Fuel Poverty and Well-Being:
A Consumer Theory and Stochastic Frontier Approach

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Abstract

Evidence and conventional wisdom suggest that general poverty has a negative effect on the well-being of individuals. However, the mechanisms through which this effect occurs are not well-understood through economic approach. In this paper, we analyse the influence of general and fuel poverty as well as the social dimension through peer comparison on the subjective well-being of households. We develop a novel approach to analyse fuel poverty and well-being based on consumer theory. Individual preferences are modelled using indifference curves and a distance function where the preferences of individuals are affected by their poverty status. We use the survey data from the official Spanish Life Condition Survey for 2013, which contains over 16,608 observations on household members. The results show that both general and fuel poverty influence the reference indifference curve but that individuals also compare themselves with their peers. The proposed model also allows us to corroborate how general and fuel poverty affect well-being and how effective policies can be designed to improve social welfare.

Keywords: distance functions, fuel poverty, general poverty, indifference curve, stochastic frontier analysis, subjective well-being.

JEL Classifications: D12, I32, Q41

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1. Introduction

Analysis of the determinants of well-being of individuals has attracted significant interest in recent years. The increase in surveys on individual welfare and studies that find the concept of subjective well-being a useful proxy for individual utility has allowed theoretical and empirical analysis of the utility function leading to important developments (See Welsch and Ferreira, 2014). On the other hand, policy makers are increasingly concerned with a particular aspect of poverty among households in the form of fuel poverty. Broadly, fuel poverty refers to the difficulty of maintaining an adequate temperature in a home, as well as lacking other essential energy services (Boardman, 1991). Some recent studies such as Liddell and Morris (2010) and Welsch and Biermann (2017) have shown that fuel poverty could affect well-being of individuals and cause social exclusion. Biermann (2016) points out that while the literature on fuel poverty has been mainly concerned with the notion and measurement of fuel poverty and policies to reduce its social impact, little is known on the direct impact of fuel poverty on individual welfare and whether (and why) fuel poverty affects individual welfare differently than other dimensions of household poverty.

In this paper, we extend the literature concerning the relationship between fuel poverty and subjective well-being by proposing a new novel approach that relies on a *primal* representation of individuals' preferences using indifference curves. To do this, we use stochastic frontier techniques (Kumbhakar and Lovell, 2000). An appealing feature of this approach is that it is rooted in consumer theory. It assumes that individuals endogenously chose their bundle of goods as consumer theory suggests. Thus, while previous studies have adopted a production or utility approach and used individual (endogenous) goods to produce welfare, our consumption-based distance functions depend on *ratios* of (endogenous) goods that can be treated as exogenous variables. Moreover, our model assumes that consumption, but not income, is the relevant well-being driver. This allows us to address potential bias caused by the fact that income is "only a noisy proxy for consumption" (Clark et al., 2008) that tend to overestimate of what is consumed when a person is young (when consumers save) and underestimate the true consumption when a person is old (when consumers do not save).

Another important issue to be addressed is the subjective or relative nature of well-being. When evaluating their well-being, individuals draw comparisons with their peers or persons bearing similar characteristics to themselves.[1] The notion that well-being is influenced by relativities such as income has been analysed in recent years (see, e.g., Dorn et al. 2007; Ferrer-i-Carbonell, 2005; Luttmer, 2005). In this context, the frontier nature of our empirical model is particularly suitable for analysing a relative concept such as subjective well-being and its relationship with fuel poverty. In the well-being setting, the frontier analysis approach implies the comparison of individuals, modelling the potential well-being (frontier) that they can achieve given their preferences and the goods they have. Once this frontier is constructed, individuals can compare their level of well-being with their potential one. Hence, the estimated frontier is a relative construct and not an absolute one. In this sense, it is noteworthy that many researchers examining the so-called

[1] As Blanchfolwer and Oswald (2004) pointed out "people probably compare themselves more with their peers than with Bill Gates".

Easterlin (1974) paradox (i.e. the differences between country and individual-level happiness) have implicitly used a “frontier” notion. For example, Clark et al. (2008) suggest that both macro and micro-level evidence are consistent with the presence of relative income terms in the utility function. In other words, happiness has an important relative component and is consistent with our application using frontier techniques.

Binder and Brockel (2012), Mizobuchi (2014) and Cordero et al. (2017) apply a frontier approach to analyse how individuals search for the highest level of happiness achievable, given a set of resources. They employ a production frontier model using nonparametric techniques.[2] We examine the effect of fuel poverty on well-being, changing the perspective from production to consumption theory. This change is not only a semantic issue. Well-being is a subjective concept and difficult to measure due to its relative nature, whereas firms’ production is an objective variable that can be measured in absolute terms. Lovell et al. (1994) uses an input distance function to estimate standard of living using a Malmquist index. The advantage of this approach is that, if preferences are homothetic, the value of the index is independent of the choice of the reference utility level. A drawback of this model is that it “treats all individuals equally” (Lovell et al., 1994, p.792) as it assumes that they have the same level of potential utility or well-being. That is, the model assumes that goods bring the same utility to all individuals irrespective of their personal characteristics. Nevertheless, personal characteristics can condition a person’s perception of own well-being (i.e. individuals’ preferences are subjective). Thus, it is not certain that the same bundle of goods will yield the same level of well-being for different individuals. The model proposed in this paper extends the previous analysis by allowing individuals to have different indifference curves according to the subjective

[2] Frontier models can be estimated using parametric or non-parametric techniques. Each technique has its own advantages and disadvantages. See Orea and Zofío (2017) for details.

nature of their preferences. This allows us to analyse whether the individuals situated above or below the poverty line represent different preferences.

In sum, the hypotheses are: i) general poverty and fuel poverty influence the preferences of individuals and their indifference curves; ii) following consumer theory, individuals endogenously choose their bundle of goods; and iii) consumption, rather than income, is the main driver of their well-being.

The remainder of the paper is as follows: Section 2 is a brief review of the literature on fuel poverty and well-being. Section 3 presents the proposed methodology. Section 4 describes the data used in our empirical application based on the *Spanish Life Condition Survey*. Spain is an ideal environment to study the effects of fuel poverty on subjective well-being because while general poverty doubled in the period 2007/2013, fuel poverty tripled in the same period. Section 5 discusses the main results of the empirical analysis. Finally, Section 6 concludes.

2. Literature Review

Fuel poverty has gained public policy relevance in recent years in Europe as well as in Australia, New Zealand and the US (see Thomson *et al*., 2017 or Bouzarovski and Petrova, 2015 for a comprehensive review). Several studies estimate expenditure functions that allow analysis of income elasticities and suggest that energy services may be characterised as necessary goods (e.g., Romero-Jordán et al., 2016; Jamasb and Meier, 2010a; Meier et al., 2013). The results of these studies, and the fact that fuel poverty is increasing in many countries, are arousing great interest on the part of researchers, consumer organisations, and policy-makers alike.

Since the pioneering works of Bradshaw and Hatton (1983) and Boardman (1991), several studies have analysed this topic in the UK. Bennett et al. (2002) analyse household data in 1997-1998 where fuel poverty (measured as households that spend more than 10% of their income on fuel), is a function of variables such as income; gas payment methods; state benefits and household type and composition. Jamasb and Meier (2011) use panel data for the period 1991-2008 to investigate fuel poverty (as ratio of energy spending over income) using a function of several variables that approximate vulnerable households. Beatty et al. (2014) analyse a possible "heat or eat" trade-off. Based on the idea that a cold weather shock implies that households must spent more than anticipated to keep warm, they find that if the weather shock has a large impact on income, a trade-off between heat or eat can occur.

