Energy efficiency investment drivers depend on the technology: implications for policy design and modelling choice

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Abstract

In this empirical paper, we analyze how the drivers and barriers of energy efficiency investments vary with retrofitting types and discuss the implications for policy design and modelling. We use a multinomial logit choice model estimated on microdata over the period 2007/2012 from the French annual survey "Energy Management" (EM) dedicated to households' energy efficiency investments. Retrofitting investments are distinguished between glazed surfaces insulation, opaque surfaces insulation, conventional or innovative (heat-pumps, renewable energy equipment) heating system replacement/installation and multiple-measures retrofit. The model combines both observed households and housing characteristics and subjective answers regarding motivations, circumstances, etc. We first find heterogeneous investment drivers between heating systems and building envelope insulation, especially regarding product lifetime. These results suggest that subsidizing retrofit cannot impact the timing of the decision but only the level of performance in case of investment in heating systems while it can impact both the timing and the level of performance in case of insulation, which have strong implications regarding subsidy efficiency and modelling choice. Secondary distinctions can be made between "conventional" and "innovative" heating systems given the economic profitability, the age of the building, the households' income and their socio professional category. Among other results leading to policy and modelling implications, we also identify specific drivers to multiple-measures retrofitting, such as the opportunities created by recent move-in or access to ownership or the expectations regarding the green value.

Introduction and motivations

Quantitative analysis on energy efficiency investment determinants form a wide body of literature on the energy efficiency gap in the residential sector (see Wilson et al. 2015 for a critical review of this literature). Studies are based on data from specifically designed surveys, such as choice experiment surveys, or from more generalist national surveys. Studies based on choice experiment surveys (Claudy et al. 2011, Michelsen & Madlener 2012, Bigano & Alberini 2014) can focus on the influence of specific choice attributes thanks to subjective answers ("stated preferences") but suffer from the hypothetical bias and are often restricted to certain retrofitting types. An exception is made in Jaccard & Dennis (2006) which compares discount rates estimates for households' investments in insulation and in heating systems and find lower discount rates for heating systems (10 %) than for insulation (20 %). Studies based on national surveys may observe a wider range of retrofitting measures which allows comparative analysis (Charlier 2012, Gans 2012). However, they rarely include stated preferences on investment drivers which limits in-depth analysis. Other studies, as in Grösche & Vance (2009), are based on similar data and focus on policy assessment. They use the differences in retrofitting types to provide heterogeneity between the choice alternatives in order to identify the policy impact. Therefore, they implicitly assume a homogenous policy response among all the retrofitting alternatives.

In this empirical paper, we analyze how the determinants of the investment decision vary with retrofitting categories. These questions regarding drivers' heterogeneity are at stake 1) for policy design and 2) for modelling works. How do heterogeneous drivers impact households' response to the policy? What are the implications in terms of policy design? These questions are related to policy debates on policy "targeting"[1], notably studied by Allcott at al. (2015). Regarding modelling, residential energy-economy models diverge in terms of heterogeneity level and assumed retrofitting dynamics. Defining the extensive margin effect of any driver as the effect on the probability of investing (i.e. on the retrofitting rate) and the intensive margin effect as the effect on the investment intensity level (quality/quantity, e.g. level of performance), some models (Giraudet et al. 2012, Charlier & Risch 2012) assume that economic factors impact both extensive and intensive margins, while others (Allibe 2012) assume that they only impact the intensive margin.[2]

We use micro-data from the French annual survey "Energy Management" (EM) dedicated to residential energy efficiency over the period 2007/2012 to estimate a discrete choice model combining both observed characteristics and subjective answers. The paper adopts a broad perspective dealing with all types of energy-efficient investments. The studied retrofitting types all involve energy efficiency investment, but it distinguishes between conventional energy systems (heating, water-heating and ventilation systems), innovative energy systems (heat-pumps and renewable energy equipment), glazed surfaces insulation, opaque surfaces insulation[3] and "multiple-measures" retrofit. Moreover, contrary to most of choice experiment surveys (Wilson et al. 2015), the EM survey questions do not focus only on the economic aspects of the decision. This is all the more relevant as renovation decisions are intrinsically multi-faceted and can be explained by the interplay of several economic, psychological and sociological factors (Gaspard, Martin, Rozo, 2017).

Results lead to a first distinction between investments in energy systems and investments in building envelope insulation. Drivers such as the opportunities created by recent move-in or access to ownership, other non-energy retrofit and the expectations regarding the green value are more specific to multiple-measures retrofitting. A second distinction can be made between "conventional" systems (boilers, radiators) and "innovative" ones (renewable energy equipment, heat-pumps) given the heterogeneous influence of the "wear and tear", the economic profitability, the age of the building, the households' income and their socio professional category. Besides, investments in glazed surfaces insulation share more similarities with investments in conventional heating systems than with investments in opaque surface insulation.

1. "Targeting" is the fact to differentiate the policy offer depending on beneficiairies or situations. The evolution of the French Tax credit promoting energy retrofits is a good illustration of this debate. After a period of increasing refinement from 2005 to 2014 in order to make the Tax credit relevant to each situations, critics have risen arguing that such complexity prevents households from understanding the policy. The 2015 reform has led to a simplified Tax credit scheme subsidizing all eligible measures with a unique tax credit rate.

