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Energy-Saving Investments in the Residential Sector: An Econometric Analysis

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In this paper, our main objective is to analyze household's expenditures in renovation works by distinguishing energy efficiency works and repair works. Thus, it is necessary to improve the *2006 Enquête Logement* database with data on energy expenditures before and after renovation to compute energy savings. Renovation expenditures are examined by taking into account two characteristics of the data set: expenditures are censored to zero and may be interdependent across expenditure types. Censoring and interdependence are analyzed through a multivariate Tobit model. This study provides two major outputs. First, in France, data on energy-savings provided by different types of renovation are not available and a contribution is due to the improvement of the database. Second, the decision to invest in energy efficient system is studied taking into account the amount of potential energy-savings due to renovation. In general, the higher the energy-savings, the larger households' expenditures in energy efficient investment.

Keywords: multivariate Tobit model, energy savings, renovation, residential sector

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1 Introduction

Today, energy consumption and GHG emissions are a key concern in France. The residential sector (with heating and hot water, lighting and appliances) consumes more energy than any other sector in France. It also has considerable potential to save energy, particularly with heating through energy-efficient, cost-effective renovations. However, households do not invest significantly in energy-saving measures even when these could save them money. The literature about this so-called energy paradox is extensive (Brown, 2001; Jaffe and Stavins, 1994; Sanstad *et al.*, 1995) with most authors arguing that market imperfections are the underlying cause of the paradox. In such a context, a better understanding of the determinants of the renovation would allow to adapt the public policies according to the various categories of households. Indeed, the success of a public policy concerning energy-savings in the residential sector can largely be determined by a good understanding of what affects the behavior of the households.

But, relatively little is known about the factors that affect decisions by households about whether to renovate and which sort of renovations to undertake. Potepan (1989) uses a logit to model the probability that the homeowner chooses home improvements. He shows that renovation activity is an inferior good. The probability of renovation is positively correlated with an increase in interest rates and negatively related to household's income. However, one limitation of this study is that it does not take into account homeowners who do not wish to renovate. Moreover, these findings stress the importance of tenure on the decision to renovate. Indeed, the landlord wants to minimize the energy systems costs (for heating and hot water) and has no return on investment while the tenant wants to minimize his energy bill. In this case, each participant has no interest to invest in energy efficient systems. Diaz-Rainey and Ashton (2009), show that a total of 27% of households explained that they did not renovate because they lived in a council property (13%) or were not owner occupiers (14%). In general, all studies agree on the fact that tenants are reluctant to invest (Arnott, Davidson, and Pines, 1983; Levinson and Niemann, 2004; Rehdanz, 2007; Davis, 2010; and Meier and Rehdanz, 2010). Bogdon (1996) analyzes the probability to make renovation works itself or to resort to contracts by distinguishing amounts attributed for each renovation. She distinguishes 10 categories of renovation and estimates models separately using probits for every kind of renovation. In these models, the explanatory variables allow to describe the household characteristics but also the building characteristics and the skill of the household regarding renovation. She obtains that the socioeconomic variables are determinants of the renovation and affect the choice to use a professional or not to realize the renovation works. Households with high incomes have a higher probability to use a company. Poortinga *et al.* (2003) conduct a joined analysis to examine which characteristics of the 23 energy-saving measures (i.e., strategy, domain, amount) are the most likely accepted. They show that households with lower educational level are more likely to accept efficient investment measures compared to those with higher educational qualification. Plaut and Plaut (2010) analyze the decision to renovate using a logit model and they show that the probability to renovate is higher in individual housing units.

However, studies taking into account the economic and financial characteristics of the renovation are still relatively rare and authors mainly used discrete choice models to analyze the decision to invest. Cameron (1985) studied the demand for energy-efficiency retrofits such as insulation and storm windows taking into account the efficiencies of the different heating systems. Using a two level nested logit model, she shows that there exists a considerable sensitivity of demand to changes in investment costs, energy prices and income. Grösche and Vance (2009) study the determinants of energy retrofit using a nested logit model. In their study, they distinguish between 13 different categories of energy renovation. They show that the costs of renovation and expected gains are key variables. Same results are obtained by Banfi *et al.* (2006). The results suggest that the benefits of the energy-saving investments are significantly valued by the consumers. Households that have a high cost of energy use are more likely to invest (Nair, Gustavsson and Mahapatra, 2010). Unfortunately, in these studies, authors observe only the decision to invest in energy efficient renovation (i.e, if the households invest or not). No information is available on the amount of expenditures. Therefore, the dependent variables are restricted to a discrete number set which brings less information than would continuous data.

One of the first papers on the decision to renovate using renovation expenditures was written by Mendelsohn (1977). Using a Tobit model, he obtains as his main result that individuals who have higher incomes will spend more on renovation. Montgomery (1992) studies the decision to renovate taking into account the household's mobility. Using U.S. data, she highlights that households, wishing to improve considerably the quality of their housing, prefer moving. She also shows that household's income is a highly significant determinant. High income and educated households are more likely to improve their home. In her model, building characteristics are important as well. The older the accommodation, the larger the expenditures in renovation. More recently, Rehdanz (2007) examines the determinants that influence energy expenditures. She analyzes the impact of socio-economic characteristics of buildings and technologies used in heating demand. Age influences heating costs: elderly people prefer increasing their comfort temperature but they spend less in energy efficient system because of mortality rates. These households are also less likely to adopt energy efficient investment measures than younger ones because of (i) uncertainty on whether the investment will be paid back during their house occupancy (Mahapatra and Gustavsson, 2008) and (ii) less awareness about energy efficiency measures (Linden *et al.*, 2006). So, the middle-aged people generally have a lower mobility rate than young people, and they tend to spend more on renovations. In a life cycle approach, earners save more during their middle age than any other time and consequently, they spend more in energy efficient system because of their saving behavior (Mendelsohn, 1977). This result is reinforced by the fact that these individuals have a higher income. These authors also highlight that the amounts dedicated to the renovations are based on the size of housing. Nair, Gustavsson and Mahapatra (2010) show that personal characteristics such as income or education and contextual factors such as age of the house and thermal discomfort influence household's preference for a type of renovation. Households who are more educated are more likely to adopt an investment measure. Unfortunately, in these studies, the information on the potential energy-savings due to energy efficient renovation is not taken into account. Indeed, none have attempted to explain directly the determinants of energy efficiency expenditures especially by taking into account the expected energy consumption after a renovation. Moreover, French empirical studies which analyze the decision to invest in energy-saving system are in very limited number.

Thus, the purpose of this study is to estimate the determinants of home energy-savings expenditures. We wish to see more particularly if the household decides to invest according a cost-benefit analysis or whether other factors such as characteristics of the buildings or the socioeconomic characteristics of the household affect the decision. Thus, it is necessary to improve the *2006 Enquête Logement* database [2] with data on energy expenditures before and after renovation. To create variables, we simulate energy expenditures using a technical software.

[2] The *2006 Enquête Logement* is presented in the next part.

Moreover, the analysis of the data is complex because of two aspects. First, about 88% of households reported zero renovation works expenditures. Another type of problem is the possible interdependence across three types of expenditures: repair works (RW), improvement insulation works (IIW) and equipment replacement works (ERW). To take into account censoring and interdependence a multivariate Tobit model is used (Amemiya, 1974 and Maddala, 1983). This study provides two major outputs. First, in France, data on energy-savings provided by different types of renovations are not available and a major contribution is due to the improvement we make of the *2006 Enquête Logement* database. Second, the decision to invest in energy efficient system is studied taking into account the amount of potential energy-savings due to renovation.

We obtain as a main result that the higher the energy-savings, the larger households expenditures in energy efficient investment.

The remainder of the paper is as follows. Section 2 presents the data and the method used to improve the database. In this section, a description of variables is made and the main descriptive statistics are presented. The model is introduced in section 3. In section 4, we discuss the results. Section 5 concludes.

2 Data, variables and descriptive statistics

2.1 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. Information is provided on the living space, heating system, household information, geographical information and renovation works. In this study, a distinction is made between energy efficient works (EEW) and repairs works (RW). 8 types of energy-saving renovations are considered (they are presented in table 1 in appendix) following the *Observatoire Permanent de l'amélioration Energétique du logement* (OPEN) definition: double-glazing, roof insulation, wall insulation, floor insulation, and mechanical ventilation, new heating system, new hot water system and chimney. These renovations can be grouped into two modalities (OPEN):

improvement of insulation (double-glazing, roof insulation, wall insulation, floor insulation) or the replacement or the introduction of equipment (mechanical ventilation, new heating system, new hot water system and chimney). 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 using the PROMODUL Software. This software is used to estimate theoretical energy consumption, greenhouse gases emission and energy expenditures for each category of dwelling, using 3CL method. This computation method is described by French decree in September 2006. PROMODUL is an extra tool that we used just to feed the model with data. In order to approximate energy expenditures precisely, the housing stock is split into different types. These categories are function of type of dwelling (individual or collective), climate zones[3] (4 zones), period of construction (5 periods), type of glazing (double or not), type of roof insulation (good, intermediate, bad), ventilation system (mechanical ventilation (MV) or not), type of main fuel (electricity, gas, oil). These categories are chosen according to the database in order to later allow for a merge. Categories are summarized in table 2 in appendix and statistics are presented in appendix in table 3.

