WORKING PAPER

N° 2024-5

THE VALUATION OF ENERGY EFFICIENCY LABELS IN THE FRENCH HOUSING MARKET

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www.tepp.eu

TEPP – Theory and Evaluation of Public Policies - FR CNRS 2042

The Valuation of Energy Efficiency Labels in the French Housing Market

Sylvain Chareyron*

Abstract: This study assesses the effect of energy efficiency labels on the private housing market using information on energy efficiency assessments of housing and property transactions in France between 2016 and 2021. We take into consideration two energy labels assigned to dwellings, one that calculates energy efficiency based on energy consumption and the other on greenhouse gas emissions. The results of the hedonic regressions show that having a higher efficiency rating has a significantly positive effect on housing prices. We also show that this effect increases with the number of annual heating degree days of the locality of the dwelling, indicating the importance of the energy-saving aspect in the market valuation of energy-efficient housing. Finally, using regression discontinuity estimates, we differentiate between the effect of the cognitive perception of labels and of the real energy efficiency gain on housing prices. Our findings reveal that the cognitive effect is predominantly observed in the least efficient dwellings.

Key words: Energy efficiency, housing prices, hedonic regression, RDD

JEL classification: D82, Q51, R31, R38

Declaration of interest: the author has no competing interests to declare.

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We thank the participants of the conferences at which this article was presented: ERUDITE Workshop (May, Créteil, France), 13th FAERE Thematic Days (May 2023, Champs-sur-Marne, France), JMA (June 2023, Strasbourg, France) and LAGV (June 2023, Marseille, France). We remain solely responsible for any errors or omissions.

1 Introduction

The growing urgency to reduce greenhouse gas emissions to minimize global warming has brought the issue of housing energy efficiency to the fore. In Europe, housing-related emissions constitute a significant portion of total greenhouse gas emissions. For example, in 2017, the residential-tertiary sector was the second largest contributor to greenhouse gas emissions in France, accounting for 20% of the country's total emissions. [1]

Since the beginning of the 2000s, public policies at the national and European level have aimed at improving the energy efficiency of the housing stock. These public policies involve, among other initiatives, the implementation of increasingly strict environmental standards in the construction of new housing and aid for the renovation of housing. The effect of these policies in saving energy, and in particular the implementation of stricter building codes is however mixed (Auffhammer, 2012; Kotchen, 2017; Levinson, 2016). Market-based environmental policy instruments can also contribute to this goal by reducing market frictions (Stavins, 2003). One of these policies has been the creation of an energy efficiency label and, in some countries such as France, an official energy assessment must be provided when selling a dwelling.

What sets this policy apart from others is that it does not impose any direct costs on private or public entities but instead operates by enhancing the quality of information available in the real estate market. By promoting greater transparency around housing environmental characteristics, this requirement aims to provide a more accurate reflection of the energy characteristics of housing options on the real estate market. This measure is therefore likely to incentivize the improvement of the environmental standards of dwellings.

However, determining the most effective way to provide information on housing energy efficiency is a complex task (Waechter et al., 2016). The information must be presented in a manner that is both easily comprehensible and accurate, with minimum distortion. Rationally processing information requires significant mental effort and other cognitive systems that involve perception and intuition may come into play (Kahneman, 2003). As shown by Lacetera et al. (2012), consumers use heuristics to process information, even when buying a high-value durable good, and these cognitive shortcuts can lead to significant mispricing.

[1] Figures from https://notre-environnement.gouv.fr/themes/climat/les-emissions-de-gaz-a-effet-de-serre-et-l-empreinte-carbone-ressources/article/les-emissions-des-gaz-a-effet-de-serre-du-secteur-residentiel.

In France and across the European Union, the chosen approach involves quantifying a dwelling's energy efficiency based on its energy consumption and greenhouse gas emissions. These continuous measurements are then positioned on a scale ranging from G (the most inefficient) to A (the most efficient). While this categorization offers potential buyers a straightforward understanding of a dwelling's energy performance, it can result in threshold effects.

The aim of this article is to assess the value the real estate market places on housing energy efficiency labels. We consider two types of energy efficiency assessment: one based on energy consumption and the other on greenhouse gas emissions (GHG). To do this, we use two comprehensive datasets, one that encompasses all energy efficiency assessments and the other, real estate transactions for the period 2016 to 2021. By merging these two datasets, we can build a large sample of transactions that incorporates both sets of information. First, we estimate usual hedonic regressions to assess price differentials between dwellings with different energy efficiency labels but similar observable characteristics. This allows to compare our results with previous elements from the literature. Also, by exploring the evolution over time and across housing characteristics of the valuation the market places on housing energy efficiency, we attempt to provide an insight into the mechanisms that explain the eventual energy premium. In particular we aim to disassociate financial utility (i.e., energy savings) generated by energy-efficient housing from non-financial utility (i.e., satisfaction in contributing to environmental protection). Second, we run regression in discontinuity estimates to disassociate the effects of housing energy efficiency improvements from the cognitive perception of the labels. The aim of this analysis is to identify price discontinuities between two rankings. As labels condense energy efficiency information into more easily understood categories, their discrete nature could create price discontinuities between the different rankings.

Our hedonic regression results show that a higher ranking in both labels (i.e., the one based on energy consumption and the one based on GHG emissions) is significantly associated with housing prices: a B-rated dwelling is valued 9% higher than a G-rated dwelling with similar observable characteristics, corresponding to an additional value of around €18,000 on average. Exploring the heterogeneity of the effect, we find that this effect increases with the number of annual heating degree days of the area where the dwelling is located, indicating the importance of the energy-saving aspect in the market's valuation of energy-efficient housing. Finally, using regression discontinuity estimates, we differentiate between the cognitive perception of labels and the gain in energy efficiency. Our findings reveal that the cognitive effect is predominantly observed in the least efficient dwellings.

Contrary to other products such as food or home appliances, few researchers have been interested in investigating the specific effect of the information provided by the energy label on housing prices. Our first contribution is therefore to investigate this aspect by estimating the effect of energy efficiency labels using a regression discontinuity design. This method, closer to an experimental design than hedonic regressions (Lee & Lemieux, 2010), limits the possibility that some of the estimated energy premium is related to other unobserved housing characteristics. Furthermore, in this setting, the nature of the RDD estimate changes somewhat from that obtained with hedonic regressions. In hedonic regressions, the continuous measurement of energy efficiency is not controlled for, so the energy label effects we observe correspond to the performance ranking of the dwelling on a scale of energy consumption or gas emissions. The effect encompasses all the mechanisms that lead to valuing an energy-efficient dwelling more than a less efficient one (i.e., both financial and non-financial utilities). However, it is expected that the energy label, a breakdown of the continuous measurement of energy efficiency, will have its own effect associated with the way information is conveyed and processed by buyers. It is therefore likely that there will be a price discontinuity between two dwellings that are comparable in terms of energy efficiency, with one dwelling positioned above and the other below the threshold for a specific label. While the label aims to reduce information asymmetry, it is also likely to introduce a significant distorting effect that should be measured. Regression discontinuity estimates enable us to compare dwellings that are very similar in term of energy efficiency, thereby allowing us to observe the specific impact of the label signal on dwelling prices.

The second contribution of the study is that is focuses on France, a European Union country where electricity prices were, over the period 2015-2020, lower on average than in most Western European countries.[2] This may lead to energy efficiency having a lower impact on housing prices than in other Western European countries on which previous studies have focused. Comparing our results to those found in other European countries where similar energy efficiency labels are in force may then highlight the effect of electricity prices on the valuation of energy efficiency. The other distinctive feature of the French situation is the mandatory

[2] Figure from https://www.statistiques.developpement-durable.gouv.fr/sites/default/files/2018-10/datalab-essentiel-153-prix-de-l-electricite-en-france-et-dans-l-union-europeenne-en-2017-octobre2018.pdf.

display of the energy efficiency diagnosis for the sale of a home. Indeed, the provision of an energy efficiency assessment has been mandatory in France since 2006, which was not the case in other European countries until 2013, and is still not in the case in other countries such as the US.[3] For instance, in the Netherlands during the period of the study conducted by Brounen & Kok (2011), the energy efficiency label was not fully mandatory. Buyers had the option to sign a waiver that exempted the seller from the obligation of certifying the dwelling's energy efficiency.

Finally, we also explore the evolution of the energy efficiency premium over time. As indicated by Das & Wiley (2014), one of the limitations of this literature is that, with the exception of the study by Reichardt et al. (2012), studies do not report how the premium is changing over time.

In the next section, we provide an overview of the literature on the valuation of energy efficiency in the real estate market and the in the institutional context. In Section 3, we describe the data and present some descriptive statistics. We present the empirical methodology in Section 4. In Section 5, we present the results of the hedonic regressions and regression in discontinuity estimates. We then discuss the results and conclude in the last section.