Fuel poverty indicators can be based on objective measures (e.g., expenditure) or subjective perceptions (feeling able to afford sufficient energy to keep homes warm). Regarding objective measures, for many years, the UK used the 10% rule. In recent years, fuel poverty in England has been measured using the Low Income High Costs (LIHC) indicator proposed by Hills (2012) while Wales and Scotland continue to use the 10% rule.[3] Moore (2012) defines the Minimum Income Standard (MIS) indicator which refers to the minimum income of a household which permits its members to opt for opportunities and choices which allow them an active integration in the society. Specifically, he states that a household will be in fuel poverty if household energy costs are larger than household income, once it is adjusted for other housing costs and the abovementioned minimum income standard.[4] Waddams et al. (2012) use a UK survey of 2000 and explore

[3] The LIHC indicator defines fuel poverty as the combination of facing high costs and having a low income. This approach is based on two thresholds – one for household income and one for energy costs.
[4] In the UK, the platform "minimumincome.org.uk", permits the calculation of MIS for households as a function of criteria for the basic needs to which all citizens should be able to accede.

the link between objective and subjective measures and find that, although both fuel poverty measures are positively related in a complex way, they both should be considered in designing social policy[5]. Miniaci at al. (2014) state that the results differ depending on the measure of fuel poverty chosen. Roberts et al. (2015) analyse fuel poverty in the UK for the 1997-2008 period. They use dynamic models of fuel poverty as a function of the nature of housing; personal characteristics; differences in energy prices and temperature across time and space. The study finds that, on average, the experience of fuel poverty in urban areas was more prolonged with a higher probability of persistent fuel poverty.

Researchers have also analysed fuel poverty in other European countries. Charlier and Legendre (2016) and Legendre and Ricci (2015) show that the proportion of fuel poor people in France, and their characteristics, differ significantly depending on the fuel poverty measure chosen. Also, the probability of falling into fuel poverty is higher for those who are retired, live alone, rent their home, use an individual boiler for heating, and cook with butane or propane. Papada and Kaliampakos (2016) use an objective expenditure-based method to analyse fuel poverty among Greek households and find that 58% of the households are energy poor. Moreover, among households under the general poverty threshold, the rate of energy poverty exceeds 90%. They also explore the relationship between various indicators and found that, when using alternative subjective indicator, the results are not identical. Lis et al. (2016a) quantifies the heterogeneity relating to the causes of energy poverty in Polish households in terms of energy efficiency and income using cluster analysis and links the types of fuel poverty with behavioural characteristics. Later, Lis et al. (2016b) seeks to explain the regional variation of fuel poverty in Poland.

[5] See also Lawson et al. (2015), Deller and Waddams (2017), Deller (2018), or Fizaine and Kahouli (2019).

The issue of fuel poverty in Spain began gathering momentum with the Tirado-Herrero et al. (2012, 2014) reports. In particular, the latter report revealed significant findings. In 2012, 17% of Spanish households (12% in 2010) had energy expenses amounting to over 10% of their annual income (equivalent to 7 million people). Additionally, in 2012, 9% of households (8% in 2010), were unable to keep their home adequately warm during winter (equivalent to 4 million people). Other reports[6] indicated that fuel poverty has worsened in recent years due to the combined effect of low energy efficiency of residential buildings, the economic crisis and energy prices. For example, average residential electricity prices in Spain increased by 73% during 2008-2015. In the same period, the natural gas bill of average Spanish household increased by 26% (Eurostat, 2016), partially due to the inclusion of costs associated with social and environmental policies. Meanwhile, unemployment grew from 8.5% in 2007 to 20.9 in 2015. For all these reason, general poverty doubled in the period 2007/2013 whereas fuel poverty tripled in the same period (Bellver, 2015).

Inspired by these trends, Romero et al. (2015) study the impact on fuel poverty of several personal and household characteristics in Spain. In this study, several fuel poverty measures are calculated and compared. Using the Spanish Life Condition Survey and the Household Budget Survey for the year 2013, the study concludes that the MIS index indicates that fuel poverty is present in 8-9% of the Spanish households (1,799,311 households representing, 6,264,432 individuals). With "the 10% threshold" indicator the percentage increases to 18.24%. With the low-income high cost indicator, the problem is present in 8.7% of the Spanish households.[7] They find using a logit model that low-

[6] See Tirado Herrero et al. (2016), Romero et al. (2015), Scarpellini et al. (2015), Phimister et al. (2015), Linares-Llamas and Romero-Mora (2015) and Linares Llamas et al. (2017).
[7] They also found that 3% of Spanish households experience fuel poverty for all three indicators, which constitutes a minimum benchmark for fuel poverty in Spain. Similar results are found in Linares Llamas et al. (2017).

income (and low energy consumption) households, with dependent children or job instability on the part of the household bread-winner are most vulnerable in terms of the threat of falling into fuel poverty. With the aim of elucidating which of the abovementioned measures proves to be the best representation of fuel poverty, the authors analyse the presence of false positives, that is, households which are considered to be in a situation of fuel poverty using one indicator, but in reality are not fuel poor in terms of the results obtained by alternative indicators and different control variables.[8] Their report concludes that the indicator based on the MIS offers the best approximation for analysing fuel poverty in Spain.

In summary, as Welsch and Biermann (2017) point out, the literature has been concerned with definitions, the empirical measurement of the incidence, intensity and consequences of fuel poverty. However, the literature on modelling the link between fuel poverty and subjective well-being is still scarce. Three notable exceptions are Biermann (2016), Churchill et al. (2018) and the abovementioned paper.

Biermann (2016) analyses life satisfaction for individuals in Germany from 1994 to 2013 and its relationship with several measures of fuel poverty. Using a simple model where reported life satisfaction is regressed on fuel poverty, a set of individual-specific variables and a set of fixed effects, he finds a negative and significant effect of fuel poverty on subjective well-being. Welsch and Biermann (2017) study the relationship between fuel poverty and affordability of electricity, heating oil and natural gas, for households using individuals in 21 European countries from 2002 to 2011. Although they do not measure household's energy poverty directly, they show theoretically that fuel

8 These variables are the income deciles to which each household belongs, the households above and below the poverty line and the deciles of energy consumption per equivalent inhabitant (the equivalent energetic consumption per inhabitant is calculated by dividing household energy consumption by the equivalent number of members, applying the OECD equivalence scale).

poverty becomes a determinant of well-being if it has to do with a minimum (required) amount of energy consumption. They use energy prices as proxy for household's energy poverty and find that energy prices have a significant effect on subjective well-being and this effect is strongest when required energy expenditures can be expected to be high. They also point out that a more in-depth analysis of how fuel poverty affect subjective well-being should be conducted combining well-being data with household level measures of fuel poverty. While the previous papers are focused on European Countries, Churchill et al (2018) to examine the effect of energy poverty on well-being in Australia. They find that being in energy poverty lowers well-being. The general conclusion that energy poverty lowers well-being is robust to alternative ways of measuring energy poverty, alternative estimation approaches and other sensitivity checks.

