Energy Efficiency Investments in a Context of Split Incentives
Evidence from French Households

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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) analyze conceptually and empirically energy-saving and reparation expenditures according to occupancy status and (ii) 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 underinvestment in energy efficiency system is linked to a fuel poverty issue but also to occupancy status. In terms of public policy, mandatory measure such as minimum standard seems appropriated.

Keywords: Energy Efficiency, Split Incentives, Fuel Poverty, Public Policy
JEL codes: Q41, Q48, D12, C01

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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 was 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. 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 theoretical and empirical evidence for the extent to which split incentives between landlords and tenant may lead to underinvestment. Moreover, we focus our attention on the link between occupancy status and housing investments. Split incentives are a huge problem in developed country especially concerning energy efficiency. On average, homeowners spend 6860 euros energy efficiency works against 2,348 euros for tenants. In addition, 62% of homeowners who report cold problems in their housing units replaced their equipment against only 32% of tenants. In this article, we also want to see if underinvestment in energy efficiency system is due to low income or/and to occupancy status. Renters are often poorer than homeowners and often spend the highest share of their income on energy cost: it is a "fuel poverty issue"[2]. 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. 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). Moreover, 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. In such In France, 9.51% of households in a situation of fuel poverty are tenants against 6.15% that are landlords. Considering a repartition according to occupancy status in different energy label (see Figure 1 in appendix A), tenants live in the most poorly insulated dwelling contrary to landlords (see Table A-1 in appendix A). Moreover, studying this repartition according to income (see Table A-2 in appendix A), wealthier people live in the most efficient housing. Given that renters are poorer than the homeowners, they live in the most poorly insulated dwelling. So there is a different distribution according to occupancy status. Low income households are less able to finance energy efficiency measures. 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). So, it seems interesting to study the decision to invest in energy system according to occupancy status and income. We want to see if the underinvestment in energy system is only due to poverty issue or if occupancy status can explain a part of the problem. Consequently, according to the results, public policy recommendations should not be the same.

Thus, in this paper, our main objectives are to (i) to analyze conceptually and empirically expenditures in energy-saving and in reparation according to occupancy status and different type of investments (energy efficiency and reparation), (ii) to show that lack of energy efficiency investment is due to low income but also to occupancy status and (iii) to provide some policy recommendations. In the conceptual part, using a framework with split incentives, we obtain a Cournot Nash equilibrium where neither agent invests. Energy cost and energy savings due to renovation are key variables as well as thermal building characteristics. In the empirical part, using the *2006 Enquête Logement* database, we find

[2] Fuel poverty is a phenomenon in which low-income households spent a huge share of their income to energy expenditures. Today, fuel 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).

evidence that tenants live in energy-inefficient dwelling and are particularly vulnerable to energy cost. We also obtain 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 energy-efficiency underinvestment is closely linked to income (or fuel poverty) issues but also to occupancy status. In terms of public policy, government should not only address low income households but also focus on the problem of split incentives. Mandatory measure such as minimum standard seems appropriated

The remainder of the paper as follows. In section 2, the literature is presented. In section 3, the decision to invest in reparation and in energy efficiency according to income and occupancy status is analyzed conceptually. In section 4, data and variables are described. Section 5 introduces the econometrics models and results are presented. Section 5 conclues.

2. Litterature Review

Occupancy status or housing tenure has been treated in the literature in many fields. Occupancy status is a factor in many decisions taken by households. For instance, some authors examine the effects of housing occupancy on individuals' job and unemployment durations (Battu et al., 2008) or have established that tenure choice and mobility decisions are correlated (Ioannides, 1987). Home ownership is seen as one of the crowning achievements in a person's life cycle. Moreover, home ownership (and the capital gains it generates) is the primary way households generate wealth. Many governments encourage ownership and try to facilitate it by public policies. Occupancy status is also a way to understand household's investment decisions. Tenants and landlords have specific determinants (income, age, capital access) that explain that their investment decisions may be different. Thus, in terms of energy efficiency, it seems prominent to explore the link between occupancy status and energy efficiency investments. Incentives for agents are different when the housing unit is occupied by a tenant instead of a homeowner. That why the split incentives issue is particularly relevant in terms of energy efficiency.

The magnitude of the split incentives problem and energy efficiency issues 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. 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.

