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Capitalization of energy labels versus Techno-economic assessment of energy renovations in the French housing market.

Abstract

While a growing number of studies evidence the existence of a green value associated to energy labels, these studies disagree on the magnitude of this green premium and lack comparison with associated renovation costs and expected savings for households. This paper investigates the green value of French houses in two regions: one urban area, the Lyon metropolis, and one rural are, the Brest area in Brittany. In a first step, the traditional hedonic analysis of transactions in those regions is coupled with Geographic Information Systems to regress prices on the intrinsic characteristics of dwellings and on the distance to various public amenities, such as parks, city center or public transports. A spatial econometric model is estimated to control for neighborhood effects. Results evidence a significant green value in both areas. If relative premium is higher in Brittany, switching to absolute terms evidences tantamount green values for each level of efficiency in the two regions, reaching about 35,000€ for low consumption houses. In a second step, using a dataset on warmth insulation costs, the paper highlights that green premiums match with the investments required to improve energy efficiency. Green value is thus consistent with the capitalization of renovation costs. Comparison with expected energy savings suggests that households' time preferences need to be strongly oriented for the future, with implicit discount rates smaller than 5% and time horizon over 20 years, to favor low-energy houses.

Keywords: Hedonic pricing ; Green Value ; Energy efficiency ; Spatial econometrics.
JEL classification: R21; Q40; L15.

1 Introduction

Since the introduction of real estate energy labels during the last decade, economic literature has regained interest in the application of hedonic methods to the housing market. Indeed, if those labels meet their goal, namely reducing information asymmetry between buyers and sellers on energy quality of traded houses, we should be able to observe a capitalization of the energy savings associated to a 'greener' house. The Energy Performance Certificate (EPC), progressively introduced in the European Union since 2002, is especially interesting: on the contrary to Energy Star label or LEED certification in the United States, it has to be realized for any building sold or rented out. The EPC, which came into force a decade ago for most Member States, ranks dwellings into seven classes, each of them identified by a letter, from A for almost zero-energy buildings to G for energy-greedy ones.

Most of recent hedonic investigations have found a significant green premium for energy-efficient buildings. In the United States, Eichholtz et al. (2010) found increased selling prices for energy-efficient office buildings. Kahn and Kok (2014) also evidenced a small premium for green-labelled houses in California. In Europe, hedonic analyzes have been applied in several countries that have adopted the EPC, estimating the sales premium at a few percents of a house price: Brounen and Kok (2011) identified a premium of 3.7% in the Netherlands, Hyland et al. (2013) found a premium of 9% in Ireland, just as Fuerst et al. (2015) in England. In Germany, Cajias and Piazolo (2013) estimated that a 1% increase in energy efficiency lead to a 0.45% increase of the market value. In France, a working paper by Leboullenger et al. (2018) identifies also a premium between 1 and 3% for green houses. However those hedonic approaches of the green value lack a detailed description of associated costs and savings. Indeed the 'engineer's approach' of the green value suggests that the premium should be more important, and is generally calculated in absolute terms rather than in percentage of the market value, as stressed for instance the techno-economic optimization of renovations made by Ferrara et al. (2013).

The present paper innovates from the existing literature on two aspects: first it analyzes separately two different real estate markets with strongly different levels of prices, one densely populated (the Lyon metropolis, center of France) and one with low density and vast rural spaces (the Brest region, in Brittany). Second, it couples the analysis of the green premium with a dataset on renovation costs, and with a thermal model enabling the estimation of associated energy savings. Results evidence that the 'green premium' should be considered in absolute terms rather than relative to the house price. Indeed, absolute premiums associated to each grade of the EPC are closely similar in the two regions investigated, despite the important differences between each market. Moreover, those premiums are consistent with corresponding renovation costs, suggesting that green value results from a Bertrand-type competition between sellers. Lastly, comparison of each label premium with its associated energy savings underlines the importance of taking into account households' time preferences to design efficient public policies and meet energy goals of the building stock.

Section 2 details the hedonic method implemented and the specification used for the spatial error model. Summary statistics of the datasets used are also presented: characteristics of traded houses, material and labor costs for warmth insulation and energy costs. A thermal model is also built to assess renovation costs to upgrade a house and associated energy performance. Section 3 presents the econometric results and the estimates of the green premium. The green value of a B-labelled house compared to a F-labelled house *ceteris paribus* is estimated at 29.7% of the price in the Brest region, against 11.1% of selling price is the Lyon metropolis. In absolute terms, both green premium amounts to 34,000€. Section 4 evidences that this consistent green value in both regions corresponds to the required investments to upgrade a house from the F-class to the B-class. A comparison with expected energy savings follows, discussing the importance of time preferences in the renovation decision. Section 5 concludes with the main findings and potential extensions.

2 Data and methods

2.1 Hedonic regression and spatial error model

A hedonic model is used in order to evaluate the effect of Energy Performance Certificate on house prices. Hedonic regression is a widespread method to evaluate the determinant characteristics of complex goods pricing. Indeed, as goods with multiple and heterogeneous characteristics offer various services to consumers, pricing of a given good depends on the level of each service it can provide. Following the seminal contribution of Rosen (1974), this method has been extensively used to estimate the role of various characteristics in housing prices, as underlined by the review of Sirmans et al. (2005). Indeed, dwellings vary by multiple intrinsic characteristics (such as size, number of rooms, presence of a pool...) but also locational advantages (proximity to the city centre, to environmental amenities, attractiveness of the neighborhood...). More recently, this method has also been used in papers addressing the issue of the green value in the residential sector.Brounen and Kok (2011), Hyland et al. (2013), Kahn and Kok (2014), Fuerst et al. (2015) or Ramos et al. (2015) are illustrative of this kind of literature.

To test the impact of energy label's various classes on the price of a houses, the natural logarithm of transaction price is regressed on houses' characteristics as specified in the following equation:

$$ln(P_i) = \alpha + \beta * X_i + \gamma * L_i + \delta * EPC_i + \xi_i \quad (1)$$

$$\text{With } \ \xi_i = \lambda * W * \xi_i + \epsilon_i \quad (2)$$

In equation 1, P_i is the transaction price of house i. X_i and L_i are respectively vectors of intrinsic characteristics (size, number of rooms, construction period, etc.) and of locational variables (distance to city centre, to the nearest underground station, to the seaboard, etc.) of house i. EPC_i is a categorical variable indicating to which Energy Performance Certificate class the dwelling i belongs. Those variables are either available in our transactions dataset (for X_i and EPC_i) or built using Geographic Information Systems (for L_i). α, β, γ and δ are vectors of coefficients to be estimated. δ is our interest vector of coefficients. ξ_i is a spatially correlated error term, whereas ϵ_i is an *i.i.d.* Gaussian random term (see equation 2). W is the spatial weights matrix, which terms are defined as follows:

$$w_{ij} = \frac{exp(-dist_{ij})}{\sum_{k \neq i} exp(-dist_{ik})}$$

The Euclidian distance between i and j is expressed in kilometers. This spatial specification of errors in our model aims at capturing the effects of unobserved spatial variables, such as neighborhood effects. This log-lin model can be easily interpreted: an increase of 1 unity of a variable z contributes to increase the price by a percentage corresponding to the estimated coefficient of the variable z.

2.2 Transaction prices, houses characteristics and geographic variables

The model detailed in the previous section is estimated separately for two French regions: first the Brest area in Brittany, gathering about 430,000 people over 2,100 km^2, and second the Lyon metropolis, gathering almost 1,400,000 inhabitants over 553 km^2. The '*Pays de Brest*' is a mostly rural area, while '*Grand Lyon*' is a dense and urban area. Those two regions were specifically chosen in order to compare the green value in two real estate markets unevenly tense, but with similar heating needs. Indeed the $D_{h.ref}$, a climatic indicator which measures the number of degrees-hour needed to heat a dwelling during a year, are similar in those regions: respectively $D_{h.ref}^{Brest} = 55000\ K$ and $D_{h.ref}^{Lyon} = 54000\ K$, while $D_{h.ref}$ ranges from $30,000$ to $71,000\ K$ in France (the kelvin K is the base unit of temperature in the International System of Units).

Another advantage of treating those areas is that their respective local authorities have made publicly available an important volume of geographic data. It enables a detailed geographic analysis of the role of various environmental and public amenities in the formation of prices.