For each category, we compute annual energy expenditures per square meter for heating and domestic hot water (subscription included). Moreover for each type of housing unit and each type of renovation (8 kinds of renovation), energy expenditures after renovation are assessed. Energy-saving according to a specific investment is computed making the difference between the energy expenditures before renovation and after renovation. Energy-savings are appraised in euros. An example of simulation is presented in appendix in table 4.

This step was not trivial and led us to eliminate a significant part of the sample, particularly households living in collective buildings with collective heating systems. Indeed, these households have an imperfect knowledge concerning their energy bill and the building characteristics. This information lack has to be considered in the analysis because studies as Carlsmith *et al.* (1990) show that households reduce their energy consumption when they informed on the energy consumed by their appliances and heating equipment.

The final sample still contains 16780 households. Then, we compare our results to

[3] A map with the different French climate zones is available in appendix in figure 1 .

household's energy expenditures available in the database before renovation. Main results concerning the comparison of energy expenditures with software estimations between effective energy expenditures by fuel and periods of construction categories are available in appendix section in table 6.

2.2 Variables and main descriptive statistics

2.2.1 Dependent variables

In this paper, we study the determinants of the investment in energy efficient system in 2006 and of the amount of household expenditures in renovation works. A distinction is made between reparation works (RW) and energy efficiency works (EEW). The energy efficiency works are split into two categories: the improvement of insulation works (IIW) and the equipment replacement works (ERW). Expenditures are a gross amount because it is not possible to know the amount of public policies households get. We note "reparation or expansion works" all the other types of renovation works. In these three cases (reparation, insulation and replacement), there is a significant proportion of households with zero expenditures (about 88%). The sample is therefore a mixture of observations with many zero and some strictly positives values. This phenomenon should be taken into account later. In average, households who renovate in insulation improvement have spent 6,245 euros, those who renovate in equipment replacement spent 5,936 euros and those who renovate in repair works have spent 6,201.

2.2.2 Independent variables

Socio-economic characteristics of households

As socio-economic characteristics, we introduce the income quintile, the degree level, the age classes and the occupation tenure. Income quintile is introduced with degree level to take into account experience effect in the model. On average, expenditures for energy efficient renovations are higher when the households are graduated. Moreover, the tenure seems to be important. Renovation works are mainly realized by homeowners. If renter occupancy discourages energy efficient investments it must discourage other investments as well, such as in improved maintenance. Finally, middle-aged people (aged between 30 and 49) seem to spend more on reparation renovations.

Characteristics of buildings

To study the decision to invest in energy efficient renovation and the amount of expenditures, it seems important to take into account building characteristics. In the 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 square of the average surface area in order to capture a non linear effect. The age of the house could influence the adoption of building insulation measures. Old houses may be in physically or esthetically poor condition, requiring the installation of new building insulation components. Energy efficient renovation expenditures are higher in the coldest zone (mainly in the zone 1). The type of housing is also taken into account. In France, there are 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.

Characteristics of renovation works

To determine the amount spent by households, we also introduce in the model the number of renovation works and the square of the number of renovation works to see if there is a non linear effect.

Considering economic and financial characteristics of renovation works seems crucial because the renovation decision is essentially driven by two determinants, investment cost and savings from reduced energy usage (see Grösche and Vance, 2009). Households may not invest significantly in energy-saving measures even when these could save them money because of the energy paradox. However, once they decide to invest, they seem to run a cost-benefit analysis to choose the most efficient measure.

The cost of investment is computed for each type of renovation according to the OPEN data (see table 7 in appendix). However, a distinction for the cost is made between renovations carried out by a hired company and those made by the households themselves. Total cost is the sum of equipment cost and labor cost. Thus, 2 different means to introduce the cost-benefit analysis in the model can be taken into account. Both methods are used to test the impact of investment's profitability on the amount of energy efficient expenditures. Moreover, households could be more sensitive to the size of energy-savings (rather short term) than just the investment's profitability (rather long term).

- **The difference in energy expenditures before and after renovation works is considered.** Method 1 is based on simulation software and gives information on theoretical expenditures before and after renovation. The difference between the energy expenditures before and after renovation for each type of renovation provides us energy-savings for a specific type of renovation. Method 2 is based on household's energy expenditures and we obtain the effective energy consumption before renovation. Cumulating the both methods, it is possible to calculate two kinds of energy-savings:

- Energy-savings 1 : it is the theoretical energy expenditures before renovation minus theoretical energy expenditures after renovation (method 1)

- Energy-savings 2: it is the effective energy expenditures before renovation (available in the database) minus theoretical energy expenditures after renovation (method 2)

- **Binary variables** are created. They take the value 1 when the investment is profitable (the net present value is greater than the total cost).

To avoid comparing an annual energy-saving in euros to a one-shot total cost, we discount the expected benefit to obtain a net present value:

$$NPV_{it} = \sum_{t=1}^{T_k} \frac{G_{it}}{(1+\phi)^{T_k}} \tag{1}$$

where ϕ is the market long term interest rate and T_k the average life of equipment. So, it is possible to compare the total investment cost to the net present value. To compute the NPV, constant energy prices and energy cost are used. Table 5 describing all variable used in the model is provided in appendix. Table 6 and table 7 summarizing energy expenditures results are provided in appendix too. The net present value is higher in renovated dwelling. Comparing the net present value computed for each kind of renovation and the renovation cost, many energy efficient renovations are profitable. In the sample, nearly 50% of households renovate their dwelling themselves. However, the percentage of profitable cost-benefit analysis is higher in not renovated dwelling. This means that a large part of households would have benefited from renovations but they decide not to renovate in 2006. This result may be an illustration of the energy paradox. Generally, cost-benefit analysis suggests insulation improvement works are more profitable than replacement works. Main descriptive statics are summarized in table 8 in appendix.

3 Model

The analysis of the data is complicated because of two aspects. First, about 88% of households reported zero renovation works expenditures. In this case, estimating a linear regression involves computational complications. If we consider the three categories of renovation, i.e, repair works, insulation works and replacement of equipment works, the share of households reported zero renovation is respectively 82.7%, 96.94% and 98.59%. So, a Tobit regression (Tobin, 1958; Amemiya, 1973 and Heckman, 1979) is used with left-censored (censored at a zero level) dependent variables.

Another type of problem is the possible interdependence across three expenditures types: repair works, improvement insulation works and equipment replacement works. The econometric model taking into account censoring and interdependence are analysed through a multivariate Tobit model (Amemiya, 1974 and Maddala, 1983). This model is an extension of the single regression model with the censored normal dependant variable. With a multivariate Tobit model, it is possible to estimate the expenditures in repair works and the expenditures in energy efficiency works, i.e, improvement of insulation and equipement replacement while taking into account the interdependence between these three types of renovations. According to Amemiya, 1974, we define an n-dimensional vectors of random variables $y_i = (y_{1i}, y_{2i}, y_{3i})$ by:

$$y_i = Ax_i + u_i \text{ if } Ax_i + u_i > 0$$

$$y_i = 0 \text{ if } Ax_i + u_i \leq 0 \quad (i = 1, 2, .., N)$$

Where x_i for each i is a $K-$dimensional vectors of known constants, A is a $n \times K$ matrix of unknown parameters, and u_t is $n-$ dimensional $N(0,\Sigma)$ and temporally independent. We assume Σ is positive definite. An alternative extension is to define y_{it} for each i (households) by:

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

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

$$y_{i3} = \alpha_{i3}^{'} x_3 + u_{i2} \quad \text{if} \quad \alpha_{i3}^{'} x_3 + u_{i3} > 0$$
$$y_{i3} = 0 \quad \text{if} \quad \alpha_{i3}^{'} x_3 + u_{i3} \leq 0$$

with $i = 1, 2, ..., n,$ where y_{i1}, y_{i2} and y_{i3} the dependent variables, x_i is a vector of independent variables, $\alpha_{i1}^{'}, \alpha_{i2}^{'}$ and $\alpha_{i3}^{'}$ are the corresponding parameter vectors of unknown coefficients, and the error terms (u_{i1}, u_{i2}, u_{i3}) are independent of x_i. These disturbances are joint normally distribued with variances σ_1^2, σ_2^2 and σ_3^2 where u_{i1} , u_{i2}, u_{i3} $\sim N(0,0,\sigma_1^2,\sigma_2^2,\sigma_3^2,\rho_{12},\rho_{13},\rho_{23})$ and the covariance is given by $\sigma_1^2,_2,_3 = \rho\sigma_1^2\sigma_2^2\sigma_3^2$.

