Split Incentives and Energy Efficiency:
Empirical Analysis and Policy Options

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Abstract

The residential sector offers considerable potential to reduce energy uses and GHG emissions, particularly with energy-efficient renovations. But, split incentives between tenants and landlords can lead to inefficient use of energy. In this paper, our main objectives are to (i) verify empirically whether tenants live in the most poorly energy-efficient home, (ii) analyze conceptually and empirically energy-saving expenditures according to occupancy status and (iii) provide some policy recommendations. We show that in rented-occupied housing units, the number of energy-savings renovations is relatively low. Tenants are double penalized: they have to pay a large amount of energy expenditures (due to a poor energy efficiency of the building), but they are poorer than homeowners and they are therefore not able to invest in energy-saving systems. We conclude that the split incentives issue is closely linked to fuel poverty. In terms of public policy, mandatory measure such as minimum standard seems appropriated.

Keywords: Energy Efficiency, Split Incentives, Fuel Poverty, Public Policy

Titre

Incitations divergentes et efficacité énergétique : étude empirique et politique publique

Résumé

Le secteur résidentiel offre un potentiel d'économie d'énergie et de réduction des émissions important, particulièrement grâce aux rénovations en efficacité énergétique. Toutefois, les incitations divergentes entre propriétaires et locataires peuvent mener à une utilisation inefficace de l'énergie. Dans ce papier, nos objectifs principaux sont (i) de vérifier empiriquement si les locataires vivent dans les logements les plus énergivores, (ii) d'analyser conceptuellement et empiriquement les dépenses en rénovation énergétique des ménages en fonction du statut d'occupation et (iii) de fournir des recommandations de politiques publiques. Nous montrons que les logements occupés par des locataires sont très peu rénovés. Les locataires sont donc doublement pénalisés : ils doivent payer une facture énergétique plus élevée que les propriétaires (à cause des caractéristiques du bâti) et n'ont pas la capacité financière de pouvoir financer des travaux en efficacité énergétique. Nous concluons que le problème des incitations divergentes est lié à un problème de précarité énergétique. En termes de politiques publiques, les mesures réglementaires comme l'introduction de standard d'efficacité énergétique pour les logements loués semblent appropriées.

Mots-clés : efficacité énergétique, incitations divergentes, précarité énergétique, politiques publiques.

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1. Introduction

The residential sector offers considerable potential to reduce energy uses and GHG emissions, particularly with energy-efficient renovations (Stern, 1998). It is often claimed that differing incentives between tenants and landlords of residential housing units lead to the inefficient use of energy (Blumstein 1980; Fisher 1989; Sutherland 1991; Jaffe and Stavins 1994a,b; Brown 2001). Split incentives are an important barrier to reducing energy consumption in the residential sector (IEA, 2007). Split incentives arise when participants in an economic exchange do not share the same goal. When the owner and the occupier of a housing unit are different people, a split in incentives occurs. While the landlord wants to minimize the purchase cost of energy systems (heating and hot water), and has no return on his investment, the tenant wants to minimize his energy bill. In this case, neither participant want to invest in an energy efficient system. The landlord is not encouraged to make investments in energy efficiency since it is the tenant who receives dividends. In Europe, a large share of households lived in rented dwellings. For example in 2012, in Switzerland, 56.1 % of the population were tenants, 46;7% in Germany and 36.3% in France (Source: Eurostat). The existence of these market failures justifies government intervention. But, the split incentives problem is not still aimed at by public policies and most particularly there is no incentive that actually affects the amount of investment in the rent[2]. Thus, with residential sector making up just over 27.5 percent of final energy consumption in France, the split incentives issue can be expected to be responsible for large share of the amount of energy consumption. In addition, 92% of energy-saving renovation work in France was done in housing units occupied by their owners (SOFRES-ADEME, 2009). However, to our knowledge, studies focus on the split incentives issues in the residential sector are in limited number.

In this paper, we provide some of the first empirical evidence for the extent to which split incentives between landlords and tenant may lead to underinvestment in France. Moreover, we focus our attention on the link between occupancy status and the problem of energy fuel poverty. Our main objectives are to (i) verify empirically whether tenants live in the most poorly energy-efficient home, (ii) analyze conceptually and empirically energy-saving expenditures according to occupancy status

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[2] Since March 2009 in France, a measure can be specifically dedicated to landlords: the compensation of investment. If a landlord invests, he can require a tenant to repay a portion of the energy-savings. The amount depends on the average surface area of a dwelling (maximum 20 euros per month). This amount is completely insufficient to make the investment profitable. Moreover, this measure is applicable only when the landlord undertakes several energy efficiency works in housing units constructed before 1990. Moreover, the application of this measure requires the agreement of the tenant.

and (iii) provide some policy recommendations. First, we find evidence that tenants live in energy-inefficient dwelling and are particularly vulnerable to energy cost. Second, we find that energy efficiency expenditures are mainly undertaken in owner-occupied dwelling. We show that tenant are double penalized: they have to pay a large amount of energy expenditures (due to building characteristics in terms of energy efficiency), but they are poorer than homeowners and they are not able to invest in energy saving systems. We conclude that the issue of split incentives in France is closely linked to a fuel poverty problem. In terms of public policy, government should not only address the problem of split incentives but also focus on fuel poverty issues. Mandatory measure such as minimum standard seems appropriated.

The magnitude of the split incentives problem was analyzed by Murtishaw and Sathaye (2006). In their study, they examine the number of housing units which are potentially affected by the problem between landlords and tenants and they assess a potential energy savings if the split incentives issue is overcoming for refrigerators and water heaters. They obtain that 35 percent of residential energy use may be affected by the split incentives problem. They show that the government should implement public policies in order to trigger energy saving investments. They underline the importance of additional information, energy performance standards, labels and building codes. Levinson and Niemann (2004) provide also some empirical evidence of the split incentives issues is the particular case where landlord pays for the energy use. Using US Department of Energy's Residential Energy Consumption Survey (RECS), they show that the behavior of households varies depending on whether they own or rent the place in which they live. In the case where the heat is included in the rent, the average winter indoor temperature is higher that when this not the case.

Moreover, split incentives seem also responsible of the energy inefficiency of dwellings. Hassett and Metcalf (1995) show that the probability to invest in energy saving measures increases when the dwelling is owner-occupied. The slow adoption rate of energy equipment could be explained in situations where the benefits and costs of energy efficiency are supported by different individuals. Everyone will have an interest in that the cost is borne by the other (van Soest and Bulte, 2001). Diaz-Rainey and Ashton (2009) found that a total of 27% of respondents do not renovate because they live in either a council property (13%) or a rented property (14%). Davis (2010) compares energy-saving system patterns between owner-occupiers and tenants using household-level data. Controlling for household income and other household characteristics, tenants are significantly less likely to use energy-saving systems. Landlords who do not pay the energy bill are also less likely to invest in energy-saving systems. More recently, Bird and Hernandez (2012) show that the split incentives problem concerns the lack of appropriate incentives to implement energy efficiency measures. The problem does not arise when the landlord occupies the dwelling. Gillingham *et al.* (2012) provide

empirical evidence quantifying the magnitude of split incentive problem in California. They find evidence of a split incentive issue when the occupant does not pay for heating or cooling. Households that pay for heating are 16 percent more likely to change the heating system. Second, they show that in owner-occupied dwellings, the homeowners have 20 percent more likely to live in dwelling where the attic or ceiling is insulated and 13 percent more likely to be live in a dwelling where exterior walls are insulated. In general, studies agree that tenants are reluctant to invest (Arnott *et al.* 1983; Levinson and Niemann, 2004; Rehdanz, 2007; Davis, 2010). Burfurd *et al.* (2012) use a laboratory experiment and study different kind of public policy interventions such as mandatory information on energy efficiency, voluntary information, mandatory minimum standard and a "cost share" treatment where landlords pay a share of the tenant's energy bill. They obtain that this last measure is not the most relevant because of landlords face to uncertainty according to the energy bill of their tenants. The public policy which leads to higher energy efficiency investments is the mandatory minimum standard. However, this measure leads to reduce the number of properties available for lease. In their study, they also show that rental properties are often associated with lower levels of energy efficiency that owner occupied-building. But, in these studies, the split incentives issue is only perceive as a lack of appropriate incentives to implement energy efficiency measures. The consequences of this issue as an important problem for low-income households and more especially renters are not considered.

In our study, we want to verify empirically if renters live in the most poorly insulated dwelling using French data. We obtain that tenants live in energy-inefficient dwelling and are therefore more vulnerable to energy cost. The public policy which seems the most appropriated is the minimum standard regulatory.