3. 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 in energy efficiency or in reparation works. They only consume in the second period. The agents are in the common the value of the housing units. This value is decomposing between a "green value" X_t (relative to energy efficiency attributes of the housing units) and housing capital value K_t (all the other housing attributes). The "green value" function is the same for both agents. This function represents the energy efficiency of the dwelling. In period 0, energy efficiency in the housing unit is a function of the energy efficiency investment level of the landlord in the dwelling IE_0^L, the energy efficiency investment level of the tenant IE_0^T, the energy efficiency when the tenant moves into the dwelling $\overline{X}$ and a capital depreciation factor

δ factor with $0<\delta<1$. Thus, energy efficiency depends on the level of investment in energy-saving systems. The higher the level of investment in energy-saving systems, the higher the energy efficiency of the housing units.

So, we have:

$$X_1 = IE_0^L + IE_0^T + (1-\delta)X_0 \tag{1}$$

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

The capital value of the dwelling in period 0 is a function of the reparation and maintenance investment levels of the landlord in the dwelling IR_0^L, the reparation and maintenance investment level of the tenant IR_0^T, the value of the housing capital when the tenant moves into the dwelling $\overline{K}$ and a capital depreciation δ factor with $0<\delta<1$.

$$K_1 = IR_0^L + IR_0^T + (1-\delta)K_0 \tag{3}$$

$$K_0 = \overline{K} \tag{4}$$

The rent (L_t) is also common to both agents. In the model, it is impossible to consider to require a portion of energy saving in the rent if an agent invests according to the French case. We have a two-period planning problem. Having optimized the both periods, we will get two reaction functions. The landlord (tenant) should decide about energy efficiency investment (or reparation/maintenance investment) taking into account the energy efficiency investment (or reparation/maintenance investment) level of the tenant (landlord). These reaction functions are the best response of each agent:

$$\begin{array}{lcl} IE_0^L = f(IE_0^T) & \text{and} & IE_0^T = f(IE_0^L) \\ IR_0^L = f(IR_0^T) & \text{and} & IR_0^T = f(IR_0^L) \end{array} \tag{5}$$

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

3.1 The landlord's problem

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

$$U(C_t^L) = Log(C_t^L) \tag{6}$$

This is a logarithmic utility function. The problem of the landlord is to maximize his utility function (6) subject to (1) , (2), (3), (4) and:

$$R_1^L + L_1 + \frac{X_1 + K_1}{1+r} = C_1^L + M_1 \tag{7}$$

$$R_1^L = (R_0^L - C_0^L - IE_0^L - IR_0^L + L_0 - M_0)(1+r) \tag{8}$$

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:

$$M_1 = -X_1^2 - K_1^2 \quad and \quad M_0 = -X_0^2 - K_0^2 \tag{9}$$

We can write the problem as follows:

$$\max_{IE_0^L, IR_0^L, C_0^L} U = Log(C_0^L) + \beta Log(C_1^L) \tag{10}$$

Having optimized period 0 and period 1 we obtain the reaction function.

So we obtain:

$$IE_0^L = -IE_0^T - \frac{r(2+r)}{2(1+r)} + \overline{X}(-1+\delta) \tag{11}$$

$$IR_0^L = -\frac{2IR_0^T(1+r) + r(2+r) - 2\overline{K}(1+r)(-1+\delta)}{2(1+r)} \tag{12}$$

We obtain that IE_0^L is a decreasing function of IE_0^T and IR_0^L is a decreasing function of IR_0^T . Landlord's energy efficiency investment depends on the intial dwelling's green value, the depreciation rate and the income return. The higher is the initial "green value" (or energy efficiency), the lower is the landlord's investment in energy-saving systems. Landlord's reparation/maintenance investment depends on the intial housing capital value, the depreciation rate and the income return. In other words, landlord's energy efficiency investment is a function of green capital and consequently depends on dwelling energy efficiency characteristics such as double glazing, period of constructions or climate area. It also depends on income return.

3.2 The tenant's problem

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

$$U(C_t^{Tne}, C_t^{Te}) = Log(C_t^{Te}) + C_t^{Tne} \tag{13}$$

Non energy goods C_t^{Tne} serve as the numeraire in this model. The shape of the utility function implies that the value is measured in terms of non energy good C_t^{Tne}, that is to say in "monetary terms". There is an exact correspondence between the utility and its monetary value. Thus, at first, all income is spent in energy goods C_t^{Te}. After a point, the expenditure on C_t^{Te} is kept constant, and all additionnal income is spent on C_t^{Tne}. We can think of good C_t^{Te} as an exemplar of necessity: it has an absolute first claim on income, but once its satisfied, all extra income can go toward other goods (see Dixit, 1992).