The above studies use a similar empirical strategy: micro-econometric life satisfaction equations where subjective well-being is assumed to be a linear function of fuel poverty, socioeconomic variables, and observed individual characteristics. Our model takes advantage of the consumption theory in order to take into account the subjective nature of well-being. This feature in turns allows us to identify two channels through which fuel poverty might affect well-being. Another distinctive feature of our model is that we use a flexible representation of individual preferences that provides a second-order approximation to the true but unobserved preferences.

3. Methodology

3.1. Theoretical background

Under the assumption of regular preferences (i.e. satisfying reflexibility; completeness and transitivity), consumer theory often uses a utility function to represent individual preferences. As this function theoretically depends on the bundle of goods chosen by the individuals, the estimated parameters are likely biased because the goods are endogenous. In order to avoid this problem, we propose estimating a distance function, a less intuitive function than the standard utility function.

To introduce the main features of the distance function, we adopt the conceptual framework proposed by Welsch and Biermann (2017) These authors consider an individual (consumer) who derives utility from energy E and a non-energy good N according to a monotonically increasing and strictly concave utility function, $W = f(E, N; z)$ where W stands for subjective well-being, and z is a set of variables related to the socioeconomic characteristics of the individual and household. In this model, utility is proxied by subjective well-being (W). By doing so, we assume that W is a positive monotone transformation of the underlying utility function.

Following Shephard (1953; 1970) and Deaton (1979), we can next define the so-called distance function as:

$$D(W, E, N; z) = \max_{\theta} \left\{ \theta \geq 1 : f\left(\frac{E}{\theta}, \frac{N}{\theta}; z\right) \geq W \right\} \tag{1}$$

where W is a particular level of well-being. Formally, D represents the maximum reduction of goods that allows for a consumer reaching W. Although graphically the distance function is just measuring the distance to an indifference curve, it fully represents the individual's preferences as the well-known utility function. If D equals unity, it implies that the consumer is located on the indifference curve obtaining the W level of well-being. A value higher than one implies that the consumer is obtaining a lower level of satisfaction than W. For this reason, the indifference curve can be regarded as a frontier and the well-being associated to the indifference curve as the potential (maximum) well-being that an individual can achieve with the current amount of goods. The difference between the reported and the potential well-being of an individual can be measured using the following *Well-being Loss Index* (WLI):

$$0 \leq WLI = \frac{1}{D} \leq 1 \tag{2}$$

The above frontier interpretation allows decomposing reported well-being of an individual into two components. The first component is the maximum well-being that individuals can obtain with a bundle of goods. That is to say, the well-being level at the indifference curve frontier. Individuals build their reference framework by comparing their vital circumstances with those of others in similar economic situation and with similar socio and household characteristics (e.g. household's neighbours). We do not have information on individual's neighbours, but their bundle of goods is likely similar to the individual's bundle of goods. Therefore, we assume that this frontier depends on the individual consumption of energy and a non-energy good. The frontier also depends on a set of socioeconomic individual variables. This allows us to relax the assumption of common preferences in previous papers as Lovell et al. (1994). Moreover, individuals in material deprivation do not likely compare themselves with individuals in a comfortable economic situation (and vice versa) but with those with incomes comparable to their own. In this case, and given that the model depends on goods instead of income, we introduce variables to capture the individual's poverty. As people tend to adapt to their life circumstances, the subjective needs reported by an individual are expected to be inferior for those with higher incomes but living in a more demanding environment in terms of their material needs (Blanchflower and Oswald, 2004). In other words, poverty shifts the indifference curve frontier to the left given that individuals living *ceteris paribus* in a poverty situation require (or conform to having) less goods.

The second component is the WLI term capturing unobserved departures from the above mentioned reference framework.[9] This term is random in nature because we do not know the emotional and affective procedures used by the individuals to compare their life circumstances with those of other individuals. As people need time to adapt to new life circumstances, the well-being losses captured by WLI might capture pace differences among individuals, or different stages of the adaptation process. The WLI term might also capture differences in the subjective needs reported by "similar" individuals. As many of the above issues may be correlated with poverty, we assume in the empirical application that WLI depends on fuel and other dimensions of poverty. More specifically, we are interested in how (general and fuel) poverty influence individuals in such a way that they are unable to achieve their relative potential well-being level (defined as maximum well-being obtained for individuals with same goods and similar individual and household characteristics).

3.2. Distance function and connection with the utility function.

We explain the relationship between the distance and the utility function by initially assuming that the distance function has the following Cobb-Douglas form:

$$D(W, E, N; z) = \phi W^{-\gamma} E^{\alpha} N^{1-\alpha} z^{\delta} \tag{3}$$

where all coefficients in (3) are assumed to be positive. The term measuring well-being losses (i.e. the value of D) is not observable and thus it cannot be used as a proper dependent variable to estimate (3). For estimation purposes we rely on the theoretical properties of distance functions. In particular, the key property for estimation is the linear

[9] D is formally identical with the input distance function (D_I) in the context of production theory. In a consumption setting, the distance function is the dual of the expenditure function. Also, WLI is called technical inefficiency in production literature.

homogeneity condition. Linear homogeneity in energy and non-energy goods imply that the distance function $D(W, E, N; z)$ can alternatively be written after taking logs as:

$$lnD(W, E, N; z) = lnD\left(W, \frac{E}{N}; z\right) + lnN \tag{4}$$

This specification immediately "produces" an observed dependent variable for the above model once (4) is inserted into (3). Indeed, rearranging terms, model (3) can be expressed as follows:

$$lnN = -ln\phi + \gamma lnW - \alpha ln\left(\frac{E}{N}\right) - \delta lnz + u \tag{5}$$

where $u = lnD \geq 0$ is a non-negative random term measuring the gap between reported and potential well-being. Once we add the traditional two-sided noise term, equation (5) can be estimated using one of the estimators proposed in the stochastic frontier literature (see Parmeter and Kumbhakar, 2014). A similar expression can be obtained if energy is used a numeraire. That is to say, results are invariant to the good chosen to impose homogeneity.

In order to explain that utility functions and distance functions are two equivalent but different approaches to modelling individual preferences, we now link our distance function model with a standard (non-frontier) utility function, that is to say, a function where individuals are located on the utility curve obtaining the maximum utility level given their bundle of goods. In fact, the utility function can be viewed as a frontier model where it is assumed that $D = 1$ (as we have explained above, a value higher than one implies that the consumer is located below the utility function, obtaining a lower level of satisfaction than W). In contrast, if we assume that the consumer could be obtaining a value less than the maximum, a proper specification of the Cobb-Douglas utility function is:

$$W = a\left(\frac{E}{D}\right)^{b}\left(\frac{N}{D}\right)^{c} z^{d} = aE^{b}N^{c}z^{d}D^{-(b+c)} \tag{6}$$

Taking logs, and after some straightforward mathematical operations, we obtain:

$$lnN = -ln\phi + \gamma lnW - \alpha ln\left(\frac{E}{N}\right) - \delta lnz + u \tag{7}$$

where $\phi = a^{1/(b+c)}$, $\gamma = (b+c)^{-1}$, $\alpha = b(b+c)^{-1}$, $\delta = d(b+c)^{-1}$, and $u = lnD$. Notice that we have got the same model as (5). That is, the utility function used is just a distance function where $D = 1$ is assumed. It is also worth mentioning that the above result shows algebraic relations not econometric ones. Econometric estimation of (6) and (7) will not give the same results simply because of the fact the explanatory variables in (6) might be endogenous if individuals endogenously chose their bundle of goods. As both energy and non-energy goods depends on the same random shocks than the non-energy goods, the ratio of quantities of two goods in (5) becomes an exogenous variable. Therefore, although goods are considered as endogenous variables in our theoretical model, the omission of these variables does not cause endogeneity problems if individual's preferences are estimated using the distance function (5) (see Coelli, 2000 or Kumbhakar, 2011 for details).