Multivariate Tobit estimates 3-equation Tobit models by the method of maximum simulated likelihood (MSL). Only models left-censored at zero can be estimated. Along with coefficients for each equation multivariate Tobit estimates the cross-equation error-correlations and the variance of the error terms. To estimate the multivariate Tobit model, we use the Geweke-Hajivassiliou-Keane (GHK) simulator. For each observation, a likelihood contribution is calculated for each replication, and the simulated likelihood contribution is the average of the values derived from all the replications. The simulated likelihood function for the sample as a whole is then maximized using standard methods (maximum likelihood in this case). For a brief description of the GHK smooth recursive simulator, see Greene (2003, 931-933). The number of pseudo-random standard uniform variates drawn when calculating the simulated likelihood is 150.

4 Results

Results of the multivariate Tobit model are compared with those obtained with univariate Tobit models. Results with are available in appendix (table 9, 10, 11 and 12). All estimations are corrected for the heteroskedasticity problem. For more information on the robustness of estimators of the Tobit model to heteroskedasticit, see Hurd (1979) and Nelson (1981)

The statistical significance of the model is examined by using a likelihood ratio test of the null hypothesis that all slope coefficients are zero. The χ^2 statistics for estimations (respectively 928.47, 810.02, 923.9 and 810.2) indicate the rejection of the null hypothesis. The interdependence of the three expenditures types was tested by applying the t-test likelihood ratio test. The tests use the fact that correlation coefficients between error terms ($\rho_{IIW,ERW}$, $\rho_{ERW, RW}$ and $\rho_{IIW,RW}$) in the three expenditures equations are constrained at zero when a univariate model is used. The t-value for the estimates of $\rho_{IIW,ERW}$, $\rho_{ERW, RW}$ and $\rho_{IIW,RW}$ are significant at 1% level, so the null hypothesis of $\rho_{IIW,ERW}=0$, $\rho_{ERW, RW}=0$ and $\rho_{IIW,RW}=0$ can be rejected. The null hypothesis of independence of renovation works expenditures is tested by using a log-likelihood ratio test in which the restricted model forces off-diagonal covariance matrix terms to zero. The resulting χ^2 statistics are statically significant, indicating a rejection of the null hypothesis. It is clear from the test results that the data should be analysed in a multivariate Tobit setting.

Moreover, several multiplied dependent variables are introduced as regressors (for instance income and education variables) to take into account the correlation between these variables. Using a LR test with and without these multiplicative variables, the null hypothesis is not rejected and we therefore prefer the models excluding them.

Socio-economic characteristics of households

First, the more graduated the individuals, the more they spend in energy efficient renovation work. Graduated people have a higher income than those with no graduation (45,540 euros/year for graduated agents and 26,979 euros/year for those who are not graduated agents that made energy efficient investment). These results are consistent with Nair, Gustavsson and Mahapatra (2010) and Poortinga *et al.* (2003). Individuals that are not graduated but spend money for energy efficient renovations exercise manual occupations. The presence of a technically skilled person in the home may also influence investment expenditures. It comes from the fact that these people may have a better understanding of new technologies and may be able to perform the installation themselves. However, income quintiles are not significant for energy efficient expenditures while income quintile 1 and 2 are negatively and statistically significant at the 1% level for repair works. Expenditures are a gross amount and take into account the amount of public aid given to households and this can explain the lack of expenditures differences between income quintile for energy efficient renovation while this is not the case for repair works. It appears that high income households are more likely either to improve their home (the same result is obtained in Montgomery, 1992).

The fact that the housing unit is owner occupied significantly and positively affects energy efficiency expenditures and reparation expenditures. On the opposite, the tenure is not significant on replacement expenditures. In France, it is compulsory for landlords to change equipments in rented housing units in case of breakdown or dysfunction. It can explain why tenure is not significant on replacement expenditures. Overall, the results confirm our hypothesis that a significant difference exists in renovation expenditures between households in rented or owner-occupied accommodation. These results are consistent with those obtained by Arnott, Davidson, and Pines (1983), Rehdanz (2007), Davis (2010) and Meier and Rehdanz (2010). From a policy point of view, landlords could have the obligation to rent dwelling with a level of energy quality set by the government.

Age influences repair works expenditures: middle-aged people (between 30 and 49) compared to elderly households (age after 65 years) who have also a lower mobility rate than young people, spend more on renovations (these results are consistent with Rehdanz, 2007). Moreover, it seems that elderly households are also less likely to renovate or refurbish their dwelling. Contrary to what descriptive statics suggested, the age has no effect on the energy efficient expenditures. These results are different from Mahapatra and Gustavsson (2008) and Rehdanz (2007). Considering that the number of homeowners is higher in this class, the econometric estimation underline that energy efficient investment is not determined by age. Morever, in a life cycle approach, earners save more during their middle age than any other time and consequently, they spend more in energy efficient system because of their saving behavior (Mendelsohn, 1977). Unfortunately, the amount of savings is not available in the database and we cannot test this assumption.

Characteristics of buildings

Energy efficient renovation expenditures are higher in the coldest zone (mainly in the zone 1) while expenditures for repair works are higher in the climate zone 3. The coefficient of average surface area is positive and statistically significant, but that of the square of average surface area is negative and statically significant. This implies that expenditures first increase with the surface area and then decline after a peak.

The coefficient of individual housing units is positive and statically significant whatever the kind of renovation. The renovation expenditures are higher in individual housing units. Indeed, in individual housing units, households have a perfect knowledge of their energy consumption and they can take fully benefit from their investment that is not the case in collective buildings, especially with collective heating. Our results are consistent with those of Plaut and Plaut (2010). In terms of public policies, it seems important to aim at the collective housing with collective heating. Individualization of the heating system could be a solution.

The coefficient of construction period is positive and significant for insulation works. Households rather spend in the oldest and lesser insulated housing units. This result is consistent with the study of Nair, Gustavsson and Mahapatra (2010) who show that households whose buildings were more than 35 years old, were more likely to undergo a major renovation such as replacing the external walls. Concerning repair works, the expenditures are higher in the most recent housing units. Repair works include expansion, finishing and embellishment works, which may explain this result. In these recent housing units, energy efficiency improvement expenditures is not necessary because of thermal regulation and labels they have to satisfy. For instance, in 2005, label "low energy buildings" is introduced which sets energy consumption to 50 $kWh_{pe}/m^2/year$.

Characteristics of renovation works

The number of renovation works has a significant and positive effect whatever the type of renovations. But the square of the number of renovations is negative and statically significant especially in the repair works cases. This implies that expenditures first increase with the number of renovation then decline after a peak. Two explanations can be proposed. First, the marginal cost of renovation declines with the amount of renovations undertaken. Second, households prefer to make several less costly renovations.

The estimated energy-savings are positive and statistically significant (i.e households with high energy expenditures before renovation and low expected expenditures after renovation are more willing to invest in energy efficient renovation). This is in line with the findings by Grösche and Vance (2009), Banfi *et al.* (2006) and Nair, Gustavsson and Mahapatra (2010). The larger the energy-savings, the more the households spend in energy efficient investments. Moreover, this result is consistent using both methods (i.e to compare theoretical and effective energy expenditures) to compute energy-savings. However, the coefficient of cost-benefit analysis for energy efficiency works is not significant. Households may prefer investments which have higher energy-savings. The households may have a preference for investments which are immediately profitable.

Generally speaking, concerning the replacement works, few variables are significant. In the database, we have no information about the possible breakdowns and the dilapidation of materials. It is possible to believe that part of the works of replacement was made following a breakdown. This could explain why replacement expenditures are globally less explained than other types of renovations.

Moreover, the number of renovations in energy efficiency is still relatively low (around 4%) even when the net present value is generally higher than the renovation costs. Therefore it would be rational for households to invest in energy-saving measures. The energy paradox seems confirmed. We can interpret this under investment as the result of market failures. But, this econometric work suggests that it also comes from many structural and socio-economic barriers. From a policy point of view, the government can reduce these barriers by supporting the communication and information in particular on the losses incurred by households who do not adopt energy efficient investments. Information focusing on the economic savings can be less effective than information stressing on the loss. Indeed, households are more likely to avoid a loss than to achieve a gain (Kahneman and Tversky, 1979).