2 Background

2.1 Previous literature

Articles that have studied the valuation of energy efficiency in the real estate market agree that there is a relatively large premium for energy-efficient dwellings, in the US (Dinan & Miranowski, 1989; Kahn & Kok, 2014), Europe (Hamilton et al., 2013; Hyland et al., 2013) and Asia (Deng et al., 2012; Zheng et al., 2012; Yoshida & Sugiura, 2015). This applies to private residential housing (Hyland et al., 2013) as well as commercial housing (Eichholtz et al., 2010, 2013) and affordable housing/public housing (Chegut et al., 2016).

When dwellings with a green certificate are compared to similar uncertified dwellings, Kahn & Kok (2014) a 2-4% premium is observed for the former. A result in the order of a 4-6% premium was obtained by Deng et al. (2012) for certified dwellings in Singapore. In Europe, where energy efficiency is generally assessed using A to G rankings, Brounen &

[3] In 2013, a European law harmonized the obligation to display the energy efficiency label when selling a dwelling.

Kok (2011) in the Netherlands and Hyland et al. (2013) in Ireland have consistently found a difference of around 10% between the highest A label and the intermediate D label.

However, some studies have found little or no premium for energy efficiency. Fuerst & McAllister (2011) found no evidence of a significant relationship between environmental and/or energy performance and the rental and capital values of commercial property assets in the UK. Cerin et al. (2014) also found a positive but limited effect of energy efficiency on housing prices in Sweden. In Germany, Amecke (2012), using the results from a survey, found that the energy performance certificates introduced in the European Union have not substantially increased the incorporation of energy efficiency information into owner-occupiers' purchasing decisions.

For their evaluations, these studies use a wide range of methods: most often hedonic regression as in the seminal article by Laquatra (1986), sometimes combined with Heckman's selection model when assessment of the energy efficiency is not mandatory (Brounen & Kok, 2011), IV approach (Aydin et al., 2020) and also propensity score matching (Kahn & Kok, 2014) or first difference (Eichholtz et al., 2013). However, to our knowledge, very few evaluations have been conducted using a regression in discontinuity design, which, as advocated by Lee & Lemieux (2010), is closest to an experimental setting. This method also permits the disentanglement of the impact of the cognitive salience of the label information from the rational financial or non-financial utility associated with having an energy-efficient dwelling.

Very few studies have also investigated the cognitive salience of housing energy efficiency labels with the exception of Civel & Cruz (2018) who conducted a field experiment to examine how energy labels influence people's perception of housing energy performance. More research has been dedicated to energy labels for home appliances (Houde, 2018; Waechter et al., 2016) and for food (Muller & Prevost, 2016).

The closest study to ours is the one by Aydin et al. (2020), which complements their main analysis with a Regression Discontinuity Design (RDD) on Energy Performance Certificates in the Netherlands. This analysis enables them to investigate the effect of information provision on housing prices. Compared to theirs, our study, which focuses on another country, France, builds on a much larger dataset, allowing us to obtain more powerfull estimates. Indeed, RDD estimates require restricting the analysis to transactions on both sides of each threshold, which may lead to a small sample size for each estimate.

2.2 The introduction of energy efficiency labels in Europe and France

The introduction of energy efficiency labels in Europe began in 2002 when the European Parliament ratified Directive 2002/91/EC on the energy performance of buildings. The Directive requires EU countries to introduce comparable energy-efficiency labels, known as Energy Performance Certificates (EPCs).

The Directive requires the disclosure of the energy efficiency label in all EU countries from 2006. However, three additional years were granted to countries unable to do so in time. In 2009, the Directive was extended to require that the ranking of the dwelling be included in all advertisements for the sale or rental of housing. The introduction of energy efficiency labels in France closely follows the EU timetable: energy efficiency labels have been mandatory for the sale of housing since November 1, 2006.

Despite the commitment to harmonizing energy efficiency labels across the EU, differences remain between countries. While energy efficiency labels have common features, such as the period of validity, they may differ in their expression of energy consumption, the minimum performance thresholds and labels, the calculation method (with software and/or on bills), etc. For example, energy labels are generally classified from A to G, but can go up to label I in Luxembourg. Some labels may also be subdivided in certain countries such as Germany, Belgium and the Netherlands (e.g. in Germany the A label is divided into A+ and A).

Although harmonization is gradual[4] and not yet complete, this initiative is one of the first on this scale to attempt to improve information on the energy characteristics of housing, after the Energy Star program in the US. The Energy Star program is not mandatory, however, and is a one-off label based on a building rating between 1 and 100.

3 Data and descriptive statistics

3.1 Data

The dataset we use in this study comes primarily from two sources: Demande de Valeurs Foncieres (DVF) between 2016 and 2021 and the Home Energy Performance Certificate (EPC) between 2013 and 2021.

[4] A directive of the European Union is currently being drafted to increase harmonization of energy efficiency labels.

The DVF dataset concerns real estate sales records, supplemented by property descriptions from the land register. For each registered sale, the nature of the property, its address and surface area, the date of transfer and the declared property value are specified.[5] We only consider sales of constructed dwellings (i.e. we exclude auctions, expropriations, sales in a future state of completion, etc.) and also exclude sales of industrial, commercial or similar premises and auxiliary housing. We only retain homes priced between 10,000 and 10 million € with a living area between 9 and 290 square meters.

The EPC Logement dataset contains the energy rating of all dwellings that have undergone an energy assessment, the date of the assessment and the assessment method.[6] There are two types of energy ratings: one based on energy consumption, the other on greenhouse gas emissions. Energy consumption is measured in $kWh/m^2/year$ and takes into account heating, cooling and domestic hot water production. Greenhouse gas emissions are measured in $CO2/m^2/year$ and take into account the same factors as energy consumption. These measurements are then divided into categories that produce two energy labels graduated by letters from A to G. Table A1 in the Appendix shows the correspondence between energy consumption, greenhouse gas emissions and the letter of the label. Dwellings rated F and G are considered energy-inefficient dwellings. The N label is assigned when the energy assessment could not be carried out for technical reasons. We have removed the N and A-rated dwellings from the database: very few dwellings had been rated A at the time our dataset was compiled, and they generally correspond to particular situations (Civel & Cruz, 2018).

Energy efficiency can be assessed in two ways: the 3CL calculation method, which is based on the geometrical and thermal characteristics of the property (walls, ceilings, floors, etc.) and its heating, cooling, hot water production, lighting and auxiliary systems for heating, ventilation and hot water; and the actual consumption method, which is based on average energy consumption based on 3-year statements (invoices) supplied by the owner.

In addition to the energy rating information, the EPC Logement dataset contains information on the location of the dwelling, the type of dwelling, the purpose of the energy assessment (sale, rental, etc)[7] and the date of construction of the dwelling.

We merged the two datasets to obtain information on the energy efficiency of as many

[5]The dataset is accessible here: https://www.data.gouv.fr/fr/datasets/demandes-de-valeurs-foncieres-geolocalisees/.
[6]The dataset is accessible here: https://data.ademe.fr/datasets/dpe-france.
[7]We only retain energy efficiency assessments carried out for the purpose of selling the dwelling.

dwellings as possible.[8] We combined them on the basis of property location (city, street and street number) and dwelling type. An energy assessment remains valid for 10 years and consequently, we retain all energy assessments carried out at the same address before the dwelling was sold. If there is any ambiguity between different energy assessments for the same address, they are not included.[9]

To explore the heterogeneity of energy efficiency on housing prices, we also add information on daily temperatures in each *département*[10] as well as the results of the first round of the 2022 French presidential election.[11] From the first dataset, we compute the number of cooling and heating degree days per year for each *département*. From the second dataset, we take information on the share of vote obtained by the Green candidate in each city.

3.2 Descriptive statistics

The total sample size is 590,446 housing units with an energy consumption label between B and G and 547,713 housing units with a greenhouse gas emission label between B and G.

Table 1 presents descriptive statistics of the dwellings sold from the total sample by energy efficiency label. In the total sample, the average price per square meter is about 3,200 € and the average dwelling size is about $92m^2$. The majority of dwellings are houses. Finally, a third of the buildings date from before 1950 and a third from the 1971- 1990 period. Dwellings classified as G and F, which are considered to be energy-inefficient dwellings, have fewer than 100,000 observations and are less frequent than other labels. The modal label for energy consumption is D, while it is E for greenhouse gas emissions.

When we divide up the sample by energy efficiency label, we find that for both energy consumption and greenhouse gas emission ratings, the best rated dwellings are consistently more expensive on average than less efficient dwellings. The most efficient dwellings were also built more recently: 47% of B-rated dwellings in terms of energy consumption were built after 2010, compared with 0% of G-rated dwellings. In contrast, 37% of G-rated dwellings and 42% of F-rated dwellings were built before 1950. However, the relationship between dwelling size and energy rating is less clear, especially for greenhouse gas energy ratings.

