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Avoiding Fuel Poverty through Insurance

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Abstract

Twenty percent of French non-fuel poor households will fall into fuel poverty. The existence of energy insurance can reduce this percentage. This article focuses on non-fuel poor households that can buy insurance that provides a basic level of energy for one year after a significant loss of income. A model of household willingness to pay for energy insurance is proposed. Several simulations are performed with French data. Given the values of the utility function parameters and the energy prices, this willingness to pay depends on the probability of loss of income wich differs according to the income deciles. This willingness is not a monotonously decreasing function of income. As a result, if the insurer does not wish to mutualize the risks, differentiated contracts will be proposed. These prices resulting from the simulations carried out are in line with the energy insurance prices currently proposed. These prices enable such insurance to generate profits for insurers. This inexpensive insurance can help avoid a supply interruption through a minimum service guarantee thereby avoiding significant costs related to fuel poverty.

Key words: Fuel Poverty, Insurance
JEL Codes: D1,Q4.

*https://www.fime-lab.org/en/home/

1 Introduction

In the French legislation, a 12th July 2010 law (named Grenelle II) defines fuel poverty as follows: "a household that has difficulties obtaining the necessary energy to satisfy his basic needs due to the inadequacy of his resources or his living conditions is in fuel poverty under this Act". This definition takes three aspects of fuel poverty into account: energy prices, household resources and habitat conditions in the dwelling. In other words, a household is fuel poor when it does not have enough resources to satisfy its basic energy needs, such as proper inside temperature, or when under bad living conditions (such as bad insulation against humidity/cold). Of course, some households experience accumulated difficulties: they live in very bad energetic performance dwellings (which we literally call "energetic strainers" in French), and they have low revenues. Since 2013, ONPE[1] (2016) estimated that approximately 20.4% of the households in France are characterized by at least one indicator of fuel poverty[2]. In absolute value, this yields 6 million households and at the same time roughly 12 million people. Fuel poverty is a serious issue that touches fairly large populations, even in a developed country such as France, in larger proportions than the famous poverty rate. Indeed, according to Boiron et al. (2015), in France in 2013, poverty (defined with a 60% threshold of the median revenue of the population) affected 8.6 million people, or 14% of the population.

Fuel poverty can lead householders to engage in risky behaviours. For example, to keep heat inside their homes, some will obstruct vents, thus

[1]ONPE (for "Observatoire National de la Précarité Energétique") has been, in France, the think tank in charge of studies linked to fuel poverty.

[2]Numerous indicators are used to identify the fuel-poor households. Rademaekers et al. (2016) provide an assessment of indicators used in the literature and in official reports. ONPE (2016) uses the following three indicators. i) The energy effort rate (EER_3d) should not exceed 10%, reduced to the first three income deciles; thus, a household is fuel poor if the following two conditions are met: the ratio (energy expenditures)/(revenue of the household) $>$ 10% and (revenue of the household)/(consumption units) $< 3^{rd}$ decile. The scale for consumption units is the same as the OECD scale, i.e., 1 CU for the first adult in the household, 0.5 CU for the other persons aged 14 years or older and 0.3 CU for the children under 14 years. ii) The French version of the LIHE (low income, high costs) indicators considers that a household is fuel poor if the two conditions of low income and high energy expenditures are met. The LIHE indicator was suggested by Hills (2011) and adopted by the British government in August 2013. According to this indicator, a household is fuel poor if its income falls below the relative poverty line and if its normative modulated energy expenditure exceeds the median household energy expenditure. The relative poverty line is set at 60% of the national median income after housing costs (e.g., rent or mortgage payments) and energy costs (e.g., electricity bills) are deducted. In the French version, energy expenditures used are declared energy expenditures instead of normative energy expenditures. Two versions of the LIHE indicator are used: the LIHE_m2 and the LIHE_CU. In the first case, the energy expenditures are divided by the surface area of the dwelling, and in the second case, the energy expenditures are divided by the consumption units. iii) The cold indicator is a subjective indicator based on the feeling of the household members in terms of thermal comfort.

generating moisture and mould. However, moisture and mould in a dwelling can cause respiratory problems (Peat et al., 1998), such as chronic asthma or rhinitis. Householders in fuel poverty are often forced to make choices with harmful consequences for their health: eating or heating, giving up care or giving up going out. The effects of fuel poverty on the physical and mental health of individuals are not questionable (see, for example, Ezratty et al., 2009, Lacroix and Chaton, 2015). Roy et al. (2010) estimate that in Great Britain, the health expenses due to poor living accommodations are £600 million per year. Taking into account the indirect costs (e.g., absenteeism at work and loss of productivity) for society, the bill amounts to £1.5 billion per year. According to Eurofound (2016), in France, the direct medical costs related to poor housing are estimated at 930 million euros, and the indirect annual costs are estimated at 20.3 billion euros. Consequently, acting against fuel poverty can generate gains for society, especially since the effects of fuel poverty are not limited to the households that suffer it. It should be noted that some low-income householders use lease arrears as an overdraft facility to manage their cash flows and pay their electricity and/or gas bills. In addition, late payments of electricity and/or gas bills can create liquidity problems for energy suppliers and for social landlords and landlords of privately owned dwellings. Thereby, Sharam (2007), who is interested in the financial stress of low-income households in Australia, specifically in Victoria, finds that rent arrears from these households are used as an overdraft facility to manage cash flow and to pay their electricity and/or gas bills. Indeed, electricity and/or gas bills are the main causes of rent arrears (63%), followed by food (34%), because households want at all costs to avoid power and/or gas cuts. In addition, fuel poverty and more generally the use of poor energy performance houses have negative consequences on the environment (energy waste and large CO2 emissions).Therefore, actions that prevent households from falling into fuel poverty help avoid costs that can be huge for society.

To mitigate the impacts of energy prices on vulnerable households, France established two types of means-tested assistance: the special gas solidarity tariff (Tarif Spécial de Solidarité - TSS) set up by the Decree of 13 August 2008 and the basic necessity tariff (Tarif de première nécéssité - TPN) for electricity set up by the Decree of 8 April 2004. These tariffs, which had the form of a deduction on electricity (from 71 euros to 140 euros per year) or gas (from 23 euros to 185 euros) bills, were replaced in 2018 by an energy voucher. Thus, the energy voucher, a new aid for paying gas and electricity bills, has been available in 4 of France's 101 departments since 1 May 2016 and in all French departments since 1 January 2018. One of the most important novelties of France's policy is that this aid concerns not only electricity and gas bills but also wood and fuel oil bills. However, during the two years of experimentation (2016 and 2017), 90% of these vouchers were used with electricity and/or natural gas suppliers. This new assistance oscillates between 48 euros and 227 euros per year (the mean amount was 148 euros). In 2018, around 4 million households participated. In November 2018, the Prime Minister, Edouard Philippe announced that the amount of the energy voucher will be increased by 50 euros from 1 January 2019. The average amount of the energy check will therefore increase from 150 to 200 euros. In addition, the number of French eligible for the device will grow.The energy voucher is paid end of March, beginning of April. The Minister of Action and Public Accounts, Gérald Darmanin, wants the payment date to be advanced.

This energy voucher is expected to target a higher number of households, and an increase of 37% has been announced by the ONPE. This voucher can also be used to help pay for energetic refurbishments in houses, such as new boilers or window insulation against humidity. However, due to the lack of vouchers used for home improvements for energy efficiency (63 out of 170,000 in 2016), this aid can be described as a short term measure.