5 Conclusion

In this paper, our main objective was to analyze the household renovation works expenditures by distinguishing energy efficiency works and repair works. We wished to see more particularly if the household decided to invest according a cost-benefit analysis or whether other factors such as characteristics of the buildings or the socio-economic characteristics of the household affected the decision. For this study, an enrichment of the *2006 Enquête Logement* database has been necessary. Renovation expenditures have been examined in a multivariate Tobit model to take into account two important characteristics: expenditures were censored to zero and might be interdependent across expenditure type. In general, investment in energy efficiency and in reparation did not fully share the same characteristics. Repair works took place in new housing units and in generally well insulated dwelling. If socio-economic characteristics of households and building characteristics were determinant for energy efficient investment, economic and financial characteristics were key concerns. Moreover, the results confirm that there is a significant difference in renovation expenditures between households in rented or owner-occupied accommodation. An important barrier to energy efficient investment in the housing sector are split incentives. Overall, the larger the energy-savings, the more the households spend in energy efficient investment. However, the energy paradox seems validated. From a policy point of view, the government can reduce economics barriers by supporting the communication and information in particular on the losses incurred by households who do not adopt energy efficient investments. It seems also important to aim at the collective housing with collective heating.

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Appendix

Table 1: The different type of renovations

	Description
Energy efficiency works (EEW)	These works improve the energy quality of dwellings.
Improvement insulation works (IIW)	Double-glazing, roof insulation, wall insulation, floor insulation
Equipment replacement works (ERW)	Mechanical ventilation, new heating system, new hot water system, chimney
Repair works (RW)	Expansion works, maintenance works, repair works, finishing and embellishment works

Table 2: Housing stock categories

	Individual housing units	**Collective buildings**
Type of fuel	Electricity, gas, oil	Electricity, gas, oil
Climate zone	4 climates zones (1 is the coldest)	4 climates zones (1 is the coldest)
Periods of construction	5 periods (before 1974, from 1975, to 1981, from 1982 to 1989, from 1990 to 2001, after 2002)	5 periods (before 1974, from 1975, to 1981, from 1982 to 1989, from 1990 to 2001, after 2002)
Glazing	Double glazing or simple glazing	Double glazing or simple glazing
Ventilation	Mechanical ventilation or not	Mechanical ventilation or not
Roof insulation	Good, intermediate, bad	Good, intermediate, bad
Type of heating		Individual: only for one dwelling, or Collective: common for the building
Total number of categories	720	1440
TOTAL		2160

Figure 1: The French climate zones

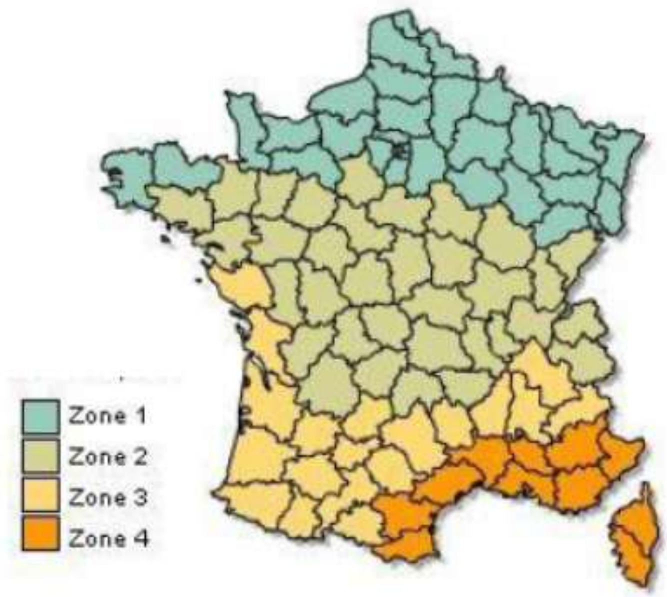

Table 3: Descriptive statics by category

	Total	Individual housing units	Collective buildings		
			Total	Individual heating	Collective heating
Periods of Construction					
Before 1974	58%	48.8%	67.4%	67.1%	68.5%
1974 - 1981	11.2%	12%	10.2%	10.4%	9.9%
1982-1989	9.3%	12.%	6.4%	6.5%	6.4%
1990-2001	16%	20.1%	11.7%	12%	10.9%
2002-2006	5.5%	7.1%	4.1%	4%	4.3%
Total	100%	100%	100%	100%	100%
Observations	*(16780)*	*(8410)*	*(8370)*	*(6682)*	*(1688)*
Climate zone					
Zone 1	29.4%	28.7%	30.1%	30.7%	27.9%
Zone 2	37.4%	37.4%	37.4%	36.2%	41.7%
Zone 3	17.1%	17.4%	16.9%	17.4%	15.3%
Zone 4	16.1%	16.5%	15.6%	15.7%	15.1%
Total	100%	100%	100%	100%	100%
Observations	*(16780)*	*(8410)*	*(8370)*	*(6682)*	*(1688)*
Double glazing					
Yes	70.7%	75.3%	66.1%	67.2%	65.8%
No	29.3%	24.7%	33.9%	32.8%	34.2%
Total	100%	100%	100%	100%	100%
Observations	*(16780)*	*(8410)*	*(8370)*	*(6682)*	*(1688)*
Mechanical ventilation					
Yes	51.5%	49.2%	47.7%	48%	46.6%
No	48.5%	50.8%	52.3%	52%	53.4%
Total	100%	100%	100%	100%	100%
Observations	*(16780)*	*(8410)*	*(8370)*	*(6682)*	*(1688)*
Roof insulation					
Bad		7.8%			
Intermediate		13.6%			
Good		78.6%			
Total		100%			
Observations		*(8410)*			

Appendix A1 An example of simulation using PROMODUL software

Information available in the *2006 Enquête Logement* database on type of fuel, climate zone, periods of construction, roof insulation, double glazing, ventilation system and type of heating is used to perform simulations. But, it is also necessary to make some assumptions:

- The absence of veranda and a south exposition for every simulation;
- The accommodation is on one level for individual housing units and on 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, dwelling characteristics in the software are informed according to 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. This procedure was repeated for each category i.e. 2160 times. For instance, 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 a bad roof insulation, without double-glazing and mechanical ventilation system, has an average theoretical energy consumption of 747 kWh/m^2/year, an average GHG emissions of 48 kg.$_{CO2}$ and spends 33.80 euros by year and per square meter for energy. Then, energy consumption, GHG emissions and energy expenditures in euros are calculated for each type of renovation separately. This example is summarized in the table 4.

Table 4: Example of simulation

	Energy in Kwh/m^2/year	GHG emissions in kg.$_{CO2}$	Expenditures by m^2 and by year in euros
Without renovation	747	48	33.8
Energy Efficiency works (EEW)			
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

*Note: 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 meters.

Table 5: Variable Description

Variables	**Name**	**Definitions**	**Units**
Dependent variables			
Expenditures in EEW	LexpIIW	The amount of renovation expenditures for improvement insulation works	in and logarithm
Expenditures in EEW	LexpERW	The amount of renovation expenditures for equipment replacement works	in and logarithm
Expenditures in RW	LexpRW	The amount of renovation expenditures for reparation works.	in and logarithm
Independent variables			
Socio-economic characteristics of households			
Degree level		Binary variable introduced for each degree level. (5 modalities)	
No qualification	Ref	Households with no qualitification	0/1
Inferior to baccalaureate	Infbac	Households qualitification inferior to baccalaureate	0/1
Baccalaureate	Bac	Households with baccalaureate	0/1
Two years after baccalaureate	Bac+2	Households with two years after baccalaureate	0/1
Superior to baccalaureate after two years	Supbac+2	Households with two years after baccalaureate	0/1
Income quintile	Quint	Binary variable introduced for each income quintile (5 quintiles)	0/1
Class of Age			
Before 30 years old	Bef30	Households aged less 30 years old	0/1
Between 30 and 39 years old	30-39years	Households aged between 30 and 39 years old	0/1
Between 40 and 49 years old	40-49years	Households aged between 40 and 49 years old	0/1
Between 50 and 64 years old	50-64years	Households aged between 50 and 64 years old	0/1
After 65 years old	Ref	Households aged more 65 years old	0/1
Tenure	Homeowners	Binary variable introduced for homeowners	0/1
Variables	**Name**	**Defintions**	**Units**
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
Between 1974 and 1981	1974-1981	Dwelling constructed between 1974 and 1981	0/1
Between 1982 and 1989	1982-1989	Dwelling constructed between 1982 and 1989	0/1
Between 1990 and 2001	1990-2001	Dwelling constructed between 1990 and 2001	0/1
After 2002	Ref	Dwelling constructed after 2002	0/1

