Table 4 summarizes the various components of the composite fuel poverty index, which is 0.13 in France.

We note that both the 10% and LIHC fuel poverty definitions encompass very similar household profiles. According to the 10% definition, *Ic* (energy inefficiency as expressed in energy

Table 5: FPI and other fuel poverty measures

	Fuel poor as defined by			Not fuel poor		
	10%	**LIHC**	**AFCP approach**	**10%**	**LIHC**	**AFCP approach**
I_p	0.2574	0.2923	0.2540	0.1538	0.1529	0.1451
I_c	0.0890	0.0651	0.0518	0.0522	0.0513	0.0526
I_r	0.190	0.1913	0.192	0.1876	0.1853	0.1844
FPI	0.1504	0.1429	0.125	0.1060	0.1041	0.1035

Figure 2: Kernel density estimate of FPI



consumption per square meter) reaches about 0.0890 for the poor, which is 70% (0.0776/0.0469) higher than for the non-poor. For the fuel poor according to the LIHC approach, *Ic* is only 27% higher than for the non-poor. By contrast, according to the AFCP approach, *Ic* for the poor represents only 98% of the indicator for the non-poor. The statistics presented in Table 5 confirm that the AFCP definition is very close to a definition of monetary poverty. The indicator of financial hardship, I_P, is indeed 86% higher for the poor than for the non-poor, whereas the difference between the poor and the non-poor is only 62% according to the LIHC definition.

Figure 2 shows the population distribution according to FPI values. Compared with other fuel poverty measures, the 10% definition seems to better include those who combine relative financial hardship with relatively high energy consumption/m2 (Table 5 and confirmed in Table 1). I_P and I_C are higher for this population than they are for the fuel poor according to the two other definitions. Relative restricted heating is the highest for the fuel poor defined according to the AFCP approach.

To demonstrate that the FPI is an adequate measure of fuel poverty, we compared the three dimensions that a relevant definition should take into account (European Fuel Poverty and Energy Efficiency, 2006; ONPE 2014) with the other measures of fuel poverty (see Table 6). The value of the FPI is quite stable among the different measures of fuel poverty.

Looking more precisely at the FPI and other monetary definitions of fuel poverty, the most interesting result is related to disposable income. The results show that the FPI truly takes into account dimensions other than just monetary constraints. For example, the FPI shows nonlinear effects of income: Households can have a high FPI (in the 10th decile) and a somewhat higher standard of living than that of the fuel poor, on average 12,462 euros for all households in the 10th decile of FPI and less than 10,749 euros for the fuel poor according to two definitions of fuel poverty in the 10th decile of FPI.

Table 6: Comparisons of the indicators and the other fuel poverty measures

Percentile of FPI	FPI	Mean PCU disposable income	Mean Temperature (°C)	Mean energy consumption /m2 (kWh)	% of fuel poor
			Poor according to the 10% definition		
1	0.057	34,468	20	38.7	0.6%
2	—	—	—	—	0%
3	0.087	18,782	17.9	55.0	0.8%
4	—	—	—	—	0%
5	0.102	20,842	21.43	175.4	1.5%
6	0.107	19,225	22.0	210.8	3.3%
7	0.116	18,382	20.0	165.4	5.9%
8	0.125	16,543	20.0	180.5	8.9%
9	0.140	15,507	20.2	254.5	17.4%
10	0.176*	12,349	19.5	331.8	45.4%**
			Poor according to the *LIHC*		
1	0.057	12,980	21.3	21.7	2.8%
2	0.074	14,304	21.3	40.0	4.3%
3	0.087	12,516	21.5	64.8	1.6%
4	0.094	10,475	20.1	53.2	4.0%
5	0.101	9,583	20.5	59.1	1%
6	0.109	14,219	20.8	120.7	5.5%
7	0.115	16,042	21.5	180.9	3.7%
8	0.125	13,408	20.8	169.5	10.1%
9	0.139	13,104	19.5	187.8	11.2%
10	0.176	10,387	19.2	282.2	39.2%
			Poor according to the *AFCP approach*		
1	0.059	15,383	20.7	20.6	11.9%
2	0.075	16,895	19.9	42.4	10.6%
3	0.086	18,209	19.9	66.6	6.3%
4	0.095	16,750	19.9	81.7	13.2%
5	0.101	16,193	20.2	100.8	9.2%
6	0.109	15,127	20.1	113.4	19.6%
7	0.115	17,023	20.3	157.5	17.0%
8	0.126	13,327	20.1	162.8	23.1%
9	0.139	12,808	19.3	179.5	22.1%
10	0.175	10,749	19.2	285.0	45.7%
			FPI of the total sample		
1	0.056	37594	20.7	48.5	
2	0.076	28684	20.3	80.3	
3	0.086	29878	20.2	117.9	
4	0.094	26399	20.0	129.1	
5	0.101	23890	19.9	146.8	
6	0.108	21522	19.9	159.4	
7	0.116	20172	19.9	183.4	
8	0.125	18029	19.8	197.9	
9	0.139	16792	19.6	242.2	
10	0.173	12462	19.2	336.5	

Note: According to the *10% ratio* definition. the 10% with the highest FPI have an average index of 0.173. **Moreover. 45.4% of the fuel poor belong in the highest decile of FPI.

The similarity of both the AFCP and LIHC definitions is confirmed in Table 6: profiles of the poor according to both definitions appear quite close together within the 10 deciles of FPI. The standard of living for the fuel poor, according to those definitions, reaches about 10,387 euros in the 10th decile, with an indoor temperature of about 19.2°C, and annual energy consumption levels of 285 and 282 kWh respectively per m2. Eventually, almost 90% of the fuel poor according to the AFCP definition belong to the three highest deciles of FPI and 70% for the 10% approach, while the LIHC approach places only 60% of the fuel poor in this area.

The FPI has the distinct advantage of including all the dimensions of fuel poverty, which was not the case for previous fuel poverty definitions. It provides a scale of fuel vulnerability rather than simply a binary indicator. It is now up to policymakers to adapt energy surveys so that FPI can help make comparisons over time and countries. However, this measurement should be associated with the roll-out of smart metering in industrialized countries. Numerous studies have demonstrated that improving information on energy consumption can lead to energy efficiency gains (Arrow and Fisher, 1974; Brounen et al., 2013; Carroll et al., 2014; Di Cosmo et al., 2014; Ehrhardt-Martinez et al., 2010; Grimes et al., 2016; Jessoe and Rapson, 2014; Matsukawa, 2004; Pon, 2017; Wolak, 2011). Moreover, smart metering can be also considered as a tool to fight climate change and to identify which households restrict their heating consumption.