Renters are often poorer than homeowners and often spend the highest share of their income on energy cost. In France, the annual disposable income is 43,700 Euros in 2010 for homeowners, 27,000 Euros for tenants living in private residential and 22,000 Euros for tenants living in public residential (Commissariat Géneral du Développement Durable, 2012). Fuel poverty is a phenomenon in which low-income households spent a huge share of their income to energy expenditures. Fuel Poverty is defined as an interaction of three different policy areas: energy, housing and incomes and are many consequences such as physical and mental health risks, over-indebtedness, bad energy quality of the building stock and CO_2 emissions (European Fuel Poverty and Energy Efficiency, 2006). Often, low-incomes households are obliged to "choose" low cost housing units and these last have lots of energy efficiency problems such bad insulation, dampness, poor heating systems etc. But, concerning literature, fuel poverty is a wide notion that has no precise definition and measure. In such a context, the problem of split incentives is therefore particularly challenging for low-income tenants. The fuel poverty line is set to 10%, i.e., 10% of the household's income is spent on energy. For instance, in Britain, fuel poverty accounts for 8-13% of the population (Boardman, 2010, chap. 2). In France, 3.8

million of households spent more than 10% of their income to heating expenditures. Moreover, low income households are less able to finance energy efficiency measures. Moreover the recent rise of energy prices (and further expected rises) will make it more and more difficult for this category of people to pay the bills (Baxter, 1998). Bird and Hernández (2012) study different policy options to increase energy efficiency in a case where split incentives exist. They focus their analysis on the low-income renters. They obtain that in Massachusetts, one solution is to implement performance standard for weatherization. Thus, in this paper, we want to show that the tenants are particularly affected by the lack of energy efficiency in the building especially in terms of fuel poverty.

The remainder of the paper as follows. In section 2, the conceptual framework is presented. In section 3, data and variables are described. Section 4 introduces the econometrics models. This section is divided in two parts. In section 3.1 the probability to live in an energy efficient home is studied and in section 4.2 the decision to invest in energy-savings renovation is analyzed. Section 5 concludes.

2. Conceptual Framework

To analyse theoretically the decision to invest, we use a framework with split incentives. We consider an economy with two types of agents: a landlord (L) and a tenant (T) who occupies the dwelling. We have two periods of time. We set a finite discrete time horizon as $t \in \{0,1\}$. During the first period, the agents have the choice between consuming or investing. They only consume in the second period. The housing quality function is the same for both agents. This function represents the value of the dwelling. We also consider this housing quality function as a proxy for measuring energy efficiency in the dwelling. In period 0, energy efficiency in the housing unit is a function of the investment level of the landlord in the dwelling I_0^L, the investment level of the tenant I_0^T, the energy efficiency when the tenant moves into the dwelling $\overline{X}$ and a capital depreciation factor δ with $0 < \delta < 1$. Thus, energy efficiency depends on the level of investment. The higher level of investment, the higher the energy quality (or energy efficiency) of the housing units.

So, we have:

$$X_1 = I_0^L + I_0^T + (1-\delta)X_0 \tag{1}$$

$$X_0 = \overline{X} \tag{2}$$

The rent (L_t) is also common to both agents. In the model, it is possible to consider to require a portion of energy saving in the rent if an agent invests. But, in order to make easier the reading of the model, we do not present these results (the effects of other parameters are strictly the same in both layouts).

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We have a two-period planning problem. Having optimized the both periods, we will get two reaction functions. The landlord (tenant) should decide about investment taking into account the investment level of the tenant (landlord). These reaction functions are the best response of each agent:

$$I_0^L = f(I_0^T) \quad \text{and} \quad I_0^T = f(I_0^L) \tag{3}$$

Using these reaction functions, a Cournot Nash equilibrium is obtained. A list of variables used in the conceptual framework is available in appendix A.1.

2.1 The landlord's problem

The landlord consumes goods and we have the following utility function:

$$U(C_t^L) = Log(C_t^L) \tag{4}$$

This is a logarithmic utility function. The problem of the landlord is to maximize his utility function (4) subject to (1), (2) and:

$$R_1^L + L_1 + \frac{X_1}{1+r} = C_1^L + M_1 \tag{5}$$

$$R_1^L = (R_0^L - C_0^L - I_0^L + L_0 - M_0)(1+r) \tag{6}$$

where R_1^L and R_0^L are respectively the landlord's income in periods 0 and 1. The income in period 1 depends on the income in the previous period less the investment, the maintenance costs and the consumption, and plus the rent. Since we consider a two-period model, this budget constraint takes into account the fact that the owner expects to recuperate the value of his home by selling it at the end of period 1. His income return in period 1 is determined by r. The homeowner can also deal with maintenance costs M_t (see Henderson and Ioannides, 1983). To avoid capital depreciation, maintenance cost are required. Even if the tenant might be charged for obvious damages through, for example, deductions from a damage deposit it is impossible to explicitly provide in rental contracts for all possible contingencies. These costs are a function of investment. In the model, these maintenance costs are supported by the homeowner. We can also perceive these last as costs of housing rehabilitation. In the absence of energy efficiency, some problems such as water infiltration problems or repair works on heating systems may occur. So, the higher is the energy efficiency of the dwelling, the lower are the maintenance costs. So, we have:

$$M_1 = -X_1^2 \quad and \quad M_0 = -X_0^2 \tag{7}$$

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We can write the problem as follows:

$$\max_{I_0^L, c_0^L} U(C_0^L, I_0^L, C_1^L) = Log(C_0^L) + \beta Log(C_1^L) \tag{8}$$

Having optimized period 0 and period 1 (first order conditions are available in appendix A.2), we obtain the reaction function. So we obtain:

$$I_0^L = -I_0^T - \frac{r(r+2)}{2(r+1)} + X(\delta - 1) \tag{9}$$

We obtain that I_0^L is a decreasing function of I_0^T. Landlord's investment depends on the initial housing quality, the depreciation rate and the income return. The higher is the initial housing quality, the lower is the landlord's investment.

2.2 The tenant's problem

The tenant can consume energy goods C_t^{Te} or non-energy goods C_t^{Tne}. We have the following logarithmic utility function:

$$U(C_t^{Tne}, C_t^{Te}) = Log(C_t^{Te} C_t^{Tne}) \tag{10}$$

The problem of the tenant is to maximize his utility function (10) subject to (1), (2) and:

$$R_1^T = C_1^{Te} p_1(X_1) + C_1^{Tne} + L_1 \tag{11}$$

$$R_1^T = (R_0^T - C_0^{Tne} - p_0(X_0)C_0^{Te} - I_0^T - L_0)(1+r) \tag{12}$$

where R_0^T and R_1^T are the tenant's incomes in periods 0 and 1. The rent reduces the tenant's wealth. $p_0(X_0)$ and $p_1(X_1)$ represent the energy cost unit in period 0 and in period 1. They depend on housing quality. In terms of energy efficiency, it means that an improvement in housing quality leads to a lower energy cost. We assume that the cost function is a linear function. f is the maximum amount of energy expenditures when housing quality is equal to zero and represents the maximum amount that a household can pay in the absence of energy efficiency. Parameter ξ is the sensitivity of the energy cost to investment. If the energy price rises the decrease of energy cost will be higher. We set:

$$p_t(X_t) = -\xi X_t + f \tag{13}$$

We can write the tenant problem as:

$$\max_{C_0^{Tne}, C_0^{Te}, C_1^{Te}, I_0^T} U(C_0^{Tne}, C_0^{Te}, I_0^T, C_{1,}^{Tne} C_1^{Te}) = Log(C_0^{Te} C_0^{Tne}) + \beta Log(C_1^{Te} C_1^{Tne}) \tag{14}$$

Having optimized period 0 and period 1, we obtain four functions. Solving the system, we obtain four equations (first order conditions and soluations are available in appendix A.3)

$$I_0^T = \frac{2f(r+1)(\beta+1) - (-(rL_0 + L_0 + L_1 - (r+1)R_0^T)\beta + 2I_0^L(r+1)(\beta+1) - 2(r+1)X(\beta+1)(\delta-1))\xi}{(r+1)(\beta+2)\xi} \quad (15)$$

As a result, the tenant's investment is a decreasing function of the landlord's investment. An interesting result is that the tenant's investment depends on energy efficiency parameters (f and ξ).