Transaction details were obtained through the French association of notaries, PERVAL. Those datasets include the precise dwelling location, transaction price, and many characteristics of the house, including total floor area, garden area, number of rooms, construction period, presence of a swimming pool, presence of a parking, month of the transaction, and the Energy Performance Certificate of the dwelling. Our dataset covers more than 70% of the transactions realized in 2016 in the two areas of interest. Transactions of "exceptional properties", such as castles, are removed from the sample. We restrict this analysis to houses, which represent 60% of dwellings in France. We choose this market as a house-owner can independently choose to renovate her house, while a condominium-owner have to agree on the renovation process with the homeowners association. In the end, the Brest sample gathered 1,242 houses transactions, with a mean price of 160,636€, and the Lyon one 1,094 houses transactions with a mean price of 365,481€.

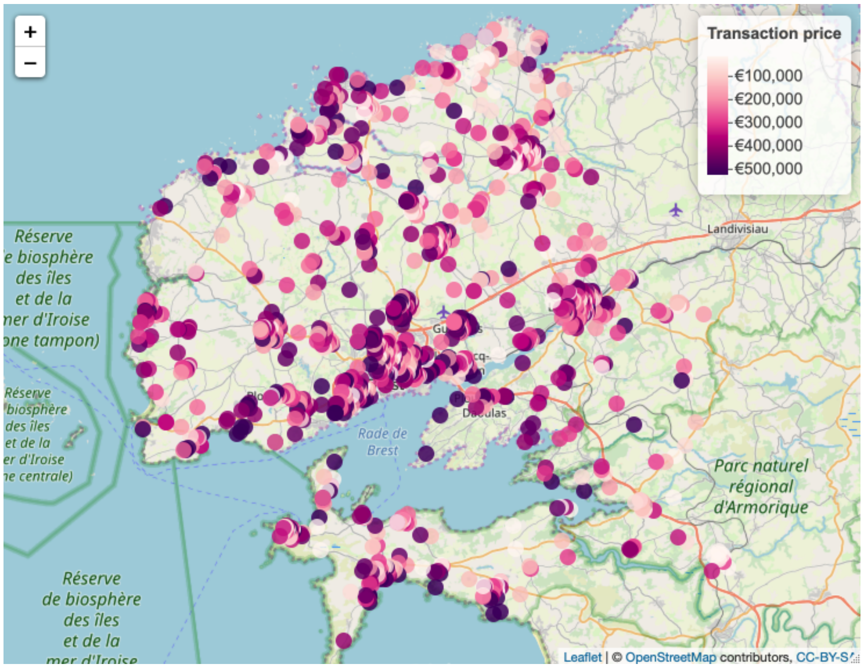

Figure 1: Map of observed prices of transactions in the Brest region

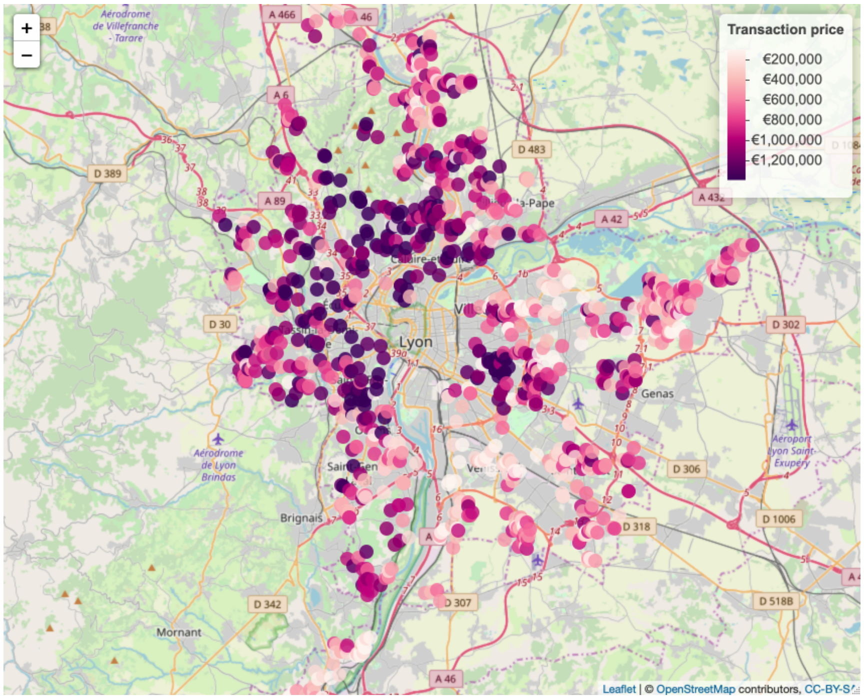

Figure 2: Map of observed prices of transactions in Lyon metropolis

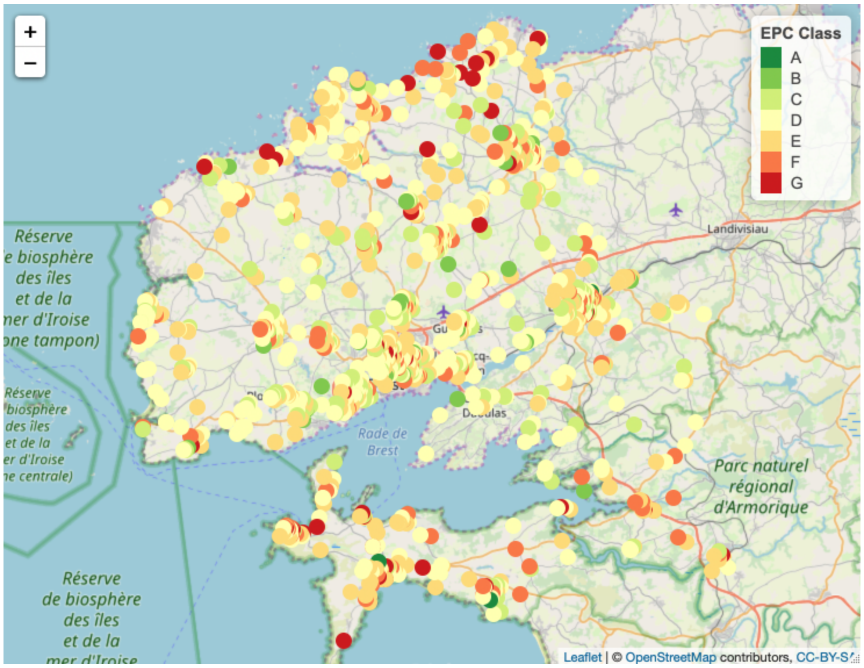

Figure 3: Map of observed Energy Performance Certificates in the Brest region

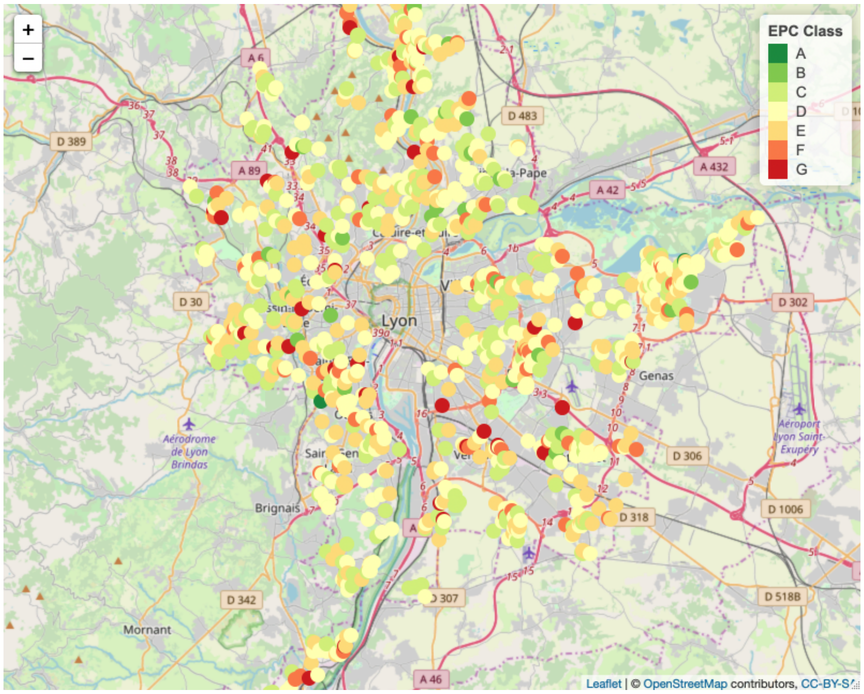

Figure 4: Map of observed Energy Performance Certificates in Lyon metropolis

Location and prices of transactions investigated are plotted in Figure 1 for Brest area and in Figure 2 for Lyon's one. We can already observe that neighborhood is a key driver of prices in the Lyon metropolis, while prices seem less dependent to location in the Brest region. Maps built with the price per meter squared is similar to those with total prices. Figures 3 and 4 indicate the EPC grades of observed transactions. On the contrary to prices, which were heavily dependent on location in the Lyon metropolis, we do not observe strong spatial correlation for this variable. This varying spatial distribution of interest variables justifies the use of a spatial econometric model. Locations are used to compute several geographical variables for each house. Datasets on public amenities are available on the websites of the two local authorities, respectively `https://geo.pays-de-brest.fr/` for the Brest region and `https://data.grandlyon.com/` for the Lyon metropolis. Using the R software and Quantum GIS, a geographic information system, Euclidian distances (in kilometers) or travel time through the street/road network (in minutes), according to which is the more relevant, have been computed. When the public amenity presents more than one point of interest, the closest one to the dwelling is selected: for instance, the travel time to the underground in Lyon is the travel time to the nearest metro station.

Tables 1 and 2 describe statistical distributions of the samples key variables. As expected, the housing market is more tense in the urban area, with transaction prices over two times superior on average in the Lyon metropolis than in Brest region. One can note that the distributions of energy labels in the two areas are similar, and that A-labelled houses represent a very small part of the samples (3 in Lyon and 3 in Brest). The construction period variable has some missing values (7% of the sample in Lyon, 4% for Brest), other key variables are complete. Two variables describe the house size, respectively the total floor area and the number of rooms. Regarding geographic variables, in both areas the travel time to the city center (indicated by the city Hall) are computed. Travel time to the nearest train station and to the nearest tramway station are also computed for both areas. For Lyon specifically, travel time to the nearest park and metro station have been added. For Brest, distance to the seaboard, distance to the nearest wind turbine and travel time to the nearest hamlet are used as additional geographic variables.

Table 1: Summary statistics, key variables for Brest region (N = 1,242)

Continuous variable	Mean	St. Dev.	Min	Max
Price	160,636	61,766	16,000	520,000
Total floor area	110.501	32.143	34	252
Total land area	1,053	1,346	28	13,674
Number of rooms	5.465	1.387	1	12
Travel time to Brest center (min)	26.974	13.060	3.000	65.800
Travel time to the nearest tramway station (min)	19.081	13.364	1.100	60.200
Travel time to the nearest train station (min)	19.645	11.020	0.200	46.300
Distance to the seaboard (km)	3.262	2.768	0.000	11.727
Distance to the nearest wind turbine (km)	7.932	4.016	0.788	19.476
Travel time to the nearest hamlet (min)	3.890	2.683	0.000	13.200

Categorical variable	Categories	Number
Construction period	Unknown	53
	Before 1850	0
	1850 / 1913	18
	1914 / 1947	119
	1948 / 1969	318
	1970 / 1980	315
	1981 / 1991	148
	1992 / 2000	63
	2001 / 2010	194
	2011 / 2020	14
Energy performance Certificate	A	3
	B	32
	C	189
	D	455
	E	382
	F	132
	G	49

Table 2: Summary statistics, key variables for Lyon metropolis (N = 1,094)

Continuous variable	Mean	St. Dev.	Min	Max
Price	365,481	161,135	100,000	1,387,300
