Energy-Efficient Investments in the Housing Sector: Potential Energy Savings vs. Investment Profitability. *An Empirical Analysis*

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An Empirical Analysis

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Abstract

Energy efficiency in the housing sector can substantially reduce greenhouse gas emissions. This article seeks to clarify, theoretically and empirically, decisions to invest in energy-saving systems, as well as verify empirically whether the energy paradox is valid. By examining renovation expenditures, taking into account both censoring and interdependence with a multivariate Tobit model, this study provides two major contributions. First, providing data about energy savings achieved according to the type of renovation improves the available database. Second, by studying the decision to invest in an energy-efficient system, this article shows both theoretically and empirically that potential energy savings are the key determinants of such investments. Yet energy efficiency renovations remain relatively rare, even when the net present value is positive. Thus, the energy paradox seems confirmed.

Keywords: Energy efficiency, multivariate Tobit model, energy savings, renovation, housing sector, energy paradox.

Titre

L'investissement en efficacité énergétique dans les bâtiments résidentiels : rendement énergétique contre rendement économique. Une étude empirique

Résumé

L'efficacité énergétique dans le secteur résidentiel est un outil de réduction des émissions de gaz à effet de serre. Cet article cherche à clarifier, théoriquement et empiriquement, la décision d'investir en efficacité énergétique. Nous voulons aussi vérifier si le paradoxe énergétique est valide empiriquement. Les dépenses en rénovations sont examinées en tenant compte de la censure et de l'interdépendance à l'aide d'un modèle Tobit multivarié. Cette étude a deux contributions majeures. Premièrement, l'enquête logement est enrichie avec des données sur les gains énergétiques à la rénovation. Deuxièmement, cet article montre que les gains énergétiques sont une variable déterminante de la décision d'investir. Finalement, nombreux sont les ménages qui n'ont pas investi alors que l'investissement était profitable. Le paradoxe énergétique semble confirmé.

Mots-clés : efficacité énergétique, Tobit multivarié, gains énergétiques, rénovation, secteur résidentiel, paradoxe énergétique.

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1. Introduction

Energy consumption and greenhouse gas (GHG) emissions are a key concern, and the housing sector (including heating, hot water, lighting, and appliances) is one of the largest energy consumers. It also offers considerable potential to reduce energy uses and GHG emissions, particularly with energy-efficient renovations (Stern, 1998). Considering the great potential of investments in energy-saving renovations, we need a better understanding of the determinants of renovation, to adapt public policies in ways that increase their appeal to various households. Literature pertaining to the so-called energy paradox is extensive (Brown, 2001; Jaffe and Stavins, 1994b; Sanstad and Howarth, 1995), explaining why households do not invest significantly in energy-saving measures even when doing so could save them money; in contrast, the importance of energy savings as a driver of investment remains unexplored in economic research.

This study accordingly seeks to (a) understand theoretically and empirically the decision to invest in energy-saving systems by distinguishing energy efficiency from repair works and (b) verify empirically if the energy paradox is valid. We appraise in particular whether expected energy savings and cost–benefit analyses drive households' decisions to invest, or if other factors, such as building characteristics or socioeconomic features, affect the decision. We know relatively little about the factors that affect households' renovation decisions and data on energy expenditures and energy savings after an energy-efficient renovation are relatively rare. Therefore, to initiate this analysis, we extend the *2006 Enquête Logement* database (presented subsequently) with data about energy expenditures before and after renovations. To create these variables, we simulate energy expenditures using technical software that can estimate theoretical energy consumption, greenhouse gas emissions, and energy expenditures for each category of dwelling, according to the type of dwelling, climate, period of construction, glazing, roof insulation, ventilation system, and type of main fuel. For 2160 simulations run before renovations, we also compute energy expenditures after eight types of energy-efficient renovations. Using the difference, we can derive energy savings due to the energy-efficient renovations and, in turn, study the effect of energy savings on the decision to renovate.

Of the few studies that acknowledge the influence of energy savings, most use discrete choice models to analyze the decision to invest. For example, with a two-level nested logit model, Cameron (1985) studies demand for energy-efficiency retrofits, such as insulation and storm windows, taking the efficiencies of different heating systems into account. She finds considerable demand sensitivity to changes in investment costs, energy prices, and income. Grösche and Vance (2009) also 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, findings that Banfi *et al.* (2006) reaffirm. Such results suggest that the benefits of energy-saving investments are significantly valued by consumers. Households with high costs of energy use thus are more likely to invest (Nair *et al.* 2010).

With this evidence, it seems important to account for the thermal characteristics of buildings when studying the decision to invest in energy-efficient systems. Thermal and building characteristics inevitably influence the amount of potential energy savings. Both Mendelsohn (1997) and Mahapatra and Gustavsson (2008) highlight that the amounts dedicated to renovations depend on the size of housing; Plaut and Plaut (2010) analyze the decision to renovate using a logit model and show that renovation probability is higher in individual housing units. Using U.S. data, Montgomery (1992) stresses the importance of the period of construction, such that older accommodations demand greater expenditures in renovation.

With this article, we estimate the determinants of home expenditures according to the amount of energy savings available, investment profitability and the building characteristics. In addition to extending sparse literature on energy-saving investments in housing, this article relates to research on environmentalism and consumer choice (Hanna, 2007; Kahn, 2007). Energy-efficient investments differ from other types of investments (Jaffe and Stavins, 1994a, 1994b, 1994c), because households often do not invest significantly in energy-saving measures even if they could save money by doing so, in the so-called energy paradox. Thus, we also appraise whether the energy paradox can be verified in the French case. Moreover, some authors (Henry, 1974; Dixit and Pindyck, 1994) suggest that the net present value rule (i.e. it is profitable to invest when the value of a unit of capital is at least as equal as to the purchase and installation costs) has to be changed. The value of the realized investment must exceed the purchase and installation costs, by an amount equal to the value of keeping the investment option[2] alive. Indeed, in this paper, we also want to assess the impact of investment profitability on the decision to invest. Results show that the net present value rule does not explain the decision to invest. The usual explanation of the energy paradox based on the existence of an option value seems valid.

In the next section, we provide a brief review of literature pertaining to energy-saving investments in the housing sector. The conceptual framework in Section 3 leads into the data and methods used to improve an existing database in Section 4, which also provides the main descriptive statistics. Section 5 introduces the econometric model. Finally, we discuss the results in Section 6 and conclude in Section 7.

2. Literature Review

Energy-saving investments seem significantly less widespread than their potential net gains would suggest. An important amount of energy could be saved a priori by investing in

[2] Under uncertainty, it is possible to delay an irreversible investment. While the homeowner is waiting, he can take advantage of an opportunity to invest, similar to what happens with a financial option. Therefore, there exists an option value of the investment project that is killed at the time of investment (see Dixit and Pindyck (1994)). This option value represents an opportunity cost of investment that must be taken into account.

energy-efficient technologies, yet market barriers and risks associated with energy-efficient investments continue to inhibit such improvements. For example, the split incentives problem (i.e., home tenure effects on the decision to invest), heterogeneity among agents, and access to capital are prominent market barriers. Thus socioeconomic characteristics, together with potential energy savings, should be taken into account in any analysis of energy-saving investment decisions. Some authors acknowledge this effect; for example, Potepan (1989) uses a Logit model of the probability that the homeowner chooses home improvements and finds a strong influence of tenure on the decision to renovate. A landlord wants to minimize energy system costs (e.g., heating and hot water) and has no return on an investment; the tenant wants to minimize the costs on the energy bill. Therefore, neither participant has an interest in investing in energy-efficient systems. Diaz-Rainey and Ashton (2009) show that 27% of households explained their choice not to renovate by noting they lived in a council property (13%) or were not owner-occupiers (14%). In general, studies agree that tenants are reluctant to invest (Arnott *et al.* 1983; Davis, 2010; Levinson and Niemann, 2004; Meier and Rehdanz, 2010; Rehdanz, 2007).