2.3 Equilibrium

Using the equations of reaction functions, we compute equilibrium.

$$I_0^L = \frac{4f(r+1)(\beta+1) + \left((\beta+2)r^2 + 2(\beta(L_0 - R_0^T + X(\delta-1)+1)+2)r + 2\beta(L_0 + L_1 - R_0^T - X + X\delta)\right)\xi}{2(r+1)\beta\xi} \quad (16)$$

$$I_0^T = -\frac{2f(r+1)(\beta+1) + (r(r+2) + (L_1 + L_0(r+1) + r(r+2) - (r+1)R_0^T)\beta)\xi}{(r+1)\beta\xi} \quad (17)$$

In order to understand the effect of each parameter, numerical results are provided in the next section.

2.4 Numerical solutions with split incentives

We use the following values for parameters: β=0.99 ; δ=0.05; r=0.05; X=2012; ξ=0.01; f=55 L0=55.86; L1=57.53;R_0^T=22075. The calibration is precisely detailed in appendix A.4.

Landlord investment is a decreasing function of tenant investment and tenant investment also is decreasing function of landlord investment. This result suggests that if an agent does not invest, the second will not invest too. The equilibrium is computed using the reaction functions (Figure 1 and 2). It is the intersection point of the reaction curves. At equilibrium, neither of the agent invests. Thus, in terms of energy efficiency, in a case where the dwelling is tenant occupied, no-one is willing to invest to improve energy efficiency. This results are consistent with (Arnott *et al.* 1983; Levinson and Niemann, 2004; Rehdanz, 2007; Davis, 2010). According that tenant lives in less insulated dwelling, it means that a large part of the housing stock would not be renovated.

Figure 1: Solutions of reaction functions
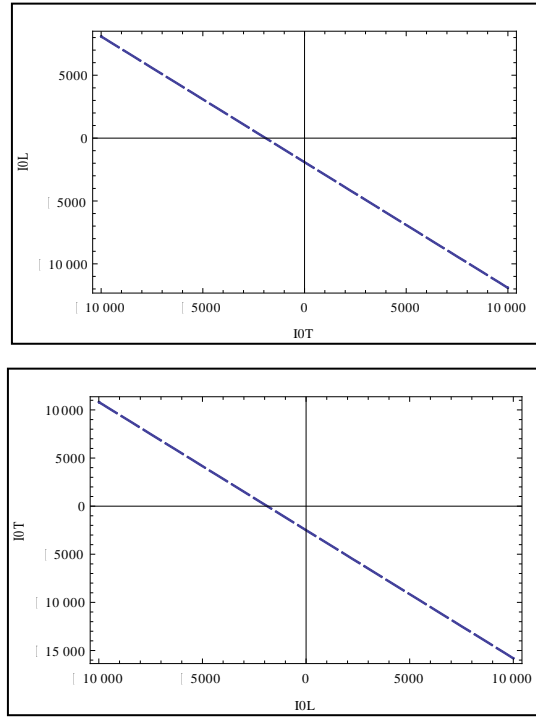
$$I_0^L = f(I_0^T) \quad \text{and} \quad I_0^T = f(I_0^L)$$

Figure 2: Equilibrium
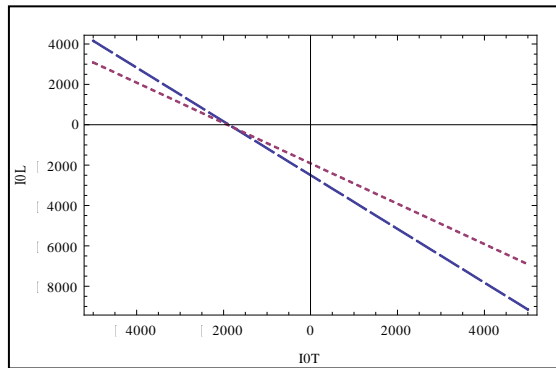
We lead some sensitivity analysis using the analytical solutions (see appendix A.5). The main result is that tenants are responsive to potential energy savings (i.e if the energy cost sensitivity to investment ξ) and intial energy cost. This result suggests that energy prices are clearly key variables in the model. Savings in euros associated with a renovation vary according to energy prices. For instance, if ξ=0.02, the tenant invests. This result is consistent with Amstalden *et al.* (2007) who draw the same conclusions in empirical studies. Expecting high energy prices triggers investment. Finally, if the initial energy cost is very high (it means a bad energy quality of the dwelling), the tenant does not invest. This result underline a very strong issue in terms of energy efficiency. Tenants who live in less

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energy efficient dwelling and who have a lower income than homeowner, do not invest, especially in the case where the energy quality is very low. A problem of energy poverty concerning tenant can be considered. These results should be verified in the empirical parts.

3. Data, variables and main descriptive statics

3.1 Data

In this study, we use the *2006 Enquête Logement*, a disaggregate household-level survey data set by INSEE. We also use the "*travaux*" database. Merging these two surveys, information is available on 22, 228 households. In this study, a distinction is made between energy efficient works (EE) and repairs works (RE) following the *Observatoire Permanent de l'amélioration Energétique du logement* (OPEN). However, in this database, information on energy expenditures before and after renovation works is not available. It is therefore necessary to create new variables. Thus, we simulate energy expenditures and energy consumption using the PROMODUL Software and merge new variables with the *2006 Enquête Logement* database[3]. The final sample still contains 16704 households.

3.2 Variables and descriptive statics

3.2.1 Energy labels and energy-savings renovations

To determine the energy efficiency of a dwelling, we refer to energy labels. Energy labels have been introduced in 1995 and aim at providing consumers information about the energy quality of a dwelling. A very efficient dwelling is classified in A (< 50 kWh$_{fe}$/m^2/year) while a very inefficient dwelling is classified in G (> 450 kWh$_{fe}$/m^2/year). A figure is provided in appendix B (Figure 3). In France, average energy consumption is 195 kWh$_{fe}$/m^2/year. Household's mainly belong to energy label D (see Figure 5 and 6).

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[3] A detailed methodology is available in Charlier (2013).

Figure 5 : Household's repartition by energy labels in frequence

Households' repartition by energy labels

Energy Labels (A–G) plotted against Frequence (0 to 40).
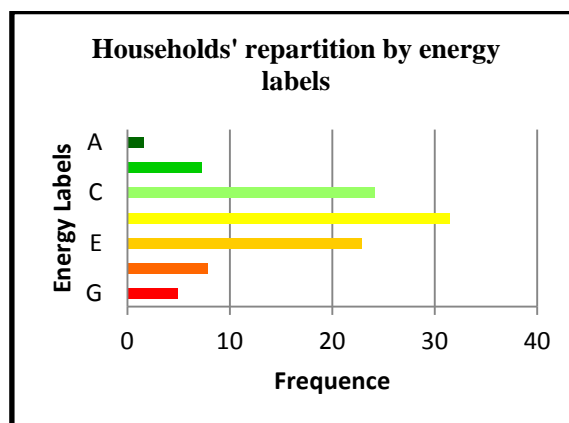
Figure 6 : Household's repartition by energy labels in percent

Households' repartition by energy labels

Energy Labels (A–G) plotted against Percent (0 to 40).
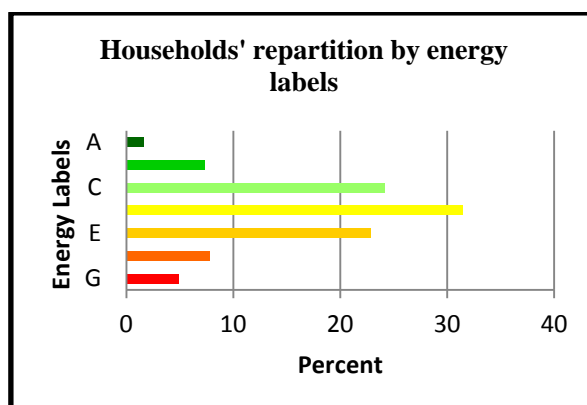
About 9% of households belong to the category F and G and only 4.8% to the category A. Most households are in the intermediate labels C, D and E. Considering a repartition according to occupancy status, tenants live in the most poorly insulated dwelling contrary to landlords (see Table 2). So there is a different distribution according to occupancy status. Renters represent 47.4% of households.

Table 2 : Repartition by label according to occupancy status in percent

Labels	Total	Landlord	Tenant
A	4.87	7.34	2.12
B	7.80	10.03	5.33
C	22.85	25.38	20.05
D	31.44	31.03	31.90
E	24.13	20.03	28.68
F	7.27	4.82	9.99
G	1.64	1.38	1.93
Total	100.00	100.00	100.00

Moreover, studying this repartition according to income (see Table 3), Wealthier people live in the most efficient housing. Given that renters are poorer than the homeowners, they live in the most poorly insulated dwelling.