Numerous public policies are in effect that provide fiscal or financial incentives to households to renovate their dwellings in order to improve energy efficiency[3]. Energy conservation is also a major issue in the fight against fuel poverty.

Non-market tools might also be more effective in addressing households' energy consumption, which accounted for almost 25% of final energy consumption in Europe in 2014. On the other hand, liberal paternalism can be used to change ten energy household behaviours. Therefore, Delmas and Lessem (2014) study the energy consumption evolution of students at UCLA after their consumption was made public compared with the setting when information was kept private. While private information does not effectively induce energy conservation, the authors found that disclosing the information allows a 20% decrease to be reached. What this tells us is that providing information can lead to behavioural changes, but it seems that being confronted by others' judgements is even more effective than only receiving information. Epley and Gilovich (1999) highlight the fact that conformism can come from social pressure with non-zero probability. Therefore, virtuous behaviour tends to be replicated, especially if information can act as a form of pressure. In addition to the fact that nudges seem effective in meeting the objectives for which they have been designed, they do so in a cost-effective way compared to more traditional policy interventions (Benartzi et al., 2017). Non-fuel poor households today may be fuel poor tomorrow (following, for example, a change in housing or a loss of income). Can they insure against this risk?

EDF and Engie do not rely only on nudges to help households control

[3]In France, eco-loans at zero rates to finance thermal renovations or the "Living better" (Habiter mieux") programme, which is, among other things, a social energy efficiency refurbishment programme, may be given as examples.

their consumptions and thus their bills but also provide payment insurance to households that meet criteria such as a job loss, job stopping (total temporary disability), hospitalization, invalidity (total and irreversible loss of autonomy) and accidental death. Engie's insurance costs 5 euros per month, allowing reimbursements of up to 5,000 euros for a maximum of one year (833 euros for a hospitalization). EDF's insurance costs range from 2 euros per month up to 8 euros. The reimbursement amounts range from 25 euros per month to 200 euros. These ex-post insurances allow people suffering income decreases to maintain acceptable energy levels. It is worth noting that they do not target fuel poor people per se but rather compensate for income loss.

The aim of this paper is to determine the maximum price that a household would be willing to pay to insure against fuel poverty and, more precisely, to ensure that if his income falls below a critical threshold that he will receive a sufficient energy level to maintain an adequate standard of living. For this, we develop an insurance model in section 2. Then, in section 3, using the 2010–2011 waves of France's Statistics on Resources and Living Conditions (SRCV)[4], we determine the likelihood that household income will fall below the insurance trigger. Section 4 is devoted to simulations. Finally, section 5 concludes the paper.

2 Modelling strategy

2.1 Assumptions and notation

We consider a householder who makes a decision regarding the consumption of two goods: a composite good X and energy E during two periods (years) $(t = 0, 1)$. We are interested in non-fuel poor households in $t = 0$. More exactly, in $t = 0$, the household income per unit of consumption (W_0) is sufficient to consume at least the energy level, denoted $\underline{e}$, needed to heat the home to an adequate standard and to meet the needs for lighting, cooking and running domestic appliances. This level of energy depends on the home's characteristics (number of rooms occupied, energy efficiency and type of heating), its location, the composition of the family and the number of hours spent in the dwelling during the year. We assume that $\underline{e}$ is observable.

Future household income is uncertain. We denote $W_1 = \widetilde{\omega} W_0$ as the household income in $t = 1$, with $f_{W_0}(\widetilde{\omega})$ being the probability density function of $\widetilde{\omega}$ knowing W_0. To hedge oneself against the effects of a significant

[4]SRCV for *Statistiques sur les Ressources et Conditions de Vie.* This survey, published by the French National Institute of Statistics and Economic Studies (INSEE), is a part of the European Union Statistics on Income and Living Conditions (EU-SILC), which uses personal interviews to collect information on income distribution, poverty, social exclusion and living conditions. This survey, which is representative of the French population, is organized around a cross-sectional component and a longitudinal component.

loss of income, the household, in the first period, can take out insurance at the price denoted p^I. In the second period, the householder will have a guarantee to consume $\underline{e}$ when his income in $t = 1$ is below a certain threshold, specifically if $\omega \leq \overline{\omega}$. Throughout this study, this insurance is named insurance against fuel poverty.

We denote the decision variable for insurance as I, where I equals 1 when the household contracts insurance and 0 otherwise. We denote the consumptions in period t by $x_t \geq 0$ and $e_t \geq 0$, and we denote the consumption vectors $(x_t)_{t=0,1}$ and $(e_t)_{t=0,1}$ by X and E, respectively. The prices are p_t^x and p_t^e.

Remark 1 *If $\overline{\omega} \rightarrow \infty$, then the insurance against fuel poverty is equivalent to prepayment.*

In $t = 0$, the consumer maximizes an intertemporal expected separable utility $U(X, E, I)$, with β being the subjective discount factor ($0 < \beta < 1$), u and v being continuous, increasing, concave functions, and α parameterizing the elasticity of substitution between energy and the composite good:

$$U(X, E, I) = u(x_0) + \alpha v(e_0) + \beta E(u(x_1) + \alpha v(e_1 + \underline{e} 1_{I=1,\omega \leq \overline{\omega}})). \tag{1}$$

Notation 2 $1_{I=1,\omega\leq\overline{\omega}} = \begin{cases} 1 & \textit{if} \quad I = 1 \;\; \textit{and} \;\; \omega \leq \overline{\omega}, \\ 0 & \textit{otherwise.} \end{cases}$

Any consumption e below the necessary level $\underline{e}$ generates disutility for the household. This disutility represents the inconvenience caused by living in poorly heated housing (such as being exposed to cold sensations or experiencing breathing problems). As a result, for all $e < \underline{e}$, $v(e) < 0$.

For all $\omega > 0$ and for all W_0, X, E and I satisfy the following budget constraints,

$$p_0^x x_0 + p_0^e e_0 + p^I I = W_0, \tag{2}$$
$$p_1^x x_1 + p_1^e e_1 = \omega W_0. \tag{3}$$

2.2 Consumption plans

The householder will carry insurance for fuel poverty risks if it increases his intertemporal utility. Consequently, he determines his optimal consumptions (X^I, E^I) without ($I = 0$) and with insurance ($I = 1$), and he purchases insurance if $U(X^1, E^1, 1) > U(X^0, E^0, 0)$.

The optimal consumptions (X^I, E^I) verify

$$x_0^I = \frac{W_0 - p_0^e e_0^I - p^I I}{p_0^x}, \tag{4}$$

$$x_1^I(\omega) = \frac{\omega W_0 - p_1^e e_1^I}{p_1^x}, \tag{5}$$

$$\frac{\frac{du(y)}{dy}\|_{y=x_0^I}}{\frac{dv(y)}{dy}\|_{y=e_0^I}} = \alpha \frac{p_0^e}{p_0^x}, \tag{6}$$

$$\frac{\frac{du(y)}{dy}\|_{y(\omega)=x_1^I(\omega)}}{\frac{dv(y)}{dy}\|_{y=e_1^I(\omega)+\underline{e}1_{I=1,\omega\leq\overline{\omega}}}} = \alpha \frac{p_1^e}{p_1^x}. \tag{7}$$

To obtain calculable solutions and further comparative statistics, we specify the utility function.