Total floor area	123.777	43.167	39	300
Total land area	802.237	718.665	27	5,757
Number of rooms	5.207	1.434	1	12
Travel time to Lyon center (min)	23.634	5.010	9.400	35.500
Travel time to the nearest metro station (min)	13.132	5.761	0.400	27.600
Travel time to the nearest park (min)	7.517	3.078	0.200	17.700
Travel time to the nearest tramway station (min)	11.471	6.887	0.400	28.700
Travel time to the nearest train station (min)	8.346	4.911	0.100	25.000

Categorical variable	Categories	Number
Construction period	Unknown	83
	Before 1850	4
	1850 / 1913	15
	1914 / 1947	124
	1948 / 1969	206
	1970 / 1980	202
	1981 / 1991	169
	1992 / 2000	113
	2001 / 2010	151
	2011 / 2020	27
Energy performance Certificate	A	3
	B	27
	C	304
	D	390
	E	259
	F	76
	G	35
Swimming pool	Yes	181
	No	913

2.3 Renovation costs and expected energy savings

In order to compare costs and benefits of energy efficiency, a technical-economic analysis is implemented using a description of typical French houses, a thermal model, a dataset on mature technologies and their costs for thermal renovations, and energy costs. This approach enables an estimation of the investment required to perform a warmth insulation of a house and upgrade its EPC class. The techno-economic analysis also provides estimates of energy savings associated to those insulation improvements.

2.3.1 Typical houses

An archetype of French house is defined using Insee (2015) statistics. Architectural characteristics and initial efficiency of each component of this typical house are described in Table 3. Architectural characteristics are assumed homogeneous within one period of construction. The thermal performance of the house is estimated through the mean U-value of its envelope. Envelope covers 4 components: external walls, roof, ground floor and windows of the house. The U-value is the heat transfer coefficient, expressed in $[W.m^{-2}.K^{-1}]$. A component's U-value is then a measure of the quantity of heat leaked by this material. This measure is the key indicator on which the EPC is estimated (see Appendix A.1 for more details). When insulating a component, its U-value decreases. As thermal norms have become more demanding since their appearance in 1974, the U-values of building materials have become smaller, inducing less heat losses for more recent houses, hence smaller energy consumptions and better initial EPC classes. For instance old houses built before 1974 and not retrofitted have a mean U-value about $2.5W/(K.m^2)$, which corresponds to a primary energy consumption over $400kWh/(m^2.an)$ and an EPC class F. On the contrary, recent houses built after the introduction of 2005 French thermal norms have a mean U-value of $0.6W/(K.m^2)$, and consume about $100kWh/(m^2.an)$ for space heating (the corresponding EPC class is C).

Table 3: Architecture and performance of French typical houses

Characteristic	Value
Total floor area	$112m^2$
Number of floors	2
Height per floor	$2.5m$
Percentage of external walls covered by glass	30%

Construction period	<1974	74-81	82-89	90-2000	2001-2005	2006-2014
Share of the housing stock	53.29%	11.2%	10.3%	11.2%	5.9%	8.1%
Uwalls	2.5	1	0.8	0.5	0.47	0.36
Uwindows	4	3	3	3	2.3	2.1
Uroof	2.5	0.5	0.32	0.26	0.25	0.2
Ufloor	1.2	1.2	0.74	0.5	0.36	0.27

2.3.2 Dataset on material and labor costs for renovation

To evaluate investment costs for dwelling thermal renovation, we use Bâtiprix (2015), a French data base on prices in construction, including both material and labor costs, and a set of academic articles and official reports dealing with the costs of renovation (see Lechtenbohmer and Schuring, 2011, and Ferrara et al., 2013). We select mature technologies, widely available on the French market. All available options and associated costs are presented in Table 4. Costs are given with a VAT of 5.5%, which is the VAT applicable in France for thermal renovations, and include both material and labor costs.

For walls, the main technologies available are interior thermal insulation (ITI), using various thicknesses of glass wool, and exterior thermal insulation (ETI), using various thicknesses of rock wool or expanded polystyrene with coating. Interior insulation is less expensive, but also less efficient. The best solution for wall insulation is a combination of interior and exterior insulation. There is also the possibility of not acting on the walls (*statu quo*) : the price is then zero and the U-value is not modified. For windows, four options are available, including the *statu quo*: double-glazed windows, double-glazed windows with argon, and triple-glazed windows. Prices are significantly higher for these technologies. For the floor, the technology is an insulation with different thicknesses of rock wool, typically used on the underside of floor slabs. For the roof, house attics can be considered as uninhabitable or convertible, inducing higher insulating costs in the latter case. The main technologies available for uninhabitable attics are rolls of mineral wool (with various thicknesses) and blown granulated rock wool. For converted attics, the main technology is mineral wool between herringbones.