The problem of the tenant is to maximize his utility function (13) subject to (1), (2),(3), (4) and:

$$R_1^T = C_1^{Te} p_1(X_1) + C_1^{Tne} + L_1 + M_1 \quad (14)$$

$$R_1^T = (R_0^T - C_0^{Tne} - p_0(X_0)C_0^{Te} - IE_0^T - IR_0^T - L_0 - M_0 - IE_0^{T^2} - IR_0^{T^2})(1+r) \quad (15)$$

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. The tenant also can deal with adjustment costs IE_0^{T2} and IR_0^{T2}. These adjustment costs increase with the volume of investment and are due to hidden costs associated with new equipment (for instance noise, power cut...). $p_0(X_0)$ and $p_1(X_1)$ represent the energy cost unit in period 0 and in period 1. They depend on the green value of the building. 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:

$$p_t(X_t) = -\xi X_t + f \quad (16)$$

We can write the tenant problem as:

$$\max_{C_0^{Tne}, C_0^{Te}, C_1^{Te}, IE_0^T, IR_0^T,} U = Log(C_0^{Te}) + C_0^{Tne} + \beta(Log(C_1^{Te}) + C_1^{Tne}) \quad (17)$$

Having optimized period 0 and period 1, we obtain four functions. Solving the system, we obtain four equations.

$$IE_0^T = -IE_0^L + \overline{X}(-1+\delta) + \frac{f}{\xi} + \frac{2\xi}{\theta + \sqrt{\theta^2 - 8(2+r)\xi^2}} \quad (18)$$

With $\theta = -2f(2+r) + (1+r)(-1+2I0EP - 2X(-1+\delta))\xi$ (19)

And

$$IR_0^T = \frac{-1-2IR_0^L-2\overline{K}(1-\delta)-r}{4+2r} \tag{20}$$

As a result, the tenant's investment is a decreasing function of the landlord's investment for both types of investment. For energy efficiency investment, the intial green value of the building is determinant of the decision to invest. Rearranging the formula, we obtaint that higher the intial green value of the building, lower the investment in energy saving systems. Thus, thermal building characteristics can explain the decision to invest. Both agents do not invest in energy-saving systems when thermal building characteristics are efficient.

3.3 Equilibrium

Using the equations of reaction functions,we compute equilibrium.

$$IR_0^L = \frac{1}{2}(-1-r+\frac{1}{(1+r)^2}+\frac{1}{1+r}+2K(\delta-1)) \tag{21}$$

$$IR_0^T = -\frac{1}{2(1+r)^2} \tag{22}$$

$$IE_0^L = \frac{-4f(1+r)+2\xi+\varphi}{2\varphi(1+r)^2} \tag{23}$$

$$IE_0^T = \frac{\varpi}{4(1+r)}-\frac{\zeta}{\varphi} \tag{24}$$

With

$$\phi = 2\text{ f }(1 + \text{r}) + \text{r }(2 + \text{r})\ \zeta \tag{25}$$

$$\varpi = 2(1-2X-r(2+r)(1+r+2X)+2(1+r)^2 X\ \ \delta \tag{26}$$

It clearly appears that landlord's investment in reparation and maintenance are a decreasing function of initial capital value. Higher the value of capital, lower the value of investment. To trigger investment in the case of reparation/maintenance works, the value of initial capital must be very low. Tenant's investment in reparation and maintenance is always negative, tenants never invest in reparation works. An interesting result is that energy efficient investment depends on energy efficiency parameters (f and ξ). In order to better understand the effect of each parameter, numerical results are provided in the next section (section 3.4)

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3..4 Numerical solutions with split incentives

Numerous studies show a link between environmental performance and financial value of dwellings (Miller et al., 2008; Furst and Mcallister, 2008, 2009, 2010). In France, the "green value is evaluated between 5% and 22% of the value of the bulding (Ademe, 2011). So, we use the following values for parameters: $\beta=0.99$; $\delta=0.05$; $r=0.05$; $\bar{X}=120.72$, $\bar{K}=1891.28$; $\xi=0.0475$; $f=24.63$. The calibration is precisely detailed in appendix B.2.

Landlord investment (in reparation and in energy efficiency) is a decreasing function of tenant investment (in reparation and in energy efficiency) and tenant investment (in reparation and in energy efficiency) also is decreasing function of landlord investment (in reparation and in energy efficiency). This result suggests that if an agent does not invest, the second will not invest too. The equilibrium is computed using the reaction functions for both types of investment (Figure 2 and 3). 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. We can compare these results with a situation where the dwelling is owner-occupied. In this case, the owner invests in energy efficiency system.