4.3. Sensitivity analysis

As mentioned previously, the indicators, data normalization techniques, weights, and aggregation methods used to construct a composite indicator can be controversial. In the case of the fuel poverty index, the selection of indicators is fairly consensual (ONPE, 2014), as is the choice of a geometric mean to avoid error measurement (due to the exclusion of one dimension). Thus, in this study, we provide some robustness and sensitivity analyses to assess the robustness of the fuel poverty composite indicator in terms of the mechanism for calculating single indicators, the normalization scheme, and the removal of extreme value data. Indeed, we can refine both the sensitivity analysis and the standardization of basic indicators by considering the minimum and maximum

Table 7: Sensitivity analysis of extreme values

Percentile of FPI	Without extreme values* for PCU disposable income	Without extreme values* for temperature	Without extreme values* for consumption	Without extreme values* for FPI
1	0.0507	0.0567	0.0593	0.0644
2	0.0756	0.0754	0.0757	0.0755
3	0.086	0.0857	0.0857	0.0856
4	0.0937	0.0937	0.0937	0.0937
5	0.1010	0.1009	0.1010	0.1010
6	0.1085	0.1086	0.1085	0.1085
7	0.1163	0.1162	0.1162	0.1162
8	0.1256	0.1257	0.1257	0.1257
9	0.1384	0.1384	0.1386	0.1386
10	0.1684	0.1717	0.1690	0.1627
Means	0.1047	0.1066	0.1089	0.1082

Note: We remove the 5% of the population whose values are the lowest and 5% of the population whose values are the highest.

Table 8: Sensitivity analysis of reference values

	Reference	With a poverty threshold of 50%	20°C temperature
P	0.69	0.57	—
P min	0.05	0.04	—
P max	3.93	3.27	—
R	1.06	—	1.01
R min	0.7	—	0.67
R max	2.63	—	2.50
Ip	0.165	0.165	0.165
Ic	0.052	0.052	0.052
Ir	0.186	0.186	0.185
FPI	0.107	0.107	0.107

values set for the poverty and restricted heating dimensions. Thus, the sensitivity of the composite indicator can be tested by defining minimum and maximum values for the reference values and can be compared with the previously obtained results. If the values are quite similar, the composite indicator shows the importance of considering three dimensions with a similar weight. This can prevent errors in measurement of fuel poverty due to changes in indicator, for example.

We proposed different sensitivity analyses to assess whether our composite indicator is robust in all three dimensions. Statistical analysis can demonstrate also the precision of the data.[8] We first conducted sensitivity analyses to extreme values (Table 7): Observations for the population with the 5% lowest and highest value for each dimension separately were removed. The results of the FPI were also compared with sensitivity to the poverty threshold and the reference temperature set by the WHO (Table 8).

Results show that the fuel poverty composite indicator continues to be around 0.107 even when we decrease the reference values from 60% of the median PCU to 50% for the poverty threshold and from 21 to 20°C for temperature. Even though the minimum and maximum values change in one indicator, the overall results are not affected. The FPI is also robust to outliers. Our methodology is thus robust and useful for classifying fuel poverty in households.

5. CONCLUSION AND POLICY IMPLICATIONS

Fuel poverty is an increasingly serious problem across countries but remains a concept that is not very well defined or measured. Even though there is a fairly clear understanding of living conditions and relative poverty, a clear definition of fuel poverty has not yet emerged. Thus, the major original feature of this paper is to provide the first fuel poverty index that takes into account the three dimensions of fuel poverty: monetary constraints, poor residential energy efficiency, and heating privation. Standard measures of fuel poverty reveal a gap that does not consider all the dimensions of fuel poverty. The advantages of proposing a composite indicator that compares fuel poverty level across households are increasingly recognized in policy analysis. Today, many households are excluded from the usual definitions of fuel poverty if we consider subjective measures such as thermal discomfort or heating restriction, and are not thus well targeted by policymakers. The FPI enables us to correct this shortcoming and constitutes a new decision-making tool with many advantages.

First, the FPI index provides a scale rather than simply defining households as fuel poor or not. It offers policymakers the possibility of choosing which population at which ranges of the FPI index need to be targeted with specific policies. Moreover, by allowing a dynamic comparison over time, the FPI can be viewed as a fuel poverty monitoring indicator to be used in evaluating public policy. For instance, a decrease in the FPI would lead us to perceive a decline in fuel poverty in general. In particular, it is now possible to identify in which dimension (monetary, energy efficiency, or heating restriction) a given policy is the most effective.

Finally, this index can be used to make comparisons not only among households inside a country, but also, once aggregated, among countries. In order to apply the FPI internationally, however, better data collection techniques are needed to compare household situations. While it may be time- and cost-effective to include subjective statements such as "I have difficulty keeping my home adequately warm" in the survey of Income and Living Conditions (EU-SILC), we can

8. This is true whatever the purpose of the paper and the science discipline. See for example papers in science such as Taner T. Optimisation processes of energy efficiency for a drying plant: A case of study for Turkey. Applied Thermal Engineering 2015;80; 247-260, Taner T, Sivrioglu M. Energy–exergy analysis and optimisation of a model sugar factory in Turkey. Energy 2015;93; 641-654.

hope that the quality and precision of the fuel poverty composite indicator will improve in parallel with improvements in data collection and fuel poverty measurements. Governments should provide further incentives to make these improvements to enhance the international comparability of these statistics. It is now up to policymakers to adapt their energy surveys so that FPI can be calculated to make comparisons over time and countries.

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REFERENCES

Allibe, B. (2012). «Modélisation des consommations d'énergie du secteur résidentiel français à long terme - Amélioration du réalisme comportemental et scénarios volontaristes.» EDF R&D. Ecole des Hautes Etudes en Sciences Sociales (EHESS).