Table 3 : Average household income according to occupancy status and energy label

Labels	Total	Landlord	Tenant
A	35673.	38235.76	25838.369
B	34793.146	35854.655	32577.057
C	31615.609	34892.	27011.672
D	28392.	32141.48	24342.73
E	25237.152	28401.248	22783.932
F	16189.	19145.097	14604.604
G	20031.391	25925.347	15370.157
Means	28196.51	32197.29	23755.01

Moreover, in 2006, only 4.10% of households undertake energy-saving renovations. They spent 6143 Euros on average. 54.6% of households who decide to make energy-savings investments are homeowners.

On average, homeowners spend 6860 Euros for insulation work against 2,348 for tenants. Concerning the replacement works, the expenditures is the practically the same on average (5600 Euros). However, 70% of tenants who have changed their equipment report bad value for money concerning the heating system (nearly 65% for homeowners). In addition, 62% of homeowners who report cold problems in their housing units replaced their equipment against only 32% of tenants. Descriptive statics suggest a problem of energy poverty for tenants. Today, energy poverty, especially in developed country, is not completely defined. Energy poverty results from a combination of three main factors (i) low income households (ii) poor thermal energy quality of occupied dwellings and (iii) cost of energy (source: European Fuel Poverty and Energy Efficiency, 2006). These situations of poor energy quality housing have consequences and cumulative costs such as social health, and enhance the degradation of housing because of absence of renovations. A French working group (De Quero and Lapostolet, 2009) decided to define energy poverty. One way to study energy poverty is to refer to the definition of the energy effort rate. It is a ratio between energy bill and income. A household is considered as "energy poor household" if energy effort rate is greater than 10 percents. In 2006, in France, energy effort rate is around 5.5% (De Quero and Lapostolet, 2009). Using data, we

have 7.7 % of energy poor households and 9.5% energy poor tenants (see Table 4). Moreover, the effort rate is higher for tenant than for homeowners.

Table 4: Effort rate (energy bill/income) according to the occupancy status and depending on effective energy efficiency investment in 2006 in %

Energy Label	Homeowners	Tenant	Means
A	2,79	2,69	2,77
B	5,19	5,68	5,35
C	5,46	7,6	6,35
D	6,22	8,92	7,51
E	7,33	10,38	9,05
F	11,08	15,44	13,92
G	7,6	13,83	11,07
Total	6.15	9.51	7.74

Income and energy cost seem to be key variables concerning the decision to live in energy efficient dwelling. These results are in line with the theoretical part. Indeed, the energy bill (i.e the energy cost) is higher in housing unit occupied by tenant.

Table 5: Energy bill according to the occupancy status and depending on effective energy efficiency investment in 2006

Energy Label	Investment in energy Efficiency works in 2006			No investment in energy efficiency works in 2006		
	Homeowners	Tenants	Means	Homeowners	Tenants	Means
A	984,29*	480	805,9	797,18	530,75	527,73
B	945,3	1470	1038,04	1042,11	1343,86	1348,65
C	1109,85	1291,62	1103,62	1103,31	1237,56	1239,79
D	1109,76	1136,15	1087,54	1086,6	1201,41	1198,75
E	1079,76	1131,32	1074,14	1073,89	1209,09	1206,41
F	749,88	1407,77	900,01	906,28	1140,72	1150,51
G	885,46	1150,83	639,8	631,41	854,55	873,92

The energy bill in 2006 for homeowners who decided to invest in energy efficiency investment is 924.29 Euros (see Table 5).

3.2.2 Dwelling and households characteristics, energy cost and energy-savings in Euros

As socio-economic characteristics, we introduce the income quintile and the occupancy status. To study the decision to live and to invest in energy efficient renovation, it seems important to take into account housing quality (i.e building characteristics). Plaut and Plaut's (2010) show that renovation expenditures are higher for individual housing units and Nair *et al.*'s (2010) demonstrate that households spend more when they live in the oldest and least insulated housing units. These results are consistent with our theoretical part. The energy efficiency (or energy quality) of the dwelling is a key variable. In the empirical model, periods of construction, the type of housing (individual housing units vs. collective buildings), the climate zone and the average surface area of the housing units are introduced. We also introduce the type of heating system (individual vs. collective). In France, there exist collective dwellings (e.g., apartment buildings) with a collective heating system. One energy bill is divided among all residents of the building contingent on shares allocated when the dwelling was purchased. The cost of excess energy consumption is borne by all residents of the building. Moreover, in this type of housing, decisions are made by majority vote at owners' meetings. The energy-saving measures have a lower probability of being accepted. Moreover, the energy efficiency of these buildings is lower. To determine the amount spent by households, we also introduce in the model the number of renovation works.

Considering the theoretical results and the literature, it seems crucial to take into account energy cost and savings (ES) from reduced energy usage. Grösche and Vance (2009) study the determinants of energy retrofit using a nested logit model, for which they distinguish 13 different renovation categories. The costs of renovation and expected gains emerge as key variables. Banfi *et al.* (2006) find similar results. Households could be sensitive to the size of energy-savings. These last depend on the energy cost. Higher the energy cost, higher the energy savings due to renovation. Households with high costs of energy use thus are more likely to invest (Nair *et al.* 2010).

To calculate energy-savings, we make the difference in energy expenditures before and after renovation works (see Charlier, 2013). A list of variables used in the empirical part is available in appendix B1.

4. Empirical models

4.1 The probability to live in an energy efficient home

We analyze the decision to live in an energy efficient home according to the occupancy status. We study the probability to live in an efficient energy dwelling (label A) according to the occupancy status.

The energy label variable data set has 7 levels that will use as our outcome variable. We have also 15 variables that we will use as predictors. The outcome variable can be considered as ordered. In each of these cases, although the outcome is discrete, the multinomial Logit or Probit model would fail to account for the ordinal nature of the dependent variable. The model is built around a latent regression in the same manner as the binomial Probit model. We begin with:

$$Y_i^* = \beta' x_i + \varepsilon_i$$

With y^* is unobserved. What we do observe is :

$$Y_i = 0 \quad \text{si} \quad Y_i^* \leq 0$$
$$Y_i = 1 \quad \text{si} \quad 0 < Y_i^* \leq \mu_1$$
$$Y_i = 2 \quad \text{si} \quad \mu_1 < Y_i^* \leq \mu_2$$
$$.$$
$$Y_i = J \quad \text{si} \quad \mu_{J-1} < Y_i^*$$

which is a form of censoring. The μ_s are unknown parameters to be estimated with β. We assume that ε is normally distributed across observations (see Greene, 2005; Cameron and Trivadi, 2009). The regression parameters are obtained by maximizing the log likelihood. The sign of the regression parameters, β, can be immediately interpreted as determining whether the latent variable, y^*, increases with the regressor. If β_i is positive, then an increase in x_{ij} necessarily increases the probability of being in the highest category ($y_i=7$), i.e in the less energy efficient dwelling and decreases the probability of being in the highest energy efficiency category ($y_i=1$).

Moreover, one of the assumptions underlying ordered logistic regression is that the relationship between each pair of outcome groups is the same. In other words, ordered logistic regression assumes that the coefficients that describe the relationship between, say, the lowest versus all higher categories of the response variable are the same as those that describe the relationship between the next lowest category and all higher categories, etc. This is called the proportional odds assumption or the parallel regression assumption.

Results show that the proportional odds assumption is violated. A generalized ordered Logit model with partial proportional odds model should be preferred. Indeed, we can also compare a model where the variables are constrained to meet the proportional odds assumption (same model than an ordered Logit model) with a model where the variables are not constrained. We can do a global test of the proportional odds assumption by contrasting the two models. This test should be in line with the Brant test. The chi-square statistic of the likelihood-ratio test shows that at least one variable does not meet the parallel line assumption. Hence, it is possible to identify the variables that meet the proportional odds assumption. The results show that only 4 of the 15 variables (1974-1981; 1982-1989, Surface and

Climate2) meet the parallel lines assumption. This model is less restrictive than the model estimated by an proportional odds model. It is also possible to propose an alternative but equivalent parameterization of the partial proportional odds model in which there is only one set of Betas but a second set of coefficients, called Gammas, can vary across the dividing points (Peterson and Harrell, 1990). The gammas indicate the extent to which the proportional odds assumption does not hold for a variable; if the gammas for a variable equal 0, then the parallel lines assumption hold for that variable. We confirm our results with this method. The generalized ordered Logit model can use the logistic distribution as the cumulative distribution and allows us to interpret this model in terms of Logits. Results for the ordered Logit model is available in appendix table C1. Results of the partial proportional odds model is available in summarized in Table 6. Parameters can be interpret as coefficients from binary logit models where the categories of the outcome variable are collapsed into two categories.