Figure 1: Equilibrium for reparation/maintenance investments

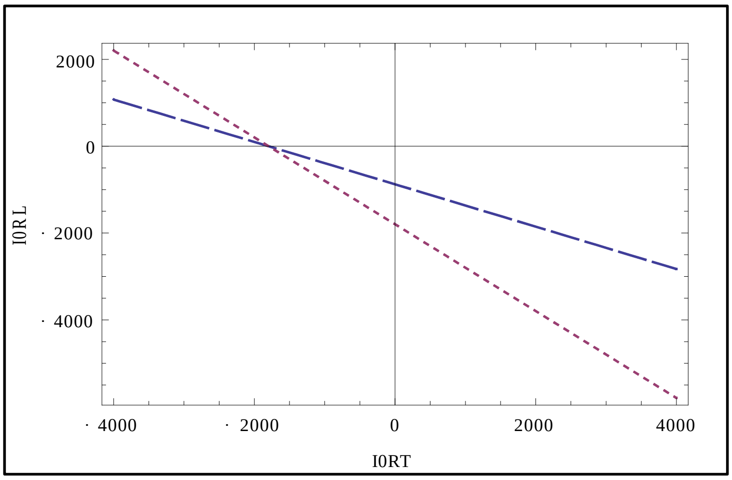
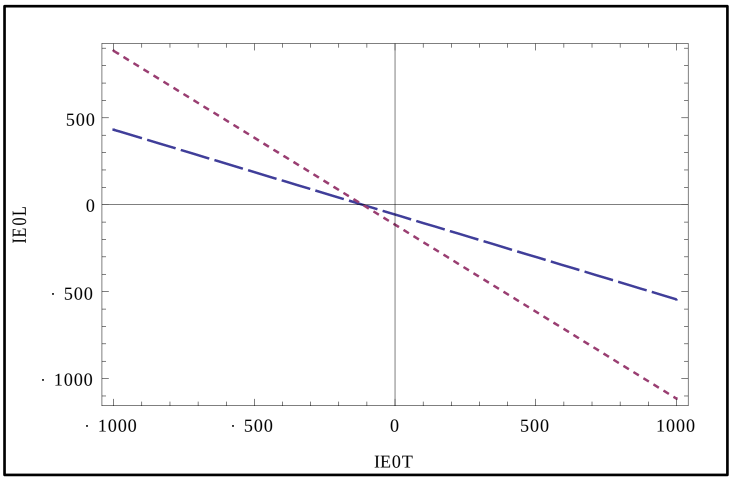


Figure 2: Equilibrium for energy efficiency investments



We lead some sensitivity analysis using the analytical solutions. 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. 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 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

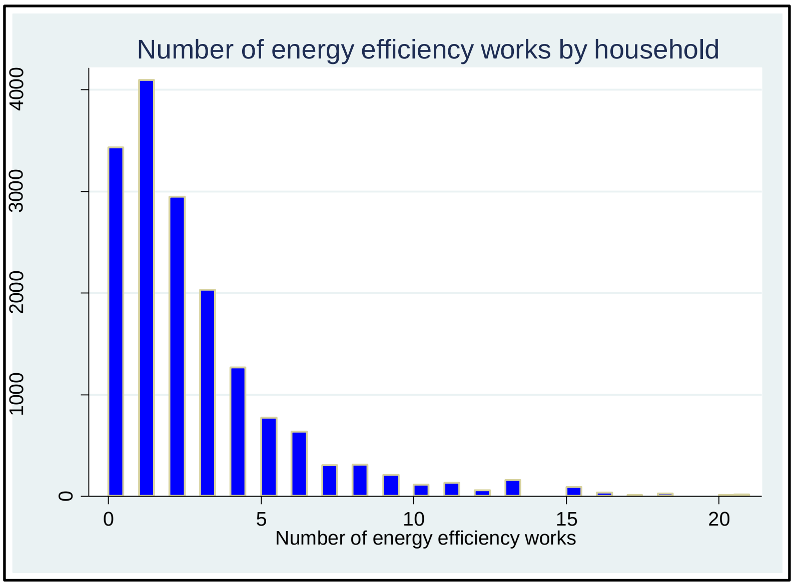
In this study, we use the *2006 Enquête Logement*, a disaggregate household-level survey data set by INSEE. We also use the "*travaux*" database. Merging these two surveys, information is available on 22, 228 households. In this study, a distinction is made between energy efficient works (EE) and repairs 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 (the method is described in Appendix C-1). The final sample still contains 16509 households.