Anderson, W., V. White, and A. Finney (2012). "Coping with low incomes and cold homes." *Energy Policy* 49: 40-52. https://doi.org/10.1016/j.enpol.2012.01.002.

Arrow, K.J. and A.C. Fisher (1974). "Environmental Preservation, Uncertainty, and Irreversibility." *The Quarterly Journal of Economic*s 88: 312–319. https://doi.org/10.2307/1883074.

Bird, J., R. Campbell, and K. Lawton (2010). "The Long Cold Winter: Beating fuel poverty. for Public Policy Research and National Energy Action." http://www.ippr.org/publications/the-long-cold-winter-beating-fuel-poverty.

Birol, F. (2007). "Energy Economics: A Place for Energy Poverty in the Agenda?" *The Energy Journal* 28: 1–6. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol28-No3-1.

Boardman, B. (1991). *Fuel Poverty: From Cold Homes to Affordable Warmth*. Belhaven Press: London;.

Bouzarovski, S., S. Petrova, and R. Sarlamanov (2012). "Energy poverty policies in the EU: A critical perspective." *Energy Policy* 49: 76–82. https://doi.org/10.1016/j.enpol.2012.01.033.

Brounen, D., N. Kok, and J.M. Quigley (2013). "Energy literacy, awareness, and conservation behavior of residential households." *Energy Economics* 38: 42–50. https://doi.org/10.1016/j.eneco.2013.02.008.

Brunner, K.-M., M. Spitzer, and A. Christanell (2012). "Experiencing fuel poverty. Coping strategies of low-income households in Vienna/Austria." *Energy Policy* 49: 53–59. https://doi.org/10.1016/j.enpol.2011.11.076.

Carroll, J., S. Lyons, and E. Denny (2014). "Reducing Household Electricity Demand through Smart Metering: The Role of Improved Information about Energy Saving." *Energy Economics* 45: 234–243. https://doi.org/10.1016/j.eneco.2014.07.007.

Charlier, D., A. Risch, and C. Salmon (2015). "Les indicateurs de la précarité énergétique en France." *Revue Française d'économie* XXX: 187–230.

Charlier, D., A. Risch, and C. Salmon (2001). "Energy Burden Alleviation and Greenhouse Gas Emissions Reduction: Can We Reach Two Objectives With One Policy?" *Ecological Economics* 8(143): 294–313.

De Quero, A. and B. Lapostolet (2009). Groupe de Travail Précarité Energétique. Plan Bâtiment Grenelle.

Department of Energy and Climate Change (2001). The UK Fuel Poverty Strategy 2001 - Government Response to the Consultation on Amending Reference to the Warm Front Scheme Eligibility Criteria. URN:11D/0036, 21 March 2011

Department of International Development (2002). Energy for the Poor: Underpinning the Millennium Development Goals, Department for International Development, London, UK.

Devalière, I. (2007). "Comment prévenir la précarité énergétique ? Les leviers possibles et les risques inhérents à la libéralisation du service de l'énergie." *Les Annales de la Recherche Urbaine* 103: 137–143. https://doi.org/10.3406/aru.2007.2723.

Di Cosmo, V., S. Lyons, and A. Nolan (2014). "Estimating the Impact of Time-of-Use Pricing on Irish Electricity Demand." *The Energy Journal* 35: 117–136. https://doi.org/10.5547/01956574.35.2.6.

Dutreix, N., C. Baecher, B. Pianu, and E. Collomb (2014). «Figure(s) de la précarité énergétique.» in: *Nomadéis Srp* (Ed.). PUCA.

Ebert, U. and H. Welsch (2004). "Meaningful environmental indices: a social choice approach." *Journal of Environmental Economics and Management* 47: 270–283. https://doi.org/10.1016/j.jeem.2003.09.001.

Efron, B. and R.J. Tibshirani (1993). *An introduction to the Bootstrap*. Boca Raton, FL: Chapman & Hall. https://doi.org/10.1007/978-1-4899-4541-9.

Ehrhardt-Martinez, K., K.A. Donnelly, and J.A. Laitner (2010). "Advanced Metering Initiatives and Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities." American Council for an Energy-Efficient Economy, Report No. E105

European Comission, OECD (2008). Handbook on Constructing Composite Indicators - METHODOLOGY AND USER GUIDE.

European Fuel Poverty and Energy Efficiency (2006). Diagnosis of causes and consequences of fuel poverty in Belgium, France, Italy,Spain and United Kingdom. EPEE project EIE/06/158/SI2.447367.

European Fuel Poverty and Energy Efficiency (2007). Definition and Evaluation of fuel poverty in Belgium, Spain, France, Italy and the United Kingdom. International Energy Europe-EPEE Project-EIE/06/158/SI2.447367.

European Fuel Poverty and Energy Efficiency (2011). Tackling Fuel Poverty in Europe - Recommandations guide for policy makers.

European University Institute 2011. EU Statistics on Income and Living Conditions.

Fahmy, E. (2011). "The Definition and Measurement of Fuel Poverty." in: Paper CFB (Ed.).

Foster, V., J.-P. Tre, and Q. Wodon (2000). *Energy prices, energy efficiency, and fuel poverty. Latin America and Carribean Regional Studies Program.* The World Bank, Washington, D.C.

Freudenberg, M. (2003). *Composite indicators of country performance: a critical assessment*. OECD, Paris.

Galvin, R. (2014). "Making the 'rebound effect' more useful for performance evaluation of thermal retrofits of existing homes: Defining the 'energy savings deficit' and the 'energy performance gap'." *Energy and Buildings* 69: 515–524. https://doi.org/10.1016/j.enbuild.2013.11.004.

González-Eguino, M. (2015). "Energy poverty: An overview." *Renewable and Sustainable Energy Reviews* 47: 377–385. https://doi.org/10.1016/j.rser.2015.03.013.

Grimes, A., N. Preval, C. Young, R. Arnold, T. Denne, P. Howden-Chapman, and L. Telfar-Barnard (2016). "Does Retrofitted Insulation Reduce Household Energy Use? Theory and Practice." *The Energy Journal* 37: 165–186. https://doi.org/10.5547/01956574.37.4.agri.

Healy, J.D. (2003). "Excess winter mortality in Europe: a cross country analysis identifying key risk factors." *Journal of Epidemiology Community Health* 57: 784–789. https://doi.org/10.1136/jech.57.10.784.