[8] The energy assessment is mandatory for the sale of a home since 2006.

[9] Unless the surface areas and energy ratings of all assessments for the same address are similar.

[10] The dataset is accessible here: https://www.data.gouv.fr/fr/datasets/temperature-quotidienne-departementale-depuis-janvier-2018/.

[11] The dataset is accessible here: https://www.data.gouv.fr/fr/datasets/resultats-du-premier-tour-de-lelection-presidentielle-2022-par-commune-et-par-departement/.

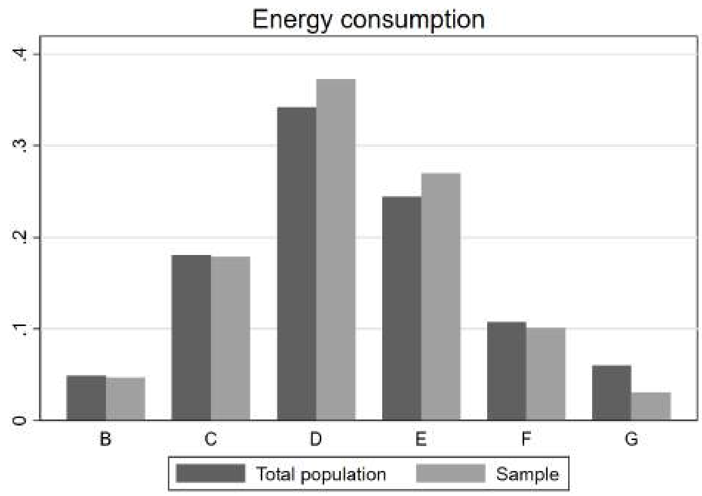
Table 1. Descriptive statistics

	Energy consumption						
	Total	B	C	D	E	F	G
Transaction	252648.4	340457.6	295091.2	254944.1	230979.5	204354.9	193891.5
price (€)	[257476.0]	[479412.8]	[253840.2]	[239037.2]	[238142.5]	[217700.0]	[226652.3]
Price per square	3169.1	4039.7	2906.8	2983.3	3196.2	3544.4	4204.3
meter (€/m^2)	[4991.4]	[8944.0]	[2929.6]	[3927.9]	[5292.8]	[6559.1]	[7996.2]
Dwelling size	92.8	102.6	109.3	95.8	86.0	75.5	64.4
(m^2)	[43.4]	[49.9]	[46.5]	[42.6]	[39.4]	[36.0]	[34.0]
Dwelling type:							
Apartment	0.39	0.49	0.37	0.41	0.38	0.36	0.38
House	0.61	0.51	0.63	0.59	0.62	0.64	0.62
Period of construction:							
Pre 1950	0.33	0.18	0.31	0.33	0.34	0.39	0.45
1951-1960	0.04	0.01	0.01	0.03	0.05	0.08	0.09
1961-1970	0.07	0.02	0.04	0.06	0.08	0.11	0.12
1971-1980	0.21	0.05	0.13	0.21	0.26	0.29	0.27
1981-1990	0.12	0.04	0.12	0.13	0.14	0.09	0.05
1991-2000	0.07	0.04	0.10	0.07	0.06	0.03	0.02
2001-2010	0.12	0.21	0.24	0.15	0.06	0.01	0.01
>2010	0.04	0.47	0.05	0.02	0.01	0.00	0.00
Observations	590446	27592	105628	219994	159661	59499	18072

	GHG emissions						
	Total	B	C	D	E	F	G
Transaction	252567.63	241989.5	257618.2	273053.0	258305.5	235411.7	207094.1
price (€)	[262129.6]	[224483.0]	[307178.0]	[245523.5]	[266065.2]	[267379.0]	[202900.3]
Price per square	3201.8	3393.0	3648.6	2982.5	3009.8	2990.7	2820.9
meter (€/m^2)	[5166.3]	[4853.2]	[7146.4]	[3894.8]	[4345.4]	[5029.4]	[4036.2]
Dwelling size	92.0	86.1	87.2	102.3	95.5	89.6	85.3
(m^2)	[43.1]	[42.7]	[44.6]	[46.3]	[41.7]	[37.6]	[34.1]
Dwelling type:							
Apartment	0.40	0.48	0.44	0.37	0.40	0.33	0.20
House	0.60	0.52	0.56	0.63	0.60	0.67	0.80
Period of construction:							
Pre 1950	0.34	0.27	0.21	0.37	0.43	0.42	0.37
1951-1960	0.04	0.01	0.02	0.03	0.05	0.09	0.12
1961-1970	0.07	0.02	0.04	0.06	0.09	0.13	0.17
1971-1980	0.22	0.11	0.19	0.20	0.29	0.32	0.32
1981-1990	0.12	0.15	0.22	0.12	0.08	0.03	0.01
1991-2000	0.07	0.10	0.10	0.08	0.04	0.01	0.00
2001-2010	0.11	0.27	0.14	0.12	0.02	0.00	0.00
>2010	0.03	0.06	0.08	0.02	0.00	0.00	0.00
Observations	547713	101994	118443	110578	121116	65841	29741

Note: Standard deviations in brackets.

Figure 1. Distribution of Energy Efficiency Labels



Note: The figure compares the distribution of energy efficiency labels in our sample with the distribution of energy labels in the housing stock at January 1, 2018.

Although drawn from the total population of energy assessments completed over the period 2013-2021 and the total population of transactions completed over the period 2016-2021, the distribution of housing characteristics and energy efficiency labels in our final sample may differ from the overall population, since we only retain energy assessments that have been matched to a transaction and vice versa.

Taking the few housing characteristics available in the DVF dataset, we compare transactions in the sample with the total population of dwellings sold between 2016 and July 2021. Table A2 shows that average transaction prices for the sample and the population are very similar. However, the sample under-represents apartments compared to houses. This is likely due to the fact that it is more difficult to perfectly match apartments to the relevant assessment than houses given that different apartments with the same street name and number may have been sold at the same address.

Figure 1 compares the distribution of energy efficiency labels based on energy consumption in our sample with the distribution of energy labels in the housing stock at January 1, 2018 as calculated by Merly-Alpa et al. (2020). The distribution of energy labels in our sample is very close to that of the overall housing stock.[12]

[12]Less than 2% of the housing stock is made-up of of A-rated dwellings.

4 Method

We first estimate hedonic regressions in order to evaluate the effect of the energy efficiency assessment on the value of dwellings. We estimate the following model:

$$log(P_{ict}) = \alpha + \lambda E_i + \beta X_i + \phi_t + \theta_c + \mu_{ict} \tag{1}$$

Where P_{ict} is the price per square meter of dwelling i in cluster c at time t. The variable of interest is E_i which is either energy consumption (in $kWh/m^2/year$) or greenhouse gas emissions (in $CO2/m^2/year$). In alternate specifications, we replace E_i by a set of dummy variables indicating the label assigned to the dwelling in terms of energy efficiency: $\sum_{v=F}^{B} \delta^v D$ with $D = 1$ if the dwelling has been assigned the energy label v and 0 otherwise. X_i is a set of hedonic characteristics of the dwelling i (i.e., dwelling type (apartment/house), dwelling size, dwelling size squared, year of construction, year of assessment and assessment method). ϕ_t are time fixed effects (month $\times$ year) and θ_c are cluster fixed effects corresponding to the combination of municipality and street.

It should be noted that the energy premium estimates obtained by hedonic regression can be biased by the omission of unobserved dwelling characteristics correlated with measures of energy efficiency. In consequence, hedonic regression estimates may partly capture a general quality premium rather than only an energy premium. However, this issue is attenuated by the fact that these unobserved housing quality characteristics are also likely to be correlated and subsequently captured by the observable housing characteristics included in the hedonic regression. Nevertheless, we complement the common hedonic regression analysis with one that is more likely to compare similar dwellings in terms of quality.

This is why, in a second step, we use the fact that dwellings just below the threshold for a given label are likely to be very similar to those just above it. This allows us to identify the specific effect of the energy label on the value of dwellings for a given level of energy efficiency. Therefore, we conduct a Sharp Regression in Discontinuity in which the continuous measurement of energy efficiency is used as the running variable. The model is as follows:

$$log(P_i) = \alpha + \lambda Label_i + f(E_i - c) + \mu_i \tag{2}$$

Where $Label_i$ is a dummy variable taking the value of 1 if dwelling i has been assigned a given label and 0 otherwise. We conduct a separate analysis for each label between B and F. In each case, we restrict the sample to dwellings that have received the label whose effect is being evaluated, and to dwellings that have received the label just below it. A separate analysis is also conducted for labels based on energy consumption and for labels based on greenhouse gas emissions. For example, to evaluate the effect of the B-label, a sample of B and C rated dwellings is used. $f(.)$ is a polynomial function applied to the running variable $E_i - c$ (i.e. the continuous measurement of energy efficiency (E_i) centered on the value at which the label changes (c)). Different parametric forms are used for the $f(.)$ function (quadratic, cubic and then linear splines, i.e. with different slopes on each side of the discontinuity).