Table 4: Mature technologies for warmth insulation

Component	Technologies	U-value ($W/m^2.K$)	Prices (€/m^2)
Walls	Statu Quo	Unchanged	0
	ITI Glass wool 4cm	0.77	71.74
	ITI Glass wool 6cm	0.5	73.85
	ITI Glass wool 8cm	0.38	75.96
	ITI Glass wool 10cm	0.3	78.07
	ETI Exp. Polyst. with coating 14cm	0.27	180.405
	ETI Exp. Polyst. with coating 15cm	0.26	183.57
	ETI Rock wool with coating 16cm	0.23	200.45
	ETI(rock 20cm) + ITI(mineral 10cm)	0.11	288.015
Windows	Statu Quo	Unchanged	0
	4/16/4 double-glazing	2	380
	4/16/4 double-glazing argon	1.7	420
	4/16/4/16/4 triple-glazing	1.2	480
Roof	Statu Quo	Unchanged	0
	Mineral wool rolls 20cm	0.2	20.045
	Mineral wool rolls 30cm	0.13	22.155
	Blown rock wool 20.5cm	0.22	34.815
	Blown rock wool 29.5cm	0.15	53.805
	Mineral wool between herringbones 10cm	0.35	85.455
	Mineral wool between herringbones 12cm	0.29	86.51
	Mineral wool between herringbones 16cm	0.22	87.565
Floor	Statu quo	Unchanged	0
	Rock wool slab underside 10cm	0.34	128.71
	Rock wool slab underside 12cm	0.29	133.985
	Rock wool slab underside 14cm	0.25	139.26

2.3.3 Minimized renovation costs

For each construction period, an efficient cost function of thermal performance is computed by ranking the different technologies in increasing order according to their ratio U-value/Price and by cumulating their costs. The obtained curve is convex, consistent with decreasing marginal gains of efficiency when investments grow. Figure 5 in section 4 gives this efficient cost function.

2.3.4 Heating energy prices

Table 5 gives the distribution of the various energies used for space heating in French houses, and their associated costs (data for the year 2016 drawn from CEREN, 2018). The average energy cost in €/kWh of houses built before 1974 is lower than the global average cost for French houses:

this is explained by a smaller share of those houses heated by electricity, in favor of natural gas and heating oil. In order to compare expected energy savings between a theoretic consumption and the real one (including a ‘rebound effect’), the thermal model described in Appendix A.1 also includes a behavioral adaptation through the intermittence factor. In theory this factor is supposed to be constant regardless of the energy performance of the house. In reality, households living in poorly efficient houses limit their own consumption, while households living in efficient houses consume more than the theoretical prediction.

Table 5: Heating energy of French houses and associated costs in 2016

Energy	Share of all houses	Share of houses built before 1974	Costs (Cts of €/kWh)
Natural gas	34.5 %	41.1%	6.96
Electricity	39.1 %	23.8%	16.48
Heating oil	18.1 %	26.4%	9.17
Wood	7.4 %	7.8%	5.8
Heating coal	0.4 %	0.7%	17.0
Urban heating	0.5 %	0.2%	10.31
Weighted average of energy costs	11.1	9.8	-

3 Econometric evaluation of the Green Premiums

Table 6 presents results from the estimation of the two spatial econometric models. Linear regression models estimated with the same variables present fair explanatory powers (pseudo-R squared between 63 and 65%), but the Moran’s test evidences spatial autocorrelation of residuals both for Lyon and Brest. Geographical variables used are thus not sufficient to control for spatial effects, justifying the use of a spatial error model. In Table 6, we can distinguish the effects of three kind of variables: the ones describing the intrinsic characteristics of houses, the ones related to their location, and the interest variable, namely the Energy Performance Certificate.

First, both in the Brest region and in the Lyon metropolis, we find as expected a strong significance and a positive impact of size variables: the total floor area, the total land area but also the number of rooms and of floors increase the price. Moreover in Lyon, the presence of a basement and especially swimming-pool increases the price. Among the intrinsic characteristics of houses, we also control for the construction period. It is important to control for this variable as it may be linked to the energy performance of the house. Indeed, after the first oil shock in 1974, the French government enforced thermal norms, which have been gradually tightened since then. Thus, as houses get more recent, they are naturally more efficient. However, the age of houses also captures other effects. For instance it might be a proxy for the house general condition. Identified effects are consistent with this hypothesis: houses built since the eighties are gradually more expensive, while houses built before the seventies are less. Nevertheless, this effect is not systematically stronger as houses get older, probably due to a ‘vintage effect’.

Second, geographical variables also appear to have an important impact on the price of houses in both areas. The travel time to the city center impacts negatively the price, evidencing a premium for houses nearer to the city center, even though this effect is less significant in Lyon. The negative effect of the travel time to the nearest metrostation is stronger in Lyon. An alternative indicator of the presence of various services in the Brest region has a more unexpected effect: it is the travel time to the nearest hamlet. When this time increases, house’s price increases as well. This suggests that in this rural zone, households value more houses located out of small town centers when keeping the same distance to the bigger city center. This is a probably due to the fact that when living in a rural zone, households have to take their car for almost any shopping activity. The travel time to the nearest rail station has a positive effect on prices in both areas, meaning that households prefer to be further from a train station. If this effect can be counter intuitive at first sight, the ambiguous effect of rail station on real estate prices has been deeply studied by Bowes and Ihlanfeldt (2001). They show that positive effects of train stations, such as reduced commuting costs or attraction for some retail activity, can be offset by several negative externality: primary the noise, and secondly an increase in criminality in the direct neighborhood. In those two particular cases, we can hypothesize that positive effect of reduced everyday commuting time can be small. Indeed those areas are well connected by various public transports (many bus lines are available for instance), and then those train stations are more used to travel out of the region. However, the noise externality associated to trains remains important, and might explain this overall negative effect of distance to the nearest train station. This rationale is especially relevant for the Lyon metropolis, and consistent with the hedonic result. The travel time to the nearest tramway station has a poorly significant effect: in the Lyon metropolis this effect is not evidenced, in line with some literature results about the impact of tramway on prices (see Papon et al. study, 2015, on the associated gains of light rail line for real estate in Paris). In the Brest region, this effect is significantly positive, meaning that households value more houses which are further from tramway stations. Similar drivers of the impact of train station can be summoned to explain this effect. One could shade this explanation by underlying that this effect could be different for houses and flats: indeed, tramways installation in cities takes up space on roads previously dedicated to cars. Households owning a car, as most households living in houses, might then fear an increase in travel time by car in the surroundings of tramway stations.

Regarding environmental amenities, interpretations of travel times are more straightforward, as a smaller distance to the seaboard is associated to a greater price in the Brest area, and a smaller travel time to a park is also associated to a greater price in Lyon. The last geographic additional variable in estimation for the Brest area (distance to the nearest wind turbine) evidences a highly significant and positive effect on price: households penalize houses close to wind farms. This effect is consistent with the results of Gibbons (2015) who showed that wind turbines impact negatively housing sales prices in England and Wales.

Last but not least, estimation results highlight a significant effect of Energy Performance Certificate class on the price of houses in both areas. The D-label is used as a reference category. On the one hand, lower classes (namely E, F and G labels) have a significantly negative effect on price, with a stronger effect as the label worsens. On the other hand, classes better than D gradually increase the price of houses, with the exception of the A-labelled houses which stands out in both areas. In the Brest region, the A-label does not have a significant effect compared to the D-label, and its effect is even negative in the Lyon metropolis. This effect roots in two possible sources. First our sample of A-labelled houses is extremely small (3 in both areas). Second, and more importantly, the French law allows to estimate the Energy Performance Certificate upon energy bills of the occupier for old houses. UFC, the national association of consumers in France, has shown that in some cases, poorly insulated houses have got an A-label as they were not occupied, and then energy bills were equal to zero.