Healy, J.D. and J.P. Clinch (2002). *Fuel poverty in Europe A cross-country analysis using a new composite measurement*. University Coll. Dublin (Ireland). Dept. of Environmental Studies.

Heckman, J.J., H. Ichimura, and P.E. Todd (1997). "Matching as an Econometric Evaluation Estimator: Evidence from Evaluating a Job Training Programme." *The Review of Economic Studies* 64: 605–654. https://doi.org/10.2307/2971733.

Heckman, J.J., R.J. Lalonde, and J.A. Smith (1999). "The Economics and Econometrics of Active Labor Market Programs." In: Orley CA, David C (Eds), *Handbook of Labor Economics*, vol. Volume 3, Part A. Elsevier. pp. 1865–2097. https://doi.org/10.1016/S1573-4463(99)03012-6.

Hills, J. (2011). "Fuel Poverty: The problem and its measurement. Interim Report of the Fuel Poverty Review." Centre for Analysis and Social Exclusion, Case Report 69.

Hills, J. (2012). "Getting the measure of fuel poverty, Hills Fuel Poverty Review. Centre for Analysis and Social Exclusion." Case report 72.

Horowitz, J.L. (2003). "The Bootstrap in Econometrics." *Statistical Science* 18: 211–218. https://doi.org/10.1214/ss/1063994976.

Host, S., D. Grange, L. Mettetal, and U. Dubois (2014). Précarité énergétique et santé : état des connaissances et situation en Ile-de-France. Pollution atmosphérique; http://www.ors-idf.org/dmdocuments/2014/Synth_PE_et_sante_WEB.pdf.

Ichino, A., F. Mealli, and T. Nannicini (2008). "From Temporary Help Jobs to Permanent Employment: What Can We Learn from Matching Estimators and their Sensitivity?". *Journal Of Applied Econometrics* 23: 305–327. https://doi.org/10.1002/jae.998.

Imbens, G.W. (2000). "Sensitivity to Exogeneity Assumptions in Program Evaluation." *The American Economic Review* 3(93): 126–132.

Jacobs, R., P. Smith, and M. Goddard (2004). "Measuring performance: an examination of composite performance indicators." Technical Paper Series 29, Centre for Health Economics.

Jessoe, K. and D. Rapson (2014). "Knowledge is (Less) Power: Experimental Evidence from Residential Energy Use." *American Economic Review* 104: 1417–1438. https://doi.org/10.1257/aer.104.4.1417.

Krugmann, H. and J. Goldemberg (1983). "The energy cost of satisfying basic human needs." *Technological Forecasting and Social Change* 24: 45–60. https://doi.org/10.1016/0040-1625(83)90062-8.

Lacroix, E. and C. Chaton (2015). "Fuel poverty as a major determinant of perceived health: the case of France." *Public Health* 129: 517–524. https://doi.org/10.1016/j.puhe.2015.02.007.

Legendre, B. and O. Ricci (2015). "Measuring fuel poverty in France: Which households are the most fuel vulnerable?" *Energy Economics* 49: 620–628. https://doi.org/10.1016/j.eneco.2015.01.022.

Matsukawa, I. (2004). "The Effects of Information on Residential Demand for Electricity." *The Energy Journal* 25: 1–17. https://doi.org/10.5547/ISSN0195-6574-EJ-VOL25-NO1-2.NADEL.

Moore, R. (2012). "Definitions of fuel poverty: Implications for policy." *Energy Polic*y 49: 19–26. https://doi.org/10.1016/j.enpol.2012.01.057.

ONPE (2014). Définitions, indicateurs, premiers résultats et recommendations—Premier rapport de l'ONPE. ONPE.

ONPE (2016). Les chiffres-clés de la précarité énergétique, Les études de l'ONPE. ONPE.

Ormandy, D. and V. Ezratty (2012). "Health and thermal comfort: From WHO guidance to housing strategies." *Energy Policy* 49: 116–121. https://doi.org/10.1016/j.enpol.2011.09.003.

Pachauri, S. and D. Spreng (2003). "Energy use and energy access in relation to poverty." CEPE Working Paper 25.

Palmer, G., T. MacInees, and T. Kenway (2008). *Cold and Poor: An analysis of the link between fuel poverty and low income*. New Policy Institute, eaga partnership charitable trust.

Phimister, E., E. Vera-Toscano, and D. Roberts (2015). "The Dynamics of Energy Poverty: Evidence from Spain." *Economics of Energy & Environmental Policy* 4: 153–166. https://doi.org/10.5547/2160-5890.4.1.ephi.

Phradan, M. and M. Ravallion (1998). "Measuring Poverty Using Qualitative Perceptions of Welfare." Policy Research Working Paper.

Pon, S. (2017). "The Effect of Information on TOU Electricity Use: An Irish Residential Study." *The Energy Journal* 38: 55–79. https://doi.org/10.5547/01956574.38.6.spon.

Ravallion, M. (1998). "Poverty Lines in Theory and Practice. Living Standard." Measurement Study Working Paper 133. https://doi.org/10.1596/0-8213-4226-6.

Ravallion, M. and B. Bedani (1994). "How robust is a poverty profile?" *The World Bank Economic Review* 8: 75–102. https://doi.org/10.1093/wber/8.1.75.

Rosembaum, P.R. and D.B. Rubin (1983). "The central role of the propensity score in observational studies for causal effects." *Biometrika* 70: 41–55. https://doi.org/10.1093/biomet/70.1.41.

Rubin, D.B. (1974). "Estimating causal effects of treatments in randomized and nonrandomized studies." *Journal of Educational Psychology* 66: 688–701. https://doi.org/10.1037/h0037350.

Sen, A. (1979). "Issues In the Measurement of Poverty." *Scandinavian Journal of Economics* 81: 285. https://doi.org/10.2307/3439966.

Taner, T. (2015). "Optimisation processes of energy efficiency for a drying plant: A case of study for Turkey." *Applied Thermal Engineering* 80: 247–260. https://doi.org/10.1016/j.applthermaleng.2015.01.076.

Taner, T. and M. Sivrioglu (2015). "Energy–exergy analysis and optimisation of a model sugar factory in Turkey." *Energy* 93: 641–654. https://doi.org/10.1016/j.energy.2015.09.007.