3.3. Functional form

In the previous section, we have assumed Cobb-Douglas preferences. Other kind of preferences have been used in the literature. For example, Welsch and Biermann (2017) assumed the following Stone-Geary utility function:[10]

[10] We have added to their utility function the effect of z on household's well-being in order to mimic our distance function in (3). Notice also that, alike Welsch and Biermann (2017), we have not imposed the restrictions $a = b$, and $c = 1 - b$. To simplify the analysis, we do not consider a reserve level for N.

$$W = a(E - R)^b N^c z^d \tag{8}$$

where R is interpreted as a required (minimum) level of energy consumption. This implies that E only adds utility if $E > R$. Also, it is assumed that fuel poverty influences wellbeing as long as it is viewed as a proxy for R. Indeed, they define fuel poverty (FP) in their theoretical model as a function of R: $FP = p_E R/y$; where p_E and y stand respectively for energy prices and income. In accordance with this definition, FP reduces individual's well-being as it increases the required level energy consumption, given the ratio income to energy prices.

Notice that in equation (2) an equality symbol to define their utility function, i.e. they assumed that $W = f(E, N, R;\ z)$. This implies that *all* individuals are in the frontier well-being function. It is also assumed that all individuals have the same preferences. In particular, the minimum energy consumption (R) in their conceptual model is a parameter to be estimated. Therefore, it is implicitly assumed that all individuals start to "feel better" when they depart from the *same* amount of energy. This can be viewed as a strong assumption if the subjective needs reported by an individual are expected to be inferior for those with higher incomes. Well-off households likely demand more energy due to their houses are quite large and they minimum comfort standards are larger than poorer households. In their empirical model they allow for differences in preferences, but they do not link them to FP. We expect that FP and other dimensions of poverty (i.e. material deprivation) is also a determinant of individuals' preferences due to the subjective nature of reported well-being.

Nevertheless, when we contrast the validity of the Stone-Geary against the Translog (see Footnote 14) we model a reserve level for all the goods we have considered.

We can relax this somewhat strong assumption using the distance function (1). To show this, we write Welsch and Biermann (2017)'s utility function in a frontier setting as follows:

$$W = f\left(\frac{E}{D}, \frac{N}{D}, R; z\right) = a\left(\frac{E}{D} - R\right)^{b}\left(\frac{N}{D}\right)^{c} z^{d} \tag{9}$$

Note that while R can be interpreted as the *frontier* minimum energy consumption, $m = R \cdot D$ represents such amount for a household that perceives a lower level of well-being than could have been achieved with his bundle of goods. This makes sense as the household is likely not achieving the same utility than others due to his perceived minimum level of energy consumption is larger. Using this new variable, we can rewrite the utility function (9) as:

$$W = a\left(\frac{E}{D}h\right)^{b}\left(\frac{N}{D}\right)^{c} z^{d} \tag{10}$$

where $h = (E - m)/E$ is the abovementioned relative measure of the difference between current and perceived minimum energy consumption. This equation indicates that the larger the perceived minimum energy consumption is, the smaller the well-being. Taking logs, and after some straightforward mathematical operations, we obtain:

$$lnN = -ln\phi + {}_{\gamma}lnW - \alpha ln\left(\frac{E}{N}\right) - \alpha lnh - \delta lnz + u \tag{11}$$

where ϕ, γ, α, δ, and u are defined before. Several comments are in order regarding the above equation based on a Stone-Geary. Notice that $h = (E - Re^{u})/E$ is a function of both the frontier minimum level of energy consumption (R) and the distance function ($D = e^{u}$). Therefore, if we assume, as Welsch and Biermann (2017), that R is proxied with a FP measure, the above frontier distance function depends on fuel poverty.[11]

[11] As mentioned above, if individual preferences depend on other dimensions of poverty, the above equation should be extended accordingly.

On the other hand, the Stone-Geary function is not separable in the well-being loss random term u. As u interacts with other utility drivers in a non-linear fashion, it is not possible to derive a closed likelihood function. This precludes using standard maximum likelihood techniques to obtain the parameter estimates. In sum, although the Stone–Geary utility function has been prominently used in the literature, it cannot be estimated with standard frontier techniques. This issue appears because the Stone–Geary utility function relies on the existence of minimum consumption levels. Other utility functions such as the Cobb-Douglas or Translog do not use this concept, and hence they are able to provide an empirical specification that is separable in deterministic and stochastic terms, and thus it can be estimated using standard maximum likelihood techniques. Moreover, many "well-behaved" utility functions such as the Cobb-Douglas and Stone–Geary utility function place significant restrictions on individual preferences.[12] A subsequent generation of less restricted or *flexible* functional forms emerged in the 70s, such as the quadratic, generalized Leontief, or Translog form. These functions are general representations of individuals' preferences as they provide second-order approximations to the true but unobserved utility function. Following Jorgenson and Lau (1975), we propose a Translog distance function, expressed using only two goods as: [13]

[12] In order to contrast the validity of the Stone-Geary utility function, we have estimated both the Stone-Geary and Translog utility functions using non-frontier techniques, and tested their equivalence using the Vuong test. The value of this test was 4.56, higher than the critical value of the normal distribution at standard levels of significance, which indicates that, for the data used, the Translog functional form is a better representation of the preferences than the Stone-Geary function.

[13] While the flexibility of the functional forms allows a more precise representation of individuals' preferences and economic behaviour, they are prone to some drawbacks. The fact that the number of parameters to be estimated increases exponentially with the number of variables in the functional form, empirical research is *de facto* restricted to the quadratic approximation. On the other hand, how to test whether the flexible functional forms are globally well-behaved remains unclear. Imposing regularity conditions globally often comes at the cost of limiting the flexibility of the functional form.

$$lnN = \beta_0 + \beta_w lnW + \beta_E ln\left(\frac{E}{N}\right) + \beta_z lnz + \beta_{ww}\tfrac{1}{2}lnW^2 + \beta_{EE}\tfrac{1}{2}ln\left(\frac{E}{N}\right)^2 + \beta_{zz}\tfrac{1}{2}lnz^2 +$$

$$+\beta_{wE} lnWln\left(\frac{E}{N}\right) + \beta_{wz} lnWlnz + \beta_{Ez} ln\left(\frac{E}{N}\right) lnz + v + u \qquad (12)$$

where we have added a traditional noise term v.

3.4. Distributional assumptions

As it is customary in the frontier literature, we assume that v follows a zero-mean normal distribution with variance σ_v^2. The non-negative term u is assumed to follow a (heteroscedastic) half-normal distribution, i.e. $u \sim N^+(0, \sigma_u^2)$. That is, u is a zero-mean normal distribution with variance σ_u^2 truncated from below at zero. Note that we are modelling the variance (not the mean) of the pre-truncated normal distribution in this specification. However, it should be taken into account that what we are finally modelling after the truncation is the mean (and the variance) of u. This implies that the larger σ_u^2, the greater is the average distance from the frontier (see Caudill et al., 1995).