3.2 Variables and descriptive statics

3.2.1 Energy-saving renovations

Moreover, in 2006, only 4.10% of households undertake energy-saving renovations. They spent 6143 Euros on average. 75% of households who decide to make energy-savings investments are homeowners. In average, households who undertake renovation works realize 3.11 numbers of works. Concerning energy efficiency works, the average is 2.97. The means of number of works is 2.65and the variance is 9.2. However, a large share of households did not undertake works in 2006 and a large share of households undertakes only 1 kind of works (see Figure 3). We have a high proportion of low values.

Figure 3: Number of energy efficiency works



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

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).

Thus, as socio-economic characteristics, we also introduce the income quintile. 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 and to explain the number of renovation works in energy efficiency. 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 by 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).

According to the conceptual part, 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. 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. A list of variables used in the empirical part is available in appendix C-3.

4. Empirical analysis of the decision to invest in energy efficiency system according to occupancy status

To analyze the decision to invest in energy system, we proceed in two steps. First, we study the decision to invest in energy efficiency and to reparation works using a bivariate Tobit setting. Second, we focus on energy efficiency works and we study the number of reparation works using a zero inflated negative binomial Poisson regression.

4.1 The decision to invest in energy-savings and in reparation works

To analyze the decision to invest in energy system, we proceed in two steps. First, we study the

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:

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

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

(22)

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

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

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 μ_{i1}, μ_{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. Results are available in Table 1. According to the results obtained in the conceptual part, thermal characteristics of the building are determinants of the decision to invest in energy efficiency system (contrary to results obtain for reparation works).

Energy-efficient renovation expenditures are higher in the coldest zone. 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. 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 especially with collective heating. 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. 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 1: Results of the bivariate Tobit model

	IE		IR	
	Coefficient	***Standard Error***	***Coefficient***	***Standard Error***
Socioeconomic characteristics of households				
Quint1	2.208	(1.36)	0.990	(1.17)
Quint2	-0.449	(-0.26)	-0.0366	(-0.04)
Quint3	-0.161	(-0.09)	1.751*	(2.02)
Quint4	-0.540	(-0.30)	1.107	(1.24)
Homeowners	5.239***	(3.41)	3.558***	(4.49)
Quint1*Homeowners	-3.949*	(-1.97)	-4.324***	(-3.92)
Quint2*Homeowners	-0.270	(-0.13)	-3.912***	(-3.53)
Quint4*Homeowners	-0.0741	(-0.04)	-2.602*	(-2.44)
Characteristics of buildings ($\overline{X}$ *and* $\overline{K}$)				
Bef1974	2.405*	(2.08)	-2.061***	(-3.51)
1974-1981	1.558	(1.16)	-1.250	(-1.76)
1982-1989	1.445	(1.01)	-2.355**	(-3.14)
1990-2001	0.162	(0.12)	-2.382***	(-3.53)
Surface	0.168***	(6.21)	0.0853***	(6.07)
Surface2	-0.000292**	(-2.89)	-0.000166**	(-2.99)
Climate1	2.742**	(2.99)	0.0967	(0.19)
Climate2	1.970*	(2.22)	-0.144	(-0.30)
Climate3	2.555*	(2.53)	1.044	(1.91)
Indhousing	2.316***	(3.86)	0.775*	(2.33)
Energy savings				
ζ	1.259***	(8.31)		
Public policy and professional				
Self production	1.907***	(3.32)	1.457***	(4.59)
Tax Credit	2.677*	(1.93)		
Likelihood ratio test of rho12 = 0:	chi2(1) = 309.126 Prob > chi2 = 0.0000			
Likelihood -16187.178				
rho	(0 .417)***	(0.0222)		

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

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.

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.

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. To avoid multicolinearity problems, we introduce a multiplicative variable between homeowners and different income quintile. For energy efficiency investment, this multiplicative is significant for only the first quintile. This result shows that the lack of investment is due to occupancy status and not to income (expect for the first quintile).

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.