2. In Allibe (2012), investment decision timing (the extensive margin) is exogenously triggered by the end of the life time of each building element while energy efficiency level (the intensive margin) is endogenously determined by a household's optimization.

3. Glazed surfaces refer to windows and opaque surfaces to wall, roof, ceiling and floor.

The remainder of the paper is structured as follows: "Data" section describes the EM survey. "Method" section presents the driver variables and the econometric model used. "Results" section presents results before discussing them and drawing implications in "Discussion and conclusion" section.

Data

ADEME, the French Agency for Environment and Energy Management, has funded since 1986 an annual survey called "the Energy Management survey" (EM survey) entirely dedicated to residential energy consumption and investments in dwellings' energy efficiency. Each year, around 10,000 households answer a first questionnaire providing socio-economic variables, housing information (type of building, heating energy source, building date, etc.), and contextual information (occupation status, move-in date). Those who have invested in energy efficiency retrofitting during the last year (around 10 % each year) answer a second questionnaire providing information on retrofitting types, investment costs, economic incentives, as well as qualitative information regarding motivations, personal context, satisfaction, etc. In this second questionnaire, each investment is described by 1 to 4 items taken from a retrofitting options list. Retrofitting options include insulation (wall – external or internal insulation, roof, attic, ceiling, windows, shutters), heating system improvement (thermostatic valves, heat cost allocators, ambient thermostat, programming equipment), new heating system (boiler, wood stove, heat-pump, radiators) or heating system replacement (with information on fuel switch), new water heating system (including solar heating) or replacement.

Respondents are willing participants and have one month to complete each questionnaire. The full sample is an unbalanced panel dataset: around 30 % of respondents are recycled each year. Given that the study is focused on the 10% of respondents having invested in retrofitting last year, only a very few respondents can be observed more than one year in the sample used in the paper. The sample is weighted to correct non-response bias[4] and to make the sample of households answering the first questionnaire national-representative[5].

In the present study, we only consider data over the 2007–2012 period since multimodal questions on barriers and drivers used in the study have been stabilized from 2007 and since the EM survey ended in 2013. We also focus on occupying-homeowners as the EM survey imperfectly measures the energy retrofitting of the rented dwelling stock. We finally exclude new buildings (i.e. built in the year of the survey) not concerned by retrofitting.

Method

In order to investigate how decision drivers vary with the retrofitting types, we use the EM survey data to combine observed characteristics with individual declarations regarding opinions, motivations and contextual factors. We first draw up statistics

4. Before adjustement, elderly and retired couples are over-represented.

5. The sample adjustment is based on the following variables : the region, the category of city, the family size, the socio-professionnal category, the head of household's age, the building type, the building completion date, the type of heating system (collective vs individual).

on the distribution of each driver in each "retrofitting-type" sub-sample and in the full sample of all occupying-homeowners living in existing buildings (including those without retrofits). Then we estimate a discrete choice model explaining the choice made by households between each retrofitting type in function of each driver. Summary statistics and econometric estimates provide complementary results: the econometric model performs in identifying the discriminating power among choice alternatives of each variable ceteris paribus but loses information regarding the size effect of a driver relatively to the others.[6]

The choice set, i.e. the retrofitting types, are distinguished between "Single measure" and "Multiple measures" retrofits. "Single measure" categories are: the insulation of opaque surfaces (roofs, walls, floor, ceiling), the insulation of glazed surfaces (mainly windows), the installation of "conventional" heating systems (gas or fuel boilers and radiators), the installation of heating regulation and ventilation systems, the installation of "innovative" heating systems (heat-pumps or renewable energy equipment such as wood heating system and solar water heater). "Multiple measures retrofits" combine at least two single measures.

DRIVER VARIABLES

Observed characteristics refer to the households and their dwelling and are selected on the basis of the literature on household investment modelling in residential energy efficiency (Cameron 1985, Dubin & Henson 1988, Jakob 2007, Michelsen & Madlener 2012). The basics of those models consist of calculating the return on retrofitting investment by comparing initial cost with future economic savings in a cost-benefit analysis, in which technological, socio-economic and contextual constraints can interact. Words in italics refer to the variables.

The **housing characteristics** variables are the *Building type* (individual houses *vs* collective flats), the *Building completion date, the Heating degree days (HDD)* and the *Category of city.* The first two variables reflect dwelling energy performance, conditioning investment profitability. The *Building completion date* is segmented following the evolution of the French thermal regulations occurred in 1974 and 1988.[7] The *Building type* variable also reflects the difficulties inherent to the collective decision process for households living in multi-family dwellings. The HDDs measure climatic conditions and impact investment profitability too. They are regional averages (over the period 1981/2011) taken from external data sources. The *Category of city* differentiates between urban and rural regions and captures aspects such as storage space availability (for fuel or wood) or supply-side features of the residential energy efficiency market.

The **households' characteristics** are: the Annual income of the dwelling, the Family size, the Age of the head of the household and the Socio-professional category. The Annual income of the dwelling determines the households' financial possibilities and their opportunity cost of time.[8] Given the life cycle theory, the family size and the age of the head of the household may reflect financial and contextual constraints. The Socio-professional category distinguishes between "Entrepreneurs" (in a wide meaning including farmers and retailers), "Managers" (including Liberals professions), "Employees" and "Inactive" (retired or unemployed people) and captures aspects linked to education, skills and eventually social status.