In order to model how fuel poverty and other dimensions of poverty influence the gap between potential and reported well-being, we specify the log of σ_u^2 as a linear function of a set of variables related with poverty. The heteroscedastic specification of the u term not only allows us to analyse how fuel poverty can influence individuals in such a way that they are unable to achieve their relative potential well-being level, but also to get unbiased parameter estimates of the distance function. Indeed, it is well-known in the frontier literature (see Kumbhakar and Lovell, 2000) that homoscedastic frontier models might seriously bias both the frontier parameters and the well-being loss indices. Thus, we include a set of variables related with poverty as determinants of well-being losses for both economic and econometric reasons.

4. Data

In order to estimate the proposed model, we use the data from the Spanish Life Condition Survey, which is an annual survey of households runs by the Spanish Statistical Office (in Spanish, *Instituto Nacional de Estadística*, INE) as part of the EU-SILC (European Union-Statistics on Income and Living Conditions). The survey provides detailed individual and household information regarding characteristics such as income, education, well-being and poverty indices. Also, it contains data at household level such as the household members, information on the dwelling, equipment or household income and other relevant economic information. We use the survey data for the year 2013 because only for this year there is a special well-being module that is particularly relevant for the purpose of our study. Our sample consists of 16,608 individuals interviewed in 2013. The definitions of all the variables used in our empirical application can be found in the Appendix.

The life cycle survey collects information on the well-being of individuals from several points of view. As subjective well-being is not a simple concept, we analyse it in relation to a single but important aspect of household life - i.e. house satisfaction.[14] Using this information, we built a continuous variable called W which is the arithmetic average

[14] Blanchflower and Oswald (2004) point out the distinction between well-being in life as a whole and well-being associated with a single area of life (*context-specific* well-being). In this sense, our empirical strategy is reasonable as house satisfaction is the domain that likely is more affected by fuel poverty.

of several indices that reflects different aspects of well-being in a household (e.g. economic satisfaction at home, surroundings, etc.).[15][16].

In order to maximize their well-being, we assume that individuals choose three goods[17] related to the dwelling: electricity expenditure (EL); gas expenditure (G) and the expenditure on other goods related to the dwelling (N).[18] To control for differences in individual preferences, we include a set of *individual* socioeconomic variables that may affect well-being: age, gender, nationality, civil status, education, individual' health and job status. We also include *household* characteristics such as number of rooms, type of home, housing tenure, whether the home is situated in a populated zone, type of building, and a variable that approximates the age of the building and the energetic (in)efficiency of the household. This way, our individual and household-specific variables allow us to estimate different reference indifference curves.

Finally, and as stated in Section 3, individuals (consumers) in a comfortable economic situation or in material deprivation might have different preferences. In order to control for these differences, we include a general poverty dummy variable (GP) in the model which indicates if an individual is at risk of social exclusion. This binary index is a statistical term defined by the OECD and refers "to the inability for individuals or

[15]As our well-being variable is an aggregate measure of several well-being indicators, we also estimated the model using different well-being indices for robustness analyses. The results were very close to those shown in Table 2, so our findings remain unchanged with alternative definitions of well-being. For example, we have estimated the model using the main well-being index "satisfaction with the house" with very similar results, which seems to support that this measure is appropriate. Results are available from authors upon request.

[16] As stated in the introduction section, individuals draw comparisons with their peers when reporting their well-being. Although the survey does not provide information about who the peers of each individual are, the frontier methods used in this paper are able to identify the "reference group" to which an individual belongs. The individuals belonging to this group can be viewed as the individual's peers, but identified econometrically, not using a survey.

[17] For easier reading the model, in Section 3 we have considered only two goods. However, the model is valid to three or more goods.

[18] Given that we include a set of regional dummy variables to capture the influence of unobservable factors specific to each region on well-being, expenditures are a good proxy of consumption if the prices of these goods are the same within the whole region.

households to afford those consumption goods and activities that are typical in a society at a given point in time, irrespective of people's preferences with respect to these items".[19] Although this also includes subjective and objective variables related with fuel poverty, this index is primarily a measure of general poverty. As a result and given that we are mainly interested in the relationship between fuel poverty and well-being, we also include some complementary measures of fuel poverty.

Concretely, we compute our fuel poverty measure FP using the MIS indicator proposed by Romero et al. (2015) because they concluded that this indicator offers the best approximation for analysing fuel poverty in Spain. As no official measures of MIS exist in Spain, Romero et al. (2015) calculated a proxy using the average social insertion income in Spain. The social insertion income (also called minimum income of insertion) is a grant that the household's bread-winner receives from the local or state public administration when he/she is in a situation of poverty, social exclusion or at risk of being.[20] Romero et al. (2015) apply the equivalence measure recommended by the OECD in order to convert MIS per person into MIS per household[21] and sum the energy expenditures for each household. They next subtract the average energy costs (AEC) of a representative household in Spain to avoid double counting the energy costs in the MIS definition.[22] Finally, we divide the above sum by the disposable household income and,

[19] The index refers "to a state of economic strain defined as enforced inability (rather than having a choice not to do so) to achieve at least 4 items from a list of 9: to pay unexpected expenses; afford a one-week annual holiday away from home; a meal involving meat, chicken or fish every other day; adequate heating of a dwelling; durable goods such as washing machine; colour television; telephone; or car; faced with payment arrears (mortgage or rent, utility bills, hire purchase instalments or other loan payments)".
[20] Usually, it consists of a salary, composed of a basic monthly amount and a variable complement, depending on the members that are part of the household. That is, the social insertion income is a household-specific standard, imputed from household characteristics. In an attempt to better capture the differences emanating from the Spanish regions, we use regional-specific social insertion incomes and not the average of these incomes in Spain.
[21] Following the OECD scale, consumer units (CU) in a household are calculated as: CU=1 + 0.5 x (household members older than 13 years - 1) + 0.3 x (household members under 13 years).
[22] This average cost is computed with the microdata obtained from the 2013 Household Budget Survey. In 2013 the average energy costs amounted to 1,188.75 euros.

as other continuous variables, include the log of this ratio as our measure of fuel poverty. Table 1 shows the summary statistics of the variables.

(Insert Table 1 here)

5. Results

The maximum likelihood parameter estimates are presented in Table 2. As the good used as numeraire is expenditure on other goods related to dwelling (N), the dependent variable is lnN. The first-order coefficients can be interpreted as elasticities at the sample mean due to we have normalized (divided) the continuous variables by their geometric mean before taking logs. The model works quite well. In particular, all the first-order parameters have the expected signs (i.e., decreasing for household goods and increasing for well-being), with both proving highly significant, which indicates that the preferences estimated comply with the theoretical requirements.

(Insert Table 2 here)

The estimated model allows the indifference curve frontier to change with household and individual characteristics. For example, we can analyse the relationship between well-being and owning a house without a mortgage versus having a mortgage or renting. The coefficients related to this variable are positive and significant, indicating that, as expected, the individuals with mortgages or rents need to be compensated with more goods in order to keep their well-being constant. In other words, individuals with mortgages or rents enjoy a lower level of well-being than those who own their house, given the same living costs (gas, energy and others) and similar personal and housing characteristics. Specifically, a household with a mortgage spends 45.1% more on household goods to achieve a similar level of well-being as the individual owning a house without a mortgage. Similarly, an individual renting at market prices incurs 64.6% more in costs than the aforementioned individual. Finally, if the individual is renting at a lower than market price or is in a house free of charge, they spend 3% more than the aforementioned individual.