5 Results

5.1 Hedonic regressions

Table 2 shows the results of the hedonic regression analysis of equation 1. Only the estimated coefficients of the variables of interest and the main control variables are presented. The models in Table 2 explain about 81% of the variations in housing prices, which is within the range of what is obtained in the literature using hedonic regressions to model housing prices.[13]

Column (1) in Table 2 includes control variables but not the variables of interest. The estimated coefficients of the main control variables are in line with expectations: the price per square meter is negatively associated with the age of the building and with the size of the dwelling. Furthermore, the price per square meter of apartments is lower than that of houses.

Column (2) includes the continuous measurement of the energy consumption of the dwellings. The relationship is significant and negative: an increase in energy consumption of $10kWj/m^2/year$ is associated with a decrease of 0.2% in the price of the dwelling, which corresponds to an average decrease of about 500€. Column (3) includes the energy consumption label. Compared with the worst energy label G, dwellings rated E to B are priced significantly higher. The effect is about a 3% price increase with each improvement in the label ranking, except for label B, which does not have a significantly different price effect compared to label C. The maximum effect is obtained for B and C labels, which are sold for 9% more than G-rated

[13] Due to the introduction of municipality/street fixed effects, about 100,000 singleton observations are removed from the estimates. Therefore, we also perform estimates where municipality/street fixed effects are replaced by municipality fixed effects. The results presented in the appendix Table A3 are similar to the main ones, although the R^2 are slightly lower.

dwellings.

Columns (4) and (5) replicate Columns (2) and (3) except that the energy efficiency effect is in terms of greenhouse gas emissions. The results are similar to those obtained for energy consumption. Increased greenhouse gas emissions is negatively associated with dwelling prices: each $10CO2/m^2/year$ increase in gas emissions is associated with a 1% reduction of dwelling prices. Ceteris paribus, dwellings with B and F labels tend to have higher prices compared to dwellings with a G label. But unlike the energy consumption label, the maximum effect is obtained from the D label: a dwelling labelled D or higher is sold for 10% more than one labelled G, which corresponds to an average of about 25,000 €.

The magnitude of the effects is within the range found by other studies in the European context. Our estimate is almost identical to the 10% price difference between B- and G-rated dwellings obtained by Brounen & Kok (2011) in the Netherlands. In contrast, it is slightly lower than the 15% price difference between B- and G-rated dwellings obtained by Hyland et al. (2013) in Ireland. This difference could be explained by higher electricity prices in Ireland than in France and the Netherlands. In 2017, electricity prices in Ireland were 35% higher than in France and 47% higher than in the Netherlands.[14]

It is possible to compare the renovation costs of moving from one label ranking to another with the benefits of this transition (i.e., the increase in the price of housing and the benefits in terms of energy savings). To do this, we use the estimates of transition costs between all label ranks provided by Giraudet et al. (2018). For example, moving from a G label to a B label costs an average of 351 $€/m^2$. Taking an average dwelling size of 64 m2for G-labeled dwellings, this gives an average cost of 22,464 €. The 9% price increase associated with having the B label, corresponding to an average of about 18,000 €, is almost enough to offset this cost. Energy-saving costs must also be factored into the comparison. Upgrading a home from a G to a B label will reduce minimum energy consumption from 450 $kWh/m^2/year$ to 51 $kWh/m^2/year$. Assuming an average price of 15.3 $€/MWh$ and a conversion of final energy into primary energy of 2.58, we obtain a reduction of $\frac{(450-51)\times 0.153}{2.58} = 23.7$ $€/m^2$ or 1,500 €per year on average. Comparing costs and benefits, the average G homeowner would recoup his investment in three years.

In the same way, we can calculate the costs and benefits of moving from a G-rated home to

[14]Figures from Eurostat: https://ec.europa.eu/eurostat/databrowser/view/ten00117/default/table.

all the other ratings. Results presented in table A4 in the appendix show that transitions to D and C labels are the most rapidly profitable. Smaller and more extreme transitions appear to be the least profitable. These calculations are, however, back-of-the-envelope calculations and do not take into account actualisation rates, for example.

5.2 Heterogeneity analysis

In this subsection, we explore the heterogeneity of the energy efficiency effect on the premium. In the previous subsection, we showed the existence of a significant overall premium for dwellings that rank well in terms of energy consumption and gas emissions. Nevertheless, this overall premium may vary with the type and location of the dwelling as well as over time.

As Kahn & Kok (2014) indicate, well-rated dwellings may provide non-financial utility that is of particular value to environmentally conscious households. Furthermore, it may be worth questioning if the premium is greater in large cities where housing is more concentrated than in the rest of the country and where pollution problems may be more prevalent. In terms of housing characteristics, we might expect the premium for apartments to be lower than for houses, as the latter are generally larger, more difficult to heat and do not benefit from the heating externalities of nearby neighbors. The financial utility of buying an energy-efficient house appears, in consequence, to be higher. Finally, the financial utility of energy-efficient housing should be higher in locations where temperatures are lower and more heating is required. Alternatively, the financial utility may also be higher in locations with particularly high temperatures where air conditioning may be required. However, this is currently not likely in France, where air conditioning of dwellings was not very common at the time of the study.[15] [16]

We examine these assumptions by interacting the dwelling's energy label with the share of votes received by the Green party in the first round of the 2017 presidential election, the location of the dwelling in one of the three largest French cities (i.e., Paris, Lyon or Marseille), a dummy variable indicating whether the dwelling is an apartment, and the number of heating

[15]The use of air conditioning, however, is increasing rapidly in France. In 2019, 22% of households use air conditioning, an increase of 50% in three years. Figures from a survey conducted by *Electricité de France* in 2019; http://www.equilibredesenergies.org/30-07-2020-la-climatisation-des-logements-residentiels-laisser-faire-ou-encadrer-intelligemment/.

[16]The cost of electricity could also be an important element influencing the energy efficiency premium although in France the cost of electricity does not depend on location.

Table 2. Hedonic regressions

	Log of transaction value per square meter				
	(1)	(2)	(3)	(4)	(5)
VARIABLES		Energy consumption		GHG emissions	
Energy consumption		-0.000***			
		(0.000)			
GHG emissions				-0.001***	
				(0.000)	
Energy label (Ref : G)					
B			0.093***		0.089***
			(0.010)		(0.006)
C			0.092***		0.097***
			(0.008)		(0.005)
D			0.064***		0.106***
			(0.007)		(0.005)
E			0.038***		0.074***
			(0.007)		(0.005)
F			0.011		0.038***
			(0.007)		(0.005)
Building characteristics :					
Dwelling size (m^2)	-0.011***	-0.012***	-0.012***	-0.011***	-0.012***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(Dwelling size)ˆ2	0.000***	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Apartment (1 = yes)	-0.357***	-0.363***	-0.362***	-0.367***	-0.366***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Period of construction (Ref : Pre 1950)					
1951-1960	-0.013***	-0.010**	-0.009**	-0.006	-0.004
	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)
1961-1970	0.001	0.001	0.002	0.006	0.007
	(0.005)	(0.004)	(0.004)	(0.005)	(0.005)
1971-1980	0.016***	0.015***	0.016***	0.016***	0.016***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
1981-1990	0.085***	0.075***	0.075***	0.065***	0.068***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
1991-2000	0.124***	0.110***	0.109***	0.101***	0.105***
	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)
2001-2010	0.196***	0.176***	0.175***	0.167***	0.175***
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)
>2010	0.261***	0.219***	0.219***	0.223***	0.230***
	(0.019)	(0.014)	(0.013)	(0.018)	(0.018)
Constant	8.548***	8.666***	8.536***	8.610***	8.495***
	(0.082)	(0.064)	(0.076)	(0.086)	(0.081)
Observations	397,397	424,562	430,712	393,382	400,117
R-squared	0.812	0.810	0.810	0.812	0.813

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors clustered at the municipality level in parentheses. The control variables in all estimations are: year ranking is established and method and version of ranking. Municipality/street and date of the transaction (year-month) fixed effects are included in all estimations.

degree days in the *département*.[17] [18]

Tables 3 and 4 present the results of the estimates with interactions for energy consumption and greenhouse gas emissions, respectively. The results are essentially similar for both measures of energy efficiency and are generally consistent with expectations. Premiums are significantly lower for apartments than for houses and increase with the number of heating degree days, confirming the importance of the energy-saving aspect in the market's valuation of energy-efficient housing. However, the results are not in line with expectations for the non-financial valuation of the energy label. Premiums are lower in cities where the Green party scored relatively high, and in large cities. These negative relationships are unexpected but these variables are only proxies for ideology. Furthermore, the analysis is exploratory and these factors may be correlated with another underlying variable that is directly related to the label premium.