Individual declarations regarding opinions, motivations and contextual factors are taken from one question dedicated to general concerns in the first questionnaire and two questions dedicated to retrofitting decision drivers in the second questionnaire. Regarding general concerns, households are asked to prioritize their concerns about diverse socio-political issues. Regarding retrofitting decision drivers, the questions are "What was the main reason why you invested in retrofitting?" and "In addition to this first motivation, what were the two main supplementary incentives among the second list below?". Households have to answer only one modality in the first question and two in the second one. The non-response rate is respectively 2 % and 10 % for the first and the second questions. For the first question, answer options are: the reduction of the energy bill, comfort improvement, thermal insulation, acoustic insulation, ventilation, the replacement of an old heating system, the green value of the real estate asset, other. For the second question, they are: the access to ownership, a recent move-in, other non-energy retrofitting, a subsidy, a zero rate loan, a classical loan, another financial support (family, inheritance), tax credit, reduced VAT, energy performance diagnosis, advertisement, institutional information, personal advices, external decision (co-ownership). Each answer option corresponds to a variable[9]. As the EM survey was not purposely designed for this study, we distribute each answer option in the following typology.

Future economic and non-economic benefits

As regards economic profitability, the EM survey distinguishes between two types of future benefits: *the Savings on the Energy Bill* and *the Green Value* (in monetary terms). The perception of the green value means that households believe that they can get benefits from the capital appreciation of their asset. This solves problems related to the possibly long payback period of such investments.

Retrofitting also provides non-economic benefits: *Comfort* and *Acoustic insulation*. Note that the EM survey also include the answer option "Thermal insulation", which is structurally correlated with surface insulation measures and does not provide any information regarding non-economic benefits. However, since each investor answers two modalities in the second question, we keep this modality to avoid treating differently surface insulation measures and other retrofitting options.

Economic incentives decreasing up-front costs

Variables identifies the two instruments perceived as the most important by households in the survey. These are the Income *Tax Credit* nationally implemented since 2005 and the *Reduced*

6. For example, if a variable is homogeneously chosen as a major driver among all alternatives, the econometric model cannot reflect it. Such ranking is only visible in the summary statistics.

7. Other thermal regulations occurred in 1979 and 1982, 2000 but cannot be considered due to sample size limitation.

8. Since the information collection and the implementation phases of a retrofitting project are time consuming.

9. Some modalities have been gathered or excluded from the analysis in case of marginal importance.

Value Added Tax (VAT) from 19.6 % to 5.5 % (or 7 % depending on the year) implemented since 1999. The *Other financial support* variable gathers other answer options relative to economic factors addressing liquidity constraints faced by households : low-interest loans including the zero-rate loan implemented since 2009 (only eligible for certain retrofitting combinations) and external financial support such as family inheritance.

Information provision

Most of market failures discussed in the energy efficiency gap literature refer to imperfect information (Gillingham & Palmer 2013). Among them, the households' lack of knowledge/awareness on energy retrofitting can be improved by information provision programs (Allcott & Greenstone 2012). In the EM survey, information provision is first distinguished between public and private vectors. Public information provision refers to *Institutional information*, provided by the French Agency for Environment and Energy Management (ADEME) and its territorial agencies called *Energy Info Office*[10] *(EIO),* and to the *Energy Performance Diagnosis (EPD)*[11]. Private information refers to either *Advertisement,* that is standardized marketing information, or to *Advices*, i.e. information got from a relative or a professional in an inter-personal relationship.

Contextual factors

Contextual factors may concern the situation of the household in the dwelling: a *recent move* into a new dwelling can trigger households' investment decision. The period of transition is often considered as an appropriate timing to retrofit (empty dwelling, non-energy retrofitting to be done, etc.). Correlated to a new move-in, the *access to ownership* often means access to the credit market and triggers the investment decision in overcoming the barriers linked to split incentives between landlords and tenants. In the absence of green value and assuming a period of occupancy long enough, a new move-in or a new ownership also mean that the household is more likely able to recover the initial investment over the starting period of occupancy. In the EM survey, the respondents can also precise if the investment decision was *made by the Co-ownership*.

Contextual factors can also be related to the dwelling. The fact to reach the end of a building component lifetime and to require its replacement is referred by the household as the break beyond repair or the necessity to retrofit a deteriorated building element and is synthetized in the "wear and tear" dummy. *Other non-energy retrofitting* undertaken for other motives ("cosmetic" types of investment, dwelling extensions, etc.) can also offer an opportunity for energy efficiency investments. In both cases, the fact to invest anyway in some retrofitting changes the counterfactual of households' decision. Compared to the default alternative, the up-front costs of the energy-efficiency investment is only the surplus due to the energy efficiency improvement (insulation layers, the differences between the standard and the high energy efficiency system, etc.), whether for economic or non-economic costs (such as opportunity cost of time, decision inertia, discomfort due to the works etc.).

10. Called "Espace Info Energie".

11. The Energy Performance Diagnosis acts as label and has been compulsory since 2007 in case of occupancy switch.

General concerns

We include three dummy variables called *Unemployment, Climate Change,* and *Energy savings*, which equal one if the households consider that problems related to respectively unemployment, climate change and promoting energy savings are one of their top priorities[12].