Variables	Name	Definitions	Units
Surface area	Surface	Average surface area per dwelling in 2006	in m^2
The square of surface area	Surface2	Square of average surface area per dwelling in 2006	in m^2
Climate zone		Binary variable are introduced for each climate zone (4 zones)	0/1
Climate zone 1	Climate1	Households who live in the climate zone 1	0/1
Climate zone 2	Climate2	Households who live in the climate zone 2	0/1
Climate zone 3	Climate3	Households who live in the climate zone 3	0/1
Climate zone 4	Ref	Households who live in the climate zone 4	0/1
Individual Housing Unit	Indhousing	Households who live in an individual housing unit	0/1
Characteristics of renovation works			
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
Energy-savings 1	LEnergySavings1	Theoretical energy expenditures before renovation minus theoretical energy expenditures after renovation (method 1)	In euros and in logarithm
Log of energy-savings 2	LEnergySavings2	Effective energy expenditures before renovation minus theoretical energy expenditures after renovation (method 2)	In euros and in logarithm
Cost Benefit analysis for IIW 1	CBinsulation1	Binary variable when the cost-benefit analysis for IIW is profitable using method 1	0/1
Cost Benefit analysis for ERW 1	CBreplacement1	Binary variable when the cost-benefit analysis for ERW is profitable using method 1	0/1
Cost Benefit analysis for IIW 2	CBinsulation2	Binary variable when the cost-benefit analysis for IIW is profitable using method 2	0/1
Cost Benefit analysis for ERW 2	CBreplacement2	Binary variable when the cost-benefit analysis for ERW is profitable using method 2.	0/1

Table 6: comparison of energy expenditures with software estimations to effective energy expenditures by fuel and periods of construction categories

	Theoretical energy expenditures by m²/year					Effective energy expenditures by m²/year				
	Total	**Individual housing units**	**Collective buildings**			**Total**	**Individual housing units**	**Collective buildings**		
			Total	Individual heating	Collective heating			Total	Individual heating	Collective heating
Fuel										
Electricity	19.4	21.1	17.4	17.2	17.8	15.2	17.2	12.9	12.8	13.4
	(4965)*	(2651)	(2314)	(1853)	(461)	(4965)	(2651)	(2314)	(1853)	(461)
Gas	15.8	19.1	13.2	13.0	13.9	13.9	18.2	10.5	10.6	10.1
	(6987)	(3068)	(3919)	(3121)	(798)	(6987)	(3068)	(3919)	(3121)	(798)
Oil	17.02	21.6	11.1	11.1	10.9	16.8	22.9	8.8	8.8	8.9
	(4200)	(2375)	(1825)	(1441)	(384)	(4200)	(2375)	(1825)	(1441)	(384)
Periods of construction										
Before 1974	16.1	20.2	13.1	13.02	13.4	14.8	20.3	10.7	10.6	10.8
	(9738)	(4092)	(5646)	(4489)	(1157)	(9738)	(4092)	(5646)	(4489)	(1157)
Between	18.5	21.9	14.6	14.4	15.1	14.8	19.3	9.4	9.1	9.5
74 -81	(1871)	(1012)	(859)	(693)	(166)	(1871)	(1012)	(859)	(693)	(166)
Between 82	20.5	22.2	17.3	16.6	19.9	16.5	19.0	11.7	11.7	11.9
-89	(1547)	(1007)	(540)	(432)	(108)	(1547)	(1007)	(540)	(432)	(108)
Between 90	18.2	20.1	14.8	15.1	13.8	15.4	18.2	10.5	10.4 (796)	11.0
-01	(2679)	(1698)	(981)	(796)	(185)	(2679)	(1698)	(981)		(185)
After 2002	18.1	19.6	15.4	14.5	19.0	14.9	16.5	12.2	12.1	12.2
	(945)	(601)	(344)	(272)	(72)	(945)	(601)	(344)	(272)	(72)
Climate zone										
zone 1	18.7	22.8	14.7	14.7	15.1	15.1	19.6	10.8	10.5	10.8
	(4923)	(2410)	(2513)	(2042)	(471)	(4923)	(2410)	(2513)	(2042)	(471)
zone 2	17.3	20.7	14.0	13.8	14.8	15.0	19.2	10.7	10.7	10.7
	(6275)	(3146)	(3129)	(2423)	(706)	(6275)	(3146)	(3129)	(2423)	(706)
zone 3	15.9	18.8	12.3	13.0	12.3	14.9	19.2	10.4	10.4	10.4
	(2883)	(1460)	(1423)	(1166)	(257)	(2883)	(1460)	(1423)	(1166)	(257)
zone 4	15.6	18.3	12.6	12.5	13.2	15.2	19.2	10.9	10.9	10.9 (254)
	(2699)	(1394)	(1305)	(1051)	(254)	(2699)	(1394)	(1305)	(1051)	
Double glazing										
Yes	17.5	20.5	14.1	13.9	14.9	15.1	11.0	10.6	10.6	10.6
	(11871)	(6334)	(5537)	(4407)	(1130)	(11871)	(6334)	(5537)	(4407)	(1130)
No	16.4	20.8	13.3	13.4	12.8	15.0	20.4	11.0	10.9	11.3
	(4909)	(2076)	(2833)	(2275)	(558)	(4909)	(2076)	(2833)	(2275)	(558)
Ventilation										
Yes	17.5	20.7	14.2	14.0	14.9	14.4	18.7	10.0	10.0	10.0
	(8134)	(4138)	(3996)	(3210)	(786)	(8134)	(4138)	(3996)	(3210)	(786)
No	16.9	20.5	13.5	13.4	13.7	15.6	20.0	11.3	11.3	11.3
	(8646)	(4272)	(4374)	(3472)	(902)	(8646)	(4272)	(4374)	(3472)	(902)
Means	17.2	20.6	13.8	13.7	14.2	15.0	19.3	10.7	10.7	10.7
	(16780)	(8410)	(8370)	(6682)	(1688)	(16780)	(8410)	(8370)	(6682)	(1688)

Note: *observations are in parenthesis.

Table 7: Energy savings, total cost and consumption depending on the type of renovation

		Improvement of insulation				Replacement of equipment				Total
		Glazing	Wall	Roof	Floor	MV	Chminey	Heating	Hot water	
Life of equipment		35	30	35	30	30	10	16	15	
NPV with theoretical energy expenditures	Sample means (1)	9935	6984	6604	1769	3177	864	7312	4469	18080
	Renovated dwelling (2)	13235	9482	8400	1627	4096	1150	9513	1380	25298
NPV with effective energy expenditures	Sample means (3)	11192	8339	9404	1819	4154	1722	9524	6231	26031
	Renovated dwelling (4)	14725	10932	9329	1966	4138	1708	9853	6221	28354
Total cost in euros	(5)	7411	8100	7548	4099	3674	4320	4322	2124	8196
Cost benefit analysis	Comparison (1) and (5)	+	-	-	-	-	-	+	+	
	Comparison (3) and (5)	+	+	+	-	+	-	+	+	
Cost without labor force (6)		3705	6237	2059	2869	2204	2592	2593	1274	3178
Energy expenditures before renovation	Theoretical in euros (9)	17.2	17.0	17.5	12.6	11.6	17.6	11.8	14.6	16.0
	Effective in euros (8)	14.5	16.0	15.9	12.2	13.1	14.0	10.0	11.8	14.7
Energy expenditures after renovation	Theoretical in euros (7)	13.1	12.2	12.2	09.9	8.4	12.9	8.8	10.9	12.4
	Effective in euros (8)	10.8	11.6	11.1	9.7	9.9	9.3	7.8	8.2	10.8
Energy Savings 1	Renovated dwelling (9)-(7)	4,1	4,8	5,3	2,7	3,2	4,7	3	3,7	3,6
Energy Savings 2	Renovated dwelling (8)-(7)	1,4	3,8	3,7	2,3	4,7	1,1	1,2	0,9	2,3
Cost benefit analysis [1]	Sample means (%)	83.7*	93.6	90.9	47.3	50.9	26.8	89.1	88.5	15.3
Method 1	Renovated dwelling (%)	83.5**	96.7	92	48.6	40.9	60.9	16.3	85.8	6.1
Cost benefit analysis [2]	Sample means (%)	68.9	69.3	65.0	45.0	46.8	28.8	60.9	61	20.5
Method 2	Renovated dwelling (%)	71.7	72.2	58.0	51.4	78.3	25.6	56.8	56.3	12.7

Note: [1] (1) is compared to (6) [2] (3) is compared to (6)* The cost-benefit analysis is profitable in 83.7% of dwellings. **The cost-benefit analysis is profitable in 83.5% of renovated dwellings.