We also investigate whether the energy efficiency premium varies over time. Variations in energy costs and the tightening of energy standards for building construction could lead to an increase in the premium over time.[19] However, other factors may also have influenced efficiency premiums in other directions. For example, as Kahn & Kok (2014) indicate, downturns in the real estate market and subsequent decreases in transaction prices may also reduce the willingness to pay more for better performing green dwellings. In this respect, the major shock of the period is the restrictions on activity due to the Covid pandemic from March 2020. However, while the pandemic may have altered the dynamics of real estate markets across the country (Chareyron et al., 2022), it did not lead to a substantial decline in housing prices in France in the short run.

Therefore, we include interactions between the label and the year of transaction in equation 1. Figure 2 shows the change in energy premiums (i.e. the difference in market valuation relative to similar G-rated dwellings) each year for energy consumption and GHG emissions

[17] In France a *département* is a geographical and administrative unit that can be thought as a county. There are 101 of them with an average population of about 660,000 inhabitants.

[18] Degree days are based on the assumption that when the outside temperature is $18°C$, there is no need to heat or cool to be comfortable. If the average temperature (i.e., maximum temperature plus minimum temperature divided by two) is below $18°C$, we subtract the average from 18 and the result is the number of heating degree days. Then, for each *département*, we sum up the number of heating degree days over one year (i.e., 2019).

[19] Substantial changes in these two directions occurred outside the period of our study. The massive increase in energy costs began in early 2022. Regarding energy standards, the most substantial change in decades has been implemented since July 1, 2021. As of this date, energy assessments will be the responsibility of the seller and lessor. In addition, by 2025, G-rated dwellings will no longer be available for rent. In 2028, the ban will apply to F-rated dwellings and from 2034 onwards to E-rated dwellings.

Table 3. Heterogeneity of the energy consumption label effect

VARIABLES	%Green	Energy consumption PLM	Flat	Heat. Days
Energy label (Ref : G)				
B	0.146***	0.106***	0.166***	-0.087
	(0.029)	(0.010)	(0.008)	(0.073)
C	0.158***	0.106***	0.176***	-0.166***
	(0.019)	(0.007)	(0.006)	(0.061)
D	0.161***	0.076***	0.145***	-0.144**
	(0.018)	(0.007)	(0.006)	(0.060)
E	0.121***	0.047***	0.098***	-0.147**
	(0.018)	(0.007)	(0.005)	(0.059)
F	0.053***	0.014**	0.049***	-0.075
	(0.019)	(0.007)	(0.005)	(0.062)
Interactions:				
B × Var col.	-0.013**	-0.280***	-0.204***	0.000**
	(0.006)	(0.104)	(0.024)	(0.000)
C × Var col.	-0.014***	-0.212***	-0.228***	0.000***
	(0.004)	(0.043)	(0.017)	(0.000)
D × Var col.	-0.020***	-0.147***	-0.215***	0.000***
	(0.004)	(0.038)	(0.017)	(0.000)
E × Var col.	-0.017***	-0.096***	-0.164***	0.000***
	(0.004)	(0.037)	(0.016)	(0.000)
F × Var col.	-0.009**	-0.019	-0.097***	0.000
	(0.004)	(0.041)	(0.018)	(0.000)
Observations	430,700	430,702	430,702	430,702
R-squared	0.810	0.810	0.811	0.810

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors clustered at the municipality level in parentheses. The control variables in all estimations are: period of construction, dwelling size, surface area of dwelling, type of housing (apartment/house), year ranking is established and method and version of label. Municipality/street and date of the transaction (year-month) fixed effects are included in all estimations. Var col. is the percentage of vote for Green candidate in the first round of the 2022 French presidential election in Column (1), a binary variable indicating that the transaction occurs in one of the three French biggest cities (Paris, Lyon, Marseille) in Column (2), a binary variable indicating that the housing is an apartment in Column (3) and the number of cooling days in Column (4).

with 2016 as the base year. In general, we observe little significant variation in premiums and no upward trend over time. It is possible that there is a slight negative trend in the effects of B and C-rated dwellings in terms of energy consumption, which may reflect the fact that these labels have become more common over time. This result is in line with those of Dalton & Fuerst (2018), who found, conducting a meta-analysis, no substantial energy efficiency premium trend in studies conducted between 2010 and 2016.

Table 4. Heterogeneity of the greenhouse gas label effect

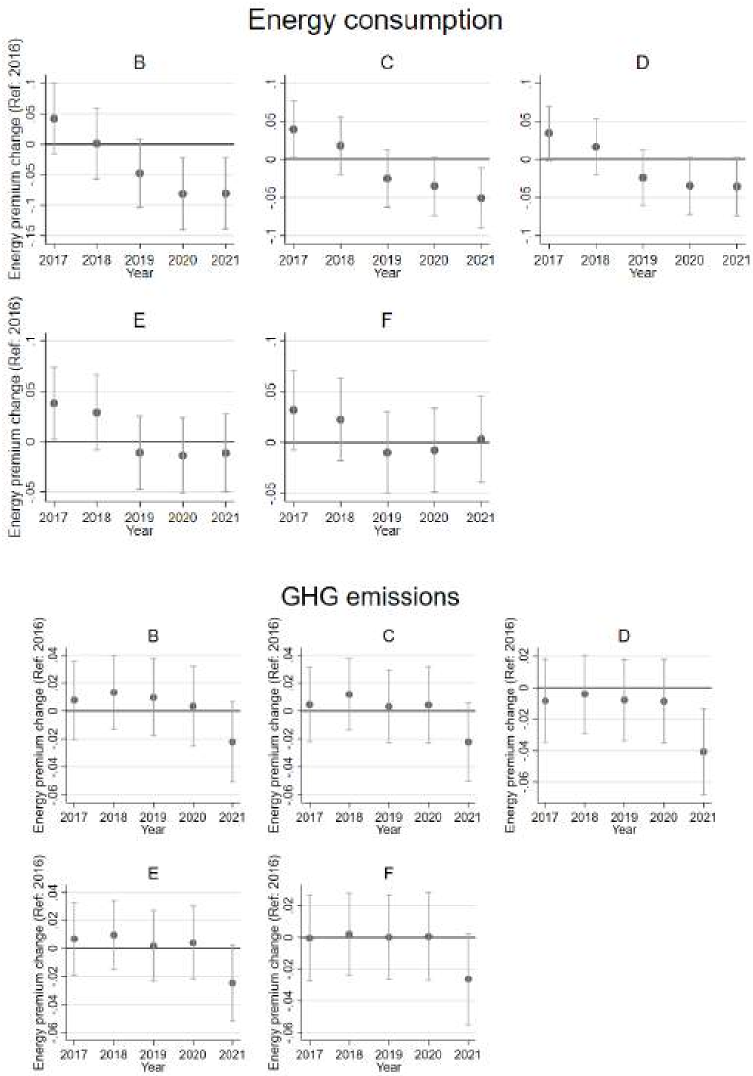
	GHG emissions			
VARIABLES	%Green	PLM	Flat	Heat. Days
Energy label (Ref : G)				
B	0.160***	0.094***	0.101***	-0.020
	(0.014)	(0.005)	(0.005)	(0.053)
C	0.132***	0.097***	0.096***	0.016
	(0.013)	(0.005)	(0.004)	(0.053)
D	0.127***	0.110***	0.116***	0.005
	(0.012)	(0.004)	(0.004)	(0.052)
E	0.114***	0.077***	0.088***	0.027
	(0.012)	(0.004)	(0.004)	(0.054)
F	0.067***	0.038***	0.041***	0.010
	(0.012)	(0.004)	(0.004)	(0.053)
Interactions:				
B × Var col.	-0.015***	-0.155***	-0.067***	0.000**
	(0.003)	(0.051)	(0.017)	(0.000)
C × Var col.	-0.009***	-0.088*	-0.039**	0.000
	(0.003)	(0.052)	(0.017)	(0.000)
D × Var col.	-0.006**	-0.137***	-0.063***	0.000*
	(0.003)	(0.052)	(0.017)	(0.000)
E × Var col.	-0.009***	-0.112**	-0.071***	0.000
	(0.003)	(0.049)	(0.017)	(0.000)
F × Var col.	-0.007**	-0.038	-0.035**	0.000
	(0.003)	(0.051)	(0.017)	(0.000)
Observations	400,107	400,107	400,107	400,107
R-squared	0.813	0.813	0.813	0.813

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors clustered at the municipality level in parentheses. The control variables in all estimations are: period of construction, dwelling size, surface area of dwelling, type of housing (apartment/house), year ranking is established and method and version of label. Municipality/street and date of the transaction (year-month) fixed effects are included in all estimations. Var col. is the percentage of vote for Green candidate in the first round of the 2022 French presidential election in Column (1), a binary variable indicating that the transaction occurs in one of the three French biggest cities (Paris, Lyon, Marseille) in Column (2), a binary variable indicating that the housing is an apartment in Column (3) and the number of cooling days in Column (4).