Vilches, A., Á. Barrios Padura, and M. Molina Huelva (2017). "Retrofitting of homes for people in fuel poverty: Approach based on household thermal comfort." *Energy Policy* 100: 283–291. https://doi.org/10.1016/j.enpol.2016.10.016.

Waddams Price, C., K. Brazier, and W. Wang (2012). "Objective and subjective measures of fuel poverty." *Energy Policy* 49: 33–39. https://doi.org/10.1016/j.enpol.2011.11.095.

WHO (1987). Health Impact of Low Indoor Temperature: report on a WHO meeting. World Health Organization for Europe, Copenhagen.

Wolak, F.A. (2011). "Do Residential Customers Respond to Hourly Prices? Evidence from a Dynamic Pricing Experiment." *American Economic Review* 101: 83–87. https://doi.org/10.1257/aer.101.3.83.

SUPPLEMENTARY MATERIALS

A. MEASURE OF RESTRICTED HEATING: AN ECONOMETRIC ESTIMATE

A.1 Model

To measure the impact of restricted heating, it is necessary to evaluate the difference in an outcome variable. We selected the mean housing temperature to verify if the restriction leads to objective differences among households who do not declare a restriction in their heating energy consumption.

Potentially constrained households are denoted as i. A vector x of control variables represents their personal attributes and housing characteristics. The binary variable (the treatment variable) denoted R, reports whether the household reports restraining its heating energy consumption. For the treated sample, we have $R=1$, and for the control group, $R=0$.

Only a perfectly randomized evaluation makes it possible to avoid selection bias in the estimate. In that case, comparing the difference in the outcome variable between treated and untreated individuals provides the impact of the treatment (Rubin, 1974). However, in most cases, independence between the probability of being treated and personal attributes cannot be assumed. In our case, restricting heating energy consumption is undoubtedly strongly linked to household characteristics, including housing conditions. The present study is based on non-experimental data. We therefore used a non-experimental method to estimate the impact of the heating consumption constraint. The impact of heating restriction ($\beta(x)$) should ideally be the difference between the outcome variable for the treated households (Y_1) and this variable if the household had not been treated (Y_0):

$$\beta(x) = E\left[Y_1 / R = 1.X = x\right] - E\left[Y_0 / R = 1.X = x\right] \tag{9}$$

where:

$$Y = RY_1 + (1-R)Y_0 \tag{10}$$

Y_0 and Y_1 cannot be observed simultaneously, so the counterfactual temperature must be calculated. We used matching estimators, which requires matching each constrained household with one or many unconstrained households. Rubin (1974) proposed matching observations on observable characteristics. Under the assumption that the heating energy constraint is solely based on differences in observable attributes, the corresponding constraint effect can be measured even if it is not random. Each constrained household was matched to an unconstrained household based on the probability of being constrained, conditionally on the different observed characteristics x. This conditional probability is the propensity score (Rosenbaum and Rubin (1983). Matching on $R(x)$ is as good as matching on x (Rosembaum and Rubin (1983). Key assumptions for identifying the constraint effect are conditional independence—or *unconfoundedness* (Rosembaum and Rubin, 1983)—and the presence of a common support for propensity score density (Heckman et al., 1999). Under these assumptions, the propensity score matching average treatment is then equal to the mean difference in temperature over the common support.

We first performed one of the most frequently used matching techniques, nearest neighbor (NN) matching, and matched the treated observations with the five closest controls. This estimator implies a comparison between each treated unit and the closest untreated observation, in terms of propensity score.

However, one drawback of the NN method is that only a small sample of unconstrained households can ultimately satisfy the criteria to constitute the common support and allow for constructing the counterfactual outcome. For this reason, nonparametric matching estimators such as kernel matching were used to construct a counterfactual match for each treated unit by using the weighted average of all untreated units. The weights ($\omega(.)$) for kernel matching are given by:

$$\omega(i.j) = \frac{K\left(\frac{P_j - P_i}{a_n}\right)}{\sum_{k\in C} \left(\frac{P_k - P_i}{a_n}\right)} \tag{11}$$

where P_i is the propensity score for a constrained household and P_j the propensity score for an untreated household included in the control sample (C). K(.) is a kernel function and a_n a bandwidth parameter. Robust standard errors were calculated using bootstrap as the estimators are asymptotically linear (Imbens, 2003). Bootstrapping standard errors also enabled us to take into account the variance due to derivation of the propensity score matching and determination of the common support (Efron and Tibshirani, 1993; Heckman et al., 1997; Horowitz, 2003). The variables used for analysis are presented in the next section.

A.2 Variables used in the matching estimate

We balanced both subsamples (treated and untreated) by using dummy variables of income percentiles, homeownership, and size of the urban area. We also included a binary variable capturing whether the household can adjust its heating energy consumption, as this is not possible in some collective housing. The housing characteristics were introduced with the construction period and the energy consumption classification, estimated by a professional agency, indicating if the housing is energy efficient. The energy classification label, from A-G, provides insight into the energy efficiency of the dwelling: The A label is the most energy efficient, while the G label is the least efficient. The database provides the energy label for each dwelling.

Finally, one way to measure household preferences is measured through the answer to the question “Do you prefer reaching your comfort temperature or saving on heating costs?” Even if this question is relative to quality of life, it is a way to measure the ranking of thermal comfort in the hierarchy of household preferences.

Urban area categories include: rural areas (urban area size 0), areas with 2,000 to 9,999 inhabitants (urban area size 1), areas with 10,000 to 99,999 inhabitants (urban area size 2), areas with 100,000 to 1,999,999 inhabitants (urban area size 3), and Paris (urban area size 4).

Including construction periods enabled us to control for thermal performance, as current thermal regulations were implemented in the 1970s. Finally, we had to ensure that the sense of restricted heating declared by the treated observations did not come only from a strong preference for heat, so we included the preference variable. Variables are summarized in Table A-1.

These first descriptive statistics suggest that restricted heating is linked to occupation status and preferences for saving heating costs. Housing also seems to be less energy efficient among households who restricted their energy consumption.