DISCRETE CHOICE MODEL SPECIFICATION

The multinomial logit model is a basic among the Random Utility Maximization models. Such models assume that individuals make their choices optimizing their level of utility. The utility associated with individual i choosing the alternative j is $V_{ij} + \varepsilon_{ij}$, composed of an observable part V_{ij} and a random term ε_{ij} which corresponds to unobservable or unknown elements. The probability that individual i chooses j among J alternatives is equal to the probability that the utility derived from the alternative j is the highest utility that one can get from all the alternatives:

$$P(Choice_i = j) \\ = P\left(\mathrm{V_{ij}} + \varepsilon_{ij} = \max\left(V_{ij'} + \varepsilon_{ij'} \ , \forall j' \in J\right)\right) \quad (1)$$

V_{ij} is assumed to be a linear function of the K observable explanatory variables. In this model, the explanatory variables are individual-specific, i.e. depending on individual i but not on alternative j. Given that residuals ε_{ij} are assumed independently and equally distributed by a Type I Extreme Value distribution (Weibull distribution), it gives:

$$P(Choice_i = j \mid X_i) = e^{V_{ij}} / \textstyle\sum_{j'=1}^{J} e^{V_{ij'}} \quad (2)$$

The model is estimated by maximum likelihood method and results are weighted to be national-representative. We define the choice set in order to ensure the validity of the Independence from Irrelevant Alternatives (IIA) hypothesis[13] and we perform collinearity tests to select the set of explanatory variables. In this model, the marginal effects of an explanatory variable on the choice probabilities vary with individuals. Therefore, in order to approach the average marginal effects on the choice probabilities, we derive the estimated probabilities with respect to all explanatory variables for all the individual observations and we present, in the results, the average over the sample for each variable.

Due to sample size limitation, data have been pooled over 2007/2012: we ignore potential evolutions in motivations over time and focus on cross-section heterogeneity. Moreover, we recall that, in the absence of alternative-specific explanatory variables, the multinomial model is more a descriptive tool performing discriminant analysis than a structural discrete choice model (Afsa Essafi 2003).

12. Other answer options to this question are "immigration", "social inequalities", "political scandal", "delinquency", "school organization", "retirement pension system", "European integration", "terrorism", "national soveirgnity", "tax". They are not included in the paper due to the principle of parsimony, their lower response rate and/or their weaker link with the study.

13. The Irrelevant Alternatives (IIA) hypothesis is that the ratio of probabilities between two alternatives does not depend on the other alternatives.

Results

Due to their complementarity, summary statistics and econometric results are jointly analyzed for each variable. Table 1 shows summary statistics on the distribution of the retrofitting types and the cross distribution between the explanatory variables and the retrofitting categories. Regarding "multiple-measures" retrofit, we distinguish between the combination of glazed (windows) and opaque surfaces (wall, roof, floor and ceiling) insulation, the combination of glazed surfaces insulation and conventional heating system installation and other "multiple-measures" retrofits.[14] The last column of Table 1 shows the distribution of household and housing characteristics for the total sample of occupying-homeowners living in buildings built before the current year. Table 2 shows the estimated average individual marginal effects of the multinomial logit model. In order to ensure the validity of the IIA hypothesis, we gather the two "conventional heating systems" and "regulation/ventilation systems" categories into one category called "conventional systems" and all "multiple-measures" categories into a single one category called "multiple retrofitting". In the econometric model, the *Move-in-date* and the *Age of the head of the household* variables are dropped due to collinearity respectively with the declared variable *Recent move-in* and the *Family size* variable.[15]

HOUSING CHARACTERISTICS

Collective flats are under-represented in retrofitting subsamples compared to the full sample, especially for the "multiple retrofitting" categories, "opaque surface insulation" and "innovative systems" (respectively 3.5 %, 3.5 % and 10 % compared to 26.9 % in the full sample, Table 1). This is confirmed in the econometrics results (Table 2): people living in multi-family dwelling are more likely to undertake glazed surfaces insulation and conventional systems installation than other retrofitting types by increasing their probability of choice by respectively 18.7 and 11.1 percentage points (p.p.). Living in recent buildings (built after 1989 rather than before 1975) decreases choice probability by 10.4 p.p. for glazed surfaces insulation and 11.4 p.p. for multiple retrofit and increases it by nearly 10 p.p. in case of investments in both "innovative" or "conventional systems". Colder climate conditions reflected by higher HDD increases choice probability for opaque surface insulation (Table 2). The Category of city does not significantly discriminate between retrofitting types, except that it is more likely to invest in innovative systems in small cities and rural areas than in the Parisian agglomeration (Table 2).

Household characteristics

Households investing in retrofitting have relatively higher income than the full sample. Income distribution is even more shifted upwards for investors in innovative systems: the fact to be in the highest income bracket (>36,300 euros)[16] rather than in the lowest one (<18,500 euros) increases the probability to invest in "innovative" systems rather than other retrofitting alternatives by 3.4 p.p. (Table 2). "Single-person households" and young people (<35 years old) are also under-represented in retrofitting subsamples compared to the full sample (Table 1). Living as a couple (at least two persons) slightly increases the probability to invest in multiple retrofitting and innovative systems installations by 3 p.p. each (Table 2). Entrepreneurs are relatively more prone to invest in multiple retrofitting and in innovative heating systems: they represent 14.3 % and 8.1 % of the respective sample compared to less than 6 % for the other retrofitting types (Table 1, confirmed in Table 2). Inactive (especially retired people) are relatively more prone to invest in glazed surface insulation and conventional systems: they represent 46 % and 43.2 % of the respective samples compared to less than 31 % for the other retrofitting types, except for opaque surfaces insulation (Table 1, confirmed in Table 2).