Bogdon (1996) also analyzes the probability of renovation using household characteristics and reveals that households with high incomes are more likely to renovate. Similar results offered by Mendelsohn (1977), who used a Tobit model, show that individuals with higher incomes spend more on renovations. Montgomery (1992) also highlights that a household's income is a highly significant determinant. High-income, educated households are more likely to improve their homes.

Rehdanz (2007) combines these notions by examining the impact of the socioeconomic characteristics and the buildings used in heating demand. Age influences heating costs: Elderly people prefer increasing their comfort temperature but spend less on energy-efficient systems. These households are less likely to adopt energy-efficient investment measures than younger ones, because of their uncertainty about whether the investment will be paid off during their house occupancy (Mahapatra and Gustavsson, 2008) and their relative lack of awareness of energy-efficiency measures (Linden *et al.*, 2006). Because middle-aged people generally have a lower mobility rate than young and elderly people, they tend to spend more on renovations. Moreover, earners save more during their middle age than any other time, which gives them more to spend on energy-efficient systems (Mendelsohn, 1977). This result is reinforced their higher average incomes.

In a joint analysis, Poortinga *et al.* (2003) examine the determinants of 23 energy-saving measures (e.g., strategy, domain, amount) on the probability to renovate. They show that households with lower educational levels are more likely to accept efficient investment measures than those with higher educational qualifications. Nair *et al* (2010) concur that education influences households' preferences for types of renovation but finds that households that are more educated are more likely to adopt an investment measure.

Unfortunately, these prior studies focus solely on the decision to invest in energy-efficient renovation (i.e., if the households invest or not), without considering the potential energy savings due to the energy-efficient renovation. Without information about the amount of expenditures, and therefore the amount of energy savings achieved through those expenditures, the dependent variables remain restricted to a discrete set that offers less information than continuous data would. Furthermore, expected energy consumption after a renovation and investment profitability has not been used to explain the determinants of energy efficiency expenditures. Studying the determinants of energy-saving expenditures, taking into account potential energy savings, investment profitability, socioeconomic factors, and building characteristics, is preferable but also more complex. First, approximately 88% of households reported no expenditures on energy-efficient renovations, so the data are censored at 0. Second, interdependence may exist across three types of expenditures: repair works (RW), improvement insulation works (IIW), and equipment replacement works (ERW). To address both censoring and interdependence, we use a multivariate Tobit model (Amemiya, 1974; Maddala, 1983) that extends the single regression model with a censored normal dependant variable. Moreover, with a multivariate Tobit model, we can estimate RW expenditures separately from expenditures in energy efficiency (i.e., IIW and ERW) while still accounting for the interdependence among the three types of renovations.

3. Conceptual framework

3.1. Theoretical model

To begin, we assume an economy with one type of agent: a homeowner (L) who occupies the dwelling. We set a finite discrete time horizon as $t \in \{0,1\}$. During the first period, the homeowner chooses between consuming or investing. In the second period, the homeowner only consumes. The function of housing quality represents the value of the dwelling; for this study, housing quality also represents the energy efficiency of the dwelling. In period 0, housing quality is a function of the investment level of the homeowner I_0^L, the housing quality when the homeowner moves into the dwelling *X*, and a capital depreciation factor δ with $0 < \delta < 1$.

Therefore,

$$X_1 = I_0^L + (1-\delta)X \quad (1)$$

The homeowner can consume energy goods C_t^{Le} or non-energy goods C_t^{Lne}. We derive the following utility function:

$$U(C_t^{Lne}, C_t^{Le}) = \ln(C_t^{Le} C_t^{Lne}) \quad (2)$$

The problem of the homeowner is to maximize the utility function, subject to Equation (1) and:

$$(R_0^L - C_0^{Lne} - p_0(X_0)C_0^{Le} - I_0^L)(1+r) + \frac{X_1}{1+r} = C_1^{Le} p_1(X_1) + C_1^{Lne}, \ (3)$$

where R_0^L and R_1^L are homeowner incomes in periods 0 and 1, respectively; $p_0(X_0)$ and $p_1(X_1)$ represent the energy service costs in periods 0 and 1, respectively, dependent on housing quality. If housing quality increases, the cost of one unit of comfort related to energy consumption decreases. In terms of energy efficiency, an improvement in housing quality leads to a lower energy service cost. We assume that the cost function is a linear function, such that f is the maximum amount of energy expenditures when housing quality is equal to zero; it represents the maximum amount that a household can pay in the absence of energy efficiency. The parameter ξ is the sensitivity of the energy service cost to investments; it also measures the sensitivity of energy savings to energy prices. If energy prices rise, the savings in energy costs due to renovation should be higher. Therefore, we set:

$$p_t(X_t) = -\xi X_t + f \ . \ (4)$$

We can write the homeowner problem as:

$$\max_{C_0^e, C_0^{ne}, C_1^e, I_0^L} U(C_0^{ne}, C_0^e, I_0, C_{1,}^{ne} C_1^e) = \ln(C_0^e C_0^{ne}) + \beta \ln(C_{1,}^{ne} C_1^e), \ (5)$$

where β is the utility discount factor. We have a two-period planning problem. Using the first-order conditions (Appendix A), we derive four equations with four unknowns. By solving this program, we obtain solutions for C_1^e, C_0^{ne}, C_0^e, and I_0:

$$I_0 = \frac{2fr(r+2)(\beta+1) + \left((2X(\beta+1)(\delta-1) - \mathrm{R}_0\beta)r^2 + (4X(\beta+1)(\delta-1) - 2\mathrm{R}_0\beta)r - \beta(\mathrm{R}_0 + X - X\delta)\right)\xi}{r(r+2)(\beta+2)\xi}, \ (6)$$

$$\mathrm{C}_1^{\mathrm{e}} = \frac{r(r+2)}{(r+1)\xi}, \ (7)$$

$$\mathrm{C}_0^{\mathrm{Lne}} = \frac{-\frac{fr(r+2)}{(r+1)^2\xi} + \mathrm{R}_0 + X - X\delta}{\beta+2}, \text{ and } (8)$$

$$C_0^{Le} = \frac{(r+1)^2(R_0 + X - X\delta)\xi - fr(r+2)}{(r+1)^2(\beta+2)\xi(f - X\xi)}. \quad (9)$$

The homeowner's investment depends on initial housing quality, income and income return rate, the depreciation factor, discount rate, and energy cost parameters (ξ and *f*). We provide some sensitivity analyses in the next section.

The consumption of both energy goods and non-energy goods is an increasing function of income. Non-energy good consumption depends positively on initial housing quality: Higher initial housing quality leads to a lower cost of energy good services, leaving more income available for non-energy goods.

3.2. Sensitivity analysis

The discount rate β is set to 0.99. The depreciation rate δ and rate of return *r* both are set to 0.05. Using French data, we can calibrate the model. The main challenge is to measure housing quality from an economic point of view. We therefore adopt a hedonic approach (for a detailed description of this methodology, see Gourieroux and Laferrere, 2009) and use average housing prices to appraise dwelling quality, such that an increase in quality (e.g., better insulation) increases housing prices. In 2006, the average price of existing homes was 181,066 euros (INSEE, 2010), and the average area was 90 square meters.