In the following, this function is defined by

$$u(y) = \ln y, \tag{8}$$

$$v(y) = \begin{cases} m(\frac{y}{\underline{e}} - 1) & \text{if} \quad 0 \leq y \leq \underline{e}, \\ \ln(1 + y - \underline{e}) & \text{if} \quad y > \underline{e}. \end{cases} \tag{9}$$

Proposition 3 *If $m \leq \underline{e}$, when the householder does not insure against major loss of income (i.e., $I = 0$) or when his lost income is inconsistent (i.e., $\omega > \overline{\omega}$), that is, the householder does not receive $\underline{e}$, then the equilibrium values are*

$$e_t^0 = \begin{cases} 0 if \quad W_t \leq |t-1|\, p^I I + \frac{p_t^e \underline{e}}{m\alpha}, \\ ea_t \ if \quad \frac{p_t^e \underline{e}}{m\alpha} < W_t - |t-1|\, p^I I \leq W_t^s, \\ eb_t \ if \quad W_t > |t-1|\, p^I I + W_t^s, \end{cases} \tag{10}$$

$$x_t^0 = \begin{cases} \frac{W_t}{p_t^x} if \quad W_t \leq |t-1|\, p^I I + \frac{p_t^e \underline{e}}{m\alpha}, \\ xa_t \ if \quad \frac{p_t^e \underline{e}}{m\alpha} < W_t - |t-1|\, p^I I \leq W_t^s, \\ xb_t \ if \quad W_t > |t-1|\, p^I I + W_t^s, \end{cases} \tag{11}$$

or

$$e_t^0 = \begin{cases} 0 if \quad W_t - |t-1|\, p^I I \leq W_t^s < \frac{p_t^e \underline{e}}{m\alpha}, \\ eb_t \ if \quad W_t > |t-1|\, p^I I + W_t^s, \end{cases} \tag{12}$$

$$x_t^0 = \begin{cases} \frac{W_t}{p_t^x} if \quad W_t - |t-1|\, p^I I \leq W_t^s < \frac{p_t^e \underline{e}}{m\alpha}, \\ xb_t \ if \quad W_t > |t-1|\, p^I I + W_t^s, \end{cases} \tag{13}$$

where

$$ea_t = \frac{W_t}{p_t^e} - \frac{\underline{e}}{m\alpha}, \tag{14}$$

$$eb_t = \frac{1}{1+\alpha}\left(\frac{\alpha W_t}{p_t^e} + \underline{e} - 1\right), \tag{15}$$

$$xa_t = \frac{p_t^e}{p_t^x}\frac{\underline{e}}{m\alpha}, \tag{16}$$

$$xb_t = \frac{1}{1+\alpha}\left(\frac{W_t}{p_t^x} - \frac{p_t^e}{p_t^x}(\underline{e}-1)\right), \tag{17}$$

and W_t^s is the single solution in the range $w_t^b = p_t^e\left(\underline{e} + \frac{1}{\alpha}\right)$ to $w_t^a = \underline{e}p_t^e(1 + \frac{1}{m\alpha})$ of the following equation: $u(xa_t) + \alpha v(ea_t) - (u(xb_t) + \alpha v(eb_t)) = 0$.[5]

If the household receives $\underline{e}$, i.e., $\omega \leq \overline{\omega}$ and $I = 1$, then the consumption for $t = 0$ (e_0^1, x_0^1) verifies (30) and (31), and the quantities applied for $t = 1$ are

$$e_1^1 = \frac{\alpha W_1}{p_1^e} - \frac{1}{1+\alpha}, \tag{18}$$

$$x_1^1 = \frac{p_e^1 + W_1}{(1+\alpha)\,p_x^1}. \tag{19}$$

Therefore, the energy consumed in $t = 1$ if the insurance is paid is equal to $e_0^1 + \underline{e}$.

Proposition 4 *If $m > \underline{e}$, then $w_t^a < w_t^b$, and for all W_t such that $W_t - |t-1|\,p^I I \in [w_a, w_b]$, there is no equilibrium. For the other values of W_t, the equilibrium is characterized in Appendix 1.*

Remark 5

Let us assume that later, $m \leq \underline{e}$.

2.3 Should the household be insured against fuel poverty?

As mentioned above, a household will take out fuel poverty insurance if the difference DU between the expected intertemporal utility obtained with insurance $U(X^1, E^1, 1)$ and that obtained without insurance $U(X^0, E^0, 0)$ is positive.

- If $W_1^s \geq \frac{p_t^e \underline{e}}{m\alpha}$,

$$DU = DU_0 + \beta\left(\int_{\underline{\omega}}^{\frac{W_1^s}{W_0}} DUa_1 f(\omega)\,d\omega + \int_{\frac{W_1^s}{W_0}}^{\overline{\omega}} DUb_1 f(\omega)\,d\omega\right), \tag{20}$$

[5] Note that ω_t^a is the solution of $ea_t = \underline{e}$ and ω_t^b is the solution of $eb_t = \underline{e}$.

where

$$
\begin{aligned}
DU_0 &= (1+\alpha)\ln\left(1-\frac{p^I}{W_0+p_0^e(1-\underline{e})}\right), && (21)\\
DUa_1 &= 1-m\alpha\left(-1+\frac{\omega W_0}{\underline{e}p_1^e}\right)+\ln\left(\frac{m}{\underline{e}}\right)\\
&+ (1+\alpha)\ln\left(\frac{\alpha}{1+\alpha}\left(1+\frac{\omega W_0}{p_1^e}\right)\right), && (22)\\
DUb_1 &= -(1+\alpha)\ln(1-\frac{p_1^e\underline{e}}{p_1^e+\omega W_0})). && (23)
\end{aligned}
$$

- If $W_1^s < \frac{p_t^e \underline{e}}{m\alpha}$,

$$
DU = DU_0 + \beta(\int_{\underline{\omega}}^{\frac{W_1^s}{W_0}} DU0_1 f(\omega)\,d\omega + \int_{\frac{W_1^s}{W_0}}^{\overline{\omega}} DUb_1 f(\omega)\,d\omega), \quad (24)
$$

where DU_0 is defined by (21), DUb_1 is defined by (23) and

$$
DU0_1 = (1+\alpha)\ln\left(\frac{p_1^e+\omega W_0}{\alpha+1}\right) - \ln(p_1^x) - \alpha\left(\frac{p_1^e}{\alpha}\right). \quad (25)
$$

Hence, the condition on the price of insurance is $p^I < \overline{p}$, where

$$
\begin{aligned}
\overline{p} &= (-\exp(-\frac{\beta}{1+\alpha}(\int_{\underline{\omega}}^{\frac{W^s}{W_0}} Df(\omega)\,d\omega + \int_{\frac{W^s}{W_0}}^{\overline{\omega}} DUb_1 f(\omega)\,d\omega)) + 1)\\
&\times \ (W_0 + p_0^e(1-\underline{e}))\,, && (26)
\end{aligned}
$$

where

$$
D = \begin{cases} DU0_1 \text{ if } \ W_1^s < \frac{p_t^e \underline{e}}{m\alpha}, \\ DUa_1 \text{ otherwise.} \end{cases} \quad (27)
$$

For all energy insurance prices greater than $\overline{p}$, it is not optimal for the consumer to contract this insurance.