Characteristics of the buildings are a determinant of the probability to live in energy-efficient housing units. The probability to live in a bad category label is explained by the period of construction (dwelling constructed before 1989). Moreover, warmest the climate zone, higher is the probability to live in energy efficient label. The type of housing as well as the type of heating system explains also the probability to live in an energy efficient dwelling. Generally, households who lived in collective buildings with a collective heating system have a higher probability to live in a bad insulation quality dwelling. Concerning collective heating system and the probability to live in bad energy quality, two explanations can be exposed. One hand, heating equipment and building insulation is lower in this type of building because energy efficient works should be voted by a majority. One other hand, households who are heated by a collective heater often use oil as fuel, which is generally associated with significantly higher energy consumption. In terms of public policy, this result underlines two implications. First, a part of households who have a collective heating system are totally unable to properly declare their actual energy expenditures. As the energy bill is paid with the other common charges (expenditures for the lift, the cleaning of common parts, gardening, etc…), energy expenditures cannot be clearly identified by the households. This is an interesting result because some households cannot properly react at any kind of price-signal because they do not properly perceive the cost of their fuel use. Thus, the individualization of the heating system can be a first step to inform households. Second, discussions about fuel poverty show that households who live in less efficient dwelling are also poorest because the price of the rent (or the price of the dwelling) is lower in this kind of dwelling. The dwelling attributes in terms of energy quality are low.

Table 6: Results of generalized ordered logit model (Baseoutcome(label=7))

Variables	Label 1	Label 2	Label 3	Label 4	Label 5	Label 6
Socioeconomic characteristics of households						
Quint1	1.208***	1.424***	1.305***	1.346***	2.080***	1.509***
	(0.142)	(0.0961)	(0.0596)	(0.0566)	(0.103)	(0.208)
Quint2	0.687***	0.583***	0.450***	0.556***	0.859***	0.538**
	(0.118)	(0.0747)	(0.0523)	(0.0563)	(0.111)	(0.228)
Quint3	0.440***	0.302***	0.204***	0.246***	0.254**	-0.149
	(0.108)	(0.0689)	(0.0509)	(0.0571)	(0.121)	(0.256)
Quint4	-0.0808	0.0278	-0.00264	0.0953*	0.0216	-0.320
	(0.0953)	(0.0652)	(0.0506)	(0.0578)	(0.127)	(0.268)
Quint5	Ref	Ref	Ref	Ref	Ref	Ref
Homeowners	-1.135***	-0.871***	-0.559***	-0.495***	-0.447***	-0.0583
	(0.0952)	(0.0530)	(0.0348)	(0.0354)	(0.0587)	(0.127)
Characteristics of buildings						
Bef1974	-0.138	0.251***	0.299***	0.502***	0.604***	1.133***
	(0.149)	(0.0915)	(0.0653)	(0.0635)	(0.0985)	(0.294)
1974-1981	-0.0520	0.316***	0.320***	0.448***	0.491***	0.666**
	(0.180)	(0.111)	(0.0782)	(0.0765)	(0.115)	(0.330)
1982-1989	0.0965	0.373***	0.299***	0.424***	0.377***	0.792**
	(0.201)	(0.119)	(0.0824)	(0.0808)	(0.125)	(0.336)
1990-2001	-0.529***	-0.164	-0.217***	-0.291***	-0.799***	-0.624
	(0.163)	(0.102)	(0.0727)	(0.0737)	(0.133)	(0.396)
After2002	Ref	Ref	Ref	Ref	Ref	Ref
surface	-0.000678	-0.000109	0.000670*	0.00109***	0.00148**	0.00289*
	(0.000844)	(0.000584)	(0.000400)	(0.000394)	(0.000651)	(0.00160)
Climate1	0.285**	0.344***	0.392***	0.951***	1.653***	1.296***
	(0.116)	(0.0755)	(0.0521)	(0.0554)	(0.114)	(0.253)
Climate2	-0.0318	0.00907	0.142***	0.662***	1.251***	0.923***
	(0.108)	(0.0697)	(0.0494)	(0.0538)	(0.115)	(0.256)
Climate3	-0.212*	-0.369***	-0.166***	0.254***	0.639***	0.387
	(0.120)	(0.0774)	(0.0575)	(0.0637)	(0.133)	(0.295)
Climate4	Ref					
Indhousing	0.693***	0.357***	0.142***	0.221***	0.105*	-0.131
	(0.0782)	(0.0494)	(0.0349)	(0.0359)	(0.0592)	(0.133)
CollHeating	0.956***	1.115***	0.666***	0.0169	-0.520***	-0.648***
	(0.122)	(0.0779)	(0.0438)	(0.0419)	(0.0744)	(0.208)
Observations	16,704 Wald chi2(90)	=	3495.15	Prob > chi2	=	0.0000

Notes: Robust standard errors are reported between brackets. These variables are defined in Table B1.

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

These results are consistent with the rapport of the European Fuel Poverty and Energy Efficiency (2006) and Baxter (1998). In this line, as we can expect, income quintiles are significant for determining the probability to live in an energy efficiency housing units. Wealthier households live in energy efficient dwelling. Moreover, and one the most interesting result concerns occupancy status. When a housing unit is owner occupied, it significantly and positively affects the probability to live in energy efficient housing units. Similar results are obtained bu Davis (2010). In terms of public policy, to improve energy efficiency of bad energy label category, regulatory measures to landlords can be a solution. These results are in line with Hasset and Metcalf (1995) and with Burfurd *et al.* (2012).

With our results, we can have a profile of the households who live in the lowest energy label category. They are often tenant with a low income, they live in collective building constructed before 1989 with a collective heating system and located in the coldest climate zone. This last result show that in terms of purchasing power parity, it seems most interesting for a poor households to live in a warmest zone (i.e. where the energy bill will be lower) than in a coldest. By realizing estimations by subgroup (landlord and tenant), we obtain similar effects for income and building characteristics variables. There is a distinct effect between occupancy status and income. The split incentive problem is accentuated by the income effect. In line with Bird and Hernández (2012), it seems therefore necessary to focus public policy on landlord with mandatory minimum standard to support low-income renters.

4.2 The decision to invest in energy-savings renovation

The decision to invest in energy saving renovation is quite complicated in two ways. First, about 88% of households reported no expenditures on renovations, so estimating a linear regression induces computational complexities. We therefore applied a Tobit regression (Tobin, 1958; Amemiya, 1973; Heckman, 1979), with left-censored (at a zero level) dependent variables. Assuming households can under-consume energy goods (i.e., the homeowner is constrained by the expenditure function), the problem of censoring demands consideration. Second, interdependence is possible across the two expenditure types. The econometric model that can account for censoring and interdependence is a bivariate Tobit model (Amemiya, 1974; Maddala, 1983), which extends the single regression model with the censored normal dependant variable. We define y_{it} for each i (households) by:

$$y_{i1} = \alpha_{i1}' x_1 + u_{i1} \quad \text{if} \quad \alpha_{i1}' x_1 + u_{i1} > 0$$

$$y_{i1} = 0 \quad \text{if} \quad \alpha_{i1}' x_1 + u_{i1} \leq 0$$

(12)

$$y_{i2} = \alpha'_{i2}x_2 + u_{i2} \quad \text{if} \quad \alpha'_{i2}x_2 + u_{i2} > 0$$

$$y_{i2} = 0 \quad \text{if} \quad \alpha'_{i2}x_2 + u_{i2} \leq 0$$

where $i = 1, 2, ..., n,$ and y_{i1} and y_{i2} are the dependent variables, x_i is a vector of independent variables α_{i1} and α_{i2} are the corresponding parameter vectors of unknown coefficients, and the error terms (μ_{i1} and μ_{i2}) are independent of x_i. These disturbances are joint normally distributed with variances of σ^2_1 and σ^2_2 where $\mu_{i1}, \mu_{i2} : N(0,0, \sigma^2_1, \sigma^2_2, \rho_{12})$ and the covariance is given by $\sigma^2_{1,2} = \rho\sigma^2_1, \sigma^2_2$. Multivariate Tobit estimates of the two-equation Tobit models rely on maximum simulated likelihood. Before choosing the multivariate Tobit framework, we compared Tobit univariate results with those of the Tobit type II models. In the Tobit type II model, we distinguish the decision to invest and the amount of expenditures, assuming that these two decisions are independent. However, in a Tobit type II model, it is necessary to establish an exclusion variable to avoid any collinearity problems. Thus, the selection equation needs an exogenous variable, excluded from the outcome equation. Unfortunately, we find no such exclusion variable in the database. Thus, multivariate Tobit seems to offer the best model. Energy-efficient renovation expenditures are higher in the coldest zone. The coefficient of average surface area is positive and statistically significant, but the square of the average surface area is negative and statistically significant. Therefore, expenditures first increase with the surface area and then decline after a peak.