Table 6: Hedonic spatial estimation for the Brest region and the Lyon metropolis

	Dependent variable: log(Price)	
	Brest region	**Lyon metropolis**
Energy Performance Certificate		
Class A	−0.010	**−0.335****
	(0.145)	(0.115)
Class B	**0.116****	**0.036****
	(0.048)	(0.022)
Class C	**0.032***	0.012
	(0.022)	(0.016)
Class D	Hold-out	Hold-out
Class E	**−0.090*****	**−0.055*****
	(0.018)	(0.016)
Class F	**−0.145*****	**−0.069*****
	(0.026)	(0.026)
Class G	**−0.280*****	**−0.073****
	(0.041)	(0.036)
Total floor area	**0.005*****	**0.003*****
	(0.0003)	(0.0002)
Total land area	**0.00004*****	**0.0001*****
	(0.00001)	(0.00001)
Number of rooms	**0.016****	**0.035*****
	(0.007)	(0.005)
Presence of a basement	0.029	**0.035****
	(0.018)	(0.014)
Presence of a swimming-pool	0.078	**0.143*****
	(0.102)	(0.017)
Construction Period		
Unknown	Hold-out	Hold-out
Before 1850	-	**−0.192***
		(0.101)
1850 / 1913	−0.003	−0.035
	(0.069)	(0.056)
1914 / 1947	−0.047	**−0.062****
	(0.042)	(0.029)
1948 / 1969	−0.061	**−0.070*****
	(0.038)	(0.027)
1970 / 1980	0.040	0.009
	(0.038)	(0.027)
1981 / 1991	**0.146*****	0.009
	(0.041)	(0.028)
1992 / 2000	**0.245*****	0.034
	(0.048)	(0.030)
2001 / 2010	**0.276*****	**0.071****
	(0.040)	(0.028)
2011 / 2020	**0.387*****	0.052
	(0.077)	(0.047)
Travel time to Brest/Lyon center	**−0.014*****	**−0.006***
	(0.005)	(0.005)
Travel time to the nearest hamlet (Brest) / Metrostation (Lyon)	**0.013*****	**−0.016****
	(0.004)	(0.006)
Travel time to the nearest train station	**0.004****	**0.012*****
	(0.002)	(0.004)
Travel time to the nearest tramway station	**0.008***	0.008
	(0.004)	(0.005)
Travel time to the seaboard (Brest) / nearest park (Lyon)	**−0.017*****	**−0.009****
	(0.005)	(0.004)
Distance to the nearest wind turbine (Brest)	**0.009*****	-
	(0.003)	
Constant	**11.314*****	**11.952*****
	(0.080)	(0.122)
Other control variables		
Month of the transaction	Not significant	Significant **
Number of floors	Significant *	Significant *
Observations	1,242	1,094
Log Likelihood	−32.929	195.213
σ^2	0.061	0.039
Akaike Inf. Crit.	147.859	−304.426
Wald Test	50.284*** (df = 1)	1,590.116*** (df = 1)
LR Test	45.138*** (df = 1)	323.638*** (df = 1)

Note: Standard deviations of estimated coefficients are reported within brackets *p<0.1; **p<0.05; ***p<0.01

To estimate the green premium of efficient houses, the B-label is considered as the Energy Performance Certificate of ‘green houses’. This is a legitimate assumption as policy-makers in France have set the B-label as the 2050 target for the whole housing stock, designing both A and B-labelled houses as low consumption buildings. Owners of B-labelled houses comply then with the most demanding norms for energy efficiency for the next decades. The ‘red’ reference (*i.e.* inefficient houses) chosen for estimating the green premium is the F-label rather the G-label. The before last label is chosen for two reasons, even if it reduces the estimated green premium (as G-label is in both regions less valued than F one). First, classes of the Energy Performance Certificate cover varying intervals of estimated primary energy consumption (see Appendix A.2). The case of the G-label stands out as it has no upper limit on consumption, and G-labelled houses can then present important heterogeneity in their respective performances. The second reason leading to the choice of the F label roots in the theoretic primary energy consumption of typical houses built since 1974. As shown in the following section, a typical French house built before the introduction of thermal norms should not have a performance worse than F. The G label then indicates the presence of important defects or architectural characteristics not referenced in our database and affecting the energy quality of the house, such as a pierced roof or a glass canopy. Measuring the green premium from this category of dwellings would be deceptive, capturing other effects than house insulation.

In relative terms, the green premium associated to the B label compared to the F label amounts to 29.7% in the Brest region and to 11.1% in the Lyon metropolis. However, energy costs are homogeneous between our two regions of interest: in France the price of electricity is the same across the country for households thanks to tariff equalization, while heating oil and natural gas prices are closely similar in the two regions (price differences are respectively below 1% and 2%). As the two regions share similar heating needs (see section 2.2), energy bills and expected savings associated to a more performant house should be similar as well, even if the urban market of Lyon is tighter than the rural one of Brest. It is then more relevant to estimate the green premium in absolute terms. Switching to absolute values, it appears that the green premium in Brest amounts to 35,300€, while in Lyon it equals 32,300€. Those two real estate markets, structurally different but sharing similar heating needs and costs, reveal close capitalizations of the green label. This result also holds when estimating the green premiums of intermediary classes. Keeping the reference as the F-label, the premium of more efficient houses, respectively in Brest and Lyon, is 6,500€ and 4,100€ for the E-label, 20,600€ and 18,100€ for the D-label, and 24,200€ and 23,400€ for the C-label.

This kind of result is consistent with the engineer’s approach of the green value, which compares investment costs and expected savings associated to energy renovations. The following section mixes this hedonic estimation of the green value with a techno-economic assessment of energy renovation.

4 Techno-economic analysis of energy renovation

4.1 Renovation investment costs

Using the description of thermal and architectural characteristics of a French typical house built before 1974 (over the half of France housing stock), a dataset on material and labor costs for renovation, and the thermal model described in Appendix A.1, the optimized renovation curve of F-labelled houses displayed on Figure 5 is obtained. On the abscissa is represented the level of investment in the thermal renovation. On the ordinate is represented the primary energy consumption which can be achieved by a renovation of this investment level. The range of the various energy classes of the Energy Performance Certificate is also displayed in order to highlight investment levels enabling to upgrade the energy label. The initial performance of the house corresponds to an investment level of 0€, meaning that the house has not been retrofitted and consumes over $400 kWh/m^2/year$ of primary energy. This consumption lies in the range of the F-label. As investment level grows, primary energy consumption decreases. We can observe some important steps which correspond to the point where increasing the energy performance requires to insulate another component of house's envelope, or to switch to a more efficient but also expensive technology. The merit order of renovation actions starts with the insulation of the roof. Indeed, the roof is responsible for approximatively 30% of heat losses, and insulation technologies are relatively cheap. Then follows the internal wall insulation and floor insulation. Replacement of windows by double-glazed ones only occurs in the fourth position of the merit order, and the last technology to be chosen is external wall insulation, highly efficient but also much more expensive. Smaller steps of the renovation curve indicate that the same set of components are insulated, but with gradually more efficient technologies (*e.g.* switching from double-glazed windows to double-glazed with argon windows).

