The spatial uneven diffusion of energy-efficiency transparency policy. An analysis of the multi-family market in Barcelona

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1. Introduction

Energy efficiency is an “opaque” residential attribute, unlike other easily appreciated features such as the quality of finishings or the functional programme. In fact, it is a multidimensional outcome, depending on factors that are not always visible or evident. Therefore, it is difficult to understand for the majority of the population and is relegated therefore from the attributes that are taken into consideration in the process of residential choice. Consequently, an “informative asymmetry” is produced concerning the energy-performance of buildings.

This lack of information is not trivial since it has pecuniary, social, and environmental repercussions. Thus, energy efficiency has a clear impact on family budgets, which can lead to situations of fuel poverty (e.g. inability to finance systems to achieve minimum thermal comfort) and greenhouse gas emissions. In addition, energy information has a proven relationship with people’s energy-saving habits (Kempton and Layne, 1994). It is important to recall that in Europe buildings are responsible for 40% of energy consumption (EPBD, 2008) (of which 63% comes from homes (Poel et al., 2007)), and for 36% of CO2 emissions (WWF, 2010).

To break energy-informational asymmetry, the European Union, inspired by previous certification schemes (e.g. LEED or BREEAM) and giving continuity to household appliances energy labels, passed the Energy Performance of Buildings Directive (EPBD 2002/91/EC) in 2002. EPBD makes it possible to give “energy-transparency” to buildings through Energy Performance Certificates (EPC) and derived labels depicting energy ratings (e.g. “G” for the worst energy performance and “A” for the best in the Spanish case). Once recast in 2010 (EPBD 2010/31/EU), the Directive has made EPCs universal in the rental and sale marketing process of property, from the very moment that advertising begins. If the Directive were to be completely implemented, it is estimated that energy demand in the EU would be reduced by 6.5% (De Ayala et al., 2016). Such a figure suggests that the building industry is, of the economy as a whole, the one with the largest room for improvement.

The main objective of the EPBD is to foster energy-informed decisions and, in addition, to allow this information to be available for citizens of any member state of the Community market. This policy is based on the hypothesis that individuals facing two properties exactly equal, except in their energy rating, will tend to choose the most efficient, which would end up positively influencing property differentiation. Eventually, such differentiation would produce a greater appreciation of the more efficient buildings reflected in higher prices, lower vacancy rates, and risk moderation for investors. Such benefits would ultimately compensate for the extra costs of building or rehabilitating with better energy performance. Eventually, such a process would improve the efficiency of the real estate stock with the usual
benefits on the vectors discussed above. In short, EPCs like the rest of the “green labels” have a role of “intermediation” (Chegut et al., 2014) and independent certification, while promoting the conservation of energy in the private realm (Brounen and Kok, 2011).

However, to activate the aforementioned mechanism, it is necessary to have information symmetry, which, in countries like Spain, despite the obligations and the sanctioning regime, seems to be far from happening. In fact, important and dynamic real estate markets such as Barcelona, as shown below, are still very energy-efficiency-opaque. Additionally, there is growing evidence, as explained in the next section, showing that energy-efficiency policies are unlikely to be diffused uniformly across space. In such a context, this paper studies, in a novel way:

1) Whether the presence of energy information of dwellings is diffused homogeneously in the space; or conversely, there are clearly recognizable spatial patterns. And, in addition,

2) If such patterns, if any, are random; or, on the contrary, are correlated to the characteristics of the dwellings and the micro-environment in which dwellings are located.

The hypothesis to test is the non-randomness of residential energy-information distribution, but the existence of patterns correlated with the structural characteristic of listed dwellings and locative attributes.

In doing so, the universe of multi-family selling and renting listings of one of the largest real estate websites in metropolitan Barcelona is used. Architectural attributes of listings are complemented by locative attributes coming from different sources. Spatial autocorrelation analyses make it possible to shed light on the geographic randomness of energy information; while logistic regressions explore whether the probability that each listing contains energy information correlates with the characteristics of the dwelling, its urban, environmental, and socioeconomic context.