Results are available in Table 7. The coefficient of individual housing units is positive and statistically significant for all types of renovation. Renovation expenditures are higher for individual housing units, where households have a perfect knowledge of their energy consumption and can fully benefit from their investment, unlike in collective buildings with collective heating. These results are consistent with Plaut and Plaut's (2010). In terms of public policies, we recall that it seems really important to focus on collective housing with collective heating.

The coefficient for the construction period (before 1974) is positive and significant for energy efficiency works. Households spend more when they live in the oldest and least insulated housing units, consistent with Nair *et al.*'s (2010). These results are also consistent with our theoretical findings. The lower the energy quality of the dwelling, the higher the investment. With regard to reparation works expenditures are highest in newer housing units. Repair works include expansion, finishing, and embellishment, which may explain this result. In these housing units, energy-efficient improvement expenditures are not necessary, because their construction already had to meet thermal regulations and labels. For example, the 2005 introduction of the "low energy buildings" label applied to households with energy consumption to 50 kWh $_{pe}$ /m^2 /year.

Table 7: Results of the bivariate Tobit model

Variables	Energy Efficiency Expenditures (EE)	Reparation Expenditures (RE)
Socioeconomic characteristics of households		
Quint1	-0.673(0.888)	-1.867***(0.506)
Quint2	-1.386 (0.899)	-2.722***(0.508)
Quint3	-0.450(0.868)	-0.367(0.479)
Quint4	-0.786(0.874)	-0.733(0.480)
Quint5	Ref	Ref
Homeowners	1.599***(0.576)	0.500(0.323)
Characteristics of buildings		
Bef1974	2.033*(1.130)	-2.013***(0.584)
1974-1981	1.347 (1.323)	-1.193* (0.704)
1982-1989	1.268 (1.394)	-2.266*** (0.745)
1990-2001	0.108 (1.277)	-2.359*** (0.670)
After2002	Ref	Ref
Surface	0.170***(0.0278)	0.0840*** (0.0141)
surface2	-0.000295***(0.000105)	-0.000161*** (5.58e-05)
Climate1	2.485***(0.903)	0.121 (0.496)
Climate2	1.801**(0.874)	-0.143 (0.478)
Climate3	2.189**(1.001)	1.071** (0.543)
Climate4	Ref	Ref
Indhousing	2.231***(0.593)	0.664** (0.328)
NB	0.778***(0.216)	0.903*** (0.129)
NB2	-0.0368**(0.0170)	-0.0471*** (0.0105)
CollHeating	-0.151 (0.735)	-0.0164 (0.394)
LES1	1.226*** (0.153)	
rho	0.4213*** (0.0218)	

Likelihood ratio test of $\rho_{EE,RE}= 0$: chi2(1) = 327.979   Prob > chi2 = 0.0000

Observations 16,704

Notes: Robust standard errors are reported between brackets. These variables are defined in Table B1. The null hypothesis B = 0 serves to test the explanatory power of the model. In the restricted model, all coefficients are set to 0 except the intercept terms and covariance matrix elements.
*Significant at 10%.
**Significant at 5%.
***Significant at 1%.

Finally, the number of renovation works had a significant, positive effect, whatever their type. But the square of the number of renovations was negative and statically significant, especially for reparation works. Thus, expenditures first increase with the number of renovations, then decline after a peak, which may reflect two explanations. First, the marginal cost of renovation decreases with the amount of renovations undertaken. Second, households prefer to make several, less costly renovations.

In relation to the theoretical results, particular attention is necessary for the energy savings variable. The estimated energy savings are positive and statistically significant (i.e., households with high energy expenditures before renovation and low expected expenditures after renovation were more willing to invest in energy-efficient renovations), in line with Grösche and Vance (2009), Banfi *et al.* (2006), and Nair *et al.* (2010).

A surprising result concerns income quintiles. Income quintiles are not significant for determining energy-efficient expenditures; income quintiles 1 and 2 appeared negatively and statistically significant at the 1% level only for repair works and not for energy efficiency works. Although this result differed slightly from the theoretical predictions, it should not be surprising, in that high income households already live in the best insulated dwelling, so they can only perform repair works. Expenditures indicate gross amounts, including public aid granted to households to encourage energy-efficient renovations, which might explain the lack of expenditure differences across income quintiles for energy-efficient renovations; this is not the case for repair works. Moreover, to test this assumption, even if only 8% of households benefit a public aid, a regression for only households who do not benefit from a public policy, the income quintile (quintile 2) become negatively and statistically significant at 5% level (table C2 in appendix) . If we exclude households who benefit from a public policy, our results are in line with the theoretical part. High income households are more likely to improve their homes (Montgomery, 1992). We also compare our results with only income quintile as explanatory variables (see Table C3 in appendix). Similar results are obtained.

When a housing unit is owner occupied, it significantly and positively affects energy-efficient expenditures and reparation expenditures. Instead, the results confirm the significant difference in renovation expenditures between households in rented versus owner-occupied accommodations. These results are consistent with those obtained by Arnott *et al.* (1983), Rehdanz (2007) and Davis (2010). One explanation for why tenants might not invest is that their expected length of occupancy is not sufficient to make their energy-saving investment profitable. This result is line with our theoretical predictions. When people are more concerned about the future, they invest more. Moreover, tenants are particular characteristics. They have low incomes and live in the most poorly insulated dwelling. They spent a great share of the income to energy expenditures. As we said previously, policy interventions also appear required (Burfurd *et al.*, 2012). In terms of public policy, to improve energy

efficiency of bad energy label category, minimum standard regulatory measures to landlords can be a solution. Introducing an obligation to retrofit tenant occupied dwellings has been already discussed during the *Grenelle de l'environnement* (Pelletier, 2008, p.86). For example, for every change in dwelling occupancy, homeowners whose dwelling is below a certain energy label (or energy consumption) threshold must upgrade it. Girauldet et al. (2011) assess this measure and obtain that this measure is effective particularly in the landlord-tenant dilemma. However, taxing tenant-occupied dwelling who live in the last energy label categories (with a carbon tax) do not seem appropriate.

According to the results, the tenants suffered a double penalty. They live in energy-inefficient housing units and are unable to renovate. To encourage energy efficiency, we must also consider measures to fight poverty. Indeed, for low-income renters, the problem of energy efficiency is mainly a question of fuel poverty.

5. Conclusion

The residential sector offers considerable potential to reduce energy uses and GHG emissions, particularly with energy-efficient renovations. This study provides two major outputs. First, empirical studies focus on the split incentives issue and most specifically through the question of fuel poverty are very rare and a contribution is due to the comprehension of the phenomenon. Second, the decision to invest in energy efficient system is studied, theoretically and empirically, taking into account energy cost and the amount of potential energy-savings due to renovation according to the occupancy status. As a main result in a conceptual part, we obtained that at equilibrium, neither of the agent invests. Thus, in terms of energy efficiency, in a case where the dwelling is tenant occupied, no-one is willing to invest to improve energy efficiency. Moreover, tenants are responsive to potential energy savings and intial energy cost. This result suggests that energy prices are clearly key variables in the model. These results are confirmed in the empirical part. We also showed that tenants are double penalized: they have to pay a large amount of energy expenditures because they live in less energy efficient housing unit, and they are poorer than homeowners. Thus, they are not able to invest in energy saving systems. We conclude that the issue of split incentives in France is closely linked to a fuel poverty problem. In terms of public policy, government should not only address the problem of split incentives but also focus on fuel poverty issues. One solution seems to promote mandatory measure such as minimum standard especially for low-income renters.