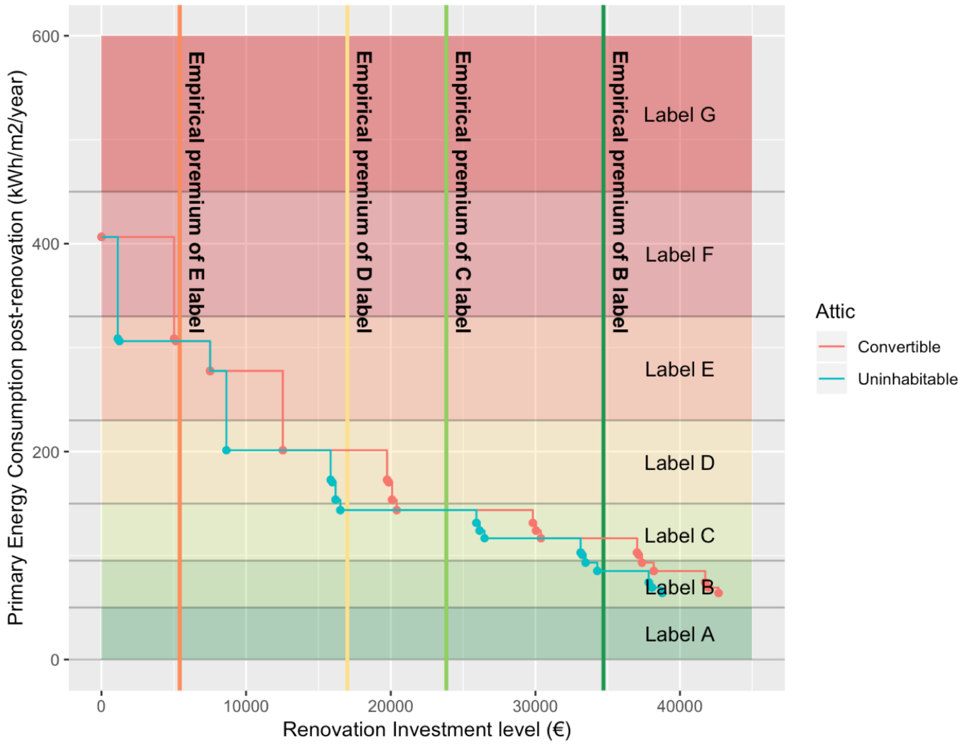

Figure 5: Renovation of a typical house built before 1974

Figure 5 also displays the empirical capitalizations of the different labels compared to the F-one, identified in the spatial econometrics section. This evidences that the green premium associated to low-consumption houses matches closely with the renovation investment level required to reach this performance level. Indeed, turning a typical house built before 1974 into a B-labelled one requires an investment of 32,000€, while the green premium estimated in the previous section amounts about 34,000€. Other intermediate premiums also fall within the range of investments required to reach corresponding levels of efficiency. A potential explanation of these very close estimates is that home sellers compete *'à la Bertrand'* in prices on the energy quality component of the house value. Indeed, the production cost of energy efficiency, *i.e.* the required investment to turn an inefficient house into a more efficient one, is homogeneous. Then, charging more than this amount will lead buyers either to choose another seller proposing a house with the same label at a lower price, or to buy an inefficient house and invest themselves in the renovation. This hypothesis is also consistent with the premium difference observed between the Brest region and the Lyon metropolis. Indeed, a previous study on the French market has found that, outside the Paris region, renovation costs are similar across the country, but slightly superior in rural areas compared to the urban ones (more precisely, observed prices are about 5% superior in rural areas, see OCRE, 2015). Whereas the 'green' premiums of houses can be explained by a Bertrand type competition on energy quality, next section explores the associated energy savings that households can expect from more efficient houses.

4.2 Discounted energy savings

In order to ease comparison, energy savings and green premiums are plotted against on Figures 6, 7, 8 and 9 (respectively for an E, D, C and B-labelled house). Energy savings are computed as the sum of discounted savings on the energy bill (in €) which are expected by living in a house more efficient than the typical not retrofitted house built before the thermal norms of 1974. Using the thermal model, two cases can be distinguished. First the case of a household forecasting energy savings only on the basis of the theoretic energy consumption (dotted curves). Second, the case of a household taking into account the rebound effect (solid curves). The rebound effect can be decomposed in two sub-effects cutting excepted savings: first households living in poorly efficient houses restrict their energy consumption, second households living in low-consumption houses over-consume energy compared to the theory. Expected savings on the energy bill are then less important when the rebound effect is taken into account. Two time horizons which could be used by households to compute expected savings are also considered. The first one, 15 years (red curves), corresponds to the expected time the household will live in the house (our dataset provides this information, revealing a mean period of ownership of 13 years in Brest and of 14 years in Lyon). The second time horizon chosen, 30 years (blue curves), corresponds to the expected lifetime of energy efficiency technologies (technologies lifetime are available in the dataset on renovation costs). Obviously, a longer time horizon implies a more important sum of expected savings today.

On Figures 6, 7, 8 and 9, the abscissa represents the discount rate, and the ordinate represents the sum of discounted energy savings. Each of those figures also displays the empirical premium associated to its label by an horizontal line. For a given discount rate and time horizon, as label gets 'greener', the sum of energy savings will be more important, but also the premium associated.

The intersection between savings curve and premium associated thus gives the implicit discount rate that equalizes for homebuyers the expected energy savings and the surplus paid to buy this house in comparison to a less efficient house. If the household's discount rate is below, then it gains a net positive surplus from buying this labelled-house. But if its discount rate is higher, the surplus would be negative: *ceteris paribus*, the household would choose the less efficient house.

For the E-label (Figure 6), matching the empirical premium with energy savings suggests that implicit discount rate used by households would be at most between 7 to 12% for an horizon of 15 years, or between 10 to 15% for an horizon of 30 years.

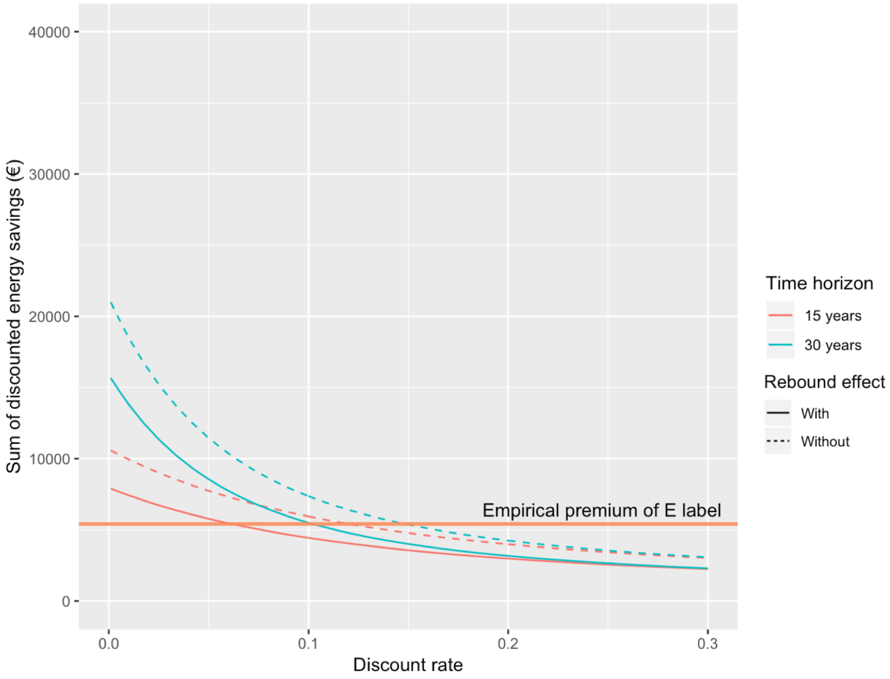

Figure 6: Energy savings versus Green premium for an E-labelled house

For the labels D and C, Figures 7 and 8 highlight smaller implicit discount rates, similar for the those two labels. Discounted savings with the 'short' time horizon (15 years) can equalize the premiums only when the rebound effect is not taken into account, and the resulting implicit discount rates are close to 0%. With the 'long' time horizon (30 years), implicit discount rates equalizing empirical premium and expected savings range from 4 to 7%.