5.3 Regression discontinuity design

As Kahn & Kok (2014) point out, a hedonic regression analysis does not identify the source of the energy efficiency premium, nor the extent to which the label information salience plays a role in price formation. In this subsection, we aim to properly identify the cognitive perception of the label by comparing buildings on either side of the threshold delineating the transition from one label ranking to another. In this way, we compare buildings that are likely to be very similar, except that some are just above the threshold while others are just below it. We

Figure 2. Heterogeneity of the Effect of the Energy Consumption Label by Year



Notes: Bars correspond to 95% confidence intervals.

restrict the sample to dwellings built before 1980, to limit the possibility that the threshold also corresponds to a difference in other dimensions, such as the age of the building. Indeed, since the introduction of energy labels, buildings can be constructed to meet the conditions of a particular label. This was not the case before the introduction of energy labels and manipulation of the assignment variable is therefore less likely before 1980.

5.3.1 Graphical analysis

First, we plot in Figure 3, for each label, the evolution of average housing prices around the threshold. Since the x-axis is energy consumption or greenhouse gas emissions, dwellings to the right of the thresholds have lower energy efficiency than those to the left. For example, a dwelling is labelled B when its energy consumption is between 51 and $90 kWj/m^2/year$ and labelled C when it is between 91 and $150 kWj/m^2/year$. We can therefore observe whether, for this energy consumption interval, a discontinuity in housing prices is found around $90 kWj/m^2/year$.

In terms of energy consumption, we observe discontinuities at the D and E label thresholds. The average prices of D-rated dwellings appear to be slightly higher than those of E-rated dwellings with similar energy consumption levels. Furthermore, E-rated dwellings appear to be more expensive on average than comparable F-rated dwellings. In terms of greenhouse gas emissions, discontinuities in dwelling prices appear between labels C and B, and between labels F and E.

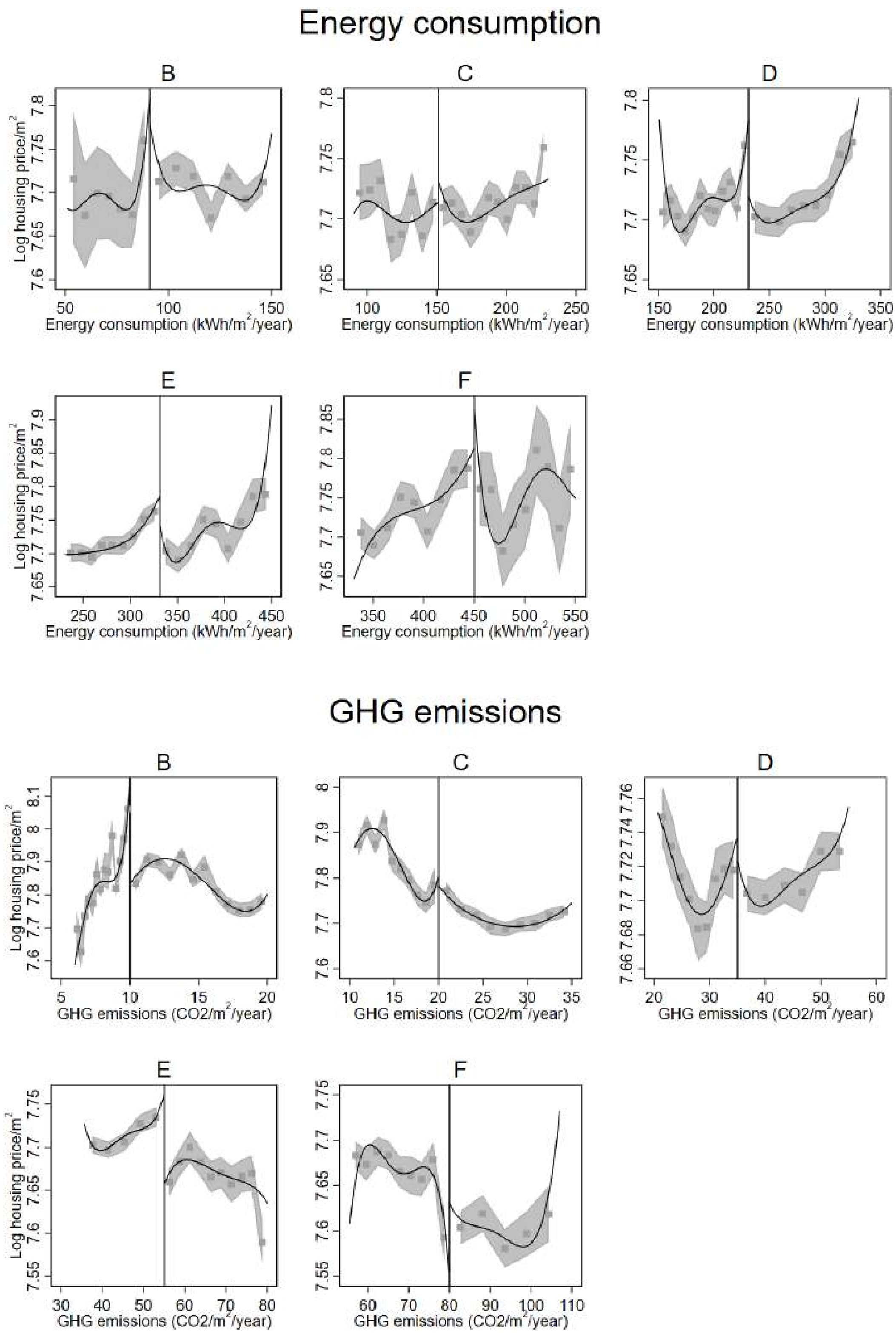
5.3.2 Regression results

We now present the results of the RDD estimates of equation 2. Table 5 presents the estimated effect of each of the two label types and for different parametric forms of the f(.) function. The results are consistent across parametric forms and, although the magnitude of the estimates varies slightly from one parametric form to another, the statistical significance is similar.

Energy labels D, E and F significantly increase dwelling prices compared to those with inferior label (E, F, G, respectively). However, the effect is limited to the E label for greenhouse gas emissions. These results are in line with the graphical observations. The positive effect of labels on dwelling prices is greater as the label rank improves, particularly for the energy consumption label. This suggests that the label signal has a greater impact on the least efficient dwellings. One explanation may be that there is a stigma associated with G- and F- rated dwellings as they are considered to be energy-inefficient dwellings. It may also be due to the fact that the range of energy consumption and gas emissions is wider for label categories that are lower in the rankings (as can be seen in Table A1 in the Appendix).

In consequence, moving from G to an F in a label produces, on average, greater energy savings than moving from C to B. This result corresponds to the findings of Civel & Cruz (2018) who found asymmetries in the perception of labels. They show that worse label rankings are judged to be indicative of poor energy performance but that the best label rankings are perceived with skepticism. On the other hand, compared to Aydin et al. (2020),

Figure 3. Transaction prices and energy consumption



Note: Shaded areas correspond to 95% confidence intervals. Triangular kernel function is used to construct the 4-degrees local-polynomial estimator.
Example of reading: For graph B, dwellings to the right of the vertical line have a C label and those to the left of the vertical line have a B label. There is no substantial price change at the threshold.

Table 5. RDD results

	Energy consumption			GHG emissions		
VARIABLES	Quad.	Cubic	Lin. Spline	Quad.	Cubic	Lin. Spline
Energy label:						
B	-0.022	-0.028	0.002	0.032	-0.011	-0.032
	(0.034)	(0.036)	(0.030)	(0.024)	(0.026)	(0.021)
C	-0.005	-0.014	0.004	-0.007	-0.031	0.020
	(0.016)	(0.019)	(0.016)	(0.019)	(0.024)	(0.019)
D	0.027***	0.038***	0.045***	0.008	0.031	0.013
	(0.008)	(0.011)	(0.011)	(0.015)	(0.019)	(0.015)
E	0.068***	0.083***	0.067***	0.041***	0.064***	0.038***
	(0.016)	(0.022)	(0.016)	(0.014)	(0.018)	(0.014)
F	0.075**	0.075**	0.066**	0.030	-0.004	0.034
	(0.033)	(0.033)	(0.032)	(0.023)	(0.027)	(0.022)

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors clustered at the municipality level in parentheses. The dependent variable is the log of the transaction price per square meter. Each estimate corresponds to a different estimation. Example of reading: the first line of the table (B) shows the estimated effect of moving from a C to a B label.

who found no significant effect of the information provided by the label, we find a significant effect, albeit limited to certain label categories.