Finally, the results show the importance of public policy. The tax credit has been introduced in 2005 to encourage households, homeowners and tenants, to renovate in energy efficiency system. This measure allows part of the expenses to be deducted from their income tax. Households can benefit of this measure mainly for heating system and insulation works and only if building professionals make the renovations. The renovation cost is often higher in this case. Results show that households who benefit tax credit spent more in energy efficiency renovation. Mouroux (2012) find similar results at micro level using fiscal data and matching models. Households who decided to undertake renovation themselves spend more because they undertake a largest number of works.

4.2 The number of energy efficiency renovations

To study the number of energy efficiency renovation works, we use a zero inflated negative binomial regression. Zero-inflated negative binomial regression is for modeling count variables with excessive zeros and it is usually for overdispersed count outcome variables. Furthermore, theory suggests that the excess zeros are generated by a separate process from the count values and that the excess zeros can be modeled independently. The two parts of the a zero-inflated model are a binary model, usually a logit model to model which of the two processes the zero outcome is associated with and a count model, in this case, a negative binomial model, to model the count process. The expected count is expressed as a combination of the two processes (Greene, 2005; Cameron and Trivedi, 2009). In this study, the two processes are that a household has decided investing in energy efficiency system vs. not invested in energy efficiency system. If not invested in energy efficiency system, the only outcome possible is zero. If decided investing in energy efficiency system, it is then a count process. The two parts of the a zero-inflated model are a binary model, usually a Logit model to model which of the two processes the zero outcome is associated with and a count model, in this case, a negative binomial model, to model the count process. The expected count is expressed as a combination of the two processes.

$$E(n_{number \text{ of works}} = k) = P(\text{not invest}) * 0 + P(\text{invest}) * E(y = k | \text{invest}) \tag{23}$$

We can test the hypothesis that a zero-inflated negative binomial model versus the zero-inflated poisson model is preferred using the zip option. A significant likelihood ratio test for alpha=0 indicates that the zero-inflated negative binomial model is preferred to the zero-inflated poisson model. So, we prefer a zero-inflated negative binomial model. We can also compare the zero-inflated model negative binomial with an ordinary negative binomial regression model using the Vuong test. A significant z-test indicates that the zero-inflated model is preferred which is the case here. Results are presented in Table 2.

A first result is about low income households. The low-income households are numerous to undertake works than whose of the fifth quintile but they undertake small renovation works which are less energy efficient. For example, households who belonging to the second income quintile who undertake 4 energy efficient renovations works have an average energy saving of 19.27 euros against 34 euros for households belonging to the fifth quintile. As previously, households who benefit tax credit undertake a largest number of works. It is also the case for households who decided to undertake renovation themselves. The cost of the renovation works is lower when the household install the equipment. The most interesting result is about the occupancy status (homeowner) which is the variable predicting excess zero. The inflate coefficient for Homeowners suggests that for each unit increase in homeowner the log odds of an inflated zero decrease by 1.056. The excess zero, the decision to not invest in energy efficiency system, is explained by occupancy status, independently from the income quintile. The occupancy status is responsible of the decision to undertake energy efficiency investments.

Table 2: results of the zero inflated negative binomial Poisson regression

	Coefficient	*Standard Error*
	Socioeconomic characteristics of households	
Quint1	0.250	(1.61)
Quint2	0.312*	(1.91)
Quint3	0.116	(0.72)
Quint4	0.473**	(2.92)
	Characteristics of buildings ($\overline{X}$ *and* $\overline{K}$)	
Bef1974	-0.203	(-1.10)
1974-1981	-0.319	(-1.35)
1982-1989	-0.203*	(-1.56)
1990-2001	-0.319*	(-1.44)
Climate1	-0.316	(-1.94)
Climate2	-0.262	(-1.72)
Climate3	-0.0911*	(-0.60)
surface	-0.0498	(-0.34)
Indhousing	-0.327*	(-1.89)
	Public policy and professional	
Tax Credit	0.784***	(4.30)
Professional	0.403***	(3.95)
inflate		
Homeowners	-1.056***	(-11.15)
	Likelihood-ratio test of alpha=0: chibar2(01) = 426.37 Pr>=chibar2 = 0.0000	
	Vuong test of zinb vs. standard negative binomial: z = 6.48 Pr>z = 0.0000	
N	16509	

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

5. Discussion

According to the results obtained in the conceptual and the empirical part, occupancy status is a key determinant of the decision to invest in energy efficiency system. This result is achieved regardless of the income effect. In the decision to invest, we can distinguish the income effect and the occupancy status effect. The split incentive problem is accentuated by the income effect. 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. They also face to disturbance costs. This result is line with our theoretical predictions. When people are more concerned about the future, they invest more. The main financial costs and benefits to retrofit buildings are differentiated when the dwelling is tenant-occupied. In the special case of split incentives, costs are barriers to invest in energy efficiency system. In this case, public policies are required (Burfurd et al., 2012). Different kind of policies can be studied: financial measures and regulatory measures. Recommendations are summarized in table 3.