Table 8: Renovation expenditures in euros and building characteristics

Variables	Means of Expenditures of different kinds of EEW in euros			Meansof Expenditures of RW in euros
Socio-economic characteristics of households				
	EEW	IIW	ERW	RW
Degree level				
No qualification	5518 *(156)**	4990 *(118)*	6655 *(47)*	6362 *(491)*
Inferior to bac	6574*(293)*	7017 *(210)*	5781 *(110)*	5798 *(967)*
Baccalaureate	5763 *(89)*	5898 *(71)*	5210 *(27)*	7637 *(278)*
Two years after	3409 *(55)*	4196 *(41)*	1792 *(21)*	5633 *(244)*
After two years	7985 *(94)*	7538 *(73)*	8835 *(31)*	6352 *(327)*
Income quintile				
Quintile 1	7175 *(139)*	7276 *(98)*	6965 *(56)*	7076 *(450)*
Quintile 2	6313 *(132)*	6617*(103)*	5191 *(39)*	5503 *(465)*
Quintile 3	5988 *(137)*	6758 *(100)*	3779 *(50)*	6003 *(476)*
Quintile 4	6644 *(150)*	6226 *(111)*	7803 *(48)*	6288 *(459)*
Quintile 5	4576 *(129)*	4375 *(101)*	5694 *(43)*	6166 *(457)*
Class of Age				
Before 30 years old	7053 *(60)*	7835 *(44)*	4655 *(20)*	6998 *(235)*
30 and 39 years old	6150 *(140)*	6418 *(105)*	5573 *(45)*	5279 *(504)*
40 and 49 years old	6508 *(170)*	6974 *(131)*	5332 *(53)*	7156 *(507)*
50 and 64 years old	5741 *(179)*	4891 *(133)*	7452 *(62)*	5876 *(607)*
After 65 years old	5458 *(127)*	5609 *(94)*	4964 *(46)*	5564 *(438)*
Tenure				
Homeowners	5901 *(374)*	5707 *(280)*	6693 *(127)*	5743 *(1214)*
Tenants	6488 *(313)*	6891 *(233)*	5053 *(109)*	6709 *(1093)*
Characteristics of buildings				
Periods of construction				
Before 1974	6218 *(398)*	6390 *(287)*	6010 *(132)*	6319 *(1312)*
1974 and 1981	6226 *(65)*	7758 *(44)*	3759 *(25)*	5036 *(258)*
1982 and 1989	7500 *(76)*	7533 *(54)*	6436 *(27)*	5399 *(222)*
1990 and 2001	5112 *(111)*	4735 *(83)*	5635 *(39)*	6044*(345)*
After 2002	6059 *(56)*	5336 *(45)*	9236 *(13)*	8413 *(170)*
Climate zone				
Climate zone 1	6370 *(208)*	6637 *(152)*	5636 *(78)*	5990 *(645)*
Climate zone 2	5717 *(267)*	5544 *(208)*	6413 *(85)*	5930 *(905)*
Climate zone 3	6587 *(100)*	6679 *(66)*	6383 *(41)*	7498 *(385)*
Climate zone 4	6498 *(112)*	6906 *(87)*	4816 *(32)*	5884 *(372)*
Type of housing				
Individual housing	6038*(389)*	6245 *(269)*	5177 *(130)*	5855 *(1161)*
Collective buildings	6303 *(350)*	6244 *(244)*	6555 *(106)*	6542*(1146)*
Characteristics of renovation works				
Means	6169 *(687)*	6245 *(513)*	5936 *(236)*	6224 *(2307)*

Note: * Number of observations are between brackets. Households without qualification who invest in energy efficient renovations spent 6 181 euros on average.

Table 9: Estimation results of univariate and multivariate models with energy-savings using method 1

Variables[4]	Univariate models			Multivariate model		
	LexpIIW	LexpERW	LexpRW	LexpIIW	LexpERW	LexpRW
Socio-economic characteristics of households						
Infbac	1.502*(0.902)	1.193(1.379)	0.904**(0.439)	1.544*(0.900)	1.209(1.392)	0.923**(0.436)
Bac	-1.219 (1.286)	-0.158(1.889)	-0.0465(0.586)	-1.065(1.278)	0.100(1.879)	-0.00676(0.576)
Bac+2	2.679**(1.272)	-0.347(2.153)	0.00171(0.656)	2.728**(1.278)	0.135(2.165)	0.0444(0.661)
Supbac+2	1.313 (1.205)	3.349*(1.732)	0.0718(0.586)	1.362(1.199)	3.491**(1.768)	0.0225(0.592)
Quint1	1.113 (1.099)	1.096(1.721)	-1.984***(0.544)	0.645(1.105)	0.798(1.764)	-2.043***(0.543)
Quint2	-0.328 (1.120)	-1.135(1.775)	-2.653***(0.540)	-0.657(1.139)	-1.403(1.788)	-2.705***(0.549)
Quint3	0.771 (1.055)	2.244(1.568)	-0.522(0.502)	0.600(1.059)	1.945(1.590)	-0.521(0.504)
Quint4	0.426 (1.048)	0.406(1.615)	-0.772(0.493)	0.403(1.048)	0.324(1.629)	-0.766 (0.493)
Bef30	0.124 (1.300)	0.782(1.901)	-0.215(0.661)	0.110(1.279)	0.724(1.903)	-0.159(0.666)
30-39 years	-0.598 (1.034)	-0.726(1.569)	0.890*(0.504)	-0.292(1.020)	-0.691(1.585)	0.896*(0.502)
40-49 years	-0.159 (0.993)	0.935(1.451)	0.901*(0.492)	0.0308(0.982)	1.221(1.471)	0.960*(0.491)
50-64 years	-0.434 (0.951)	-2.150(1.482)	0.429(0.471)	-0.217(0.953)	-1.889(1.496)	0.466(0.471)
Homeowners	1.579**(0.713)	1.622(1.064)	0.609*(0.346)	1.591**(0.715)	1.659(1.065)	0.575*(0.346)
Characteristics of buildings						
Bef1974	2.716*(1.456)	-0.238 (2.084)	-2.736***(0.610)	3.053**(1.457)	0.0645(2.074)	-2.610***(0.616)
1975-1981	1.576 (1.689)	-0.291(2.398)	-2.006***(0.734)	2.281(1.689)	0.0103(2.405)	-1.791**(0.744)
1982-1989	0.539 (1.749)	1.789(2.398)	-2.923***(0.769)	0.720(1.749)	1.838(2.376)	-2.834***(0.779)
1990-2001	0.483 (1.636)	-0.133(2.303)	-2.981***(0.696)	0.306(1.624)	-0.423(2.293)	-2.925***(0.699)
surface	0.169***(0.0307)	0.243***(0.0362)	0.0816***(0.014)	0.181***(0.0322)	0.233***(0.0358)	0.0843***(0.00946)
surface2	-0.0003**(0.0001)	-0.005***(0.001)	-0.0002***(5.51e-05)	-0.0003**(0.0001)	-0.0005***(0.0001)	-0.0002***(3.44e-05)
Climate1	1.817*(1.036)	2.900*(1.600)	0.195 (0.495)	1.637 (1.061)	2.897*(1.600)	0.163 (0.492)
Climate 2	1.102 (1.004)	2.900* (1.541)	-0.136 (0.477)	1.098 (1.036)	2.922*(1.535)	-0.0840 (0.477)
Climate 3	1.544 (1.155)	1.293 (1.835)	1.108**(0.542)	1.767(1.169)	1.656 (1.825)	1.129**(0.539)
Indhousing	2.186***(0.694)	1.759(1.072)	0.670**(0.327)	1.996***(0.685)	1.736 (1.082)	0.655**(0.326)
Characteristics of renovation works						
NB	0.594**(0.249)	0.596(0.398)	0.867***(0.130)	0.746***(0.233)	0.807**(0.378)	0.895***(0.126)
NB2	-0.0212(0.0194)	-0.0369(0.034)	-0.0452***(0.011)	-0.0312*(0.0173)	-0.0506 (0.0313)	-0.0466***(0.010)
LES1	1.789***(0.311)	1.55***(0.483)		1.951***(0.313)	1.837***(0.480)	
Constant	-54.16***(2.930)	-67.34***(4.041)	-20.37***(1.268)	-55.68***(3.380)	-68.31***(4.331)	-20.73***(1.145)
N	16780	16780	16780	16780	16780	16780
Log-likelihood	-3610.3059	-1823.1465	-12066.59	-17251.828		

$\rho_{IIW,ERW}$ = 0.488***(0.036)
$\rho_{IIW,RW}$ = 0.429***(0.023)
$\rho_{ERW,RW}$ = 0.319***(0.033)
H0 independent expenditures $\chi^2(3)$=492.986
H0 B_j^b=0 $\chi^2(77)$=928.47

[4] Note: robust standard errors are reported between brackets. *, **, and ***indicate statistical significance at 10%, 5% and 1% levels, respectively. The variables are defined in table 9. The null hypothesis B =0 is used to test significance of the explanatory power of the model. The restricted model is one in which all coefficients are set to zero except the intercept terms and covariance matrix elements.