Results clearly show that the probability that a given listing contains energy-rating information is not random, but there is an important spatial autocorrelation. Therefore, the more abundant the presence of EPC rating information in a local environment, the larger the probability that a given listing discloses such information. In addition, the worse the dwellings are, and especially if they were built before national building regulations required minimal measures of thermal insulation, the less likely their energy performance is to be reported. This situation is further aggravated by the fact that the low-income population occupies such dwellings. Thus, the worst quality dwellings do exhibit information asymmetry obscuring the energy performance to the population that could benefit the most from bill savings.

The rest of the paper is organized as follows: first, the literature regarding spatial diffusion of energy-efficiency policies as well that regarding the effect of EPCs on the residential market is briefly reviewed: then the case study, methodology, and sources of information are presented: the results constitute the next section and in the conclusions, the findings are framed in the context of the EPBD policy.

2. Impact of EPC on the residential market and evidence on the uneven diffusion of energy-efficiency policies

The generalization of EPCs is relevant since it acts as a regulated indicator which, while only referring to energy performance, serves as a distinctive feature of buildings. Given this exceptional event, different investigations have studied the incidence of this information on consumer behaviour, and especially on prices. Thus, the studies on the incidence of EPC in the European residential market have come to complement the conclusions drawn with other “green” certification schemes such as the British BREEAM, the French HE, the Helvetic Minergie or the most widely spread from US (in origin) LEED and Energy Star (Marmolejo, 2016).

After Denmark, the Netherlands was one of the first states to transpose the EPBD and, at the same time, the first country in which the effect of EPCs on prices was studied. Brounen & Kok (Brounen and Kok, 2011) analyse, through hedonic analysis, information from 170 thousand residential transactions, concluding that energy ratings are related to prices. In particular, dwellings “G” rated (the worst in terms of energy-performance) receive a −5% “brown-discount” concerning the intermediate “D” rated, while rated “A” dwellings receive +10% market premium. The study by Bio Intelligence Service et al. (Bio Intelligence ServiceLyons, 2013) conducted in different EU cities finds a positive relationship between energy ratings and prices. In their study, for each performance rating, sales prices increase from 0.40% in Oxford to 10.00–11.00% in cities such as Vienna. In fact, the positive impact of energy efficiency is greater on dwellings offered for sale than on those marketed for rent. For example, in Vienna, for each EPC rating, rental prices increase from 5.00 to 6.00%, roughly half that on dwellings for sale. This finding is not exclusive to the residential market, since it had already been reported for offices and other certification schemes. In any case, this conclusion highlights that the tenure regime has serious implications on the importance that users give to energy performance. Not all previous studies have found a linear or continuous relationship between the EPC ratings and prices. Pontus et al. (2014) conclude that Swedish dwellings located in the lower quartile of prices, the correlation between energy-efficiency and the price is negative, i.e.: the higher the efficiency, the lower the price. In addition, in the upper tier of expensive housing, energy efficiency was not significant. Hyland et al. (2013) find in Ireland that the impact of an EPC rating on a 2-room apartment equals an increase of 2.30%, whereas in dwellings with 3 rooms and 4 or 5 rooms the increase is lower, situated at 1.70% and 1.60% respectively. Fuerst et al. (2015) departing from 300,000 dwellings transactions in England have found that the greatest impact of the EPC ratings occurs in townhouses, and that in the apartments it is greater than in isolated houses. This could suggest several things, among others, that potential energy savings are more important for the cheaper dwellings occupied by low-income households. In Spain, the incidence of EPC in the residential market has also been studied. De Ayala et al. (De Ayala et al., 2016) analyse opinion values coming from respondents in 5 cities (Madrid, Bilbao, Seville, Vitoria, and Malaga), finding that dwellings rated as “A”, “B” or “C” have a value, in the opinion of their owners, 9.80% higher than those rated as “D”, “E”, “F” or “G”. Marmolejo (2016) uses listing values for a sample of homes for sale in metropolitan Barcelona and finds market premium of 5.11% from improving the performance from “G” to “A”, or 9.62% if it is accepted that the perception of EPC ratings is nominal. Marmolejo-Duarte and Chen (2019) using a pooled hedonic model, found for the same metropolis that the effect of EPC ratings increases over time, possibly indicating a larger repercussion as the policy is implemented.