Table 3: Public policy recommendations

	Landlord	Tenant
Benefits to energy efficiency investment	• Bonus on the housing market value • Bonus on the housing rental value	• Energy savings • Productivity savings (stress, health risks…) • Less dependence on rising energy prices
Costs to energy efficiency investment	• Significant investment Expenditures and maintenance costs • Negotiation with the tenant • Deterioration of housing • Direct or indirect rebound effect (rising of energy consumption)	• Significant investment expenditures • Indirect costs or disturbance costs
Public policy recommendations	• Repercussion on rent (lump-sum or Share of investment expenditures) • Mandatory measures to retrofit buildings • Mandatory measures to limit Rebound effect or carbon tax. • Largest deposit	• Capital Access and subsidies • Mandatory measures to improve energy efficiency • Repercussion on rent (lump-sum or share of investment expenditures)

Tenants have specific characteristics. They have low incomes and live in the most poorly insulated dwelling. They spent a great share of the income to energy expenditures. Thus, taxing (with a carbon tax) tenants who live in the last energy label categories do not seem appropriate. The tenants suffered a double penalty. They live in energy-inefficient housing units and are unable to renovate. To encourage energy efficiency, financial measure dedicated to landlords can be unfair. Largest deposits or repercussion of the landlord’s investment on the rent can be a solution but only for wealthier tenants. Moreover, to limit the rebound effect, the investment repercussion on the rent should go along with mandatory measures. But, in this case, the problem of low-income tenants who live in less insulted dwelling is not solved and they are still vulnerable to rising energy prices. Only measure to encourage capital access can be considered as well as subsidies but before renovations. Low income households have not the cash to pay investments. In terms of public policy, to improve energy efficiency of bad energy label category, minimum standard regulatory measures to landlords can be a solution. 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. 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. Finally, mandatory measures can cover the landlord against possible deteriorations.

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 energy efficiency investments are 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. In terms of public policy, government should not only address the problem of split incentives but also focus on income issues. One solution seems to promote mandatory measure such as minimum standard especially for low-income renters.

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Appendix

A. Introduction

Figure 1: dwelling energy label in kWh_{ef}/m^2/year

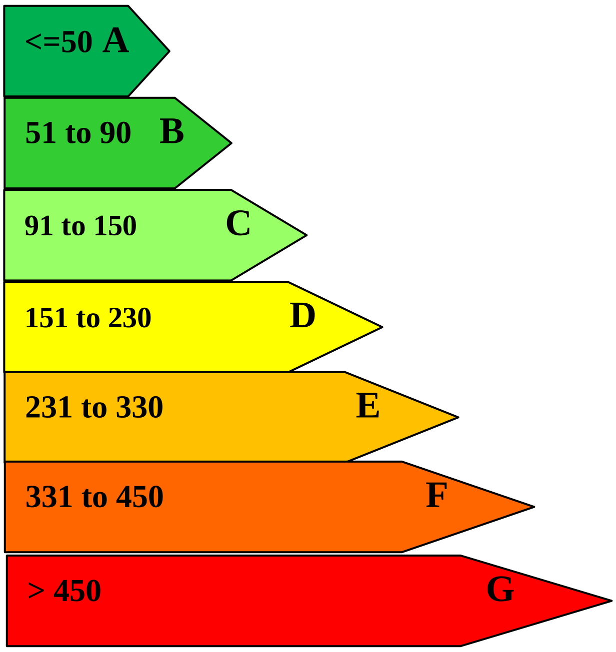

Table A-1 : Repartition by label* according to occupancy status in percent

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

* 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).

Table A-2 : 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

B. Conceptual Framework

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

Table B-1: List of variables used in the conceptual framework

Variables	**Description**
$\overline{X}_t$	Housing energy efficiency in time t
$\overline{K}_t$	Housing capital in time t
IR_0^L,	Landlord's reparation/maintenance investment in time t
IR_0^T	Tenant's reparation/maintenance investment in time t
IE_0^L,	Landlord's energy efficiency investment in time t
IE_0^T	Tenant's energy efficiency 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

B.2 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[3]. 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). Numerous studies show a link between environmental performance and financial value of dwellings (Miller et al., 2008; Furst and Mcallister, 2008, 2009, 2010). In France, the "green value is evaluated between 5% and 22% of the value of the building (Ademe, 2011). According to the "green value of the dwelling" $\overline{X}=120.72$ and $\overline{K}=1891.28$.