3 Identifying at-risk fuel poverty households

3.1 Households at risk of fuel poverty

To be able to offer an insurance contract, one needs to better know the possible users or subscribers. Chaton and Lacroix (2018) employ an analysis of the probabilities of falling into or avoiding fuel poverty by relying on the cold feeling indicator reported by households. Using a mover/stayer model and three waves (2009-2011) of SRCV, they evaluate that "80% *of the non-fuel-poor will not fall into fuel poverty;* 11.93% *of non-fuel-poor will become* *fuel poor and then will exit this state of poverty"*. They use econometric models to identify the stability and mobility determinants in different states (non-fuel poverty and fuel poverty). Their subsequent results help to target populations that are likely to fall into fuel poverty. Hence, unemployment is the main factor contributing to the deterioration of the state of fuel poverty (as defined by the cold feeling indicator). It increases the risk of being confined to this state. Financial difficulties greatly increase the risk of falling into fuel poverty. Widows and/or tenants are more likely to become fuel poor than other householders.

The household observations in the SRCV database over five consecutive years (2010-2014) provide a profile of households that are not in fuel poverty and that will fall into fuel poverty. Therefore, using the energy effort rate with a threshold of 10%[6], we find that unemployed people are more likely to be hit by fuel poverty, often with a delay. The delay might be due to decreases in social benefits over time or, if people become employed again, their new jobs not paying as well. Retired people represent a large share of fuel poor people. Farmers are also at risk. By contrast, craftsmen or those in liberal professions apparently are very unlikely to be affected by fuel poverty. Single parent families (particularly single mothers) and people living alone are at risk.

3.2 The likelihood that household income falls below the trigger threshold of insurance

We determine the probability of an annual growth in household income. More specifically, we find a simple functional form in order to fit the distribution g of data $\omega_{i,t} = \frac{W_{i,t}}{W_{i,t-1}}$ (where $W_{i,t}$ is the income of household i in t, and $W_{i,t-1}$ is the income for the previous year). Then, we modify the support of the distribution so that it equals the interval $[\min\{\omega_i\}, \max\{\omega_i\}]$, and we approach the new distribution f via a Padé approximant.

Thus, using the 2010 and 2011 waves of SRCV[7], we have $t = 2011$, $\omega^0 = \min\{\omega_i\} = 0.02$ and $\max\{\omega_i\} = 46.13$. Figure 1 is the histogram of $\omega_{i,2011}$. We find that the distribution g of ω_i is a Student's t-distribution with a location parameter of 1.01138, scale parameter of 0.1209, and 1.33

[6]According to this indicator, if the percentage of income that a household allocates to meet its energy needs is greater than 10%, then the household is considered to be experiencing fuel poverty.

[7]The number of observations is 8476.

degrees of freedom (see Figure 1)[8]. Thus, the median is 1.01. Note that the probability that a household has an income at most equal to that of the previous year is 0.458. The probability for a household to have only 80% (or 70%) of its income from the previous year is 0.122 (resp., 0.072).

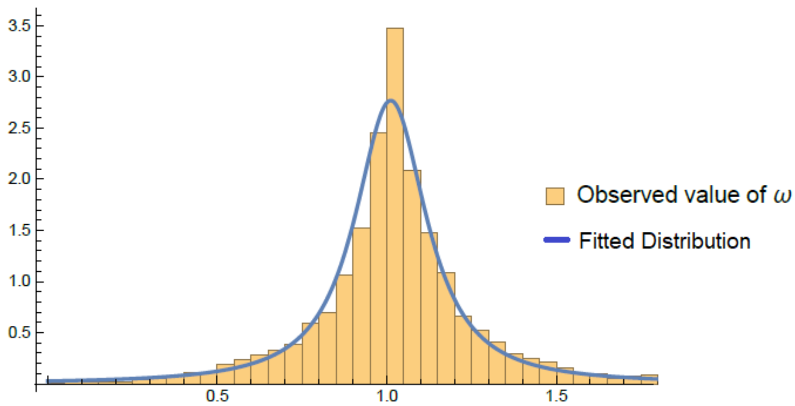

Figure 1. Histogram of ω_i for $t = 2011$ and distribution $g(\omega)$.

We consider the Padé approximant to this Student's t-distribution on the support $[\omega^0, 43.13]$ about the point ω^0, with a numerator of order 10 and a denominator of order 0, i.e.,

$$f(\omega) = \sum_{k=0}^{10} \gamma_k (\omega - \omega^0)^k. \tag{28}$$

See Table 1 for the value of γ_k and Figure 2 for the representation of $f(\omega)$ and its approximation.

k	0	1	2	3	4	5
γ	0.0285	0.0659	0.1079	0.1523	0.1972	0.2409
k	6	7	8	9	10	
γ	0.2822	0.3197	0.3524	0.3792	0.3993	

Table 1. Value of γ_k (parameters of Padé approximant $f(\omega)$)

[8]The table below gives some statistics on the estimation of the ω_i distribution function. The Cramér-von Mises test shows a good fit.

	Statistic	P-Value
Anderson-Darling	36.5476	0.
Cramér-von Mises	5.70554	8.73746×10^{-14}
Pearson χ^2	4370.17	$4.876504040936876 \times 10^{-871}$

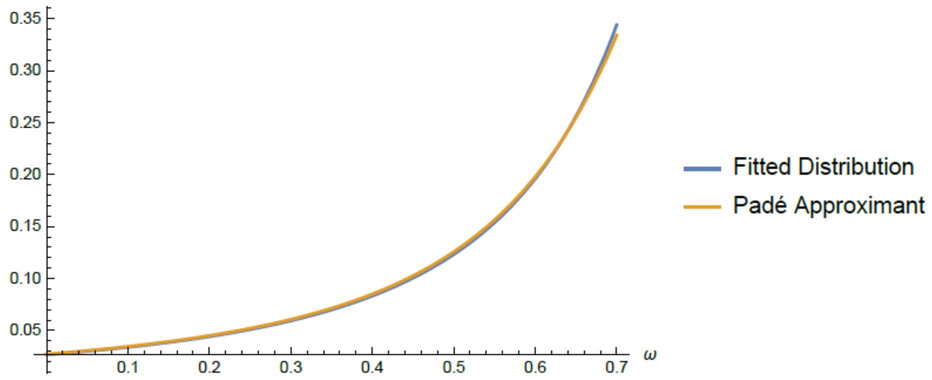

Figure 2. Probability density function

The probability ω has also been calculated and approximated in each income decile. The results are presented in Appendix 2.

4 Simulations

Given $f(\omega)$ defined by (28), we simulate the price threshold $\overline{p}$. To achieve this, the following assumptions regarding the values of the parameters are used: $p_0^e = 0.1756$ euros per kWh, $p_1^e = 0.18$ euros per kWh, $\alpha = 0.04$, $m = 3$, and $\underline{e} = 6550$ kWh. According to Eurostat, the value "17.56 MWh" corresponds to the average electricity price for household consumers in France in the second half of 2017. As previously reported, $\underline{e}$ depends, among other factors, on the housing size, the quality of the thermal insulation and the household composition (e.g., size and number of attendance hours for family members in the housing during the day). Thus, according to Selectra[9], the average electricity consumption for heating in kWh depending on the surface area and the insulation of the dwelling is provided in Table 2, and the average electricity consumption of the water heater in kWh depending on the number of occupants in the dwelling is given in Table 3. By adding the average electricity consumption of electrical appliances, Selectra calculates the average electricity consumption of an all-electric household (Table 4). The value of 6550 kWh corresponds to the average electricity consumption of a household comprising two persons living in fully electric and well insulated dwellings of 40 m^2.