However, most of the studies have overlooked the spatial implications of EPC and the spatial attributes impacting the EPC adoption. This trend is generalized to the study of other energy-efficiency policies where geographical aspects such as space, locative and socioeconomic attributes are not fully explored. However, energy systems, both from the production and consumption sides are necessarily embedded in particular settings (Bridge et al., 2013), where resource availability, the cost of energy, public incentives, and social aspects are relevant. In this latter aspect, the work of Graziano & Gillingham (Graziano and Gillingham, 2015), in Connecticut, demonstrates that the likelihood of households installing PV systems in the present is influenced by the installation of PV systems by neighbors in the past. The conclusion of Noonan et al. (2013) for Greater Chicago regarding the installation of energy-efficient HVAC systems are in the same line. So, the spatial peer effects on the adoption of energy-efficient technologies seem to be an important trigger in the diffusion of transition to a low-carbon society. Similar arguments have been signaled by Sánchez-Braza and Pablo-Romero when exploring the effect of tax bonuses to promote solar thermal systems in Spain (Sánchez-Braza and Pablo-Romero, 2014). An increasing research body has examined the spatial embedded factors
influencing the adoption of energy-efficiency housing measures. Accordingly, such factors have been organized in environmental aspects (e.g. climate); personal factors (e.g. income, environmental concern); economic (e.g. energy prices); housing attributes (e.g. size, typology and age) and policy-related (e.g. tax rebates and subsidies) (Kwan, 2012; Davidson et al., 2014; Morton et al., 2018).

Regarding the EPC scheme, exceptions to the non-spatial approach are the works of Brounen & Kok (Brounen and Kok, 2011), Morton et al. (2018); Droutsa et al. (2016), López-González et al. (Gangolells et al., 2015) and Gangolells et al. (Gangolells et al., 2015) carried out in the Netherlands, England, Greece, La Rioja and Catalonia respectively (the latter two in Spain). All of them, except the two firsts, have been limited to a descriptive analysis of the main indicators contained in the EPCs. For example, in Catalonia it has been found that buildings located in milder winter climates (e.g. B3 and C2) are somewhat more efficient than those located in the coldest winter climates (D3 located in the Pyrenean fringe). In La Rioja, where the winter is more continental, the contrary has been found. These spatial analyses aim to diagnose the energy performance of existing buildings in the context of rehabilitation policies (Gangolells et al., 2015) and energy planning (López-González et al., 2016). The work of Brounen & Kok (Brounen and Kok, 2011) in the Netherlands is different since it relates to the presence of energy information in dwellings to the residential and socio-economic attributes of the locations. These latter authors analyse 177,000.00 homes transacted before it was mandatory to include EPCs in all advertisements. Their conclusions indicate that the probability that a sold dwelling is certified is not random, but it is related to its architectural attributes and its socioeconomic environment. In particular, the smaller houses built in the post-war period between 1970 and 1990 were more likely to have an EPC. Likewise, this probability increased if the dwelling was located in the densest neighbourhoods, with low-income residents and a high proportion of “green parties” voters. In other words, in the absence of an obligation to certify dwellings, energy-efficiency information appears to respond to an element of real estate differentiation in lower quality dwelling submarkets, targeting lower-income socioeconomic groups, which could potentially benefit from residential energy expenditure. In this line, Marmolejo & Chen (Marmolejo-Duarte and Chen, 2019) have researched whether the effect of EPC rating is the same in different residential submarkets in Barcelona. Their work found that such effect is null in the case of state-of-the-art apartments boasting the best of the constructive qualities and functional amenities; on the contrary, in the case of low-quality homes located in working-class neighbourhoods the brown discount of a “G” rated property is 32% compared to another “A” rated. The authors suggest that when architectural amenities are absent EPC ratings do play an incorrect role in price differentiation. The work of Marmolejo et al. (Marmolejo-Duarte et al., 2020a) supported by a geographically weighted regression arrives at similar conclusions. Morton et al. (2018) have researched, in England, the spatial property and socioeconomic attributes affecting the EPC assessment uptake in the context of the UK Green Deal. In their models, the uptake rate (i.e. the number of homes EP certified per 1,000 homes) appears positively affected by the presence of young families, university-educated population, detached homes, and large households; whereas real estate dynamism, personal income, and energy efficiency of the existing housings appears inversely correlated.