A.3 Results

A.3.1 First step

In our two-step analysis, we first calculated the propensity scores (the probability of being constrained). The probability of restricting heating energy consumption is significantly influenced by standard of living, homeownership, whether it is possible to adjust the heating, preference for heating cost savings, and construction period. These results are in line with Healy (2003); Healy and Clinch (2002). Being a homeowner of a recent residence and belonging to the highest percentile seems to protect against restricted heating. However, being able to adjust the heating system has a positive and significant impact. On average, the literature reports that having a collective boiler or being linked to a district heating system prevents more fuel poverty as previously defined.

Table A-1: Summary statistics according to heating restriction

	All sample		Unrestricted households		Restricted households	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Percentile 1	0.1730	0.3783	0.1474	0.3546	0.2643	0.4414
Percentile 2	0.1838	0.3874	0.1756	0.3806	0.2130	0.4098
Percentile 5	0.2312	0.4217	0.2590	0.4382	0.1321	0.3390
Percentile 4	0.2187	0.4135	0.2258	0.4183	0.1933	0.3953
Age	55.6946	15.3273	55.9028	15.4837	54.9507	14.7457
Homeowner	0.7472	0.4347	0.7780	0.4157	0.6371	0.4813
Possible to adjust the heating	0.8197	0.3845	0.8073	0.3945	0.8639	0.3432
House	0.7274	0.4454	0.7355	0.4412	0.6982	0.4595
Urban area size 0	0.2558	0.4364	0.2662	0.4421	0.2189	0.4139
Urban area size 1	0.1230	0.3285	0.1209	0.3261	0.1302	0.3368
Urban area size 3	0.1915	0.3936	0.1839	0.3875	0.2189	0.4139
Urban area size 4	0.1311	0.3376	0.1314	0.3380	0.1302	0.3368
Preference for saving heating costs	0.4055	0.4911	0.3054	0.4607	0.7633	0.4255
Construction period: after 1971	0.5626	0.4962	0.5743	0.4946	0.5207	0.5001
DPE classification A or B	0.0237	0.1522	0.0265	0.1607	0.0138	0.1168
Heating restriction	0.2187	0.4135				
Observations	2.318		1.811		507	

Table A-2: Estimate of the propensity scores

	Coeff.	**Standard errors**
Percentile 1	0.235**	(0.102)
Percentile 2	0.0607	(0.101)
Percentile 5	-0.334***	(0.105)
Percentile 4	-0.0412	(0.0997)
Age	-0.000602	(0.00214)
Homeowner	-0.245***	(0.0810)
Possible to adjust the heating	0.377***	(0.0890)
House	0.0553	(0.0882)
Urban area size 0	-0.0491	(0.0908)
Urban area size 1	0.0300	(0.107)
Urban area size 3	0.0226	(0.0922)
Urban area size 4	0.0710	(0.110)
Preference for comfort for heating	-1.051***	(0.0650)
Construction period: after 1971	-0.0885	(0.0642)
DPE classification A or B	-0.336	(0.251)
Constant	-0.366**	(0.179)
Log likelihood	-1022.55	
No observations	2318	

*** Significant at 1%. ** significant at 5%. * significant at 10%

The estimate of the propensity scores (Table A-2) also suggests that restricted heating comes more from budget constraints than from low energy efficiency of housing. The preference variable is strongly significant and positive: the constrained households declare a preference for heating cost savings, rather than a more comfortable inside temperature. Finally, the energy classification does not seem to have any impact on the propensity scores.

After matching, we checked the balancing property. It is necessary to ensure that the household characteristics of the control and treated groups are comparable after matching (Table A-3 and Table A-4). Thus, two indicators are commonly used: the standardized percentage bias and the propensity score estimates of explanatory variables (Rosenbaum and Rubin 1983). The overall bias decreases significantly after matching, from 9.2% to 1%.

Table A-3: Matching quality 1

	Heating preference for comfort	
	Standardized percentage bias	**LR χ^2**
Before matching	9.5%	415.5
After matching	1.7%	$p > c^2 = 0.000$ ***

Table A-4: Matching quality 2

Variable	Unmatched / Matched	Mean Treated	Mean Control	% bias	% reduct. bias	t	p>t
Percentile 1	U	0.2643	0.14743	29.2		6.20	0.000
	M	0.25992	0.25277	1.8	93.9	0.26	0.795
Percentile 2	U	0.21302	0.17559	9.5		1.92	0.054
	M	0.21429	0.21758	–0.8	91.2	–0.13	0.899
Percentile 5	U	0.13215	0.25897	–32.4		–6.03	0.000
	M	0.13294	0.14017	–1.8	94.3	–0.33	0.738
Percentile 4	U	0.19329	0.22584	–8.0		–1.57	0.117
	M	0.19444	0.1947	–0.1	99.2	–0.01	0.992
Age	U	54.951	55.903	–6.3		–1.24	0.216
	M	55.075	55.127	–0.3	94.6	–0.05	0.957
Homeowner	U	0.63708	0.77802	–31.3		–6.51	0.000
	M	0.64087	0.66073	–4.4	85.9	–0.66	0.509
Possible to	U	0.86391	0.80729	15.3		2.94	0.003
adjust the heating	M	0.8631	0.86307	0.0	100.0	0.00	0.999
House	U	0.69822	0.73551	–8.3		–1.67	0.096
	M	0.69643	0.71405	–3.9	52.7	–0.61	0.540
Urban area size 0	U	0.21893	0.26615	–11.0		–2.15	0.031
	M	0.22024	0.22748	–1.7	84.7	–0.28	0.783
Urban area size 1	U	0.13018	0.12093	2.8		0.56	0.575
	M	0.12897	0.13467	–1.7	38.3	–0.27	0.789
Urban area size 2	U	0.21893	0.18388	8.7		1.77	0.076
	M	0.21825	0.21167	1.6	81.2	0.25	0.799
Urban area size 4	U	0.13018	0.13142	–0.4		–0.07	0.942
	M	0.12897	0.11731	3.5	–839.2	0.56	0.574
Preference for comfort	U	0.76331	0.30536	103.3		20.11	0.000
	M	0.7619	0.71062	11.6	88.8	1.85	0.065
Construction period	U	0.52071	0.57427	–10.8		–2.15	0.032
After 1971	M	0.52381	0.51958	0.9	92.1	0.13	0.893
Energy class 1	U	0.01381	0.0265	–9.0		–1.66	0.097
	M	0.01389	0.01182	1.5	83.7	0.29	0.771

Figure A-1 shows that the deviation is largely reduced after matching. Before matching, the distribution of confounders was different between two groups (heating preference for comfort and heating preference for energy savings), while the residual imbalance between matched groups was almost negligible (standardized bias ≤ 1% across all variables).