[9]Selectra is a French company that specializes in comparisons of electricity, gas and internet offers.

Given the parameter values used, $W_1^s < \frac{p_1^e \underline{e}}{m\alpha}$, and consequently, $D = DU0_1$.

Size (m^2) / insulation	20	30	40	50	75	100	120
Bad	3300	4600	5900	7200	10400	13650	16250
Medium	2850	3950	5000	6100	8800	11500	13650
Good	2450	3300	4150	5000	7200	9350	11050

Table 2. Average electricity consumption for heating (kWh) according to the surface area and the insulation of the dwelling (source: Selectra)

Number of persons in the household	1	2	3	4	5	6
Water heater consumption (kWh)	725	1475	2200	2925	3625	4250

Table 3. Average water heater electricity consumption according to household size (source: Selectra)

Size / insulation	20 m^2 - (1)	30 m^2 - (2)	40 m^2 - (2)	50 m^2 - (3)
Bad	4300	5800	7450	9750
Medium	3800	5450	7000	9150
Good	3350	5000	6550	8650
Size / insulation	75 m^2 - (4)	100 m^2 - (5)	120 m^2 - (6)	
Bad	14050	17550	20650	
Medium	12450	15500	18350	
Good	10500	13750	15750	

Table 4. Average electricity consumption of an all-electricity household according to the surface area (the household size) and the insulation of the dwelling (source: Selectra)

The insurance is offered to households that have enough income in $t = 0$ to consume at least $\underline{e}$, i.e., $W_0 \geq w_1^a + p^I$. Therefore, given the parameter values used, only households with annual incomes above $(10735 + p^I)$ euros could buy insurance.

Figure 3 presents the threshold price as a function of initial income W_0 for two trigger threshold values, $\bar{\omega} = 0.4$ and $\bar{\omega} = 0.7$. Obviously, households are willing to pay more for insurance for higher triggers. The willingness to pay for insurance, $\bar{p}$, is not a monotonic function of the initial income. Indeed, below a certain annual household income (equal to $160,613$ euros in our simulation), the price threshold is a decreasing function of income. Above this income, $\bar{p}$ is an increasing function. One explanation is that for the same function of the distribution of losses in income, the income losses of low-income households have greater impacts on their abilities to meet their energy bills than those of wealthy households. As a result, these modest households are more likely than wealthier households to enter into an insurance contract in order to have a minimum level of energy when losing income. On the other hand, the willingness to pay to ensure a minimum energy level for very high income households is a growing function of income. Note that $\min(\bar{p}(W_0)) = 47.32$ euros. This means that households are willing to pay at least a little less than 4 euros per month. A household with an annual income of $10,830$ euros is ready to pay a maximum of 91.18 euros (i.e., approximately 7.6 euros per month) for energy insurance. These values are close to those proposed by the existing insurances.

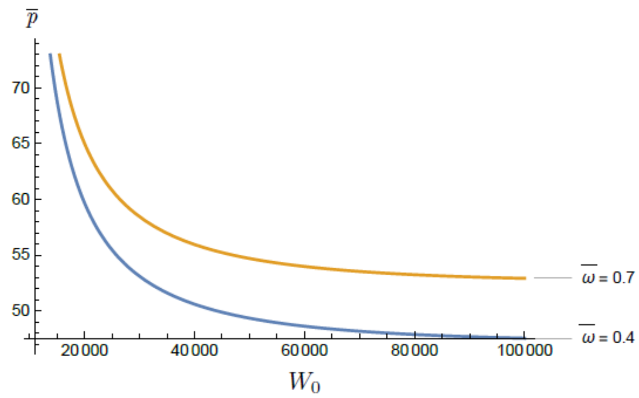

Figure 3. Insurance threshold price when the probability distribution of ω is the same regardless of the decile of income.

However, since the probability ω differs according to the income deciles (see Figures A2.1 – A2.10), the threshold depends on the decile[10]. Consequently, simulations for each income decile were performed. The maximum price that households are willing to pay for energy insurance based on income in year $t = 0$ is shown in Figure 4. This threshold price does not decrease according to decile because it depends on the probability of loss of income, which differs according to the deciles. Thus, in our simulations, households of the third decile are willing to pay more for their energy insurance than those of the second decile. The minimum and maximum values of $\bar{p}$ for each decile are given in Table 4. Note that the minimum value for the last decile is obtained for $W_0 = 208,700$ euros per year. For any income in $t = 0$ above this value, $\bar{p}$ is an increasing function of household income. Nevertheless, for all $W_0 \in]63,210; 1,810,000]$, $\bar{p} < 68.81$. Therefore, given the values cho-

[10]The upper limits (deciles) of annual household disposable income, in euros, used are D1 = 13,630, D2 = 17,470, D3 = 21,120, D4 = 25,390, D5 = 30,040, D6 = 35,060, D7 = 41,290, D8 = 49,350, and D9 = 63,210; i.e., 10% of households have incomes below 13,630.

sen for the parameters (in particular, $\bar{\omega} = 0.4$)[11], the maximum price that households are willing to pay for energy insurance is between 2.26 and 5.94 euros per month.

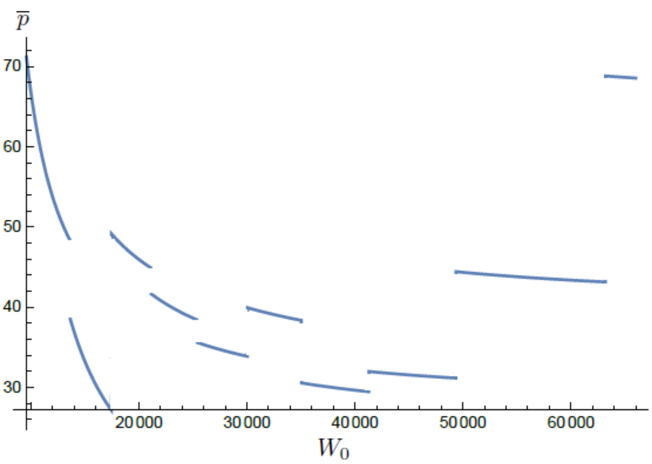

Figure 4. Insurance threshold price when the probability distribution of ω differs by income decile ($\bar{\omega} = 0.4$).

$\bar{p}$	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}
Max	71.20	38.57	49.12	41.66	35.60	39.94	30.54	31.98	44.42	68.81
Min	48.30	27.11	44.89	38.40	33.87	38.35	29.45	31.15	43.13	65.96

Table 5. Minimum and maximum values of $\bar{p}$ (in euros) for each decile ($\bar{\omega} = 0.4$, $W_0 < 1,810,000$ euros).

The price thresholds were calculated for different $\bar{\omega}$ values (see Table A3.1 for the minimum and maximum values of $\bar{p}$ for each decile according to $\bar{\omega}$). The minimum price threshold (25.7 euros per year, i.e., 2.14 euros per month) is observed for households in the second income decile when income equals $D2 = 17,470$ euros per year and $\bar{\omega} = 0.2$. The maximum threshold (79.34 euros per year, i.e., 6.61 euros per month) is observed for households in the last decile when $\bar{\omega} = 0.7$ and income equals $D9 = 63,210$ euros per year. Let us remember that Engie's insurance costs 5 euros per month and that EDF's insurance costs from 2 euros per month up to 8 euros.