Therefore, there are no reasons to believe that the inclusion of energy performance information is stationary across a metropolis such as Barcelona, therefore it is necessary to explore its spatial patterns and correlation with both residential architectural features and socioeconomic as done next.

3. Case study, data, and methodology

This paper focuses on the functional metropolitan area of Barcelona (AMF) delimited following the travel-to-work criteria proposed by Roca et al. (Roca-Cladera et al., 2009). This approach allows also us to identify functional inner-subcentres that might influence residential market dynamics and residential retrofits. AMF is made up of 184 municipalities in 3760 sq. km and 5.22 million inhabitants in 2016. After delimiting the case study, the method consists of:

1) Recovering all the multi-family sale and rent listings from Habitacilia, one of the largest real estate web listings in Catalonia. Such housing typology is the primary kind of dwellings in urban areas in Spain.

2) Compiling a GIS at the dwelling level complemented with other contextual datasets. Locational features were transferred using a 300 m buffer around each housing.

3) Analyzing the spatial patterns of energy-performance information disclosure in the listings.

4) Exploring, using a logistic model, whether the presence of energy-performance information is correlated with the architectonic and urban attributes of listings including spatial autocorrelation.

The dataset consists of 49,424 apartments listed on April 1st, 2016, of which 87% were offered for sale and 13% for the rental market. This proportion exhibits large parallelism with the housing tenure: according to the National Institute of Statistics in 2016 73.7% of the Catalan population owned their home. For each dwelling there are 250 architectural and locative attributes organized in the following conceptual dimensions:

- Architectural and real estate

It includes market features such as transaction type, price, and yield. Also, architectural attributes like the typology of the apartment (e.g. conventional, penthouse, duplex, etc.), area, number of bedrooms, bathrooms, toilets, quality of the kitchen, quality of the design/finishes, heating, air-conditioning, chimney, story, lift, terrace area, cellar, laundry room, year of construction and refurbishment, garden and communal pool. Presence of energy-performance information and, if applicable, energy ratings (“A”-best-“G”-worst). All this data comes from the Habitacilia dataset.

- Urban and environmental quality

This includes the environmental quality concerning noise, lack of greenery, cleanliness of streets, delinquency and pollution, as well as the condition, age and use of neighbouring buildings and land uses according to the Corine-Land-Cover project aimed at providing land uses coming from teledetection Percentage of manufacturing employment and advanced services (as proxies of externalities of such activities), proximity to the sea (both as a dummy and linear distance), and protected natural parks according to data from the National Geographic Information Centre. Climate zones have also been calculated and digitalised according to the criteria of Appendix B.1 of the DB-HE of the CTE (i.e. Construction Code) according to its wording of September 2013, departing from the Digital Terrain Model (DTM 200 m). The temperature (for the coolest and warmest months) and radiation, both recovered from the Iberian Climate Atlas of the Autonomous University of Barcelona, were also systemized. Such Atlas provides information at 500 m × 500 m cells.

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1 Said profitability is calculated, for each municipality, as the ratio between the annual unit rent and the unit sales price. The profitability allows to transform rents into sale prices in order to be able to use the complete sample in the regression analysis explained later.

2 The quality characteristics have been constructed as dummy variables from the semantic analysis of the free texts in advertisements. Such semantic procedure consists of identifying adjectives implying high quality, superior design, views, natural light, architectural style, conservation, among others.