5.3.3 Robustness

The validity of the regression in discontinuity analysis relies on the assumption that any discontinuity at the threshold is due to the label change. As mentioned above, restricting the sample to dwellings built before 1980 limits the possibilities of manipulation. Nevertheless, it is possible that homeowners may carry out renovations in order to place the home just above the threshold to qualify for a higher label category. However, it seems unlikely that they would be able to precisely target label thresholds due to uncertainty about the exact effect of renovation on energy rating.

We are conducting two empirical investigations into this question. First, we verify that there is no discontinuity in dwellings characteristics at the thresholds. Second, we verify that there is no discontinuity at the thresholds in the density of the running variable. Figures A1 and A2 plot the evolution of the proportion of apartments, average dwelling size and year of construction as a function of energy consumption and gas emissions, respectively. We observe almost no discontinuity in these three dimensions at the thresholds from one label to the next. There are more discontinuities in the case of labels based on greenhouse gas emissions, but they remain limited relative to the number of tests carried out. Figure A3 shows the densities of energy consumption and gas emission variables. The vertical bars correspond to the label thresholds. There is no particular discontinuity in the density of the two variables at the thresholds corresponding to the transition from one label rank to the other.

We also conduct two robustness checks, on the sensitivity of RDD results with the inclusion of control variables and bandwidth variation. As indicated by Lee & Lemieux (2010), if the RD design is valid, it is not necessary to include the controls to obtain consistent estimates of the treatment effect. Covariates only reduce the sampling variability and thus increase the precision of the estimates. Table A5 shows the results of regressions similar to those in Table 5 but including controls for housing type, construction date and transaction date. While the results are similar to the main findings, there is a slight increase in significance for the effect of label D. The RDD approach is based on the idea that two dwellings close to the threshold are similar regardless of which side of the threshold they belong to. This assumption is plausible, but the question is how far from the threshold can we consider that the dwellings remain similar? In the main results, we have kept all dwellings of both labels on either side of the threshold. Although the range of energy efficiency within each label is not necessarily very wide, it may be necessary to restrict the sample. To check the sensitivity of the results to bandwidth, we estimate local linear and quadratic regressions using optimal bandwidths (Calonico et al., 2019).[20] The results presented in Table A6 are consistent with the main ones.[21] However, the estimated effects of label E are slightly less significant, and the magnitude of the estimated effect of label D is higher compared to those in Table 5.

6 Conclusion and Policy Implications

In this study, by linking real estate transactions to the assessment of housing energy efficiency from complete datasets, we have shown that there is a significant premium for energy efficient dwellings in France. This is true for energy efficiency assessments in terms of both energy consumption and greenhouse gas emissions. However, the effect decreases with increased energy efficiency since most of the price difference occurs between the lowest G label and the intermediary D label.

[20] We use different bandwidths on either side of the threshold since the range of energy efficiency is not the same for each label.

[21] We used Stata's Rdrobust package.

A number of factors explain the higher market valuation of dwellings with good energy labels. The higher valuation of energy-efficient dwellings in locations where more heating is needed suggests the presence of a financial utility component. However, we found less support for the existence of a non-financial utility component in the valuation of energy-efficient dwellings. The results of the regression in discontinuity estimates also indicate that the cognitive perception of the label has an influence on property prices of the least efficient dwellings.

The greater restrictions on renting out the worst-performing homes had not been implemented at the time of the study. This public policy, announced in 2021 and which will prohibit the rental of G-rated dwellings in 2025, F in 2028 and E in 2034, is likely to increase the price difference between the worst-performing dwellings and intermediate or best-performing dwellings. The implementation of these restrictions also highlights the fact that signaling the energy efficiency of housing by means of labels, in addition to reducing information asymmetry, enables public policies to target certain segments of the real estate market. Furthermore, although energy prices were relatively low during the time period analyzed, they increased substantially in European countries after the Russian invasion of Ukraine in 2022. This is also likely to increase the energy efficiency premium.

While they enable the gradual incorporation of energy efficiency into housing prices, labels, by summarizing information into energy efficiency brackets, create threshold effects. This distortion of information may nevertheless be preferable to more precise information based on a continuous measurement of energy consumption or greenhouse gas emissions, which may be less easy to assimilate. However, a score from 1 to 100, for example, might be simpler and less likely to generate a threshold effect. On this question, however, it is difficult to provide empirical evidence because most countries have chosen energy efficiency labels or green certificates as indicators rather than exact measurements of energy efficiency.

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Appendix

Table A1. Label classifications

Energy label	Energy consumption ($kWh/m^2/year$)	GHG emissions ($CO2/m^2/year$)
A	<50	<5
B	≥ 51 and <90	≥ 6 and <10
C	≥ 91 and <150	≥ 11 and <20
D	≥ 151 and <230	≥ 21 and <35
E	≥ 231 and <330	≥ 36 and <55
F	≥ 331 and <450	≥ 56 and <80
G	>450	>80
N	Not calculated	Not calculated

Table A2. Comparison of characteristics between matched dwellings and the total population of transacted dwellings

	(1) Sample	(2) Population
Transaction price (€)	252648.4 [257476.0]	212464.8 [321073.8]
Dwelling type:		
Apartment	0.39	0.48
House	0.61	0.52
Observations	590,446	6,831,060

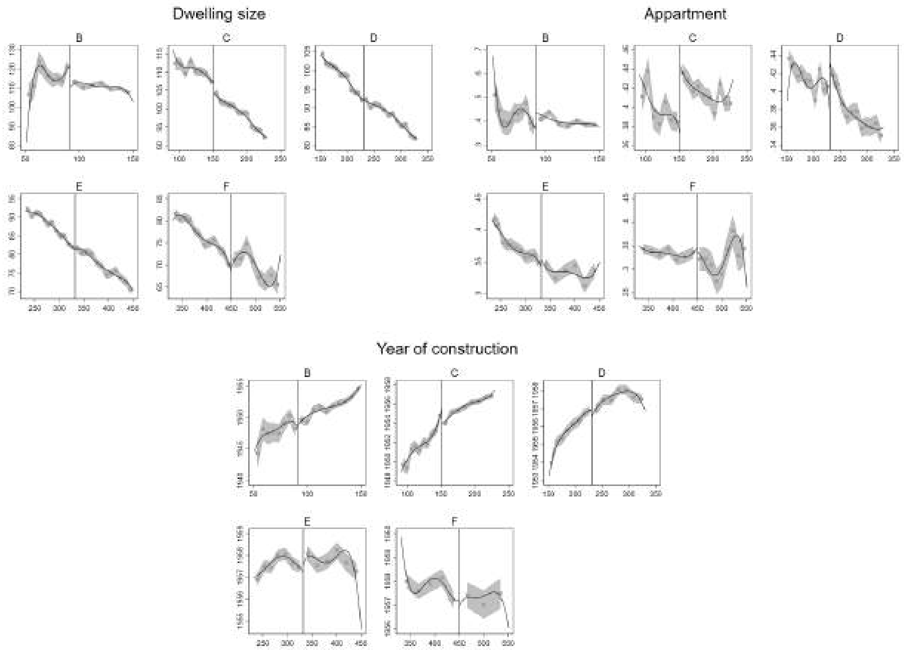
Notes: Dwellings transacted between 2016 and July 2021 are considered.

Table A3. Robustness: hedonic regressions with municipality fixed effects

	Log of transaction value per square meter				
	(1)	(2)	(3)	(4)	(5)
VARIABLES		Energy consumption		GHG emissions	
Energy consumption		-0.000***			
		(0.000)			
GHG emissions				-0.001***	
				(0.000)	
Energy label (Ref : N)					
B			0.084***		0.077***
			(0.011)		(0.006)
C			0.064***		0.088***
			(0.007)		(0.005)
D			0.041***		0.085***
			(0.007)		(0.005)
E			0.027***		0.050***
			(0.006)		(0.005)
F			0.013**		0.025***
			(0.006)		(0.004)
Building characteristics :					
Dwelling size (m2)	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(Dwelling size)ˆ2	0.000***	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Apartment (1 = yes)	-0.268***	-0.345***	-0.345***	-0.346***	-0.346***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Period of construction (Ref : Pre 1950)					
1951-1960	-0.024***	-0.020***	-0.019***	-0.012*	-0.012**
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
1961-1970	-0.012*	-0.011	-0.011	-0.003	-0.002
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
1971-1980	0.022***	0.023***	0.023***	0.024***	0.023***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
1981-1990	0.109***	0.104***	0.104***	0.090***	0.090***
	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)
1991-2000	0.163***	0.157***	0.155***	0.144***	0.145***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
2001-2010	0.216***	0.207***	0.204***	0.191***	0.195***
	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)
>2010	0.298***	0.277***	0.266***	0.282***	0.284***
	(0.029)	(0.022)	(0.021)	(0.029)	(0.029)
Constant	8.475***	8.508***	8.453***	8.522***	8.422***
	(0.052)	(0.054)	(0.051)	(0.053)	(0.054)
Observations	510,419	544,903	551,731	505,724	513,347
R-squared	0.698	0.693	0.694	0.695	0.697