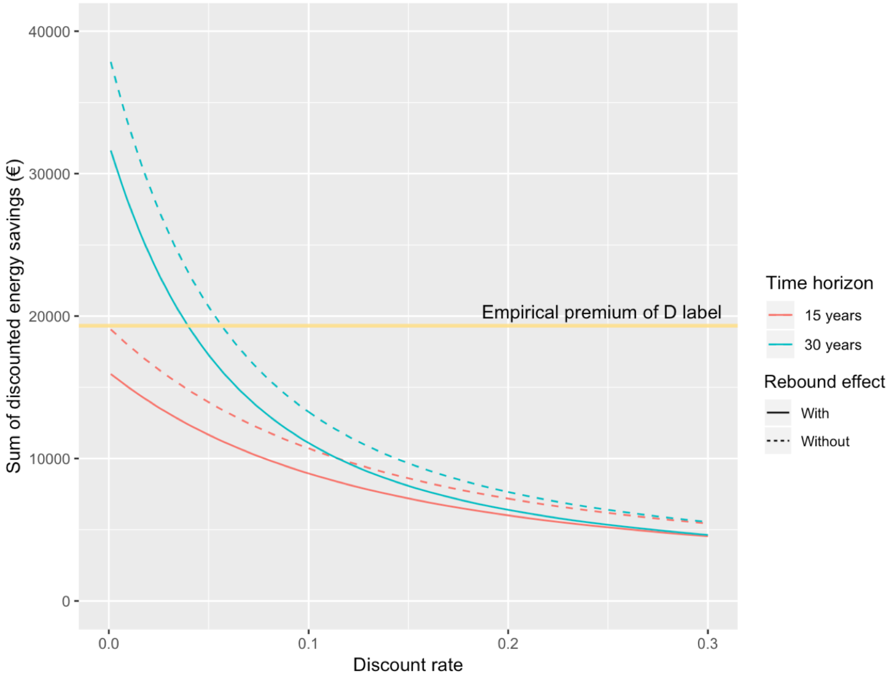

Figure 7: Energy savings versus Green premium for a D-labelled house

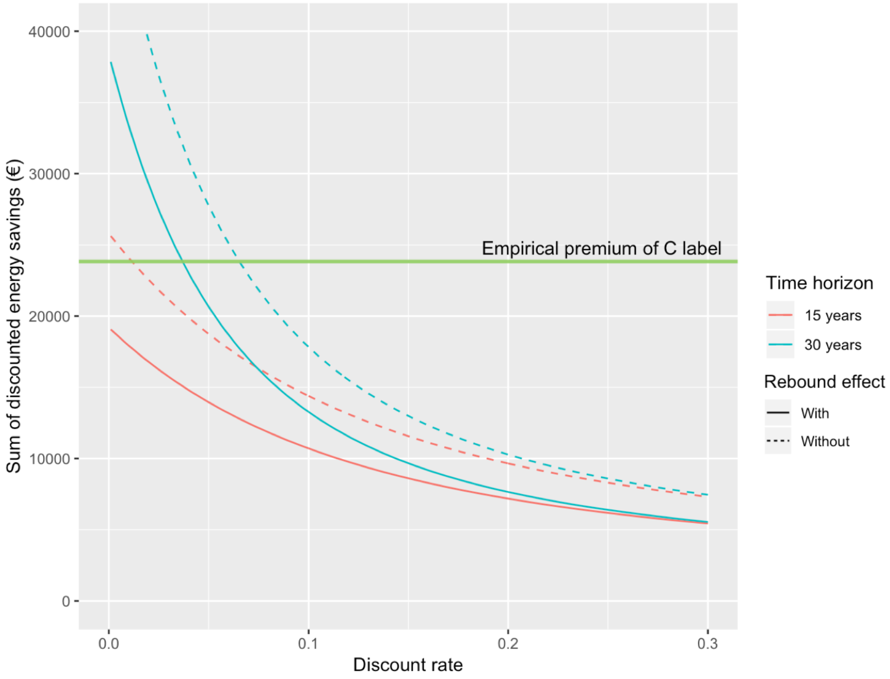

Figure 8: Energy savings versus Green premium for a C-labelled house

Last but not least, the case of B-label furthers this trend. When the time horizon considered is 15 years, the green premium always exceeds the energy savings, no matter the discount rate. In the case of a 30 years time horizon, these savings can fully explain the green premium when the discount rate discount rate is low enough. In the case where subjects do not take into account the rebound effect, the green premium is superior to savings for all discount rates above 4%. This result is even more striking when the rebound effect is taken into account. The sum of discounted savings is then less than the green premium for all discount rates above 2%.

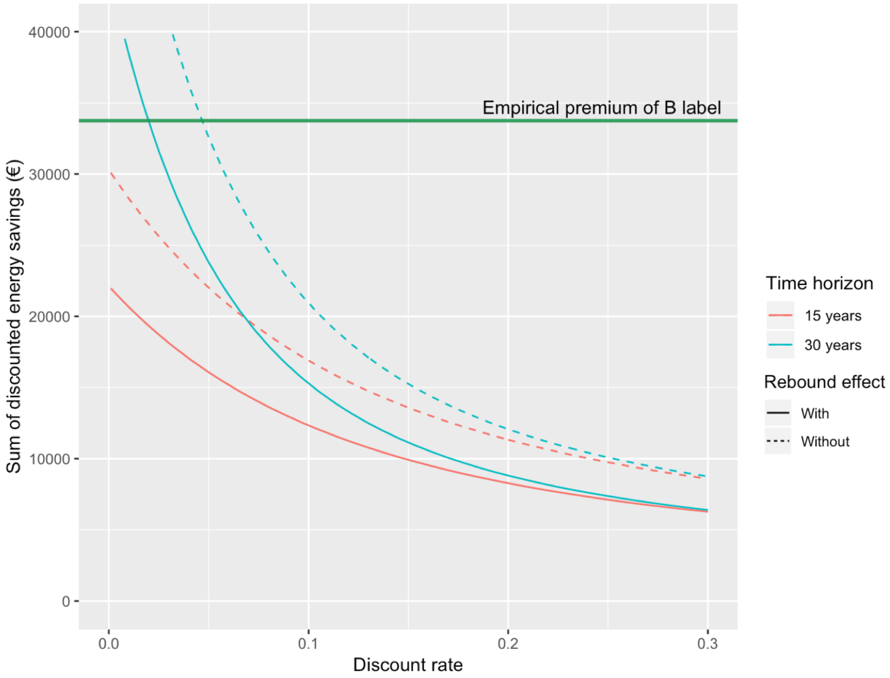

Figure 9: Energy savings versus Green premium for a B-labelled house

According to national statistics published by the Bank of France (2017), in 2016 mean effective interest rates on loans to households was about 4%. However many academic studies have shown that discount rates used by households are largely superior to what standard economic works assume as rational, namely the previously mentioned real interest market rate that amounts 4%. Hausman et al. (1979), Coller and Williams (1999) and Harrison et al. (2002), while using different empirical approaches (respectively observed choices for room air conditioners, a controlled laboratory experiment and a field experiment in Denmark), all reveal discount rates largely superior to 10% for households but also underline their large heterogeneity. In a recently published paper, De Groote et al. (2018) use a large sample of Belgian households to show that over 90% of implicit discount rates used by households to invest in photovoltaic panels fall within the range of 12% to 17%. This investment decision in energy production can be compared to the investment decision in energy renovation as return-on-investment time are similar. Using this range of discount rates, in all the scenarios considered (15 or 30 years time horizon, rebound effect taken into account or not), previous figures suggest that, in theory, only the E-labelled houses premium could be acceptable for home-buyers as the surplus associated would be positive. The magnitude of other premiums (D, C and B labels), significantly higher than savings when using previously mentioned discount rates above 10%, leaves room for different interpretations.

First, the gap between savings and premiums is probably smaller as time preferences of households are strongly disperse. For instance, the small sample of home-buyers who accept to pay the important premium of B-labelled houses probably have a marked preference for the future, with longer time horizons and smaller discount rates than other households.

A second and complementary interpretation of this gap between premiums and expected savings is supported by the study of ADEME (2018). This survey was conducted on an important sample of French house owners who proceeded to a warmth insulation between 2014 and 2016. It highlights that beyond energy savings, the thermal renovation presents important other advantages for households. Three main benefits can be cited to explain this green value beyond energy savings. First ancillary benefits, such as improved thermal comfort, reduced exposition to external noise and moisture issues, were targeted by the study of Jakob (2006) who hypothesizes that they could represent utility gains of the same order of magnitude than energy savings. Results of the present paper could be consistent with this hypothesis: co-benefits could be as much valuable as energy savings for households. Second advantage of owning a house labelled as 'low-consumption', or at least labelled C or D, lies in the protection against future changes in public policies. French policy-makers have set the target for the whole building stock to be labelled as 'low-consumption' at the 2050 horizon. This target is not legally binding for now, policy-makers favoring rather incentives such as subsidies and zero-interest loans to motivate owners. However, a first attempt was made to make renovations mandatory for inefficient houses (labelled below D) in the 2015 French law for the energy transition. Whereas this article of the 2015 law has been censored by the constitutional council due to imperfect specifications[1], it remains an important signal that policy makers might, in the next decade, enforce a legislation on this topic to constrain owners of poorly efficient houses to invest in renovation. Therefore, buying a house already labelled D or higher is an efficient way to protect one's investment from the regulatory uncertainty. Third, a last potential root of the green premium is the 'moral value' of living in a more environmentally friendly house. Brounen and Kok (2011) showed in the case of Netherlands that the proportion of green voters in a given neighborhood modifies households' behavior regarding the Energy Performance Certificate, suggesting that the Willingness-to-Pay for energy efficiency could vary among households according to their environmental beliefs.