We also need to define domestic energy service costs, depending on the energy label. To determine dwelling quality, we refer to French energy labels, introduced in 1995 to provide consumers with information about the energy quality of a dwelling. A very efficient dwelling is classified A (< 50 kWh_{ef}/m^2 /year); an inefficient dwelling would earn a classification of G (> 450 kWh_{ef}/m^2 /year). In France, average energy consumption is 195 kWh_{ef}/m^2 /year (or D). Energy costs average 0.0967 euros per kWh, which indicates 1697 euros for a dwelling of average size and average consumption. Renovations (e.g., wall and roof insulation, improved heating systems) that improve energy efficiency enough to move the dwelling into a higher label classification cost 12,000 euros. After such a renovation, the energy cost decreases to 0.0812 euros per square meter. Using Equation (4), we thus compute ξ and get $\xi = 0.05$, so f is equal to 10750, as we summarize in Table A-I in appendix. We summarize our results with Figures 1 and 2.

With regard to building characteristics, we find that greater energy efficiency of a dwelling leads to lower investments—an unsurprising result. Households invest only when their housing units offer poor energy quality; they invest more if the depreciation factor is high, because of the impact of the dwelling on energy cost. That is, a higher depreciation factor increases the energy service cost, which leads to a higher investment, so that the household can receive the greater benefits of its investment. The results also show that the more a household is concerned about the future (larger β), the higher is its level of investment. For income, we find a surprising result, in that greater income leads to lower investments. However, in France, high income households also live in the best insulated dwellings (larger X), so energy efficiency investments are less necessary. Finally, energy service cost parameters are key variables. The greater the sensitivity of the energy service cost to investment (ξ), the lower the investment. But if energy costs in the absence of energy quality are high, as is the case in the oldest and least insulted dwellings, investments increase. For investments to occur, energy service costs must be high. In terms of energy efficiency, these results highlight the importance of energy costs and the profitability of investments as determinants of the decision to invest. In terms of the consumption of energy goods, we note that when housing quality is good and income is high, the level of energy consumption is high too. Thus, if the consumption of energy service become cheaper, it increases. This result suggests a potential rebound effect in energy goods consumption after investment.

Figure 1: Sensitivity analyses: investment

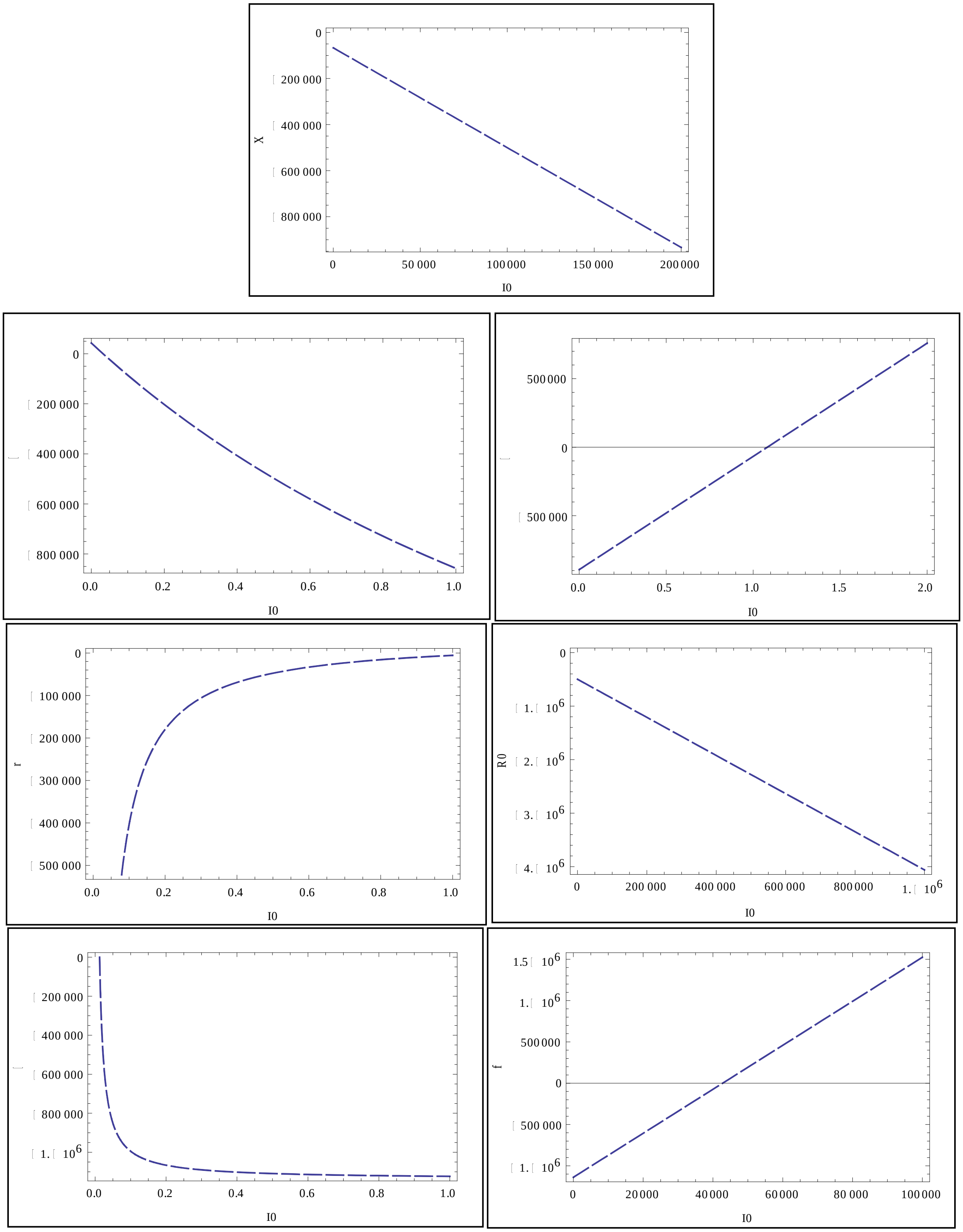
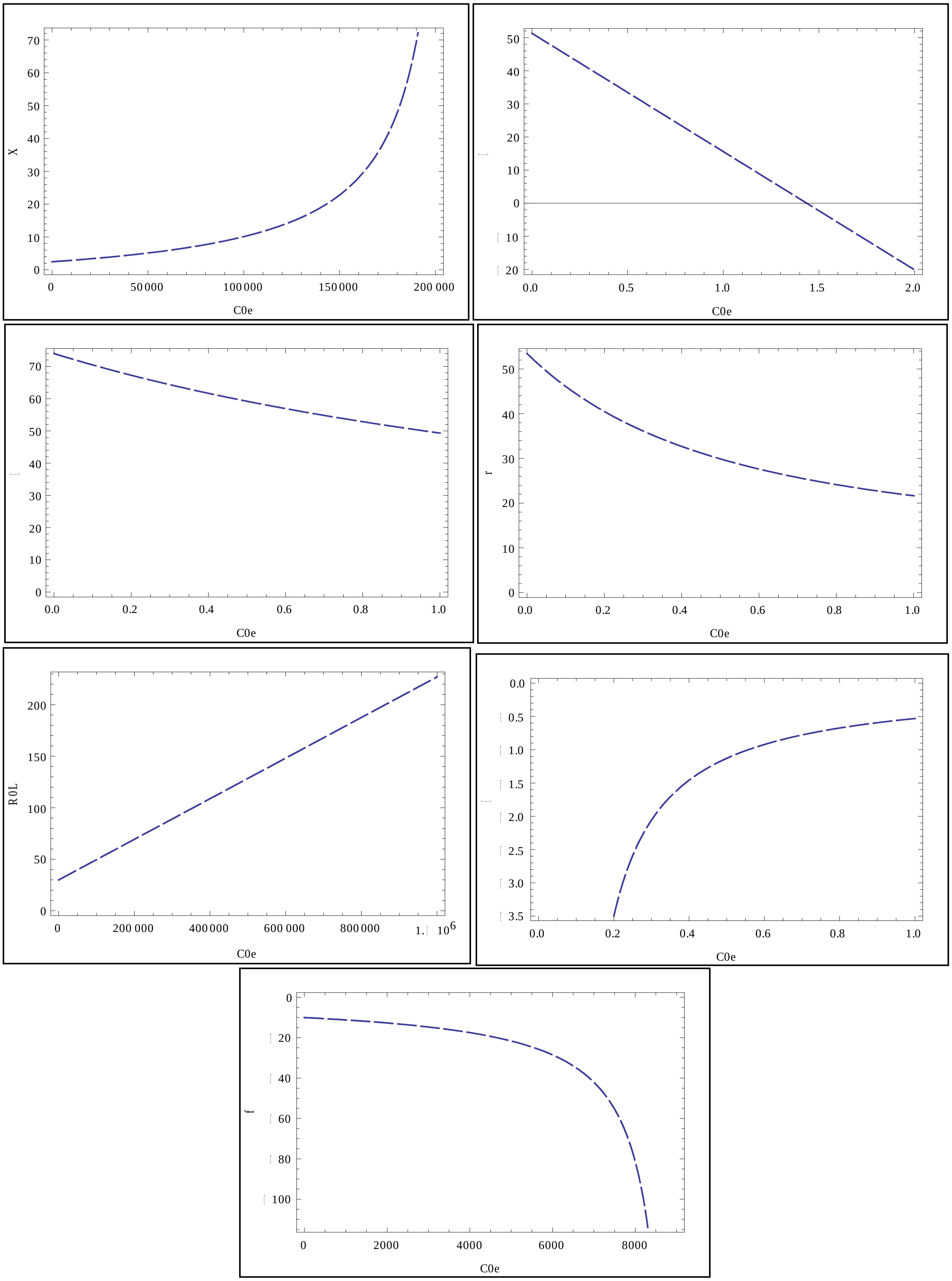