Table 10: Estimation results of univariate and multivariate models with cost-benefit analysis using method 1

Variables[5]	**Univariate models**			**Multivariate model**		
	LexpIIW	LexpERW	LexpRW	LexpIIW	LexpERW	LexpRW
Socio-economic characteristics of households						
Infbac	1.505*(0.906)	1.206(1.383)	0.899**(0.439)	1.527*(0.881)	1.222(1.378)	0.922**(0.442)
Bac	-1.335(1.289)	-0.192(1.889)	-0.0564(0.586)	-1.208(1.268)	0.0698(1.879)	-0.0157(0.581)
Bac+2	2.742**(1.279)	-0.276(2.151)	-0.0088(0.656)	2.796**(1.236)	0.219(2.126)	0.0304(0.658)
Supbac+2	1.275(1.206)	3.289*(1.735)	0.0658(0.586)	1.318(1.190)	3.419*(1.750)	0.0191(0.595)
Quint1	1.186(1.100)	1.174(1.724)	-1.986***(0.544)	0.737(1.090)	0.903(1.744)	-2.047***(0.542)
Quint2	-0.342(1.121)	-1.118(1.781)	-2.652***(0.540)	-0.662(1.117)	-1.376(1.780)	-2.706***(0.551)
Quint3	0.752(1.054)	2.169(1.573)	-0.515(0.502)	0.578(1.042)	1.857(1.566)	-0.512(0.502)
Quint4	0.364(1.052)	0.318(1.619)	-0.771(0.494)	0.347(1.035)	0.241(1.611)	(0.495)
Bef30	0.0802(1.302)	0.887(1.898)	-0.212(0.661)	0.0390(1.274)	0.748(1.886)	-0.151(0.649)
30-39 years	-0.593(1.032)	-0.731(1.562)	0.893*(0.504)	-0.291(1.031)	-0.756(1.553)	0.901*(0.504)
40-49 years	-0.178(0.996)	0.902(1.451)	0.907*(0.492)	0.00985(0.990)	1.136(1.445)	0.966**(0.492)
50-64 years	-0.521(0.950)	-2.234(1.480)	0.431(0.471)	-0.294(0.945)	-2.022(1.471)	0.469(0.471)
Homeowners	1.587**(0.716)	1.703(1.059)	0.607*(0.346)	1.598**(0.707)	1.721(1.058)	0.573*(0.348)
Characteristics of buildings						
Bef1974	2.478*(1.460)	-0.352(2.069)	-2.739***(0.610)	2.846**(1.404)	-0.0579(2.046)	-2.618***(0.603)
1975-1981	1.766(1.692)	0.0554(2.414)	-2.009***(0.734)	2.556(1.645)	0.385(2.376)	-1.800**(0.731)
1982-1989	1.123(1.747)	2.486(2.405)	-2.931***(0.769)	1.414(1.698)	2.641(2.380)	-2.844***(0.760)
1990-2001	0.263(1.639)	-0.177(2.292)	-2.978***(0.696)	0.105(1.573)	-0.504(2.276)	-2.923***(0.692)
surface	0.158***(0.0298)	0.229***(0.0361)	0.0816***(0.014)	0.169***(0.0182)	0.218***(0.0339)	0.0842***(0.00949)
surface2	-0.0025**(0.001)	-0.005***(0.001)	-0.00015***(5.5e-05)	-0.0003***(6.3e-05)	-0.004***(0.001)	-0.0002***(3.4e-05)
Climate1	1.062(1.033)	2.247(1.600)	0.193(0.495)	0.827(1.026)	2.137(1.575)	0.159(0.496)
Climate 2	0.536(1.003)	2.392(1.544)	-0.139(0.477)	0.495(1.002)	2.335(1.515)	-0.0888(0.472)
Climate 3	0.936(1.153)	0.687(1.835)	1.107**(0.542)	1.124(1.146)	0.952(1.797)	1.126**(0.539)
Indhousing	2.874***(0.680)	2.358**(1.053)	0.671**(0.327)	2.760***(0.673)	2.460**(1.044)	0.659**(0.324)
Characteristics of renovation works						
NB	0.572**(0.250)	0.583(0.397)	0.868***(0.130)	0.717***(0.251)	0.789**(0.369)	0.895***(0.130)
NB2	-0.0195(0.0194)	-0.0352(0.0336)	-0.0453***(0.0106)	-0.0293(0.0195)	-0.0488(0.0298)	-0.0466***(0.0106)
CBinsulation1	0.388***(0.072)	2.157*(1.108)	-0.221(0.341)	-0.426(0.692)	2.031*(1.100)	-0.242(0.343)
CBreplacement1	-0.935(2.100)	-2.054(3.303)	-0.409(0.978)	-0.739(1.995)	-1.643(3.309)	-0.399(0.930)
Constant	-50.78***(2.916)	-65.95***(3.998)	-20.20***(1.294)	-51.99***(2.555)	-66.23***(3.891)	-20.54***(1.175)
N	16780	16780	16780	16780	16780	16780
Log-likelihood	-3625.2194	-1826,18	-12066		-17274.25	
					$\rho_{IIW,ERW}$ = 0.488***(0.036)	
					$\rho_{IIW,RW}$ = 0.426***(0.023)	
					$\rho_{ERW,RW}$ = 0.318***(0.033)	
					H0 independent expenditures $\chi^2(3)$=486.8	
					H0 B_i^b=0 $\chi^2(81)$=810.02	

5 Note: robust standard errors are reported between brackets. *, **, and ***indicate statistical significance at 10%, 5% and 1% levels, respectively. The variables are defined in table 9. The null hypothesis B =0 is used to test significance of the explanatory power of the model. The restricted model is one in which all coefficients are set to zero except the intercept terms and covariance matrix elements

Table 11: Estimation results of univariate and multivariate models with energy-savings method 2