General concerns

Both Table 1 and Table 2 show that households' concerns regarding unemployment, climate change and energy savings are not very discriminating. Nevertheless, households claiming concerns for Energy savings are more prone to invest in multiple retrofitting whereas those concerned by Unemployment are slightly more prone to invest in windows insulation (Table 2).

Future economic and non-economic benefits

Savings in the energy bill are among the most important motivations (always above 20 %) and clearly prevail on *Green value* (always below 7 %) (Table 1). Considerations on future energy bills increases choice probability for innovative systems by 7 p.p. while expectations on green value capitalization increases choice probability for building envelope insulation by 7 p.p. Both motivations increase choice probability for multiple measures retrofitting by 7 p.p. (Table 2). The desire of *Comfort* is widely shared (always above 30 %, Table 1)[17] except for systems (respectively 11.3 % and 23 % for "conventional" and "innovative" systems). Table 2 confirms that *Comfort* prevails in case of investment in insulation measures and multiple-measures retrofits as opposed to investment in systems.

Economic incentives decreasing up-front costs

Tax Credit and *Reduced VAT* are perceived as major incentives. Whereas considerations on *Reduced VAT* is quite homogeneous among retrofitting types (between 13 and 28 %, Table 1), the importance of *Tax credit* varies a lot. In Table 2, the influence attributed to the *Tax Credit* increases choice probability for windows insulation, innovative systems and multiple retrofitting by respectively 9.7, 7.6 and 4.5 p.p. and decreases choice probability for opaque surface insulation and conventional systems by respectively 15.3 and 6.5 p.p.. However, households have largely declared *Tax credit* as important even for opaque insulation measures (15 % in Table 1). The importance attached to *Other financial supports* (low-interest loans and inheritance) is secondary (always below 12.5 %, Table 1), except for multiple retrofitting (18.5 %). *Other financial supports* increases choice probability for multiple-measures retrofit by 11 p.p. (Table 2).

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14. Further categorization leads to too small sample size.

15. The *Move-in date* variable comes from answers to the question "When did you move into you new flat?" while the *Recent move-in* variable is a possible answer to the 2nd question about motivations to retrofit. *Age of the head of the household* and *Family size* variables are interrelated due to household life cycle.

16. As income brackets (answer option) proposed in the questionnaire have changed over the period, this split in three income groups is the only common split possible.

17. Results regarding hidden benefits may be biased for opaque surface insulation due to the presence of the *Thermal insulation* answer option.

Table 1. Summary statistics over 2007/2012.