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Appendix

A. Conceptual Framework

A.1 A list of variables used in the conceptual framework

Table 1: List of variables used in the conceptual framework

Variables	Description
X_t	Housing quality in time t
I_t^L	Landlord's investment in time t
I_t^T	Tenant's investment in time t
δ	Capital depreciation factor
C_t^L	Landlord's goods consumption
C_t^{Te}	Tenant's energy goods consumption
C_t^{Tne}	Tenant's non energy goods consumption
ζ	Sensitivity of energy cost to housing quality
f	Maximum amount of energy expenditures when housing quality is equal to 0
β	Utility discount factor
$P_t(X_t)$	Energy cost (depending on housing quality)
L_t	Rent in time t
r	Income return
M_t	Maintenance costs

A.2 The landlord's program – first order conditions

$$\frac{\partial U^L}{\partial C_0 P} = \frac{(-r-1)\beta}{-(I_0^T + I_0^L + X(1-\delta))^2 + \dfrac{I_0^T + I_0^L + X(1-\delta)}{r+1} + L_1 + (r+1)\left(-X^2 - C_0^L - I_0^L + L_0 + R_0^L\right)} + \frac{1}{C_0^L} = 0$$

$$\frac{\partial U^L}{\partial I_0^L} = \frac{\beta\left(-r - 2(I_0^T + I_0^L + X(1-\delta)) + \dfrac{1}{r+1} - 1\right)}{-(I_0^T + I_0^L + X(1-\delta))^2 + \dfrac{I_0^T + I_0^L + X(1-\delta)}{r+1} + L_1 + (r+1)\left(-X^2 - C_0^L - I_0^L + L_0 + R_0^L\right)} = 0$$

A.3 The tenant's program - first order conditions

$$\frac{\partial U^T}{\partial C_1^e} = \frac{\beta(-L_1 - C_1^{Te}(f - (I_0^T + I_0^L + X(1-\delta))\xi) + C_1^{Te}((I_0^T + I_0^L + X(1-\delta))\xi - f) + (r+1)(-C_0^{Tne} - I_0^T - L_0 + R_0^T - C_0^{Te}(f - X\xi)))}{C_1^{Te}(-L_1 - C_1^{Te}(f - (I_0^T + I_0^L + X(1-\delta))\xi) + (r+1)(-C_0^{Tne} - I_0^T - L_0 + R_0^T - C_0^{Te}(f - X\xi)))} = 0$$

$$\frac{\partial U^T}{C_0^e} = \frac{(r+1)\beta(X\xi - f)}{-L_1 - C_1^{Te}(f - (I_0^T + I_0^L + X(1-\delta))\xi) + (r+1)(-C_0^{Tne} - I_0^T - L_0 + R_0^T - C_0^{Te}(f - X\xi))} + \frac{1}{C_0^{Te}} = 0$$

$$\frac{\partial U^T}{C_0^{ne}} = \frac{(-r-1)\beta}{-L_1 - C_1^{Te}(f - (I_0^T + I_0^L + X(1-\delta))\xi) + (r+1)(-C_0^{Tne} - I_0^T - L_0 + R_0^T - C_0^{Te}(f - X\xi))} + \frac{1}{C_0^{Tne}} = 0$$

$$\frac{\partial U^T}{I_0^L} = \frac{\beta(-r + C_1^{Te}\xi - 1)}{-L_1 - C_1^{Te}(f - (I_0^T + I_0^L + X(1-\delta))\xi) + (r+1)(-C_0^{Tne} - I_0^T - L_0 + R_0^T - C_0^{Te}(f - X\xi))} = 0$$

A.4 Calibration

The discount rate β is set to 0.99. The depreciation rate δ and the rate of return r are set to 0.05.

Now, French data are used to calibrate the model. The main difficulty lies in measuring housing quality from an economic point of view. We therefore refer to the hedonic approach[4]. We use average housing prices to appraise dwelling quality. Specifically, it means that an increase in quality (for example, better insulation) increases housing prices. In 2006, the average price per square meter is nearly 2012 euros (see INSEE, 2010).

We also need domestic energy cost depending on the energy label (see figure 3). Energy cost is on average 0.0967 euros per kWh and therefore 18.85 euros by square meter for a dwelling with the this average consumption. Renovations (such as wall and roof insulation or improvement of heating system) that improve sufficiently the energy efficiency to reach a higher label cost 12 000 euros i.e 145 euros by square meter in means. In the case in which the dwelling is renovated, the energy cost decreases to 0.0899 euros. Using equation (6), we compute ξ and we get $\xi = 0.05$. f is equal to 55 euros per square meter and by year. (Using the 2006 enquête Logement database and values for energy

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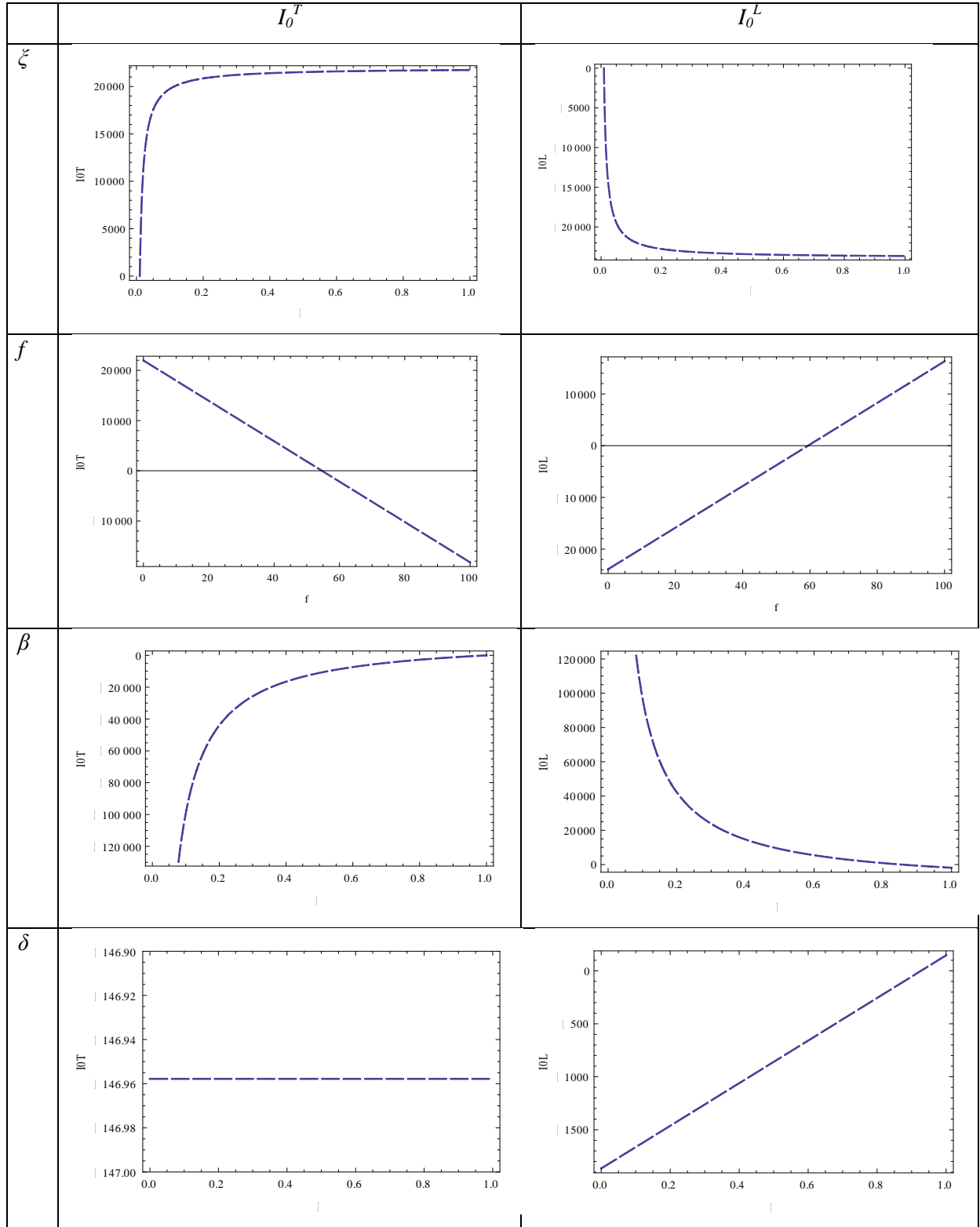[4]A detailed methodology is described in Gouriéroux (2009).

cost when theoretical energy consumption is greater than 650 kWh$_{ef}$ /m²/year) . Results are summarized in Table 1.

Table 1: Calculation of energy price sensitivity to investment

Housing quality $\overline{X}$	Energy Consumption in kWh$_{ef}$ /m^2 /year	Total energy cost in euros	ξ
2012	195	18.85	
2145	150	17.52	0.01

However, income and rent values are necessary to compute the equilibriums.. We therefore consider that the length of one period is one year. The average rent is 4.65 euros per square meter (419 euros for a dwelling in average). Rent in period 1 is computed taking into account the index of rent reevaluation. So, we have L_0=55.86 ; L_1=57.53 ; R_0^T is the disposable income of the tenant. Using data from INSEE (2009), we have R_0^T=22075.