The expectation of discounted cost by decile and $\bar{\omega}$ for an insurer,

$$\beta p_1^e \underline{e} \int_{\underline{\omega}}^{\bar{\omega}} f(\omega)\, d\omega, \tag{29}$$

[11]$\bar{\omega} = 0.4$ means that households in $t = 1$ having incomes below 40% of their incomes in $t = 0$ will receive $\underline{e}$ if they have taken out energy insurance.

is shown in Figure 5. These expected costs are below the previously calculated threshold prices ($\bar{p}$). Therefore, without uncertainty regarding the price of energy and given the information on the distribution of future incomes, offering energy insurance is profitable (in expectation).

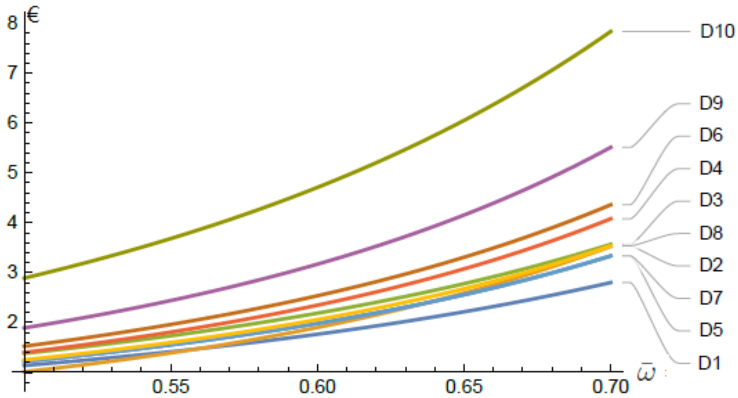

Figure 5. Expection of discounted cost (in euros) by decile (Di) for an insurer function of $\bar{\omega}$ ($p_1^e = 0.18$ euros per kWh, $\beta = 0.05$, $\underline{e} = 6550$, $\underline{\omega} = 0.02$.

5 Conclusions

This article proposes a two period energy insurance model for households. This model allows the threshold insurance price to be determined while taking into account the distribution of future incomes, the price of the energy good, the weight of that good in the household's utility function, the volume of insured energy (which may be likened to an energy subsistence level) and an insurance trigger ($\bar{\omega}$ percentage of income). The threshold prices resulting from the simulations carried out are in line with the energy insurance prices currently proposed. These prices obviously enable such insurance to generate profits for insurers. This inexpensive insurance can help avoid a supply interruption through a minimum service guarantee ($\underline{e}$). It protects households from fuel poverty, which, according to the Official Journal of the European Union (C151/28)[12] of 17/06/2008, means exclusion from a dignified life. In effect, it allows households with significant income losses to be able to heat and illuminate their homes, thus not needing to choose between staying warm or putting food on the table. This insurance avoids housing deteriorations due to lack of heating, such as the development of mould. In addition, it helps reduce health problems. In fact, headaches as

[12]This Official Journal of the European Union (C151/28) is on Opinion of the European Economic and Social Committee on the Communication from the Commission: Towards a European Charter on the Rights of Energy Consumers.

well as chronic respiratory (bronchitis), neurological (depression) or osteo-articular (osteoarthritis) health problems appear more frequently in households that are insufficiently heated. This insurance can prevent households from making budgetary decisions that would force them to give up some care. Therefore, this inexpensive insurance avoids significant costs related to fuel poverty. As a result, this insurance might one day be an obligation.

Other simulations could be carried out to offer more differentiated insurances. For example, the level of provided energy, which was considered identical for each household, could depend on the composition of the household and the characteristics of the dwelling. In addition, instead of considering a percentage of income as a trigger for insurance, a maximum income level ($\bar{W}_1$), identical for each decile, could be considered. Thus, any household that has paid for insurance and that has an income in $t = 1$ below $\bar{W}_1$ will receive $\underline{e}$.

Among the possible extensions of the model, the problems of moral hazard (modifications of the behaviours of the household after the signature of the contract) and adverse selection (which may be due to asymmetric information as to the distribution of income and or utility function parameters) can be considered.

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APPENDICES

Appendix 1. Equilibrium when $m > \underline{e}$.

If $m > \underline{e}$, then $\omega_t^a < \omega_t^b$, and for all W_t such that $W_t - |t-1|\, p^I I \in [w_a, w_b]$, there is no equilibrium. For the other values of W_t, equilibrium is characterized as follows:

$$e_t^0 = \begin{cases} 0 \text{ if } & W_t \leq |t-1|\, p^I I + \frac{p_t^e \underline{e}}{m\alpha}, \\ ea_t \text{ if } & \frac{p_t^e \underline{e}}{m\alpha} < W_t - |t-1|\, p^I I \leq \omega_t^a, \\ eb_t \text{ if } & W_t > |t-1|\, p^I I + \omega_t^b, \end{cases} \tag{30}$$

$$x_t^0 = \begin{cases} \frac{W_t}{p_t^x} \text{ if } & W_t \leq |t-1|\, p^I I + \frac{p_t^e \underline{e}}{m\alpha}, \\ xa_t \text{ if } & \frac{p_t^e \underline{e}}{m\alpha} < W_t - |t-1|\, p^I I \leq \omega_t^a, \\ xb_t \text{ if } & W_t > |t-1|\, p^I I + \omega_t^b, \end{cases} \tag{31}$$

where ea_t is defined by (14), eb_t is defined by (15), xa_t is defined by (16) and xb_t is defined by (17).

Appendix 2. The likelihood of lost revenues by income decile.

The distribution g of ω_i for each decile estimated from the 2010 and 2011 waves of SRCV is as follows:

- for the first two deciles: a mixture distribution, the cumulative distribution function (CDF) of which is given as a sum of the CDFs of the component distributions
  - Laplace double-exponential distribution with mean 0.6515 and scale parameter 0.3485 and Cauchy distribution with location parameter 1.7879 and scale parameter 0.1565 for the first decile

– Laplace double-exponential distribution with mean 1.0387 and scale parameter 0.1658 and lognormal distribution with mean 0.7508 and standard deviation 0.4064 for the second decile

each with weights of 0.6515 and 0.3485 for the first decile and 0.9351 and 0.0649 for the second.

- for the other deciles : a Student's t-distribution with location parameter μ, scale parameter σ and ν degrees of freedom. The values of μ, σ and ν for each decile are given in Table A2.1.

Decile	μ	σ	ν
3	1.030	0.126	1.651
4	1.017	0.148	2.191
5	1.010	0.116	1.762
6	1.008	0.148	2.097
7	1.002	0.135	2.199
8	1.001	0.117	1.790
9	0.972	0.148	1.977
10	0.959	0.184	1.920

Table A2.1. Values of the parameters of the Student's t-distributions

The parameters γ_k of the Pade approximation of these distributions are given in Table A2.2.

k	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}
0	0.0226	0.0069	0.0299	0.0479	0.0194	0.0238	0.0195	0.0323	0.0324	0.03927
1	0.0415	0.0413	0.0872	0.1950	0.0549	0.0756	0.0653	0.1109	0.1057	0.1137
2	0.0830	0.1245	0.1734	0.5096	0.1051	0.1564	0.1418	0.2560	0.2271	0.2167
3	0.1538	0.2501	0.2899	1.0738	0.1685	0.2648	0.2511	0.4926	0.4008	0.3387
4	0.2354	0.3771	0.4372	1.9711	0.2435	0.3965	0.3925	0.8496	0.6267	0.4674
5	0.2964	0.4548	0.6146	3.2628	0.3278	0.5443	0.5624	1.3579	0.8987	0.5886
6	0.3138	0.4571	0.8189	4.9484	0.4187	0.6987	0.7539	2.0481	1.2040	0.6875
7	0.2857	0.3938	1.0448	6.9072	0.5130	0.8476	0.9564	2.9451	1.5212	0.7496
8	0.2279	0.2969	1.2842	8.8211	0.6073	0.9775	1.1563	4.0622	1.8203	0.7626
9	0.1617	0.2035	1.5257	10.0812	0.6975	1.073	1.1563	5.3904	2.0625	0.7171
10	0.1033	0.2432	1.7547	9.6911	0.7795	1.1220	1.4785	6.886	2.2011	0.6081
ω_0	0.07	0.04	0.15	0.3	0.06	0.08	0.09	0.22	0.11	0.02

Table A2.2. Values of the parameters γ_k of the Pade approximation for each decile (D)

In Figures A2.1– A2.10, the distribution of ω for each decile and its Pade approximation are plotted on the interval [0,0.8].