The type of dwelling also influences well-being. Living in a flat implies expenditure which is 2.5% greater in order to obtain the same level of well-being as an individual living in a detached or semi-detached, given similar individual and housing characteristics. Lastly, with identical personal and housing characteristics, an increase of 1% in the number of rooms implies 0.15% more expenditure in order to maintain the same level of well-being. Dwellings in which people are under 65 years of age and live alone require fewer resources than other types of dwellings. For example, individuals older than 65 living alone need 4.3% less than those under the age of 65. In contrast, households with two adults and dependent children need 50.7% more resources. Also, in line with Roberts et al. (2015), living in an under-populated zone increases well-being, requiring 12.7% less expenditure than in the case of houses situated in heavily populated zones.

With respect to the rest of individual's variables, women, *ceteris paribus,* need to purchase 1.5% more than men in order to obtain the same level of well-being. Europeans require more goods (5.4%) than Spaniards. Single persons need less housing goods than individuals with another marital status to feel satisfied with their house. This difference ranges from 7% less in the case of married persons to 14.8% less in the case of divorcees.

The results indicate that individuals with more education demand more in terms of the needs of their household and these demands increase with the level of education - from 5.1% for secondary education (first cycle) to 14.3% for university education. In contrast, retired people need 2.1% more than people employed, ceteris paribus. People with chronic disease need to purchase 1.5% more than healthy people. As regard overall health, people with very bad health need 4.8% more resources than those with very good health. Finally, once we control for other socio-economics characteristics, the age variable does not seem to be significant in explaining subjective well-being of households.

The results related to poverty are also important. They confirm that poor persons require fewer goods than those with greater purchasing power in order to achieve a similar level of well-being. More specifically, and according to the coefficient of the general poverty dummy variable (GP), individuals in material deprivation need 4.5% less household goods to reach a similar level of satisfaction relative to an individual who does not experience severe material deprivation. Moreover, the result for the fuel poverty variable is interesting given that, even taking into account material deprivation, being in fuel poverty moves to the left the indifference curve significantly. Specifically, if fuel poverty increases by 1%, individuals reduce, ceteris paribus, their bundle of goods by 0.13%. Finally, the variable Old (whether the household has indoor toilets or not), is negative and significant indicating that people living in a home without a toilet consume 33% less than others for a given level of subjective well-being. Finally, unemployed people need to consume 4.2% less than the employed people.

In summary, the estimation of indifference curve frontier model offers an interesting result given that all the variables which indicate different aspects of poverty shift the indifference curve to the left. This implies that, ceteris paribus, the individuals who live in a situation of poverty appear to need (or conform to having) less goods. In other words, poor people seem to exhibit different preferences and as a result, their indifference curves shift to the left.

It is important to recall that we have included the poverty variables in the frontier on theoretical and empirical grounds: First, to capture the heterogeneity in individual preferences. Given that their coefficients are significantly different from zero, we can reject homogenous preferences among individuals with different poverty levels. Moreover, both the estimated indifference curves and well-being loss indices will be biased if we drop the poverty variables from the frontier.[23]

Once the frontier is estimated taking into account the "reference group" to which an individual belongs, it is possible to analyse the loss of well-being due to poverty. The results for the determinants of well-being losses are also reported in Table 2. Recall that increases in the standard deviation of u represent increases in the distance to the frontier indifference curve, and hence well-being losses.

The results show that general poverty and fuel poverty have a positive and significant sign, indicating that both signify loss of well-being. These results imply that once we control for material deprivation, individuals experiencing fuel poverty tend to achieve a lower level of well-being than those who are not fuel poor. That is to say, if energy expenditures, jointly with minimum standard income, represent an important percentage of disposable income. This implies that individuals have to forego other goods which can satisfy their other needs - to some degree, this result captures a form of substitution between "household basic goods" and other goods (e.g., leisure goods). It thus implies a reduction in well-being of an individual as a result of being in a fuel poverty situation. On the other hand, the variable Old is positive and significant, indicating that there is an additional loss of welfare related with the age of the home and the need for extra expenditure to obtain similar well-being than people with the same bundle of goods. This result could also be an indication of additional costs associated with low energetic

[23] For robustness reasons, we re-estimated the model without poverty variables in the frontier, and the results confirm our expectations as the rejected specification of the frontier biased the estimated coefficients. The results of the rejected specification are available under request.

efficiency of these homes, for example, they may have less access to new and more energy efficient equipment.

Next, we calculate the Well-being Loss Index (WLI) for each individual. As previously explained, the value of these indices range between 0 and 1. An index value equal to unity indicates that individuals reach 100% of their relative potential well-being, given their bundle of goods and characteristics. In contrast, a value of the index close to 0 would mean that the individual is far from their potential well-being. Table 3 shows the Pearson rank correlation coefficients between subjective well-being and Well-being Loss Index (WLI) with poverty variables. Regarding well-being, the expected and significant signs inversely relate welfare and (general and fuel) poverty. On the other hand, in relation to well-being loss indices and poverty, the estimated coefficients are, as expected, negative and significant which indicate that individuals who live in poverty tend to exhibit loss of well-being.

As shown in Table 4 the value of the Well-Being Loss Index is on average 87%. This means that, at the mean, individuals possess a below-potential level of well-being, based on a given goods endowment and the characteristics of the consumers and as such, they require 13% more resources to reach their full well-being potential.

(Insert Table 3 and 4 here)

Finally, Figure 1 shows the relationship between WLI and the fuel poverty index (FP). The results confirm those obtained in Table 2: even after controlling for general poverty, being in fuel poverty increases the distance to the indifference curves, implying greater welfare losses than for individuals who are not in a situation of fuel poverty.

(Insert Figure 1 here)

6. Conclusions and Policy Implications

In this paper we have developed a new approach to analyse how general poverty and fuel poverty affect the well-being of individuals. The theoretical model allows us to capture consumer preferences via modelling of indifference curves. Taking into account that subjective well-being and poverty tend to overlap to some degree, we propose a frontier model which permits the construction of relative frontier functions based on the maximum potential well-being that individuals can achieve in the sample. We use a theoretical framework based on consumer theory. The proposed model permits estimation of individual indifference curves which take into account their consumption of goods, personal characteristics and the surroundings. Moreover, the distance function approach allows us to estimate the model consistently, even when goods can be endogenously determined by the individual.

We apply the theoretical model using data from the 2013 Spanish Life Condition Survey. Our results confirm that well-being is a relative and subjective concept (Clark et al, 2008; Dorn et al. 2007; Ferrer-i-Carbonell, 2005 or Luttmer, 2005) indicating that preferences differ depending on individuals' circumstances. Similarly, Lovell et al. (1994) for Australia and Deutsch et al. (2003) and Ramos and Silber (2005) for the UK suggest that possession of resources does not guarantee well-being. But the authors also explain that this does not imply that material goods are of no value. Lovell et al. (1994, p.802) state that "it is perfectly possible for people to enjoy having a large house, income security, a holiday house, etc., yet not rank highly in terms of social interaction, health, optimism, and so on". This is precisely the key idea of our paper - that it is necessary to take into account the characteristics of individuals and their environment in order to properly measure how goods can influence individual well-being.