We also wanted to check the region of common support to see if we had enough overlap between the treatment and control groups to make reasonable comparisons. The "common support or overlap condition: $0 < P(Ti = 1|Xi) < 1$ ensures that treatment observations have comparison observations nearby in the propensity score distribution" (Heckman et al., 1999).

A.3.2 Second step

The second step consists of the calculation of temperature differentials using nearest-neighbor and kernel matching methods. The sensitivity of the results to a deviation from the assumption of conditional independence of potential outcomes (CIA) is presented in the sensitivity analysis

Figure A-1: Standardized percentage bias before and after matching

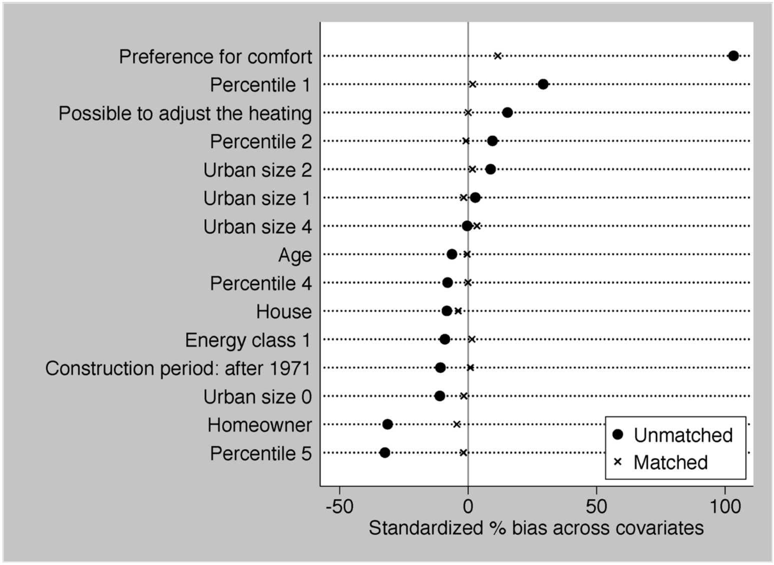

Table A-5: Mean average treatment effect

	Average restriction effect	Robust standard errors
Nearest neighbor (5) matching	-0.4604762	0.10308***
Kernel matching	-0.4928	0.091068 ***

Notes: *** Significant at 1%. ** significant at 5%. * significant at 10%

section. Households reporting restricted heating live, on average, in less heated housing, or at least in slightly cooler housing. On average, the temperature in their residence is 0.46 to 0.49 degrees lower[9] (Table A-5).

This result confirms that omitting restricted heating from the calculation of fuel poverty leads to an underestimation of the phenomenon. Considering that the average restriction influences temperature, a relevant fuel poverty measure should include not only monetary constraints, but also energy consumption (as a proxy of energy efficiency) and temperature to measure thermal privation. This could be a way to integrate a monetary aspect, an energy-efficiency aspect, and the aspect of well-being through mean temperature. The impact of restricted heating could be captured in a normative way. For this reason, we consider it necessary to develop a numeric index (FPI) capturing these three aspects of fuel poverty.

A.4 Sensitivity analysis after matching

Matching is based on the assumption that selection into the treatment group is only driven by observable factors, or the CIA.

This assumption has the main consequence that the choice of temperature is independent of the probability of restricting heating consumption. For more information about this assumption, see Ichino et al. (2008). Results are presented in Table A-6 below. The first four columns contain the probabilities Pij. For each value we give at U, the next two columns present, respectively, the

9. This result is confirmed when performing radius matching and stratification matching methods.

Table A-6: Sensitivity analysis

Fraction *u* =1 by treatment/outcome					Outcome effect	Selection effect	Report restricting consumption	SE
	P_{11}	P_{10}	P_{01}	P_{00}				
					temperature			
No confounder	0	0	0	0	—	—		
Neutral confounder	0.50	0.50	0.50	0.50	1.010	1.004	–0,486	0.004***
					Confounder like:			
Percentile 2	0.18	0.22	0.18	0.17	1.068	1.287	–0,488	0.006***
Percentile 1	0.35	0.25	0.15	0.15	1.033	2.117	–0,493	0.013**
Homeowner	0.58	0.65	0.78	0.78	0.989	0.497	–0,492	0.015**
Cooling system	0.13	0.03	0.10	0.07	1.497	0.591	–0,482	0.006***
Possible to adjust the heating	0.82	0.87	0.75	0.83	0.613	1.496	–0,477	0.008***
House	0.68	0.70	0.67	0.77	0.596	0.807	–0,494	0.008***

*** Significant at 1%. ** significant at 5%. * significant at 10%, ns not significant

outcome effect (i.e., the effect of u on the untreated outcome, controlling for observables x) and the selection effect (i.e., the effect of u on preference for comfort, controlling for observables x).

The first four columns give the four probabilities, s_{ij}, which define the distribution of the unobservable components by restricting heating consumption and outcome. Column 5 gives the outcome effect. Similarly, column 6 presents the selection effect. The two last columns provide the effect and the standard error of restricting heating consumption, controlling for the observable x and the unobservable U. We present the results of a sensitivity analysis for households that restrict their heating consumption when the distribution is comparable for income, ownership, having a cooling system, and the ability to adjust the heating.

For example, P11 equals 0.18, i.e. 18% of households who restrict their heating consumption by 0.488 Celsius belong to percentile 1. The effect of restricting heating consumption is just slightly higher than in the situation without a confounder (-0.488 vs. -0.486), but the effect is still negative and significant and almost the same.

Overall, the results of the sensitivity analysis for temperature indicate that the simulated matching estimators do not differ from the baseline estimates and remain statistically positive and significant, whatever the type of distribution chosen for U. All these simulations support the robustness of the matching estimates, whatever the distribution chosen for U.