Figure 2: Sensitivity analyses: energy good consumption



4. Data, Variables, and Descriptive Statistics

4.1. Data

We use the *2006 Enquête Logement*, a disaggregated, household-level survey data set provided by INSEE. We also use the "*travaux*" database. By merging these two surveys, we obtain information about 22,228 households, related to the living space, heating systems, household information, geographical conditions, and renovation works. This study distinguishes between energy efficient works (EEW) and repair works (RW) and considers eight types of energy-saving renovations (see Table D-I in appendix), following the definitions provided by the *Observatoire Permanent de l'amélioration Energétique du logement* (OPEN): double-glazing, roof insulation, wall insulation, floor insulation, mechanical ventilation, new heating system, new hot water system, and chimney. These renovations can be grouped into two modalities according to OPEN: improvement of insulation (double-glazing, roof insulation, wall insulation, and floor insulation) and replacement or introduction of equipment (mechanical ventilation, new heating system, new hot water system, and chimney).

However, this database contains no information on energy expenditures before or after renovations, so we needed to create new variables. Thus, 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; see Appendix B), period of construction (five periods), type of glazing (double or not), type of roof insulation (good, intermediate, bad), ventilation system (mechanical ventilation [MV] or not), and main type of fuel used (electricity, gas, oil). The choice of these categories reflected our effort to merge the databases subsequently. We summarize the categories in Table C-II and present the relevant statistics in Table C-II in appendix C.

For each category, we compute annual energy expenditures per square meter for heating and domestic hot water (subscription included). We obtained 2160 simulations before 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). An example of the simulation is presented in Appendix C-III.

This step was not trivial; it led us to eliminate part of the sample. The descriptive statics, taken before and after this merging process, revealed that the representativeness of the sample was not affected, so it was not necessary to weight the sample. The final sample contains 16,780 households. We compared our results against households' energy expenditures, available in the database before renovation, and provide the results of this comparison of energy expenditures using software estimations with energy expenditures available in the database in Table C-IV in appendix C.

4.2. Dependent variables

A list of variables is available in Table C-V in appendix C. We study the determinants of investments in energy-efficient systems in 2006 and the amount of household expenditures on renovations, distinguishing between reparation works (RW) and energy efficiency works (EEW) and specifying EEW as the improvement of insulation works (IIW) and equipment replacement works (ERW). Expenditures are gross amounts, because it is not possible to determine the amount of public support households receive. For RW, IIW, and ERW, a significant proportion of households show zero expenditure (about 88%). The sample therefore mixes observations with many zeros and some strictly positives values, a trait we address subsequently. In the analysis, households that undergo IIW renovations spend 6245 euros, those that undertake ERW spend 5936 euros, and RW households spend 6201 euros, on average (see Table C-VI in appendix C for more renovation expenditure statistics).

4.3. Independent variables

4.3.1. Socioeconomic characteristics of households. As socioeconomic characteristics, we include income quintile, degree level, age classes, and occupation tenure. Income quintile and degree level together account for experience effects, sensitivity to investments, and household technical skills. On average, expenditures for energy-efficient renovations tend to be higher when members of the households have more education. Moreover, job tenure seems important, because renovations usually are realized by homeowners. If renter occupancy discourages energy-efficient investments, it could discourage other investments as well, such as improved maintenance. Finally, middle-aged people (30–49 years) spend more on renovations, compared with elderly households (65 years or older), and exhibit a lower mobility rate than young people, such that they should spend more (Rehdanz, 2007).

4.3.2. Characteristics of buildings and number of renovations. To study the decision to invest in energy-efficient renovation and the amount of expenditures, we account for building characteristics (housing quality), including the period of construction, type of housing (individual units vs. collective buildings), the climate, and the average surface area of the housing units. We also introduce the square of the average surface area, to capture a nonlinear effect. The age of the house could influence the existing building insulation. In addition, older houses may be in physically or aesthetically poor conditions. Descriptive statics suggest that energy-efficient renovation expenditures are higher in the coldest zone (zone 1; see Appendix B). Furthermore, in

France, collective dwellings (e.g., apartment buildings) share collective heating systems, with energy bills divided among all residents of the building, contingent on the shares allocated when they purchased their dwelling. The cost of excess energy consumption is borne by all residents. These residents also vote on collective topics, such as energy-saving measures, at owners' meetings. Finally, to determine the amount spent by households, we introduce the number of renovations and its square value into the model.

4.3.3. Energy savings and cost–benefit analyses. Previous theoretical results suggest it might be interesting to analyze the energy service cost and potential energy savings from the decision to invest in energy-efficient systems. Grösche and Vance (2009) show that renovation decisions are essentially driven by two determinants, investment costs and savings from reduced energy usage. Yet households also might not invest in energy-saving measures, even when they would save money, because of the energy paradox. Once they decide to invest, households run a cost–benefit analysis to choose the most efficient measure. That is, they compute the cost of investment for each type of renovation, according to the OPEN data (see Table C-VII). The costs differ for renovations carried out by a hired company and those performed by the households themselves; the total cost is the sum of equipment and labor. Thus, we use two different methods to introduce the cost–benefit analysis into the model and test for the impact of investment profitability on the amount of energy-efficient expenditures. We also acknowledge that households may be more sensitive to the size of energy savings (short term) rather than investment profitability (long term).