In this sense, our results indicate that individual preferences differ depending whether they are in poverty. This is true for both poverty concepts analysed: general poverty and fuel poverty. In terms of our theoretical model this is reflected in different indifference curves, i.e., individuals adapt their needs to their possibilities, so that the expenditure required to obtain a given level of utility is lower in the case of consumers who are in poverty. Furthermore, the relationship between fuel poverty and subjective well-being persists even when controlling for general poverty, which indicates that they reflect different effects and, therefore, it is preferable to analyse them separately.

There are two major limitations in this study that could be addressed in future research. First, one limitation of the study is the specific database we use. The aim of the study only permits using the year for which there is extensive information on the well-being of individuals. A panel database structure could be a useful extension to the article. Second, the results indicate that the preferences of individuals are different depending on their situation of poverty in general and energy poverty in particular. However, this is a result obtained for a specific developed country. Future work can include not only other developed countries but also developing countries.

These results can be interpreted from a policy point of view. First, in our model, an individual identified as fuel poor could achieve a similar or even higher level of well-being than a better-off individual because they have different preferences (as found here). In these cases, inequalities in housing well-being between low- and high-income households tend to be attenuated. However, well-off households are more able to invest in new energy saving technologies or producing their own energy. This pattern is a powerful potential driver of increasing inequalities in housing well-being and general well-being for the future, and a challenge for policy design. Second, we analysed the factors that prevent individuals from reaching their maximum level of well-being with a given bundle of goods, personal and household characteristics as well as those of the reference group to which they belong. These results indicate that being in situations of general and fuel poverty both explain the losses in well-being. Our results suggest that, in order for an individual in general poverty to reach the same level of well-being as an individual who is not in poverty, they should receive an increase in income equivalent to 5.6% of their household expenditure. On the other hand, people living in old houses (without indoor toilet) require an income increase equivalent to 13.5% to reach the same level of well-being as someone who is not in that situation.

In summary, we show that poverty and welfare are negatively correlated. This is obviously not new. However, what is new in our findings is that "fuel poverty" (an aspect of general poverty) influences the welfare of individuals in a different and significant way. Therefore, it is important to undertake specific measures to address fuel poverty which is, as highlighted in the introduction, growing faster than general poverty. In Spain, various measures have been developed to eradicate fuel poverty at national, regional and local levels. At national level, a social bond or discount of 25% on electricity bills has been provided for some consumer groups. However, this has been regarded as being insufficient for addressing the problem[24] and it has been modified in 2017.[25]

[24] Only 20% of the users eligible for "*Bono Social*", are in need of it given their income levels. According to the "*Comisión Nacional de los Mercados y la Competencia*" (National Securities Market Commission), at the end of 2013 a total of 2,509,030 consumers were eligible. Of these, the majority, 80% were eligible because they had contracts for up to 3 kW, that is, without taking into account any income criteria. The remainder of the beneficiary groups of "*Bono Social*" such as pensioners (11.2%), large families (5.8%) and households with all their members in unemployment (1.7%), only amount to 500,000 households. Moreover, this only affects the electricity bill and does not include other types of energy.

[25] Real Decreto 897/2017, de 6 de octubre: https://www.boe.es/boe/dias/2017/10/07/pdfs/BOE-A-2017-11505.pdf.

Therefore, a relevant policy question is what are the most efficient and equitable measures to address this problem. Lump sum payments as opposed to price supports have economic properties that can make this mechanism part of the solution. Direct payments have also been used as part of subsidy reduction programs. The analysis of our Well-being Loss Index could shed some light on this issue. Our results indicate that an individual with a high percentage of basic household expenses (including electricity) (decile 9), would need to be compensated with 5% of their expenses to reach the same level of well-being as a household at decile 1. This difference increases to 10% when we analyse individuals in extreme fuel poverty (decile 10). That is to say, only a movement of one decile doubles the compensation required. This result indicates that the loss of welfare is not linear, and a compensation would be more efficient (in terms of increasing the welfare of an individual), if it is focused on households who have high rates of fuel poverty. Although it may be necessary to take into account other socio-economic factors, this study is a step towards better understanding and thereby, designing better measures to reduce the fuel poverty.

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Figure 1. Relationship between WLI and lnFP

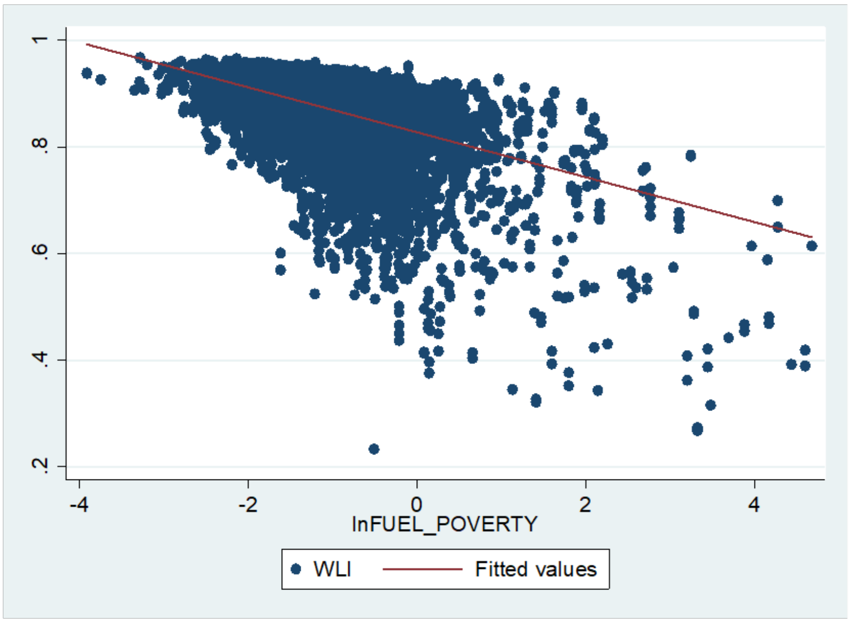

Table 1: Summary statistics

Continuous variables			
Variable	**Units**	**Average**	**St. Dev.**
W	index	6.74	1.53
EL	€	388.6	205.8
G	€	315.5	278.3
N	€	1240.9	1219.6
Age	years	50	18.5
Rooms	number	4.93	0.94
FP	ratio	0.57	3.31

Dummy variables			
Variable	**Frequency (%)**	**Variable**	**Frequency (%)**
Man	47.81	Employed	40.36
Woman	52.19	Unemployed	16.3
Spanish	92.2	Retired	18.45
European	1.9	Inactive	24.88
Non-European	5.9	One person	3.94
Single	29.4	One person +65	4.41
Married	56.7	No children	47.72
Separated	1.9	Children	47.22
Widowed	8.6	Owned	57.32
Divorced	3.4	Owned with mortgage	27.08
Primary	26.7	Rented	7.6
2nd Education I	27.1	Rent cheap	8
2nd Education II	21.3	High urban area	46.89
Prof. Education	0.2	Low urban area	21.16
University	24.8	No urban area	31.95
Chronic	33.81	Old	0.2
No Chronic	66.19	No Old	0.8
Excellent health	18.11	No flat	40.26
Good health	51.37	Flat	59.74
Fair health	21.23	GP	5.11
Bad health	7.15	No GP	94.89
Very bad health	2.13		