In their large study on the French renovations, ADEME (2018) also found that, whereas many French house owners retrofitted their houses in the 2014-2016 period, most of warmth insulations were limited to small interventions, such as the one enabling to upgrade from the F-label to the E-label. This observation on the French market strengthens the hypothesis that most of implicit discount rates used by households are too high to favor low-consumption houses (*i.e.* B-labelled ones), despite the fact that they constitute the target of French policy-makers. Until today, French public policies trying to incentivize energy retrofitting have mainly rely on tax credits rather than zero-interest loans. Given the capitalization of renovation investments in houses prices and the future preferences required to favor those investments, one could recommend to develop the use of interest free loans. For instance, a relevant measure could be to extend their repayment time,

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[1] See `https://www.conseil-constitutionnel.fr/decision/2015/2015718DC.htm`

today constrained at 15 years, as we evidenced that this time horizon might be too short.

5 Conclusion

Existing literature on energy efficiency has often opposed the economic approach and the engineer approach. This opposition has been extensively documented in the studies on the energy efficiency gap and on the energy paradox, underlining differences between technologists', economists' and social optimal level of energy efficiency (see the recent review by Gerarden et al, 2017). This article suggests that the two approaches are not irreconcilable. Using a dataset on houses transactions in two French regions, it evidences that 'low-consumption' houses benefit from of a significant green premium on the real estate market. Capitalization of energy label information is more important in relative terms in the rural area, but in absolute terms rural and urban green premiums are similar, reaching about 35,000€ for low-consumption houses. These tantamount absolute green values correspond to the required investment in mature technologies to improve energy efficiency. A legitimate assumption is that a Bertrand-type competition occurs between sellers on the energy quality component of houses, preventing them from selling a low-consumption higher than its renovation cost. On the buyer side, the paper highlights that this green value can only be fully explained by discounted energy savings if households preferences are strongly oriented towards the future. This result advocates for the development of zero-interest loans. The remaining green value, beyond energy savings, could be explained by various co-benefits of energy-efficient houses, such as improved thermal comfort or protection against regulatory uncertainty. Those ancillary advantages could be important motives to emphasize in order to trigger more investments in energy renovations.

Relevant extensions of this work could focus on disentangling the relative importance of the various co-benefits that could explain the 'green surplus' of efficient houses. Moreover, the dynamic dimension of the renovation decision should also be studied: as underlined by ADEME (2018), households decision rely heavily on word-of-mouth processes. Lastly, the extension of the use of free-interest loans raises other questions about energy labelling of houses, as this policy device involves a more advanced but also more expensive thermal audit than the Energy Performance Certificate.

Acknowledgments

A Appendix

A.1 Thermal model

On the basis of a thermal model inspired by the 3CL-DPE method, a French official method to estimate building energy consumption for space heating (MEDDE (2012), MEDDE (2009)) and using the PhD thesis realized by Allibe (2012), the performance of the envelope (represented by the mean U-value = U_G) is linked to the primary energy consumption for space heating: $Cons_{peh}$ expressed in $[kWh/(m^2.an)]$. This conventional consumption in primary energy for heating is the value used to attribute an EPC class to a house. The corresponding relation is stated in Eq. (3).

$$Cons_{peh}(U_G) = K_{final \to primary} * \frac{U_G * A_{envelope} * D_{h.ref} * I}{Boil_{eff} * L_s} \tag{3}$$

In the previous equation, U_G is the mean U-value, and main variable, of the building $[W/(K.m^2)]$. It is calculated by an algorithm on the basis of the architecture and materials of each building.

Other parameters are fixed. $A_{envelope}$ is the total area of the building envelope $[m^2]$. It is calculated by the program thanks to information on building's architecture. L_s is the total floor area $[m^2]$. In order to estimate the need per m^2, the total living space area in the house needs to be provided. $Boil_{eff}$ refers to the boiler efficiency. It depends on the particular heating system of the dwelling. The efficiency of a regular boiler is usually between 0.85 and 0.95 ; for this paper we will assume that this efficiency is equal to 0.9 for all houses. $K_{final \to primary}$ is computed as the mean standard transformation coefficient of final energy into primary energy. Given the distribution of heating energies in the French houses stock, we use $K = 1.6$. For more details on heating energy in French houses, see ADEME (2013).

$D_{h.ref}$ is the number of degrees - hour needed to heat up the space during a year (depending on the climate) $[K.h]$. The 3CL-DPE method[2] provides $D_{h.ref}$ for all French metropolitan departments ; these numbers are computed under the assumption that a temperature of 18^oC with the heating system is targeted, considering that other contributions (lighting, biological heat) will be enough to reach the setpoint temperature of 19^oC. In the model the average value across French metropolitan departments of Lyon and Brest, which have similar heating needs as detailed in section 2.2, is used. The $D_{h.ref}$ is thus set at 54500 $K.h$.

I is the factor of intermittence. As a house is not continuously occupied during the year, especially during working hours, heating systems can be turned off. The factor of intermittence is between 0 and 1, the reference value for houses is $I_0 = 0.85$. Contrary to the conventional consumption prediction model ($Cons_{feh}^{theoretic}$, which is used to estimate the EPC class of the house), the behavioral consumption model ($Cons_{feh}^{behavioral}$) integrates the behavior of households by allowing the variation of intermittence. On the one hand, when U_G is high, the intermittence is lower: households adopt strategies to reduce their consumption (decrease temperature setpoint

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[2] See `https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000026601023&categorieLien=id`

in bedrooms, or turn off heating at night). But on the other hand, when U_G is small, the intermittence will be close to 1: a better insulated dwelling allows to choose a higher temperature setpoint higher. This is the "rebound effect": a gain in energy efficiency implies a lower cost for the same energy service and then demand for that service may increase. The expression of this $I = f(U_G)$ is inspired by Allibe (2012):

$$I(U_G) = \frac{I_0}{1 + 0.1 * (\frac{U_G}{U_{G_0}} * \frac{A_{envelope}}{L_s} * \frac{H_{c0}}{H_c} - 1)} \tag{4}$$

Where H_c is the ceiling height per floor (in $[m]$). $H_{c_0} = 2\ m$ and $U_{G_0} = 1\ W/(K.m^2)$ are references values. This thermal model is used to estimate the theoretical and behavioral consumption of a typical house. When comparing these consumptions to the average observed consumption in France (RAGE (2012)), it appears that the behavioral model gives a fair estimation of real consumption rates.

For instance, the prediction of total French energy consumption for residential heating is $30.6 Mtoe$. This estimation is obtained by combining the thermal model with the description of the French housing stock (see Tables 3 and 5). According to official figures given by CEREN (2018), residential energy consumption in 2016 for space heating was 28.1 $Mtoe$ in France. The real energy consumption is then 8% inferior to the calculated one. Two main factors explain this over-estimation. Firstly, already refurbished buildings are not taken into account. Secondly, in the last thirty years, the average area of houses has strongly increased, from $96m^2$ in 1984 to $112m^2$ in 2014 (see Insee, 2015). But this evolution is not represented in the model, resulting in an overestimation of the total area of old houses, which consume more, and an underestimation of the total area of recent houses, which consume less. This gap between predicted and real consumption is still significantly smaller than the ones found in the literature until now for space heating in France (22% for Mata et al., 2014, and 18% for Ribas Portella, 2012).

A.2 Energy Performance certificate design

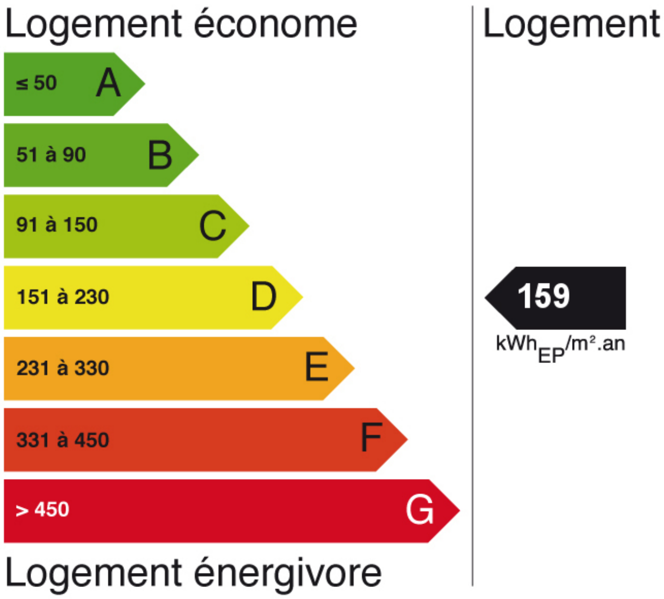

Figure 10: EPC classes cover various range of energy consumption

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