First, we consider the difference in energy expenditures before and after the renovation. Accordingly, Method 1 relies on simulation software and provides information about theoretical expenditures before and after renovation. The difference provides the value of the energy savings for a specific type of renovation. Second, Method 2 reflects each household's energy expenditures, such that we obtain effective energy consumption before renovation. By combining both methods, we can compute two kinds of energy savings:

1. Theoretical energy expenditures before renovation minus theoretical energy expenditures after renovation (Method 1).
2. Effective energy expenditures before renovation (available in the database) minus theoretical energy expenditures after renovation (Method 2).

The binary variables created to reflect these calculations take a value of 1 if the investment is profitable (net present value is positive).

To avoid comparing annual energy saving against a one-shot total cost, we discounted the expected benefit to obtain a present value (PV):

$$PV_{it} = \sum_{t=1}^{T_k} \frac{G_{it}}{(1+\phi)^{T_k}}, \qquad (10)$$

where ϕ is the market long-term interest rate, and T_k is the average life time of equipment. It thus becomes possible to compare the total investment cost to the PV of the benefits. To compute the PV, we used constant energy prices and energy costs.

The investment profitability of a household is difficult to appraise for several reasons. First, varying expectations of future energy prices result in varying expectations of the profitability of renovation. Second, hidden costs (e.g., noise during the renovation) and benefits (e.g., integrating the value of investment into the selling price) affect this probability. Unfortunately, data on hidden costs and benefits are not available, so we cannot account for them in the profitability analysis.

Energy savings are higher for IIW than for RW. The PV is higher in renovated dwellings. Generally, the cost–benefit analysis thus suggests that IIW are more profitable than RW, though computing the net PV for each type of renovation implies that many energy-efficient renovations are profitable. In the sample, nearly 50% of households renovated their dwelling themselves, yet profitable outcomes, according to the cost–benefit analysis, were more widely available to non-renovated dwellings. That is, many households would have benefited from renovations but decided not to renovate in 2006 (nearly 50%), a potential indicator of the energy paradox.

Next, we compared households with a profitable cost–benefit analysis that undertook energy-efficient renovations with those for which the cost–benefit analysis would have led to profitable investments but that did not undertake renovation works (see Table C-VIII), to explain this potential energy paradox. Households with a profitable cost–benefit analysis that did not undertake energy savings renovations in 2006 belong to the first income quintile, are tenants, and live in collective buildings. Moreover, they are either young or retired and generally unemployed. Finally, they express strong mobility desires (willingness to change housing units). These descriptive statics suggest two findings. First, households might not renovate due to market barriers, such as capital access, or due to the existence of split incentives, which verifies the energy paradox. Second, households may not have an incentive to invest because they prefer to remain mobile, and their expected tenure is not sufficient to make their energy-saving investment profitable.

5. Model

The data analysis is complex in two ways. First, about 88% of households reported no expenditures on renovations, so estimating a linear regression induces computational complexities. If we consider three categories of renovation, the shares of households that reported no renovations were 82.7% for RW, 96.94% for IIW, and 98.59% for ERW. We therefore applied a Tobit regression (Tobin, 1958 ; see also 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 three expenditure types. The econometric model that can account for censoring and interdependence is a multivariate Tobit model (Amemiya, 1974 ; Maddala, 1983), which extends the single regression model with the censored normal dependant variable. With a multivariate Tobit model, it is possible to estimate the expenditures in RW and in EEW, while still taking into account interdependence across the three types of renovations. Similar to Amemiya (1974), we define an n-dimensional vector of random variables $y_i = (y_{1i}, y_{2i}, y_{3i})$ by:

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

$$y_i = 0 \quad \text{if} \quad Ax_i + u_i \leq 0 \;\; (i = 1, 2, .., N) \text{,} \qquad (11)$$

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_i is $n-$ dimensional $N(0, \Sigma)$ and temporally independent. We assume Σ is positive definite. An alternative extension would define y_{it} for each i (households) by:

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

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

$$y_{i2} = \alpha_{i2}^{'} x_2 + u_{i2} \quad \text{if} \quad \alpha_{i2}^{'} x_2 + u_{i2} > 0 \text{,} \qquad (12)$$

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

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

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

where $i = 1, 2, ..., n,$ and y_{i1} , y_{i2} , and y_{i3} are 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 distributed with variances of σ_1^2, σ_2^2, and σ_3^2, where u_{i1}, u_{i2}, u_{i3} : $N(0,0,\sigma_1^2,\sigma_2^2,\sigma_3^2,\rho_{12},\rho_{13},\rho_{23})$, and the covariance is given by $\sigma_{1,2,3}^2 = \rho\sigma_1^2\sigma_2^2\sigma_3^2$.

Multivariate Tobit estimates of the three-equation Tobit models rely on maximum simulated likelihood. Only models left-censored at zero can be estimated. Along with the coefficients for each equation, the multivariate Tobit approach estimates the cross-equation error correlations and the variance of the error terms. To estimate the multivariate Tobit model, we used the Geweke-Hajivassiliou-Keane (GHK) simulator, which computes, for each observation and each replication, a likelihood contribution. The simulated likelihood contribution is the average of the values derived from all replications. The simulated likelihood function for the whole sample then can be maximized using standard methods (i.e., maximum likelihood). Greene (2003) offers a brief description of the GHK smooth recursive simulator. The number of pseudo-random standard uniform variants drawn to calculate the simulated likelihood is 150.

6. Results

Before choosing the multivariate Tobit framework, we compared Tobit univariate results with those of the two-part models. In the two-part model, we distinguish the decision to invest and the amount of expenditures, assuming that these two decisions are independent. The zero and positive values are generated by the same process, so two-part models are not well-suited. We also compared our results with those of a selection model, which assumes that the two parts in the model are not independent. However, in a selection 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. The results of the multivariate Tobit model also can be compared with those obtained using univariate Tobit models. These results are available in Appendix D. All estimations are corrected for the heteroskedasticity problem (see Hurd (1979) ; Nelson (1981)).

We also controlled for multicollinearity by introducing several multiplied dependent variables as regressors (e.g., income, education) to account for their potential correlation. Using a likelihood ratio test with and without multiplicative variables, the null hypothesis was not rejected, so we prefer models that exclude them. In an estimation without income quintiles (Appendix D Tables D-V), the results did not change. We therefore conclude there was no multicollinearity problem between income quintiles and degree levels.

We again used a likelihood ratio test to examine the statistical significance of the model, according to the null hypothesis that all slope coefficients are 0. The χ^2 statistics for estimations (928.47, 810.02, 923.9, and 810.2) indicate the rejection of the null hypothesis. For the test of the interdependence of the three expenditure types, we applied a t-test likelihood ratio, which constrains the correlation coefficients among error terms ($\rho_{IIW,ERW}$, $\rho_{ERW,RW}$, and $\rho_{IIW,RW}$) in the three expenditure equations to 0 when a univariate model is used. The t-value for the estimates of $\rho_{IIW,ERW}$, $\rho_{ERW,RW}$, and $\rho_{IIW,RW}$ were significant at the 1% level, so each null hypothesis can be rejected. Regarding the null hypothesis of the independence of renovation work expenditures, we used a log-likelihood ratio test in which the restricted model forces off-diagonal covariance matrix terms to equal 0. The resulting χ^2 statistics were statically significant, so we reject this null hypothesis. The test results affirm that the data should be analyzed in a multivariate Tobit setting.