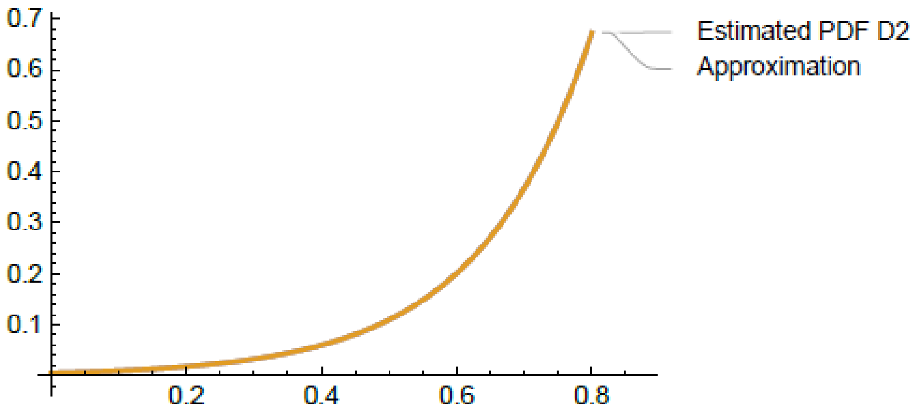

Figure A2.2. Distribution of ω for the second decile.

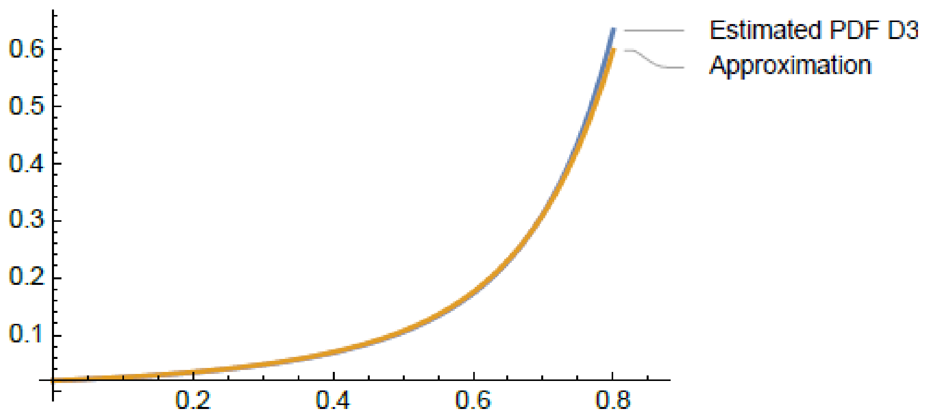

Figure A2.3. Distribution of ω for the third decile.

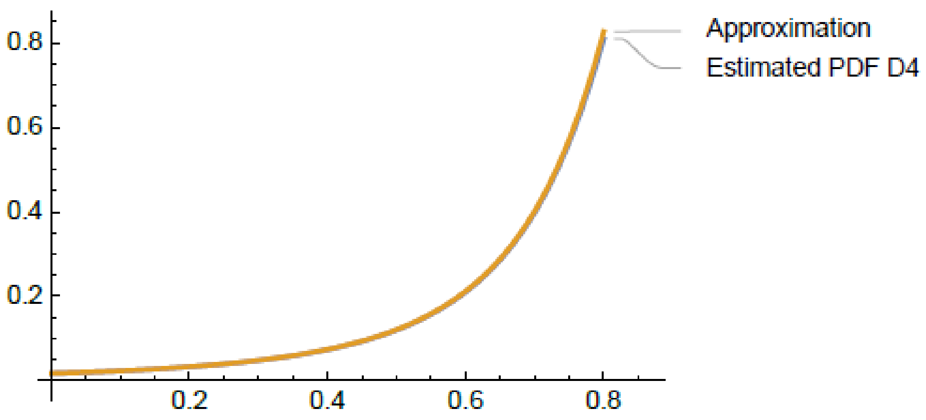

Figure A2.4. Distribution of ω for the fourth decile.

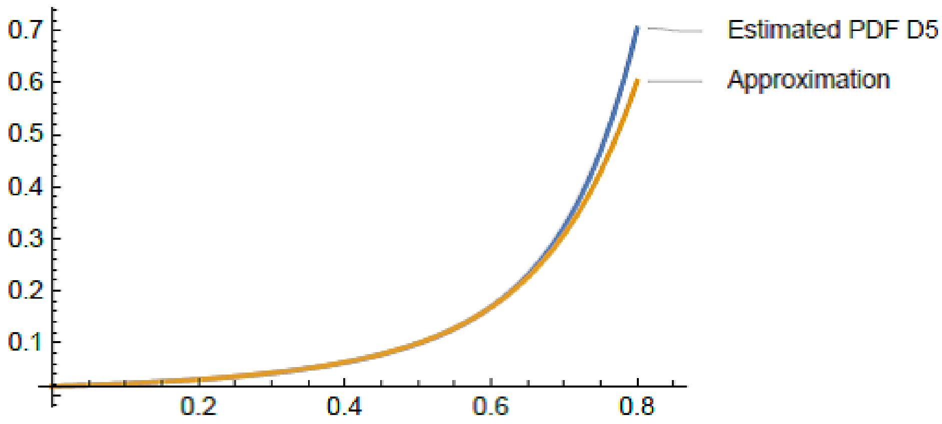

Figure A2.5. Distribution of ω for the fifth decile.

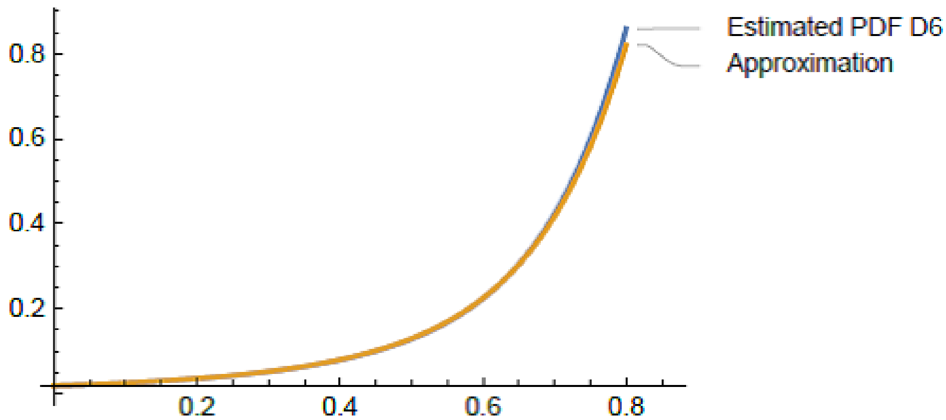

Figure A2.6. Distribution of ω for the sixth decile.