Variables[6]	Univariate models			Multivariate model		
	LexpIIW	LexpERW	LexpRW	LexpIIW	LexpERW	LexpRW
Socio-economic characteristics of households						
Infbac	1.499*(0.902)	1.195(1.379)	0.904**(0.439)	1.541*(0.893)	1.209(1.377)	0.923**(0.442)
Bac	-1.209(1.286)	-0.155(1.889)	-0.0465(0.586)	-1.057(1.282)	0.104(1.880)	-0.00682(0.592)
Bac+2	2.670**(1.272)	-0.353(2.152)	0.00171(0.656)	2.718**(1.251)	0.129(2.142)	0.0441(0.660)
Supbac+2	1.309(1.205)	3.355*(1.732)	0.0718(0.586)	1.357(1.192)	3.494**(1.746)	0.0225(0.594)
Quint1	1.303(1.097)	1.257(1.717)	-1.984***(0.54)	0.855(1.091)	0.991(1.742)	-2.043***(0.546)
Quint2	-0.284(1.120)	-1.103(1.774)	-2.653***(0.54)	-0.609(1.105)	-1.364(1.780)	-2.705***(0.537)
Quint3	0.777(1.055)	2.250(1.568)	-0.522(0.502)	0.605(1.041)	1.949(1.561)	-0.520(0.503)
Quint4	0.426(1.047)	0.405(1.615)	-0.772(0.493)	0.403(1.024)	0.321(1.609)	-0.766(0.493)
Bef30	0.129(1.300)	0.777(1.901)	-0.215(0.661)	0.721(1.899)	-0.159(0.667)	
30-39 years	-0.598(1.034)	-0.726(1.569)	0.890*(0.504)	-0.294(1.025)	-0.692(1.565)	0.896*(0.504)
40-49 years	-0.159(0.993)	0.935(1.451)	0.901*(0.492)	0.0294(0.986)	1.220(1.450)	0.960*(0.494)
50-64 years	-0.432(0.951)	-2.153(1.482)	0.429(0.471)	-0.218(0.944)	-1.893(1.472)	0.467(0.474)
Homeowners	1.580**(0.713)	1.620(1.064)	0.609*(0.346)	1.594**(0.706)	1.657(1.065)	0.575*(0.344)
Characteristics of buildings						
Bef1974	2.665*(1.455)	-0.281(2.081)	-2.736***(0.610)	2.989**(1.440)	0.00732(2.060)	-2.610***(0.614)
1975-1981	1.531(1.688)	-0.330(2.396)	-2.006***(0.734)	-0.0341(2.363)	-0.0341(2.363)	-1.791 (0.734)
1982-1989	0.515(1.749)	1.764(2.398)	-2.923***(0.769)	0.692(1.713)	1.814(2.370)	-2.834***(0.77)
1990-2001	0.497(1.635)	-0.126(2.303)	-2.981***(0.696)	0.314(1.614)	-0.419(2.292)	-2.925***(0.700)
surface	0.169***(0.03)	0.243***(0.04)	0.0816***(0.01)	0.181*** (0.04)	0.234***(0.036)	0.0843***(0.03)
surface2	-0.003**(0.001)	-0.0002**(5.51e-5)		-0.003**(0.002)	-0.005***(0.001)	-0.002(0.00116)
Climate1	1.871*(1.036)	2.939*(1.600)	0.195(0.495)	1.689*(1.018)	2.939*(1.576)	0.163(0.491)
Climate 2	1.140(1.004)	2.928*(1.541)	-0.136(0.477)	1.134(0.991)	2.951*(1.512)	-0.0839(0.474)
Climate 3	1.577(1.154)	1.319(1.834)	1.108**(0.542)	1.799(1.140)	1.683(1.799)	1.128**(0.537)
Indhousing	2.121***(0.696)	1.712(1.074)	0.670**(0.327)	1.929***(0.687)	1.682(1.068)	0.655**(0.326)
Characteristics of renovation works						
NB	0.593**(0.249)	0.594(0.398)	0.867***(0.130)	0.745***(0.246)	0.806**(0.374)	0.895***(0.132)
NB2	-0.0211(0.0194)	-0.0367(0.0338)	-0.0452***(0.011)	-0.0312*(0.0187)	-0.0505*(0.0305)	-0.0466***(0.0110)
LES 2	1.916***(0.322)	1.650***(0.498)		2.077***(0.317)	1.942***(0.489)	
Constant	0.593**(0.249)	0.594(0.398)	0.867***(0.130)	0.745***(0.246)	0.806**(0.374)	0.895***(0.132)
N	16780	16780	16780	16780	16780	
Log-likelihood	-3608.9602	-1822.8272	-12066.59	17252.		
					$\rho_{IIW,RW}$ = 0.429***(0.023)	
					$\rho_{ERW,RW}$ = 0.319***(0.033)	
					H0 independent expenditures $\chi^2(3)$=493.017	
					H0 B_j^b=0 $\chi^2(77)$=929.3	
	0.593**(0.249)	0.594(0.398)	0.867***(0.130)		0.745***(0.246)	

[6] Note: robust standard errors are reported between brackets. *, **, and ***indicate statistical significance at 10%, 5% and 1% levels, respectively. [a] The variables are defined in table 9. [b] The null hypothesis B_j =0 is used to test significance of the explanatory power of the model. The restricted model is one in which all coefficients are set to zero except the intercept terms and covariance matrix elements

Table 12: Estimation results of univariate and multivariate models with cost-benefit analysis using method 2

Variables[7]	Univariate models			Multivariate model		
	LexpIIW	LexpERW	LexpRW	LexpIIW	LexpERW	LexpRW
Socio-economic characteristics of households						
Infbac	1.510*(0.906)	1.207(1.382)	0.900**(0.439)	1.532*(0.881)	1.221(1.384)	0.923**(0.439)
Bac	-1.317(1.289)	-0.149(1.890)	-0.0561(0.586)	-1.187(1.318)	0.116(1.880)	-0.0150(0.584)
Bac+2	2.750**(1.279)	-0.239 (2.154)	-0.00975(0.656)	2.805**(1.220)	0.236(2.153)	0.0309(0.656)
Supbac+2	1.280(1.206)	3.350*(1.734)	0.0638(0.586)	1.324(1.197)	3.460**(1.748)	0.0185(0.586)
Quint1	1.178(1.099)	1.179(1.722)	-1.990***(0.544)	0.729(1.107)	0.896(1.728)	-2.050***(0.541)
Quint2	-0.341(1.121)	-1.111(1.777)	-2.657***(0.540)	-0.659(1.117)	-1.379(1.760)	-2.709***(0.537)
Quint3	0.740(1.052)	2.191(1.571)	-0.516(0.502)	0.568(1.050)	1.856(1.559)	-0.512(0.499)
Quint4	0.364(1.051)	0.348(1.617)	-0.771(0.494)	0.345(1.027)	0.249(1.604)	-0.763(0.490)
Bef30	0.0867(1.303)	0.828(1.902)	-0.209(0.661)	0.0418(1.254)	0.710(1.898)	-0.147(0.660)
30-39 years	-0.582(1.033)	-0.753(1.566)	0.892*(0.504)	-0.281(1.001)	-0.753(1.560)	0.899*(0.501)
40-49 years	-0.177(0.996)	0.859(1.452)	0.906*(0.492)	0.00918(1.003)	1.111(1.448)	0.964**(0.489)
50-64 years	-0.513(0.950)	-2.237(1.481)	0.431(0.471)	-0.288(0.940)	-2.003(1.469)	0.467(0.471)
Homeowners	1.581**(0.716)	1.678(1.062)	0.606*(0.346)	1.594**(0.721)	1.700(1.058)	0.571*(0.346)
Characteristics of buildings						
Bef1974	2.486*(1.458)	-0.378(2.069)	-2.737***(0.610)	2.849*(1.465)	-0.0774(2.081)	-2.616***(0.606)
1975-1981	1.775(1.691)	0.0524(2.415)	-2.005***(0.734)	2.564(1.686)	0.390(2.422)	-1.796**(0.725)
1982-1989	1.120(1.747)	2.460(2.406)	-2.927***(0.769)	1.411(1.742)	2.627(2.420)	-2.841***(0.764)
1990-2001	0.279(1.637)	-0.183(2.293)	-2.978***(0.696)	0.117(1.630)	-0.502(2.306)	-2.923***(0.696)
surface	0.158***(0.0298)	0.230***(0.0361)	0.0816***(0.014)	0.169***(0.0149)	0.219***(0.0342)	0.0842***(0.0118)
surface2	-0.003**(0.0011)	-0.005***(0.001)	-0.002***(5e-05)	-0.0003***(5.1e-05)	-0.0005***(0.0001)	-0.0002***(4.5e-05)
Climate1	1.052(1.033)	2.257(1.599)	0.194(0.495)	0.824(1.034)	2.147(1.589)	0.159(0.488)
Climate 2	0.532(1.004)	2.422(1.542)	-0.141(0.477)	0.497(1.008)	2.367(1.529)	-0.0912(0.471)
Climate 3	0.938(1.153)	0.714(1.836)	1.106**(0.542)	1.134(1.147)	0.995(1.813)	1.124**(0.537)
Indhousing	2.868***(0.680)	2.343**(1.053)	0.671**(0.327)	2.755***(0.656)	2.445**(1.053)	0.658**(0.325)
Characteristics of renovation works						
NB	0.569**(0.250)	0.584(0.398)	0.868***(0.130)	0.715***(0.257)	0.786**(0.370)	0.896***(0.125)
NB2	-0.0194(0.0194)	-0.0353(0.0338)	-0.0453***(0.011)	-0.0291(0.0201)	-0.0485(0.0299)	-0.0467***(0.0099)
CBinsulation2	0.482***(0.074)	1.873*(1.126)	-0.200(0.347)	-0.530(0.707)	1.765(1.109)	-0.227(0.344)
CBreplacement2	0.451(1.166)	1.571(1.653)	-0.304(0.579)	0.582(1.145)	1.521(1.654)	-0.250(0.575)
Constant	-50.80***(2.917)	-66.00***(3.995)	-20.20***(1.293)	-52.01***(2.544)	-66.27***(4.125)	-20.54***(1.225)
N	0.569**	0.584	0.868***	16780	16780	16780
Log-likelihood	-3625	-1825	-12066		-17273.8	
					$\rho_{IIW,ERW}$ = 0.486***(0.036)	
					$\rho_{IIW,RW}$ = 0.426***(0.023)	
					$\rho_{ERW,RW}$ = 0.318***(0.033)	
					H0 independent expenditures $\chi^2(3)$=487.2	
					H0 B_j^b=0 $\chi^2(81)$=810.02	

[7] Note: robust standard errors are reported between brackets. *, **, and ***indicate statistical significance at 10%, 5% and 1% levels, respectively. [a] The variables are defined in table 9. [b] The null hypothesis B_j =0 is used to test significance of the explanatory power of the model. The restricted model is one in which all coefficients are set to zero except the intercept terms and covariance matrix elements