6.1. Socioeconomic characteristics of households

The more education households possess, the more they spend on energy-efficient renovations, consistent with Nair *et al.* (2010) and Poortinga *et al.* (2003). People without higher education who spend money for energy-efficient renovations tend to work in manual occupations. Thus, the presence of a technically skilled person in the home may influence investment expenditures, because they likely have a good understanding of new technologies and may be able to perform installations themselves. However, income quintiles are not significant for determining energy-efficient expenditures; income quintiles 1 and 2 appeared negatively and statistically significant at the 1% level for repair works. Although this result differed slightly from the theoretical predictions, it should not be surprising, in that high income households already live in the best insulated dwelling, so they can only perform repair works. In Table D-VI we present the results with income quintile as the only explicative variable, and the effect is strictly the same as in the complete estimations. Expenditures indicate gross amounts, including public aid granted to households to encourage energy-efficient renovations, which might explain the lack of expenditure differences across income quintiles for energy-efficient renovations; this is not the case for repair works. Overall, high income households are more likely to improve their homes (Montgomery, 1992).

When a housing unit is owner occupied, it significantly and positively affects energy-efficient expenditures and reparation expenditures. Tenure is not significant for determining replacement expenditures though. In France, landlords are required to change equipment in rented housing units if they suffer a breakdown or dysfunction, which may explain this lack of effect. 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), Davis (2010), and Meier and Rehdanz (2010). Policy interventions also appear required (Burfurd *et al.*, 2012). From a policy perspective, landlords might be obligated to rent only dwellings with a preset level of energy quality. Another explanation for why tenants might not invest is that their expected length of tenure is not sufficient to make their energy-saving investment profitable. This result is line with our theoretical predictions. When people are more concerned about the future, they invest more.

Contrary to what the descriptive statics suggested, age had no effect on energy-efficient expenditures. These results are different from those offered by Mahapatra and Gustavsson (2008) and Rehdanz (2007). The number of homeowners is greater in this class, so the econometric estimates underline that energy-efficient investments are not determined by age. Moreover, with a life cycle approach, earners save more during their middle age than any other time, such that they can spend more on energy-efficient systems (Mendelsohn, 1977). Unfortunately, the amount of savings is not available, so we cannot test this rationale.

6.2. Characteristics of buildings

Energy-efficient renovation expenditures are higher in the coldest zone (zone 1); expenditures for repair works are higher in climate zone 3. The coefficient of average surface area is positive and statistically significant, but that of 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.

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

The coefficient for the construction period is positive and significant for insulation works. Households spend when they live in the oldest and least insulated housing units, consistent with Nair *et al.*'s (2010) finding that households in buildings more than 35 years old were more likely to undergo a major renovation (e.g., replacing external walls). These results are also consistent with our theoretical findings. The lower the energy quality of the dwelling, the higher the investment. With regard to RW, 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. Finally, the number of renovation works had a significant, positive effect, whatever their type. But the square of the number of renovations was negative and statically significant, especially for RW. Thus, expenditures first increase with the number of renovations, then decline after a peak, which may reflect two explanations. First, the marginal cost of renovation decreases with the amount of renovations undertaken. Second, households prefer to make several, less costly renovations.

6.3. Energy savings and cost–benefit variables

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). Moreover, this result is robust across both our theoretical and effective energy expenditure methods for computing energy savings. Households paid particular attention to the sensitivity of the energy service cost to their investment. The greater the energy savings, the more they spent on energy-efficient investments. However, the coefficient of the cost–benefit analysis for energy efficiency was not significant. Households may simply prefer investments that lead to greater energy savings or investments that offer immediate returns. This result also suggests that the net present value rule has to be changed. The usual explanation of the energy paradox based on the existence of an option value seems valid. Moreover, as we expected, a household's profitability investment is difficult to calculate, due to hidden costs and benefits. Therefore, preference heterogeneity across renovation attributes might exist and explain this result but remain hidden to us.

Generally, few variables are significant for replacement works. The database contains no information about possible breakdowns or dilapidated materials. We cannot specify which proportion of replacement works were in response to a breakdown. This gap could explain why replacement expenditures are globally more difficult to explain than other types of renovations. If equipment gets changed because of a breakdown, financial incentives by governments might trigger more efficient equipment replacements.

Finally, from a policy perspective, government can reduce barriers by communicating information about the losses incurred by households that fail to adopt energy-efficient investments. Brounen and Kok (2011) show that the information provided by energy labels may encourage energy conservation in the housing sector. Information focusing on economic savings might be less effective than information stressing losses, because households prefer to avoid a loss more than they seek to achieve gains (Kahneman and Tversky, 1979).

7. Conclusion

Energy efficiency in the housing sector can help reduce GHG emissions. Our main objective with this study has been to analyze household renovation expenditures by distinguishing energy efficiency works from repair works. In particular, we sought to determine if households decide to invest according cost–benefit analyses or if other factors have more substantial effects, using both theoretical and empirical assessments. This article contributes to literature on energy-saving investments, environmentalism, and consumer choice. In particular, we extend the *2006 Enquête Logement* database by introducing data about the energy savings realized through renovations. In addition, we examined renovation expenditures with a multivariate Tobit model, to account for expenditures that are censored at zero and that may be interdependent across expenditure types. We find in general that socioeconomic characteristics of households and building characteristics are determinants of energy-efficient investments, but so are potential energy savings. We confirm this result both theoretically and empirically. Overall, the greater the energy savings, the more households spend on energy-efficient investments. However, investments in energy efficiency and repair do not share the same determinants. Repair works take place in new housing units and well-insulated dwellings, likely after an equipment breakdown. From a policy perspective, financial incentives by government could trigger more efficient equipment replacements. The number of renovations for energy efficiency remains relatively low (around 4%), even if the net present value is positive, which suggests the presence of the energy paradox. It would be rational for households to invest in energy-saving measures, but they largely do not. We interpret this underinvestment as a result of market barriers or mobility desires.

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Appendix A. Model and first-order conditions

$$\frac{\partial U}{\partial C_1^e}=\frac{b\left(\frac{I_0+X(1-d)}{r+1}-C_1^e(f-(I_0+X(1-d))x)+C_1^e((I_0+X(1-d))x-f)+(r+1)(-C_0^{ne}-I_0+R_0-C_0^e(f-Xx))\right)}{C_1^e\left(\frac{I_0+X(1-d)}{r+1}-C_1^e(f-(I_0+X(1-d))x)+(r+1)(-C_0^{ne}-I_0+R_0-C_0^e(f-Xx))\right)}=0$$

$$\frac{\partial U}{\partial C_0^e}=\frac{(r+1)b(Xx-f)}{\frac{I_0+X(1-d)}{r+1}-C_1^e(f-(I_0+X(1-d))x)+(r+1)(-C_0^{ne}-I_0+R_0-C_0^e(f-Xx))}+\frac{1}{C_0^e}=0$$