	Glazed surfaces insulation	Opaque surfaces insulation	Conventional heating systems	Innovative heating systems	Heating regulation & ventilation	Opaque & glazed surfaces insulation	Glazed surfaces insulation & conventional heating	Multiple retrofitting combination	Total sample investors and non-investors
N	1567	1058	437	419	271	360	362	229	32343
Row % among investors	33.3	22.5	9.3	8.9	5.8	7.7	7.7	4.9	
Housing characteristics:									
HDD (Mean)	2044	2079	2056	2040	2051	2078	2038	2005	2032
Building type (Col. %)									
Individual house	71.5	90.0	71.7	96.5	67.2	91.3	80.5	96.5	73.1
Collective flat	28.5	10.0	28.3	3.5	32.8	8.7	19.5	3.5	26.9
Building completion date (Col. %)									
< 1974	66.2	67.8	70.4	44.4	42.8	77.6	71.7	66.7	57.0
1975/1988	27.2	20.2	17.2	23.3	31.4	18.7	20.5	20.4	22.1
1989/last year	6.6	12.0	12.4	32.3	25.9	3.7	7.9	12.8	21.0
Category of city (Col. %)									
Parisian agglomeration	14.1	8.1	13.7	4.6	15.5	6.0	11.5	4.1	13.1
> 20.000 inha.	40.5	31.2	45.4	23.6	41.2	31.9	40.0	28.8	38.8
<20.000 inhab./ rural	45.4	60.7	40.9	71.9	43.4	62.1	48.6	67.1	48.1
Household characteristics:									
Annual income of the dwelling (Col. %)									
<18500 euros	18.5	20.0	18.3	10.3	12.9	17.7	14.8	18.2	22.5
18500 /36 300 euros	50.4	50.8	46.1	53.8	44.7	57.0	50.7	46.7	48.0
>36 300 euros	31.1	29.2	35.7	36.0	42.4	25.3	34.5	35.1	29.6
Socio-professional category (Col. %)									
Entrepreneur	4.5	5.4	5.6	8.1	4.3	11.2	7.5	14.3	6.4
Managers	28.7	27.4	26.8	28.0	42.5	26.9	38.0	32.9	26.8
Employees	20.8	27.9	24.5	34.5	25.0	30.5	26.6	30.2	23.4
Inactive	46.0	39.3	43.2	29.4	28.2	31.3	28.0	22.7	43.3
The head of household's age (Col. %)									
<35 years old	0.1	0.5	0.0	0.4	0.6	0.0	0.0	0.7	0.5
35-54 years old	39.7	42.7	42.0	58.2	54.7	49.0	55.7	63.9	41.7
>54 years old	60.2	56.9	58.0	41.4	44.7	51.0	44.3	35.4	57.8
Family size (Col. %)									
1 person	26.1	21.1	22.3	8.1	23.6	17.8	15.7	11.7	26.4
1 couple	39.1	38.3	40.3	35.9	34.1	38.5	33.5	34.9	36.9
>2 persons	34.9	40.6	37.4	56.0	42.4	43.7	50.8	53.4	36.7
Move_in date (Col. %)									
< 3 years	14.0	15.1	10.3	12.4	29.6	26.6	34.2	36.6	11.1
3 / 10 years	26.6	33.4	26.2	43.0	26.7	32.4	30.2	30.8	30.4
> 10 years	59.5	51.5	63.5	44.6	43.8	41.1	35.6	32.5	58.6
Subjective answers (% answering "yes")									
Future economic and non-economic benefit									
Savings on the Energy Bill (1)	20.8	32.6	32.4	73.6	39.0	35.9	30.4	53.2	
Green Value (1)	3.9	5.5	1.2	3.3	1.9	6.1	4.0	5.2	
Comfort (1)	32.0	24.3	11.3	23.0	44.4	33.9	33.1	31.4	
Thermal insulation (1)	35.9	44.4	0.2	0.8	2.6	36.1	25.8	11.5	
Acoustic insulation (1)	5.7	1.2	0.0	0.0	0.0	1.5	2.4	0.0	
Economic incentives									
Tax credit (2)	39.6	15.4	30.4	64.0	4.6	24.3	26.5	50.7	
Reduced VAT (2)	27.7	14.8	18.9	19.4	12.9	13.6	16.2	14.0	
Other financial support (2)	7.2	5.4	10.1	11.6	0.7	11.0	12.5	18.5	
Information provision									
Institutional info. (EIO) (2)	1.6	3.8	3.3	4.7	1.5	2.0	2.5	5.8	
Energy Performance Diagnosis (EP) (2)	2.2	4.3	4.9	3.1	1.9	6.3	4.9	3.3	
Advertisement (2)	4.0	3.5	2.1	3.0	5.7	1.7	1.4	2.2	
Advice (2)	9.8	16.2	19.7	16.2	20.1	9.4	13.3	8.8	
Contextual factors									
Recent ownership (2)	9.9	9.3	4.9	5.1	14.4	22.5	25.2	20.2	
Recent move-in (2)	3.3	3.0	2.1	2.4	9.4	8.0	15.5	11.0	
Co-ownership's decision (2)	1.2	4.0	4.1	0.4	2.6	2.1	2.5	2.4	
Wear and tear (1)	18.8	5.7	66.3	11.3	25.0	7.5	27.3	13.3	
Other retrofitting (2)	4.6	11.9	4.0	3.6	10.1	9.6	6.5	5.4	
General concern									
Unemployment	68.5	66.1	69.2	63.0	67.9	64.1	67.5	60.1	67.0
Climate change	25.3	25.4	26.4	25.7	29.9	29.1	25.2	22.3	26.5
Energy savings	22.4	23.6	25.0	24.1	22.6	24.4	27.6	29.8	22.2

Note: (1) refers to answer options of the question *"Among the following list, what was the main reason why you invested in retrofitting?"*, (2) refers to answer options of the question *"In addition with this first motivation, what were the two main supplementary incentives among the second list below?"*

Interpretation example: as regards the households and housing characteritics: 18.52% of households investing in glazed surfaces insulation belongs to the first income level. As regards households' declarations on the drivers, 20.75% of households investing in glazed surfaces insulation declares that the savings in the energy bill is the main motivation.

Table 2. Multinomial logit model's average marginal effect estimates.

	Glazed surf. insulation	Opaque surf. insulation	"Conventional" systems	"Innovative" systems	Multiple retrofitting
Housing characteristics					
Building type *(ref : individual house)*					
Collective flat	0.187***	-0.144***	0.111***	-0.051***	-0.104***
Building completion date *(ref : < 1974)*					
1975/1988	0.054***	-0.021*	0	0.023***	-0.056***
1989/last year	-0.104***	0.02	0.099***	0.098***	-0.114***
HDD	-0.001	0.044**	0.01	-0.006	-0.047***
Category of city *(ref : Parisian agglomeration)*					
> 20.000 inhabitants	-0.005	-0.032	0	0.003	0.034*
<20.000 inhabitants / rural	-0.03	-0.011	-0.016	0.028**	0.029
Household characteristics					
Annual income of the dwelling *(ref : <18500 euros)*					
18500 /36 300 euros	-0.009	-0.019	0.007	0.026***	-0.005
>36 300 euros	-0.011	-0.044**	0.023	0.034***	-0.002
Family size *(ref : 1 person)*					
1 couple	-0.049***	0.005	-0.022*	0.023**	0.043***
>2 persons	-0.036*	-0.001	-0.024*	0.03***	0.031*
Socio-professional category *(ref : Entrepreneur)*					
Managers	0.035	0.038*	0	0.016	-0.089***
Employees	0.004	0.047**	-0.009	0.033***	-0.074***
Inactive	0.08***	0.043**	0.01	0.005	-0.139***
Subjective answers:					
Economic and non-economic benefit					
Savings on the Energy Bill	-0.129***	-0.011	-0.004	0.071***	0.074***
Green Value	-0.016	0.071***	-0.14***	0.018	0.067**
Comfort	0.038**	-0.056***	-0.062***	-0.001	0.081***
Acoustic insulation	1.049	0.421	-1.395	-0.674	0.599
Thermal insulation	0.21***	0.149***	-0.313***	-0.187***	0.14***
Economic incentives					
Tax credit	0.097***	-0.153***	-0.065***	0.076***	0.045***
Reduced VAT	0.076***	-0.042***	-0.008	-0.009	-0.017
Other financial support	-0.01	-0.104***	-0.012	0.016	0.11***
Information provision					
Institutional info. (EIO)	-0.14***	0.056**	-0.016	0.034**	0.065**
EPD	-0.117***	0.044	-0.002	-0.013	0.087***
Advertisement	0.065**	0.006	-0.009	0.009	-0.072*
Advice	-0.099***	0.024*	0.046***	0.019*	0.01
Contextual factors					
Ownership	-0.034*	-0.038**	-0.051***	-0.035**	0.158***
Recent Move-in	-0.078***	-0.068**	0.017	-0.041**	0.17***
Co-ownership's decision	-0.29***	0.213***	-0.043	-0.005	0.125***
Wear and tear	0.04*	-0.246***	0.128***	0.001	0.077***
Other retrofitting	-0.163***	0.103***	-0.003	-0.004	0.067***
General concern:					
Unemployment	0.024*	0.009	0.005	-0.012*	-0.026**
Climate change	-0.008	0.007	0.013	-0.015*	0.003
Energy savings	-0.02	-0.003	0.004	-0.008	0.028**
Nb of observations	4038			Log likelihood	-6818.1213
Market shares (row %)	33.32	22.5	15.05	8.91	20.22