B. RESULTS

Table B-1: Profile of fuel-poor households according to definitions

	Measure of fuel poverty according to…													
	10%			AFCP			LIHC			FPI			Whole sample	
	Mean	Std. Dev.	*t* test◊	Mean	Std. Dev.	*t* test◊	Mean	Std. Dev.	*t* test	Mean	Std. Dev.	*t* test‡	Mean	Std. Dev.
Percentile 1	0.520	0.501	***	0.503	0.501	***	0.740	0.440	***	0.136	0.040	***	0.193	0.395
Percentile 2	0.281	0.451	***	0.309	0.463	***	0.226	0.420	ns	0.118	0.028	***	0.190	0.393
Percentile 5	0.104	0.307	***	0.131	0.338	***	0.030	0.171	***	0.110	0.027	**	0.186	0.390
Percentile 4	0.081	0.274	***	0.057	0.232	***	0.004	0.062	***	0.097	0.022	***	0.214	0.410
Percentile 5	0.012	0.111	***	0.000	0.000	***	0.000	0.000	***	0.081	0.021	***	0.216	0.412
Homeowner	0.642	0.481	***	0.491	0.501	***	0.402	0.492	***	0.104	0.032	***	0.695	0.461
Possible to adjust the heating	0.837	0.370	ns	0.735	0.442	***	0.676	0.469	***	0.109	0.032	ns	0.805	0.396
Preference for comfort for heating	0.446	0.498	ns	0.510	0.501	***	0.543	0.500	***	0.114	0.035	***	0.412	0.492
Climate zone 1 (coldest – North)	0.680	0.468	ns	0.582	0.494	ns	0.695	0.462	***	0.108	0.035	ns	0.583	0.493
Climate zone 2	0.272	0.446	ns	0.337	0.473	ns	0.220	0.415	***	0.110	0.032	**	0.328	0.470
Climate zone 3 (warmest – South)	0.049	0.216	ns	0.081	0.273	ns	0.085	0.280	ns	0.099	0.031	***	0.089	0.285
Energy consumption per m2	278.3	141.4	***	162.028	119.633	ns	203.7	126.5	***				164.1	136.8
Construction period before 1919	0.298	0.459	***	0.227	0.420	***	0.170	0.377	ns	0.118	0.037	***	0.164	0.370
Construction period between 1919 and 1945	0.152	0.360	***	0.113	0.317	ns	0.096	0.296	ns	0.115	0.036	***	0.096	0.294
Construction period between 1946 and 1970	0.252	0.435	ns	0.252	0.435	**	0.279	0.450	***	0.107	0.035	ns	0.212	0.409
Construction period between 1971 and 2005	0.239	0.428	**	0.252	0.435	**	0.299	0.459	ns	0.102	0.031	***	0.309	0.462
Construction period between 1946 and 1970	0.040	0.198	***	0.109	0.312	***	0.103	0.305	**	0.102	0.031	***	0.157	0.364
Construction period after 2005	0.018	0.134	**	0.047	0.212	ns	0.051	0.221	ns	0.106	0.030	ns	0.063	0.243

(continued)

Table B-1: Profile of fuel-poor households according to definitions *(continued)*

	Measure of fuel poverty according to…													
	10%			AFCP			LIHC			FPI			Whole sample	
	Mean	Std. Dev.	*t* test◊	Mean	Std. Dev.	*t* test◊	Mean	Std. Dev.	*t* test	Mean	Std. Dev.	*t* test‡	Mean	Std. Dev.
House	0.794	0.406	ns	0.496	0.501	***	0.406	0.493	***	0.112	0.032	***	0.666	0.472
Temperature	19.828	1.525	ns	19.796	1.786	*	19.917	2.176	ns				19.982	1.573
Report restricting heating consumption	0.364	0.482	ns	0.360	0.481	***	0.420	0.495	***	0.120	0.036	***	0.232	0.422
% cutting or strongly restricting heating	0.636	0.482	ns	0.640	0.481	***	0.580	0.495	***	0.104	0.032	***	0.769	0.422
% limiting the heating time in the day	0.080	0.272	*	0.094	0.292	***	0.113	0.318	***	0.120	0.033	***	0.051	0.220
% limiting the number of heating weeks in the year	0.043	0.204	*	0.075	0.264	***	0.088	0.285	**	0.120	0.037	***	0.039	0.194
% not heating some rooms	0.010	0.101	*	0.033	0.178	***	0.045	0.208	*	0.136	0.047	***	0.014	0.118
% using auxiliary heater instead of main heater	0.165	0.372	***	0.109	0.312	***	0.113	0.318	**	0.118	0.036	***	0.077	0.267
% others	0.036	0.188	ns	0.024	0.155	ns	0.024	0.152	ns	0.125	0.029	***	0.028	0.165
Cold discomfort	0.245	0.431	***	0.316	0.466	***	0.403	0.492	***	0.116	0.038	***	0.192	0.394
Cold discomfort Insufficient heating installation	0.033	0.180	ns	0.112	0.317	ns	0.152	0.362	ns	0.100	0.038	***	0.119	0.324
Cold discomfort Installation failure	0.135	0.346	ns	0.156	0.365	ns	0.129	0.338	ns	0.116	0.116	ns	0.128	0.334
Cold discomfort Financial reasons (privation)	0.299	0.463	***	0.154	0.363	**	0.151	0.361	ns	0.128	0.033	***	0.126	0.332
Cold discomfort Bad insulation	0.216	0.416	ns	0.339	0.476	ns	0.362	0.484	ns	0.124	0.040	***	0.306	0.461
Cold discomfort Unpaid power provider	0.000	0.000	ns	0.000	0.000	ns	0.000	0.000	ns	–			0.002	0.048
Wrong setting	0.016	0.128	ns	0.044	0.206	ns	0.048	0.216	ns	0.081	0.031	***	0.043	0.204
Harsh winter	0.182	0.390	ns	0.119	0.326	**	0.096	0.297	ns	0.117	0.037	ns	0.178	0.383

*t test between fuel poor and not fuel poor. *** Significant at 1%. ** significant at 5%. * significant at 10%, ns not significant ‡differences of means values of FPI according to household characteristics. For example, the value of FPI is statistically different for households belonging to the first decile relative to others.