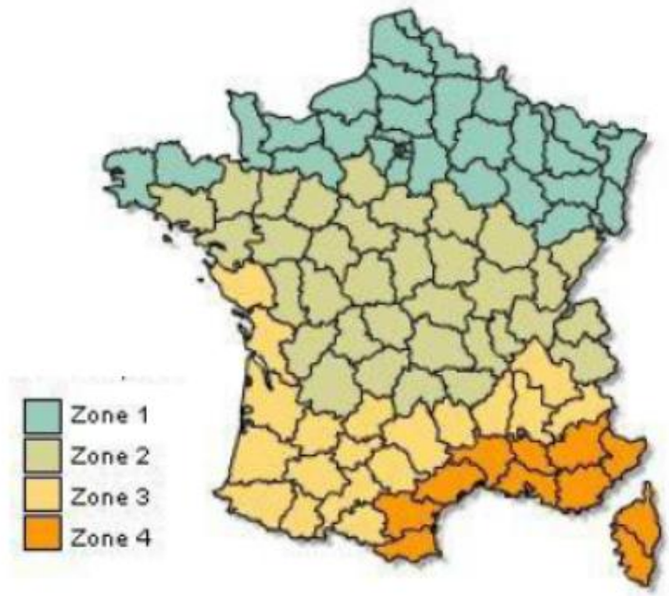
$$\frac{\partial U}{\partial C_0^{ne}}=\frac{(-r-1)b}{\frac{I_0+X(1-d)}{r+1}-C_1^e(f-(I_0+X(1-d))x)+(r+1)(-C_0^{ne}-I_0+R_0-C_0^e(f-Xx))}+\frac{1}{C_0^{ne}}=0$$

$$\frac{\partial U}{\partial I_0}=\frac{b\left(-r+C_1^e x+\frac{1}{r+1}-1\right)}{\frac{I_0+X(1-d)}{r+1}-C_1^e(f-(I_0+X(1-d))x)+(r+1)(-C_0^{ne}-I_0+R_0-C_0^e(f-Xx))}=0$$

Table AI: Calculation of energy price sensitivity to investment

Housing Quality X	Energy Consumption in kWh_{ef}/m^2/Year	Energy Cost in €/m²/Year	Total Energy Cost (euros)	ξ
181,066	195	0.0967	1697	
193,066	150	0.0812	1096	0.05

Appendix B. French climate zones



Appendix C. Data, variables and descriptive statics

Table C-I: Different renovation types

Type	Description
Energy efficiency works (EEW)	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 C-II: Housing stock categories

	Individual Housing Units	Collective Buildings
Type of fuel	Electricity, gas, oil	Electricity, gas, oil
Climate zone	Four zones (1 is the coldest)	Four zones (1 is the coldest)
Periods of construction	Five periods (before 1974, 1975–1981, 1982–1989, 1990–2001, after 2002)	Five periods (before 1974, 1975–1981, 1982–1989, 1990–2001, after 2002)
Glazing	Double or simple glazing	Double or simple glazing
Ventilation	Mechanical ventilation or not	Mechanical ventilation or not
Roof insulation	Good, intermediate, bad	Good, intermediate, bad
Type of heating		Individual for one dwelling, or collective and common for the building
Number of categories	720	1440
TOTAL		2160

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

Information available in the *2006 Enquête Logement* database, regarding the type of fuel, climate zone, periods of construction, roof insulation, double glazing, ventilation systems, and type of heating, was used to perform the simulations. 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. 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-III: 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-IV: Comparison of energy expenditures

	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)
1974–1981	18.5	21.9	14.6	14.4	15.1	14.8	19.3	9.4	9.1	9.5
	(1871)	(1012)	(859)	(693)	(166)	(1871)	(1012)	(859)	(693)	(166)
1982–1989	20.5	22.2	17.3	16.6	19.9	16.5	19.0	11.7	11.7	11.9
	(1547)	(1007)	(540)	(432)	(108)	(1547)	(1007)	(540)	(432)	(108)
1990–2001	18.2	20.1	14.8	15.1	13.8	15.4	18.2	10.5	10.4 (796)	11.0
	(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										
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)
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)
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)
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)

Notes: Number of observations are in parenthesis.

Table C-V: 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			
Socioeconomic characteristics of households			
Degree level		Binary variable introduced for each degree level (5 modalities)	
No qualification	Ref	Households with no qualification	0/1
Inferior to baccalaureate	Infbac	Households qualification inferior to baccalaureate	0/1
Baccalaureate	Bac	Households with baccalaureate	0/1
Two years after baccalaureate	Bac+2	Households with two years post-baccalaureate	0/1
Superior to baccalaureate after two years	Supbac+2	Households with more than two years post-baccalaureate	0/1
Income quintile	Quint	Binary variable for each income quintile (5 quintiles)	0/1
Age			
Less than 30 years	Bef30	Households with persons aged less than 30 years	0/1
30–39 years	30-39years	Households with persons aged 30–39 years	0/1
40–49 years	40-49years	Households with persons aged 40–49 years	0/1
50–64 years	50-64years	Households with persons aged 50–64 years	0/1
Older than 65 years	Ref	Households with persons aged more than 65 years	0/1
Tenure	Homeowners	Binary variable introduced for homeowners	0/1
Characteristics of buildings			
Periods of construction		Binary variables are introduced for each period of constructions	0/1
Before 1974	Bef1974	Dwelling constructed before 1974	0/1
1974–1981	1974-1981	Dwelling constructed between 1974 and 1981	0/1
1982–1989	1982-1989	Dwelling constructed between 1982 and 1989	0/1
1990–2001	1990-2001	Dwelling constructed between 1990 and 2001	0/1
After 2002	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	Ref	Households in climate zone 4	0/1
Individual housing unit	Indhousing	Households in an individual housing unit	0/1

Variables	Name	Definitions	Units
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 and cost–benefit variables			
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 C-VI: Renovation expenditures in euros and building characteristics

Variables	Means of Expenditures (euros)			
	EEW	IIW	ERW	RW
Socioeconomic characteristics of households				
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)*
Age				
Less than 30 years	7053 *(60)*	7835 *(44)*	4655 *(20)*	6998 *(235)*
30–39 years	6150 *(140)*	6418 *(105)*	5573 *(45)*	5279 *(504)*
40–49 years	6508 *(170)*	6974 *(131)*	5332 *(53)*	7156 *(507)*
50–64 years	5741 *(179)*	4891 *(133)*	7452 *(62)*	5876 *(607)*
Older than 65 years	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)*
1974–1981	6226 *(65)*	7758 *(44)*	3759 *(25)*	5036 *(258)*
1982–1989	7500 *(76)*	7533 *(54)*	6436 *(27)*	5399 *(222)*
1990–2001	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)*
Means	**6169 *(687)***	**6245 *(513)***	**5936 *(236)***	**6224 *(2307)***

Notes: The number of observations are in brackets. Households without qualification that invest in energy-efficient renovations spent 6181 euros on average.

Table C-VII: Energy savings, total cost, and consumption by type of renovation

		Improvement of Insulation				**Replacement of Equipment**				**Total**
		Glazing	Wall	Roof	Floor	MV	Chimney	Heating	Hot water	
Cost–Benefit Analysis										
Life of equipment		35	30	35	30	30	10	16	15	
PV 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
PV 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 without labor force	(6)	3705	6237	2059	2869	2204	2592	2593	1274	3178
Comparison PV/Cost	Comparison (1) vs. (5)	+	-	-	-	-	-	+	+	
	Comparison (3) vs. (5)	+	+	+	-	+	-	+	+	
Cost benefit analysis (1) vs. (6)	Sample means (%)	83.7*	93.6	90.9	47.3	50.9	26.8	89.1	88.5	51.37
Method 1	Renovated dwelling (%)	83.5**	96.7	92	48.6	40.9	60.9	16.3	85.8	81.35
Cost benefit analysis (3) vs. (6)	Sample means (%)	68.9	69.3	65.0	45.0	46.8	28.8	60.9	61	68.8
Method 2	Renovated dwelling (%)	71.7	72.2	58.0	51.4	78.3	25.6	56.8	56.3	69.1
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
Energy Savings										

		Improvement of Insulation				Replacement of Equipment				Total
		Glazing	Wall	Roof	Floor	MV	Chimney	Heating	Hot water	
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	1,7	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

Notes: PV = present value.