*(resp. ** and ***) significant at 10% level (resp. 5% and 1%). (Std errors not reported)

Note : Innovative systems include heat-pump and equipment producing renewable energy (wood stove, solar heater water, etc.). Conventionnal heataing systems refer to boilers, radiators, heating regulation and ventilation systems. The sum in row of all marginal effects is zero. Due to different market shares, a Interpretation example: to be in the highest income bracket (>36300 euros) rather than in the lowest one (<18500 euros) increases the probability to invest in "innovative" systems by 3.4 percentage points.

Information provision

Information provision is quite important for households (18 and 30 % considering all information vectors). Interpersonal information (*Advices* variable) is the most important vector (between 9 and 20 %). Its influence nonetheless decreases in case of multiple-measures retrofit (9 %), i.e. when the technical complexity or the costs increase (Table 1). *Advices* increases choice probability for conventional systems by 4.6 p.p. (Table 2). "Standardized" information provision (both private and public) is perceived as more marginal : <5 % for the *territorial agencies (Energy Info Office)*, <6,3 % for the *Energy Performance Diagnosis (EPD)*, <6 % for *Advertisement*. However, while public information provision (respectively *EPD* and the *territorial agencies*) increases choice probability for multiple retrofitting (by 8.7 and 6.5 p.p.), private information provision (*Advertisement*) increases choice probability for windows insulation 6.5 p.p. (Table 2).

Contextual factors

Recent move-in or *ownership* are important drivers for multiple-measures retrofitting (>30 %) but not for single-measure retrofitting (<13 % all together except for regulation and ventilation systems, Table 1). *Recent move-in* or *ownership* increase choice probability for multiple retrofitting by respectively 16 and 17 p.p. (Table 2). The co-ownership's decision is a very minor driver (always <4 %, Table 1). "*Wear and tear"* is a major driver for conventional heating systems (66.3 %) but interestingly not for innovative heating systems (11.3 %). In a minor way, we find the same difference for respectively glazed (18.8 %) and opaque surface insulation (5.7 %, Table 1). *Other retrofitting*, i.e. the opportunity to realize energy efficiency retrofitting in the same time as a non-energy renovation ("cosmetic" ones or extensions), appears as a secondary driver (always below 10 %, Table 1). However, it increases choice probability for opaque surface insulation and multiple retrofit by respectively 10.3 and 6.7 p.p. (Table 2).

Discussion and conclusion

RESULTS SUMMARY

Table 3 summarizes econometric results: ++ (resp. --) means that the variable has a significant positive (resp. negative) marginal effect above 10 (resp. below -10) percentage points for the considered retrofitting type compared to other alternatives. + and - are the same for significant effects of lower magnitude.

A first distinction should be made between investment in energy systems and investment in building envelope insulation given the heterogeneous influence of non-economic benefits (e.g. comfort) and of "wear and tear". In terms of households and housing profile, the difficulties inherent to multi-family dwellings and dense urban areas like the Parisian agglomeration especially impede investments in building envelope insulation and multiple-measures retrofitting. Second, some drivers are specific to multiple-measures retrofitting: the opportunities created by recent move-in/ownership or by other non-energy retrofits, the expectations regarding the green value, the importance of financial supports related to liquidity constraints and of public information provision. Considering that *Energy Performance Diagnosis (EPD)* acts as a signal for energy performance, the influence of the EPD may be related to the importance attached to the green value. These specificities are often shared with investment in opaque surfaces insulation. Among heating systems, additional distinction should be made between "conventional" and "innovative" systems given the importance attached to "wear and tear" for "conventional" systems and to economic profitability for "innovative" ones. In terms of household profile, high income households and "Entrepreneurs" are also more prone to invest in innovative systems while Inactive (Elderly) people tend to invest more in conventional systems (and windows). This corroborates the idea that innovators have higher financial capacities and higher social status (Rogers 1962)[18]. Finally, investments in windows insulation share more similarities with investments in conventional heating systems than with investments in opaque surface insulation given the importance attached to wear and tear or private information provision (advertisement).