We also need domestic energy cost depending on the energy label (see figure 1). 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 ζ and we get ζ=0.0475 f is equal to 23.63 euros per square meter and by year. (Using the 2006 enquête Logement database and values for energy cost when theoretical energy consumption is greater than 650 kWh_{ef} /m²/year) . Results are summarized in Table 1.

Table B-2: Calculation of energy price sensitivity to investment

Housing quality $\overline{X}$	Energy Consumption in $kWh_{ef}/m^2/year$	Total energy cost in euros	ζ
100.6	195	18.85	
128.6	150	17.52	0.0475

However, income and rent values are not necessary to compute the equilibriums.

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

C. Data

Appendix C-1 **Example simulation using PROMODUL software**

We simulate energy expenditures using the PROMODUL Software, which can estimate theoretical energy consumption, GHG emission, and energy expenditures for each category of dwelling, using the 3CL method. This computation method was described by French decree in September 2006. Thus PROMODUL provides a tool to feed the model with data. To approximate energy expenditures more precisely, we split housing stocks into different types, as functions of the type of dwelling (individual or collective), climate zones (four zones), period of construction (five periods), type of glazing (double or not), type of roof insulation (good, intermediate, bad), ventilation system (mechanical ventilation or not), and main type of fuel used (electricity, gas, oil). The choice of these categories reflected our effort to merge the databases subsequently. It is also necessary to make some assumptions:

- No verandas and southern exposures for every simulation.
- The accommodation is on one level for individual housing units and an intermediate level for collective buildings.
- The same type of fuel is used for heating and hot water.
- Only the best renovation solution is chosen.

For each dwelling, the characteristics are informed by assumptions and information available in the *2006 Enquête Logement* database. Energy consumption, GHG emissions, energy expenditures, and energy savings provided by a renovation in euros are calculated for each type of renovation. Then, for each type of housing unit and each type of renovation, we assessed energy expenditures after the renovation. To compute the energy saving due to a specific investment, we took the difference between energy expenditures before and after renovation (measured in euros). This procedure was repeated for each category, that is, 2160 times.

For an individual housing unit, using electricity as a main fuel, constructed before 1974, with an average surface area of 110 square meters, located in the first climate zone, with poor roof insulation, without double-glazing or mechanical ventilation systems, we thus calculate an average theoretical energy consumption of 747 kWh/m^2 /year, an average GHG emissions of 48 kg.$_{CO2}$, and spending of 33.80 euros by year and per square meter for energy, for example. Then we can calculate energy consumption, GHG emissions, and energy expenditures in euros for each type of renovation separately, as summarized in Table AI.

Table C-2: Example of simulation

	Energy in Kwh/m²/Year	GHG Emissions in kg.$_{CO2}$	Expenditures by m2 and Year in euros
Without renovation	747	48	33.8
Improvement Insulation works (IIW)			
Double glazing	703	45	32.3*
Wall insulation	661	42	30.7
Roof insulation	622	38	29.1
Floor insulation	667	42	30.9
Equipment replacement works (ERW)			
Mechanical ventilation	645	41	30.9
New heating system	713	46	32.6
New hot water system,	740	47	33.6
Chimney	686	37	31.2

*After a double glazing renovation, the average energy expenditures are 32.3 euros per square meters, so energy savings are equal to 1.5 euros per square meter.

Table C-3: List of variables used in the empirical part:

Variables	Name	Definitions	Units
Dependent variables			
Number of renovation works in energy efficiency	NBEE	Number of energy-efficiency renovation works in 2006	continuous
Expenditures in EE	IE	The amount of renovation expenditures for energy efficiency works	in and logarithm
Expenditures in RE	IR	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 ($\overline{X}$ *and* $\overline{K}$)			
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
Energy savings			
Energy-savings 1	ζ	Theoretical energy expenditures before renovation minus theoretical energy expenditures after renovation (method 1)	In euros
Public policy and professional			
Tax credit	TaxCredit	Binary variables are introduced when household benefits a tax credit	0/1
Self-production	Self-Production	Binary variables when households asks for a professional to undertake works	0/1