*The cost–benefit analysis is profitable in 83.7% of dwellings.

**The cost–benefit analysis is profitable in 83.5% of renovated dwellings.

Table C-VIII: Households and the energy paradox

	Renovated Housing Units, Profitable Cost–Benefit Analysis 1	Not Renovated Housing Units, Profitable Cost–Benefit Analysis 1	Repartition of Households with Profitable Cost–Benefit Analysis 1
Income			
Quintile 1	19.15 %*	20.46 %	20.36 %
Quintile 2	19.52 %	19.91 %	19.88 %
Quintile 3	20.07 %	19.98 %	19.99 %
Quintile 4	22.28 %	20.58 %	20.71 %
Quintile 5	18.97 %	19.07 %	19.06 %
Tenure			
Homeowners	54.14 %	48.3 %	51.31 %
Tenants	45.86 %	51.7 %	48.69 %
Type of dwelling			
Individual housing units	44 %	27.77 %	28.81 %
Collective buildings	55 %	72.23 %	71.19 %
Age			
Less than 30 years	8.29 %	12 %	11.36 %
30–39 years	19.52 %	22.13 %	21.94 %
40–49 years	26.23 %	21.51 %	21.78 %
50–64 years	27.54 %	24.78 %	24.92 %
Older than 65 years	18.42 %	19.58 %	20 %
Labor Market			
Employed	61.88 %	58.96 %	59.18 %
Unemployed	38.12 %	41.04 %	40.82 %
Mobility desire			
With the mobility desire	30.94 %	39.50 %	38.86 %
Without the mobility desire	69.06 %	60.50 %	61.14 %

*19.15% of households with a profitable cost–benefit analysis who undertake energy-efficient renovations belong to the first income quintile.

Appendix D. Estimation results

Table D-I: Univariate and multivariate models with energy savings using Method 1

Variables	Univariate Models			Multivariate Model		
	LexpIIW	LexpERW	LexpRW	LexpIIW	LexpERW	LexpRW
Socioeconomic 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 and number of renovation works						
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)
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)
Energy savings and cost–benefit variables						
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_i^b=0 $\chi^2(77)$=928.47		

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

Table D-II: Univariate and multivariate models with cost-benefit analysis using Method 1

Variables	Univariate Models			Multivariate Model		
	LexpIIW	LexpERW	LexpRW	LexpIIW	LexpERW	LexpRW
Socioeconomic 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 and number of renovation works						
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)
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)
Energy savings and cost–benefit variables						
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 $B_i^b=0$ $\chi^2(81)=810.02$	

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

*Significant at 10%.

**Significant at 5%.

***Significant at 1%.

Table D-III: Univariate and multivariate models with energy savings Method 2

Variables	Univariate Models			Multivariate Model		
	LexpIIW	LexpERW	LexpRW	LexpIIW	LexpERW	LexpRW
Socioeconomic 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 and number of renovation works						
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**(5.5e-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)
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)
Energy savings and cost–benefit variables						
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)	

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

Table D-IV: Univariate and multivariate models with cost–benefit analysis using Method 2

Variables	Univariate Models			Multivariate Model		
	LexpIIW	LexpERW	LexpRW	LexpIIW	LexpERW	LexpRW
Socioeconomic 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 and number of renovation works						
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)
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)
Energy savings and cost–benefit variables						
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	

Notes: Robust standard errors are reported between brackets. These variables are defined in Table VI. The null hypothesis B_j = 0 serves to test the explanatory power of the model. In the restricted model, all coefficients are set to 0 except the intercept terms and covariance matrix elements.

*Significant at 10%.

**Significant at 5%.

***Significant at 1%.

Table D-V: Multivariate models with energy savings using Method 1 without income quintile variables

Variables	Multivariate Model		
	LexpIIW	LexpERW	LexpRW
Infbac	1.552*(0.878)	1.159(1.329)	1.291**(0.426)
Bac	-1.003(1.251)	0.0475(1.829)	0.551(0.550)
Bac+2	2.743**(1.211)	-0.0478(2.018)	0.770 (0.633)
Supbac+2	1,319(1.109)	3.305*(1.582)	
Quint1	-	-	-
Quint2	-	-	-
Quint3	-	-	-
Quint4	-	-	-
Bef30	0.136(1.300	0.843(1.875)	-0.166(0.659)
30-39 years	0.0395(0.980)	-0.564(1.553)	1.081**(0.495)
40-49 years	0.00918(1.003)	1.287(1.412)	1.258***(0.481)
50-64 years	-0.240(0.933)	-1.852(1.444)	0.708(0.462)
Homeowners	1.574**(0.705)	1.735*(1.040)	0.939***(0.339)
Bef1974	3.071*(1.431)	0.158(2.044)	-2.580***(0.616)
1975-1981	2.316(1.657)	0.0640(2.388)	-1.782**(0.737)
1982-1989	0.703(1.714)	1.881(2.352)	-2.818***(0.763)
1990-2001	0.275(1.606)	-0.328(2.275)	-2.920***(0.697)
surface	0.182***(0.0306)	0.233***(0.0343)	0.08 38***(0.0066)
surface2	-0.0003***(0.000111)	-0.0005***(0.0001)	-0.0002***(1 .79e-05)
Climate1	1.828*(1.028)	2.927(1.566)	0.137(0.489)
Climate 2	1.090(1.000)	2.904(1.498)	-0.0982(0.467)
Climate 3	1.803(1.146)	1.687 (1.764)	1.174**(0.529)
Indhousing	1.997***(0.687)	1.754*(1.064)	0.694**(0.321)
NB	0.753***(0.244)	0.829**(0.377)	0.895***(0.122)
NB2	-0.0316µ(0.0201)	-0.0526(0.0310)	-0.0469***(0.00967)
LES1	1.962*** (0.306)	1.839***(0.480)	
Constant	-55.67***(2.834)	-68.12***(3.595)	-22.71***(1.225)
N	16780	16780	16780
Log-likelihood	-17268		
	$\rho_{IIW,ERW}$ = 0.492***(0.036)		
	$\rho_{IIW,RW}$ = 0.437***(0.023)		
	$\rho_{ERW,RW}$ = 0.327***(0.033)		
	H0 independent expenditures $\chi^2(3)$= 502.33		
	H0 Bjb=0 $\chi^2(81)$= 812.93		

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

Table D-VI: Estimation results: multivariate models with only income quintile variables

Variables	Multivariate Model		
	LexpIIW	LexpERW	LexpRW
Quint1	-0.332	-0.652	-2.263***
	(1.032)	(1.558)	(0.482)
Quint2	-1.375	-2.687	-2.738***
	(1.067	(1.649)	(0.493)
Quint3	0.156	1018	-0.465
	(1.033)	(1.143)	(0.473)
Quint4	-0.066	-0.473	-0.712
	(1.033)	(1.555)	(0.473)
Log-likelihood -17560			
	$\rho_{IIW,ERW}$ = 0.524***(0.034)		
	$\rho_{IIW,RW}$ = 0.454***(0.023)		
	$\rho_{ERW,RW}$ = 0.347***(0.032)		
	H0 independent expenditures $\chi^2(3)$ = 590.141		
	H0 Bjb = 0 $\chi^2(81)$= 812.93		

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

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