A.5 Sensitivity analysis

	I_0^T	I_0^L
ξ		
f		
β		
δ		

	$I_0{}^T$	$I_0{}^L$
L_0	*(plot: I0T vs L0, decreasing line from 0 to −100000; x-axis 0–100000)*	*(plot: I0L vs L0, increasing line from 0 to 100000; x-axis 0–100000)*
L_1	*(plot: I0T vs L1, decreasing line from 0 to −1000; x-axis 0–1000)*	*(plot: I0L vs L1, increasing line; y-axis 0–1500; x-axis 0–1000)*
r	*(plot: I0T vs r, curve from 150 to 125; x-axis 0.0–1.0)*	*(plot: I0L vs r, curve from 1760 to 1790; x-axis 0.0–1.0)*
$R_0{}^T$	*(plot: I0T vs R0T, increasing line from 0 to 1.×10⁶; x-axis 0–1.×10⁶)*	*(plot: R0L vs R0T, decreasing line from 0 to −1.×10⁶; x-axis 0–1.×10⁶)*
X	*(plot: I0T vs X, flat line at 146.96; y-axis 146.90–147.00; x-axis 0–100)*	*(plot: I0L vs X, decreasing line; y-axis 0 to −8000; x-axis 0–10000)*

Figure 3: dwelling energy label in kWh $_{ef}$ /m ^{2} /year
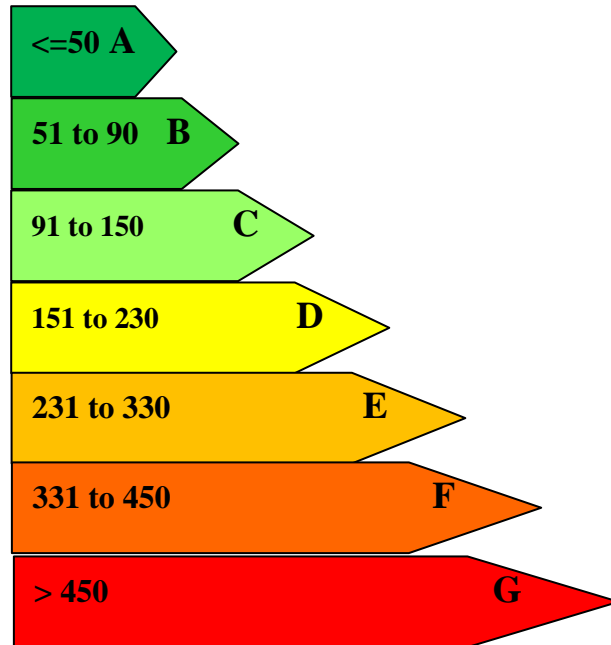
Table B1: List of variables used in the empirical part:

Variables	Name	Definitions	Units
Dependent variables			
Energy Label	Label	7 categories - A very efficient dwelling is classified in 1 while a very inefficient dwelling classified in 7	1-7
Expenditures in EE	LexpEE	The amount of renovation expenditures for energy efficiency works	in and logarithm
Expenditures in RE	LexpRE	The amount of renovation expenditures for reparation works.	in and logarithm
Independent variables			
Socioeconomic characteristics of households			
Income quintile	Quint	Binary variable for each income quintile (5 quintiles)	0/1
Occupancy status	Homeowners	Binary variable introduced for homeowners	0/1
Characteristics of buildings			
Periods of construction		Binary variables are introduced for each period of constructions	0/1
Before 1974	Bef1974	Dwelling constructed before 1974	0/1
1974–1981	1974-1981	Dwelling constructed between 1974 and 1981	0/1
1982–1989	1982-1989	Dwelling constructed between 1982 and 1989	0/1
1990–2001	1990-2001	Dwelling constructed between 1990 and 2001	0/1
After 2002	Before 2002 - Ref	Dwelling constructed after 2002	0/1
Surface area	Surface	Average surface area per dwelling in 2006	in m^2
Square of surface area	Surface2	Square of average surface area per dwelling in 2006	in m^2
Climate zone		Binary variable for each climate zone (4 zones)	0/1
Climate zone 1	Climate1	Households in climate zone 1	0/1
Climate zone 2	Climate2	Households in climate zone 2	0/1
Climate zone 3	Climate3	Households in climate zone 3	0/1
Climate zone 4	Climate4 -ref	Households in climate zone 4	0/1
Individual housing unit	Indhousing	Households in an individual housing unit	0/1
Number of renovation works	NB	Number of energy-efficiency renovation works in 2006	continuous
	NB2	Square of number of energy-efficiency renovation works in 2006	continuous
Collective heating system	CollHeating	Dwellings with a collective heating system	0/1
Energy savings and cost–benefit variables			
Log Energy-savings 1	LEnergySavings1	Theoretical energy expenditures before renovation minus theoretical energy expenditures after renovation (method 1)	In euros and in logarithm

C. Results of estimations

Table C1: Results of ordered Logit model (Baseoutcome(label=7))

Name	Coefficients	Standard error
Socioeconomic characteristics of households		
Quint1	1.412***	(0.0480)
Quint2	0.519***	(0.0445)
Quint3	0.233***	(0.0432)
Quint4	0.0322	(0.0441)
Quint5	ref	
Homeowners	-0.562***	(0.0291)
Characteristics of buildings		
Bef1974	0.374***	(0.0501)
1974-1981	0.364***	(0.0616)
1982-1989	0.336***	(0.0642)
1990-2001	-0.238***	(0.0555)
After2002	Ref	
Surface	0.000817**	(0.000343)
Climate1	0.0662***	(0.0003)
Climate2	0.350***	(0.0376)
Climate3	-0.0214	(0.0452)
Climate4	Ref	
lndhousing	0.209***	(0.0295)
Collheating	0.306***	(0.0291)
Cut 1	-2.234***	(0.0789)
Cut 2	-1.154***	(0.0750)
Cut 3	0.275***	(0.0739)
Cut 4	1.723***	(0.0743)
Cut 5	3.498***	(0.0780)
Cut 6	5.341***	(0.0961)

Wald chi2(15) = 2449.59

Prob > chi2 = 0.0000

N=16704

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

Table C2: results of the multivariate tobit for households who do not benefit of the public policy

Variables	Energy Efficiency Expenditures (EE)	Reparation Expenditures (RE)
Socioeconomic characteristics of households		
Quint1	-0.848 (0.908)	-2.173*** (0.523)
Quint2	-1.737* (0.927)	-2.981*** (0.525)
Quint3	-0.567 (0.886)	-0.538 (0.493)
Quint4	-0.882 (0.891)	-0.670 (0.491)
Quint5	Ref	
Homeowners	1.476** (0.590)	0.423 (0.333)
Characteristics of buildings		
Bef1974	2.328** (1.156)	-2.118*** (0.605)
1974-1981	1.399 (1.358)	-1.289* (0.728)
1982-1989	1.616 (1.419)	-2.198*** (0.769)
1990-2001	0.408 (1.307)	-2.538*** (0.693)
After2002	Ref	
surface	0.169*** (0.0293)	0.0797*** (0.0135)
surface2	-0.000294***(0.000112)	-0.000148***(5.33e-05)
Climate1	2.396** (0.932)	0.278 (0.512)
Climate2	1.935** (0.900)	-0.0703 (0.494)
Climate3	2.544** (1.025)	1.158** (0.561)
Climate4	Ref	
Indhousing	2.059*** (0.609)	0.410 (0.338)
NB	0.827*** (0.233)	0.978*** (0.136)
NB2	-0.0441** (0.0196)	-0.0526*** (0.0114)
CollHeating	-0.00935 (0.752)	0.0561 (0.405)
LES1	1.197*** (0.158)	
$\rho_{EE,RE}$	0.4115***(0.0228)	

Likelihood ratio test of rho12 = 0:

chi2(1) = 287.44 Prob > chi2 = 0.0000

Observations 15731

Notes: Robust standard errors are reported between brackets. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table C3: Results with only income quintile as explanatory variables

Variables	Energy Efficiency Expenditures	Reparation Expenditures
Socioeconomic characteristics of households		
Quint1	-1.153	-2.071***
	(0.894)	(0.504)
Quint2	-1,326	-2.863***
	-0,997	(0.509)
Quint3	-0.571	-0.424
	(0.884)	(0.482)
Quint4	-1.042	-0.810*
	(0.893)	(0.484)
Quint5	Ref	Ref

Likelihood ratio test of rho12 = 0:

chi2(1) = 380.778   Prob > chi2 = 0.0000

Observations 16704

Notes: Robust standard errors are reported between brackets. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

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