IMPLICATIONS IN TERMS OF INVESTMENT DECISION MODELLING AND PUBLIC POLICY DESIGN

Results show the heterogeneous influence of contextual factors, especially those linked to technical constraints ("wear and tear") and to the housing market (move-in/access to ownership). Regarding investment decision modelling, it implies to explicitly represent 1) dynamics in the housing market when considering global retrofitting investments or building envelope insulation and 2) product lifetime when considering heating systems.

In terms of policy implications, as investments in systems are mainly driven by "wear and tear", it first implies that economic incentives such as tax credits are unable to impact the timing of the investment decision (extensive margin) but can only impact the investment decision on the intensive margin. Second, given the heterogeneity of investments drivers, the implementation of a uniformed policy scheme among all energy efficiency investments types does not seem to be the most appropriate strategy. Rather than considering "wear and tear" or recent move-in/access to ownership as "ancillary conditions", i.e. "are any factors that affect the individual's choices but are not relevant to what the social planner would choose" (Gillingham & Palmer 2013), we should wonder how to take into account these factors in order to improve the cost-efficiency of the policies. Finally, if we consider that the biggest energy efficiency potential lies in multiple retrofitting, results show that we should pay more attention to financial support able to solve liquidity constraints, to the promotion of a perceived and effective green value on the housing market and to the implementation of a widely available public information provision.

In the French context, these findings can question the implementation in 2015 of a unique tax credit rate among all retrofitting types in all situations, even though the 2015 reform increases the clarity of the scheme. It is also interesting to note that, while the Tax Credit was purposely implemented to promote energy savings, the investment category which is the most

18. Rogers' theory on innovation diffusion categorizes adopters into innovators, early adopters, early majority, late majority and laggards. It notably describes innovators as individuals willing to take risks, with the highest social status and with financial liquidity.

Table 3. Summary of the econometric results.

	Gazed surf. insulation	Opaque surf. insulation	"Conventional" systems	"Innovative" systems	Multiple retrofitting
Building characteristics					
Collective flats compared to individual house	++	--	++	-	--
Relatively recent building (> 1989 compared to <1974)	--		+	+	--
HDD (energy needs due to climatic conditions)		+			-
Relatively small city category (<20 000 inhab. compared to Paris)				+	
Households characteristics					
Relatively high income household		-		+	
Relatively large family size (>1 person compared to 1)	-		-	+	+
Socio-professional category:					
Inactive compared to Entrepreneur	+	+			--
Employees compared to Entrepreneur		+		+	--
Subjective answers:					
Future economic benefits					
Savings on the energy bill	--			+	+
Green value		+	--		+
Future non economic benefits : Comfort	+	-	-		+
Economic incentives decreasing up-front costs					
Tax credit, reduced VAT	++	--	-	+	+
Other financial support (e.g. loan, inheritance)		--			++
Information provision					
Public sector (EPD and EIE)	--	+		+	++
Private sector (Advertisement)	+				-
Interpersonal (Advice)	-		+		
Contextual factors					
Recent ownership or move-in	-	-	-	-	++
Wear and tear		--	++		+
Other non-energy renovation	--	++			+
Co-ownership decision	--	++			++
General concern					
Energy savings					+
Unemployement	+			-	-

Note: ++ = the stated preferences has a significant positive marginal effect above 10 percentage points (or that several variables inside the category are significantly positive), + = that the stated preferences has a significant positive marginal effect between 0 and 10 percentage points. -- = the stated preferences has a significant negative marginal effect below -10 percentage points (or that multiple modalities are significantly positive), - = that the stated preferences has a significant negative marginal effect between -10 and 0 percentage points.

Note 2: Innovative systems include heat-pump and equipment producing renewable energy (wood stove, solar heater water, etc.). Conventionnal heataing systems refer to boilers, radiators, heating regulation and ventilation systems.

driven by the Tax Credit, namely windows insulation, is also the least efficient when considering future energy savings. The proposition made by the non-profit organization NégaWatt and the consortium of building industries and businesses "Insulate Earth against CO_2" (Salomon et al. 2005) and discussed during the Grenelle de l'Environnement (Pelletier 2008) is more in line with these findings. This proposition included an obligation to retrofit existing dwellings in case of transactions in the housing market associated with specific financial support through extra mortgage with low-interest rate in order to promote multiple retrofitting.[19] The initial law project for "Energy Transition and Green Gowth" included a retrofitting obligation in case of occupancy switch from 2030 onwards but was rejected by the Constitutional Council due to too vague provisions with respect to the impact on private property right. However, the final law voted in August 2015 has enforced the obligation to invest in energy conservation measures in case of opportunities created by non-energy works such as outdoor wall insulation in case of façade restoration, roof insulation in case of roof repair and indoor wall insulation in case of new rooms furnishing. Considering that such non-energy works are often undertaken in case of occupancy/ownership switch, this can be viewed as an appropriate first step for this type of regulation. More importantly, this obligation only bears on opaque surface insulation measures, which is well targeted, as we have seen that the investment in non-energy works is a specific driver to opaque surface insulation.

19. See Giraudet et al. (2011) for an academic assessment of these proposition.

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