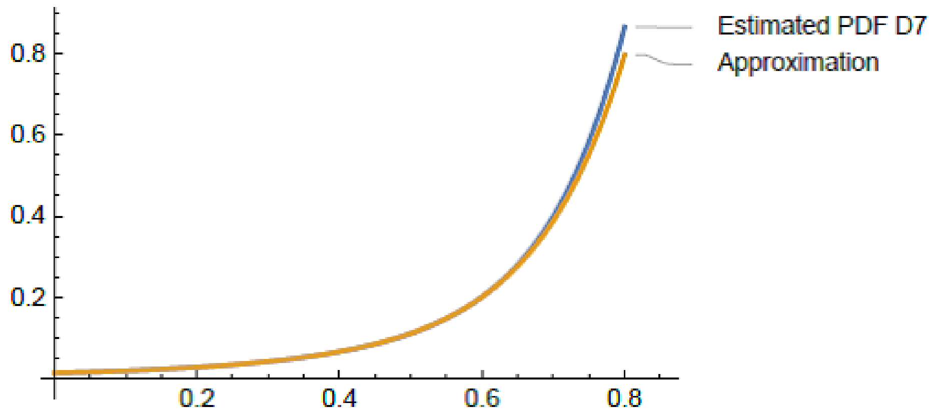

Figure A2.7. Distribution of ω for the seventh decile.

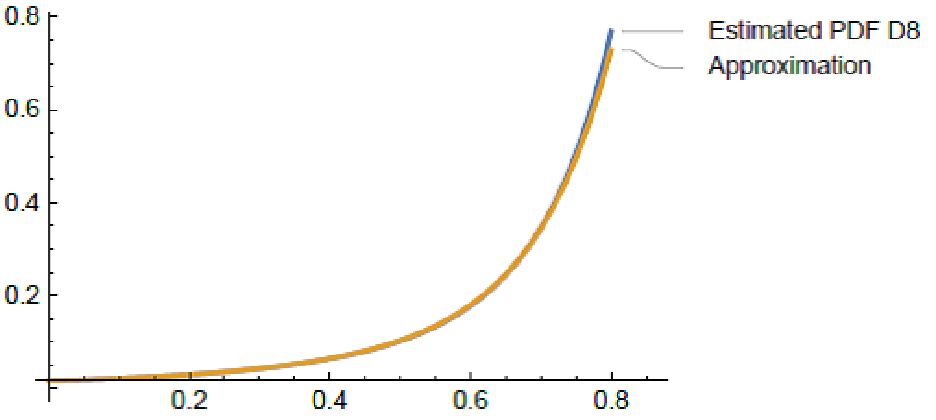

Figure A2.8. Distribution of ω for the eighth decile.

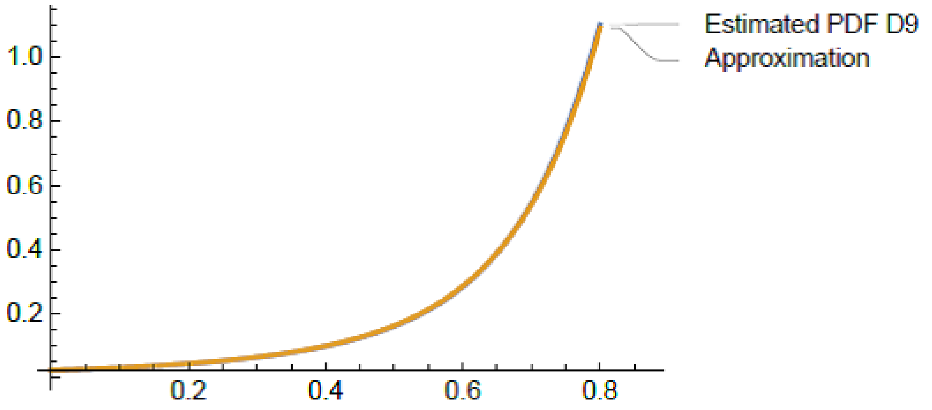

Figure A2.9. Distribution of ω for the ninth decile.

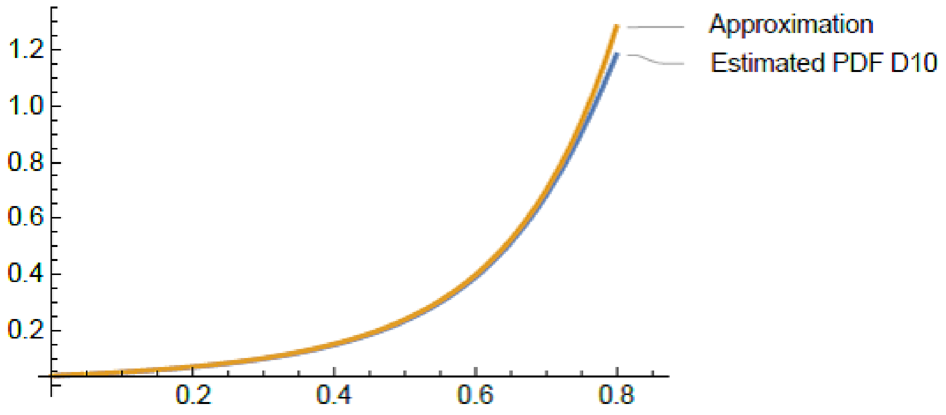

Figure A2.10. Distribution of ω for the tenth decile.

$\bar{p}$	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}
$\bar{\omega} = 0.2$, Max	**69.37**	37.13	47.05	39.63	33.83	37.76	*28.76*	30.20	41.76	64.73
$\bar{\omega} = 0.2$, Min	46.57	*25.70*	42.85	36.39	32.11	36.18	27.68	29.38	40.49	**61.91**
$\bar{\omega} = 0.3$, Max	**70.35**	37.78	48.11	40.63	34.71	38.83	*29.62*	31.08	43.05	66.74
$\bar{\omega} = 0.3$, Min	47.48	*26.33*	43.89	37.38	32.99	37.24	28.54	30.25	41.77	**63.89**
$\bar{\omega} = 0.5$, Max	**72.10**	39.66	50.25	42.91	36.63	41.27	*31.68*	33.05	46.08	71.30
$\bar{\omega} = 0.5$, Min	49.20	*28.20*	46.02	39.64	34.90	39.69	30.60	32.22	44.80	**68.43**
$\bar{\omega} = 0.6$, Max	73.22	41.25	51.70	44.61	38.01	43.10	*33.29*	34.50	48.40	**74.58**
$\bar{\omega} = 0.6$, Min	50.33	*29.79*	47.48	41.35	36.28	41.51	32.20	33.68	47.11	**71.72**
$\bar{\omega} = 0.7$, Max	74.76	43.68	53.78	47.22	40.06	45.86	*35.82*	36.75	51.95	**79.34**
$\bar{\omega} = 0.7$, Min	51.88	*32.24*	49.56	43.97	38.33	44.29	34.73	35.93	50.67	**76.50**

Table 5. Minimum and maximum values of $\bar{p}$ (in euros) for each decile ($W_0 < 1,810,000$ euro)

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