Table 2. Parameter estimates

Variables	Coeff.	t-stat.	Prob.	Variables	Coeff.	t-stat.	Prob
Goods and Wll-being				**2nd Education I**	0.051	6.28	0.00
ln(EL)	-0.389	-79.09	0.00	**2nd Education II**	0.106	11.69	0.00
ln(G)	-0.167	-45.17	0.00	**Prof. Education**	0.090	1.59	0.11
ln(N)	-0.444	-89.01	0.00	**Universtiy**	0.143	15.19	0.00
ln(W)2	0.093	7.44	0.00	**Chronic**	0.015	2.00	0.05
ln(EL)2	-0.058	-8.07	0.00	**Good Health**	0.000	0.06	0.95
ln(G)2	-0.038	-8.05	0.00	**Fair Heath**	0.001	0.06	0.95
ln(N)2	-0.002	-0.28	0.78	**Bad Health**	0.010	0.70	0.48
ln(W)2	0.057	5.49	0.00	**Very Bad Health**	0.048	2.01	0.04
ln(EL)ln(W)	-0.042	-3.30	0.00	**Unemployed**	-0.042	-5.09	0.00
ln(G)ln(W)	0.087	7.70	0.00	**Retired**	0.021	1.83	0.07
ln(EL)ln(N)	0.011	2.00	0.05	**Inactive**	-0.003	-0.36	0.72
ln(N)ln(W)	-0.045	-4.35	0.00	***Household characteristics***			
ln(G)ln(N)	-0.010	-2.54	0.01	**ln(Rooms)**	0.153	11.05	0.00
ln(G)ln(EL)	-0.010	-2.54	0.01	**One Person >65**	-0.043	-2.08	0.04
Individual Characteristics				**No children**	-0.371	-25.69	0.00
ln(Age)	0.007	0.45	0.65	**Children**	-0.507	-33.68	0.00
ln(Age)2	0.017	0.74	0.46	**Owned with mortgage**	0.451	56.31	0.00
Woman	0.015	2.58	0.01	**Rented**	0.646	44.01	0.00
European	0.054	2.76	0.01	**Rented cheap**	0.030	2.84	0.00
Non European	-0.017	-1.26	0.21	**Low urban area**	-0.026	-3.43	0.00
Married	0.070	7.72	0.00	**No urban area**	-0.127	-16.42	0.00
Separated	0.081	3.92	0.00	**Flat**	0.025	3.72	0.00
Widow	0.077	5.09	0.00	**Old**	-0.330	-3.31	0.00
Divorced	0.148	9.13	0.00	***Poverty variables***			
				Ln(FP)	-0.135	-16.39	0.00
				GP	-0.045	-1.88	0.06
				intercep	0.253	6.49	0.00

Determinants of well-being losses

Variables	Coeff.	t-stat.	Prob
Ln(FP)	0.75	10.00	0.00
GP	0.43	2.03	0.04
Old	1.73	3.14	0.00
intercep	-3.74	-6.16	0.00

Notes: 16,608 observations. As the good used as numeraire is N., the dependent variable is lnN. The model also includes a set of regional dummy variables as determinants of both potential well-being and well-being losses that are not reported here.

Table 3. Pearson correlations of poverty variables with W and WLI

	FP	GP	OLD
W	-0.057 (0.000)	-0.201 (0.000)	-0.049 (0.531)
WLI	-0.297 (0.000)	- 0.182 (0.000)	-0.099 (0.000)

Note: Probabilities in brackets.

Table 4. Estimated Well-being Loss Index

	Observations	WLI Mean	WLI Min	WLI Max
Total Sample	16,608	0.871	0.232	0.967
General poverty				
No	15,839	0.873	0.232	0.967
Yes	769	0.817	0.315	0.942
Aged house				
No	16,569	0.871	0.268	0.967
Yes	39	0.736	0.232	0.888
Fuel Poverty (deciles)				
D1	1660	0.902	0.755	0.967
D2	1661	0.892	0.569	0.958
D3	1661	0.888	0.645	0.955
D4	1661	0.886	0.524	0.960
D5	1661	0.876	0.583	0.949
D6	1661	0.872	0.572	0.946
D7	1661	0.870	0.590	0.944
D8	1661	0.863	0.522	0.945
D9	1661	0.851	0.232	0.941
D10	1660	0.806	0.267	0.953

Appendix: Variable definitions

Variable	Definition
Continuous variables	
W	This measure is the sum of several satisfaction indices that take values from 0 to 10: satisfaction with the economic situation at home; Satisfaction with the house; Satisfaction with the recreational areas or green area where you live; and Satisfaction with the quality of the area where you live.
EL	Expenditures on electricity per consumer units at home (€ 2013).
G	Expenditures on gas per consumer units at home (€ 2013).
N	Housing-related bills (water; sewage and rubbish tariffs; community costs; homeowner's insurance or council tax) per consumer units at home (€ 2013).
Age	Age of the individual (years).
Rooms	Number of rooms of the household.
FP	(Household MIS + Household energy costs-AEC]/Disposable household income

Appendix: Variable definitions (cont.)

Variable	Definition
Dummy variables	
GP	Equal to unity if the household in severe material deprivation.
Man	Equal to unity if the individual is a man.
Woman	Equal to unity if the individual is a woman.
Spanish	Equal to unity if the individual is Spanish.
European	Equal to unity if nationality is a European country, excluding Spain.
Non-European	Equal to unity if nationality is a non-European country.
Single	Equal to unity if the individual is single.
Married	Equal to unity if the individual is married.
Separated	Equal to unity if the individual is separated.
Widowed	Equal to unity if the individual is widowed.
Divorced	Equal to unity if the individual is divorced.
Primary	Equal to unity if the individual has completed primary education.
2nd Education I	Equal to unity if the individual has completed secondary education I.
2nd Education II	Equal to unity if the individual has completed secondary education II.
Prof. Education	Equal to unity if the individual has completed professional education.
University	Equal to unity if the individual has completed university studies.
Chronic	Equal to unity if the individual is chronically ill.
Non Chronic	Equal to unity if the individual is not chronically ill.
Excellent health	Equal to unity if individual’s health is very good.
Good health	Equal to unity if individual’s health is good.
Fair health	Equal to unity if individual’s health is fair.
Bad health	Equal to unity if individual’s health is bad.
Very bad health	Equal to unity if individual’s health is very bad.
Employed	Equal to unity if the individual is employed.
Unemployed	Equal to unity if the individual is unemployed.
Retired	Equal to unity if the individual is retired.
Inactive	Equal to unity if the individual is other kind of labour inactivity.
One person	Equal to unity if it is a household with one person under 65 years of age.
One person +65	Equal to unity if it is a household with one person over 65 years of age.
No children	Equal to unity if it is a household with two adults without children and others.
Children	Equal to unity if it is a household with two adults with children.
Owned	Equal to unity if it is an owned house without a mortgage.
Owned with mortgage	Equal to unity if it is an owned house with mortgage.
Rented	Equal to unity if it is a rented or sublet house at market price.
Rented cheap	Equal to unity if it is a rented or sublet house at a below market price.
High urban area	Equal to unity if the house is in a very populated zone.
Low urban area	Equal to unity if the house is in an average populated zone.
No urban area	Equal to unity if the house is in a sparsely populated area.
Old	Equal to unity if there is toilet inside the dwelling.
No Old	Equal to unity if there is not toilet inside the dwelling.
No flat	Equal to unity if individual leaves in a detached or semi-detached house.
Flat	Equal to unity if the individual leaves in a flat.