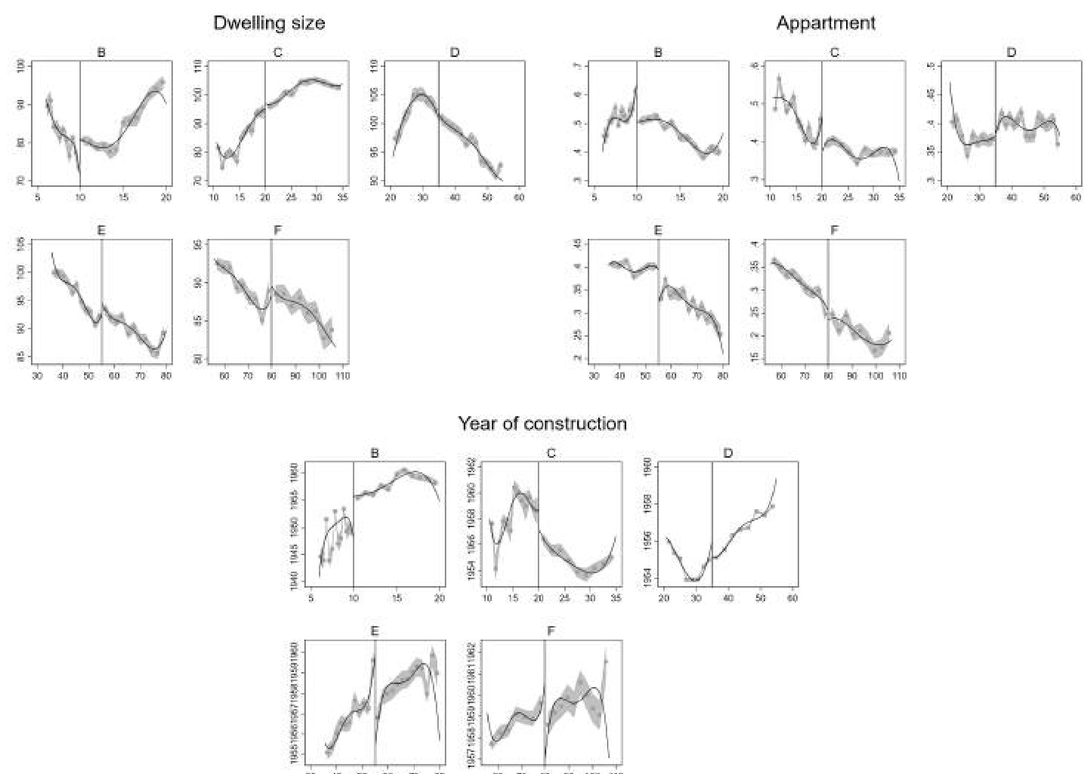
Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors clustered at the municipality level in parentheses. The control variables in all estimations are: year the ranking is established and method and version of label established. Municipality/street and date of the transaction (year-month) fixed effects are included in all estimations.

Figure A1. Robustness: Housing characteristics by energy consumption



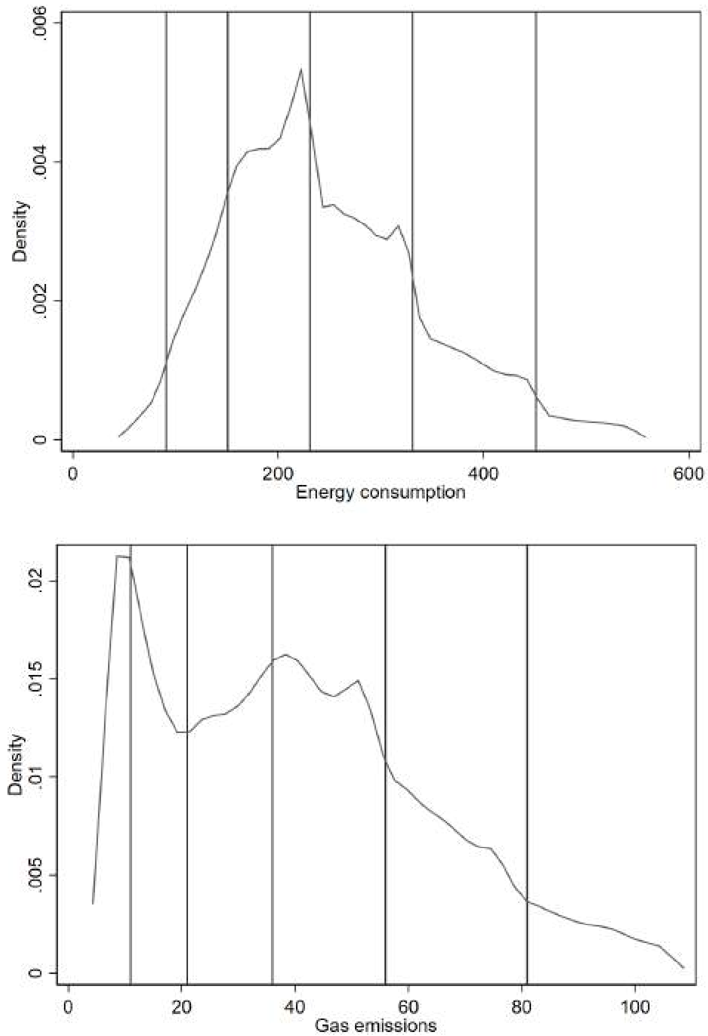
Note: Shaded areas correspond to 95% confidence intervals. Triangular kernel function used to construct the 4-degree local-polynomial estimator.

Figure A2. Robustness: Housing characteristics by GHG emissions



Note: Shaded areas correspond to 95% confidence intervals. Triangular kernel function used to construct the 4-degrees local-polynomial estimator.

Figure A3. Robustness: Density of energy consumption and GHG emissions



Note: Epanechnikov density estimates with bandwidth of 1.64. Vertical bars correspond to label thresholds.

Table A4. Comparing the Costs and Benefits of Transitions between Label Rankings

Initial label	Final label	Average transition costs (€)	Average price increase (€)	Average reduction of in annual energy costs (€)	Payback period (year)
G	B	22464	18032	1518	3
G	C	17344	17838	1366	0
G	D	12864	12409	1139	0
G	E	8704	7368	835	2
G	F	4864	2133	455	6

Table A5. RDD results (with controls)

	Energy consumption			GHG emissions		
VARIABLES	Quad.	Cubic	Lin. Spline	Quad.	Cubic	Lin. Spline
Energy label:						
B	-0.014	-0.022	0.015	0.016	-0.011	-0.030
	(0.033)	(0.035)	(0.029)	(0.022)	(0.024)	(0.019)
C	0.014	0.007	0.022	0.011	-0.013	0.028*
	(0.016)	(0.018)	(0.015)	(0.018)	(0.023)	(0.017)
D	0.013	0.022**	0.031***	0.023	0.043**	0.028**
	(0.008)	(0.010)	(0.010)	(0.014)	(0.018)	(0.014)
E	0.061***	0.070***	0.060***	0.033**	0.050***	0.031**
	(0.014)	(0.019)	(0.014)	(0.013)	(0.016)	(0.013)
F	0.038	0.050	0.034	0.019	-0.005	0.021
	(0.028)	(0.031)	(0.027)	(0.021)	(0.025)	(0.020)

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors clustered at the municipality level in parentheses. The dependent variable is the log of the transaction price per square meter. Each estimate corresponds to a different estimation. The control variables in all estimations are: date of the construction, date of the transaction (year and month), type of dwelling (apartment/house) . Example of reading: the first line of the table (B) shows the estimated effect of moving from a C to a B label.

Table A6. RDD results (with varying bandwidths)

	Energy consumption		GHG emissions	
VARIABLES	Lin.	Quad.	Lin.	Quad.
Energy label:				
B	0.164**	0.138	0.031	-0.024
	(0.081)	(0.098)	(0.047)	(0.054)
C	0.028	0.072	-0.016	-0.062
	(0.030)	(0.044)	(0.045)	(0.083)
D	0.084***	0.083***	0.058**	0.090**
	(0.025)	(0.031)	(0.026)	(0.039)
E	0.025	0.014	0.051**	0.046
	(0.038)	(0.044)	(0.025)	(0.039)
F	-0.005	-0.018	-0.104*	-0.175*
	(0.057)	(0.079)	(0.056)	(0.090)

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors clustered with plugin residuals at municipality level in parentheses. The dependent variable is the log of the transaction price per square meter. The bandwidth varies on either side of the cutoff and is obtained with MSE-optimal bandwidth selectors. Each estimate corresponds to a different estimation. The control variables in all estimations are: date of the construction, date of the transaction (year and month), type of dwelling (apartment/house) . Example of reading: the first line of the table (B) shows the estimated effect of moving from a C to a B label.

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