3 Such information come from households’ opinion in the Census.
• Accessibility

This includes the distance to the functional sub-centre and the metropolitan centre (calculated on the Tele-Atlas-road 2011 network), dummy variables for centralities and locations, as follows:

In brief, it is assumed that the probability that a listed offer discloses the energy-performance information of the dwelling is a function of its characteristics and location, as follows:

\[
\ln \left( \frac{p}{1-p} \right) = K + \sum_{i=1}^{n} \beta_i X_i + \sum_{j=1}^{m} \gamma_j X_j + \sum_{k=1}^{s} \delta_k X_k + \sum_{l=1}^{t} \epsilon_l + \epsilon
\]  

(1)

In (1) “p” is the probability that EPC-information is disclosed in the property advertising of a given apartment, and therefore “p/1-p” is the quotient between the probability that this information is disclosed and the probability that it is not (this quotient is known as an odd ratio). “X_1” are the housing and architectural characteristics of the dwelling, “X_2” is a vector that includes the indicators of urban and environmental quality of its environment, “X_3” is a vector constructed with indicators of accessibility and centrality and “X_4” is a vector that includes the socioeconomic indicators of the population residing in the immediate environment of the respective dwelling. Within the centrality indicators, fixed effects are used to identify the CBD and subcenters, since they are dynamic property markets at the time that contain old homes since such subcenters, in metropolitan Barcelona, were formerly independent towns. Both aspects might affect EPC disclosure.

In the dataset, the average apartment has an area of 93 sq. m (with a balcony or terrace of 11 m2), 2.9 rooms, and 1.4 bathrooms. 22% of the offers have a storage room and a 49% laundry area; 48% have air conditioning and 68% heating; conversely, chimney only accounts for 6% of the dataset. Only 12% of the dwellings have a community pool and 16% a common garden; however, 66% are lift serviced. The semantic analysis of the free texts indicates that 19% have been recently retrofitted, although the average construction year is 1968, only 5% of the offers argue exceptional designs or qualities, although in 37% there is a good state of preservation/quality of the kitchen.

The apartments that are on sale, concerning those that are for the rental market, are in statistical terms according to the ANOVA test: larger (with a larger number of rooms, have wider balconies or terraces); they also exhibit a large proportion of structural amenities such as storage room, laundry, community swimming pool, and common garden; on the other hand, are newer (1970 versus 1958). However, the apartments that are offered for rent are in taller buildings (indicating a central location), have a lift in a larger proportion, as well as air conditioning, are retrofitted in a higher proportion, and exhibit a higher quality kitchen. Thus it seems there is a trade-off: dwellings for rent are older and have less structural amenities (e.g. number of rooms) than are compensated with other amenities (e.g. air conditioning). This finding makes it mandatory to control the tenure of transactions in the econometric analysis.

The Spanish transposition of the EPBD (CTE, 2006; RD 47/2007, RD 235/2013) and its recast establishes a classification of new and existing buildings on an “A”-“G” scale from greater to lesser efficiency, based on CO\textsubscript{2} emissions per sq. m/year from different ranges according to: 1) the climatic zones set in the DB-HE of the CTE; 2) the use for which the building is intended; and 3) whether it is new or existing (Gangolells et al., 2015). Although, as of June 1st, 2013, according to these regulations, it is mandatory that all real estate advertising leading to a sale or new rentals includes the EPC label, only 15% of the offers studied here include such information. We are, therefore, facing an energy-performance “obscure” market. Obscurity that is accentuated if it is considered that, according to estimations of the Buildings Performance Institute Europe, 80–90% of the buildings do not exhibit EPCs because they are not transacted.

Most of the 7511 apartments with EPC information are “E” rated (50%), followed by: “G” (19%), “F” (12%), “D” (11%), “C” (4%), “B” (2%), and “A” (3%), considering an ordinal scale (A = 7, G = 1) the average EPC rating stands for 2.87. Therefore, the energy reality of the residential stock offered in metropolitan Barcelona is deficient, when compared, for example, with the work of Fuerst et al. (2015) who have found that the English mean with transaction data is, using the same ordinal scale, at 3.83. Furthermore, the Catalan residential stock resembles the Greek case where only 3% of the buildings are “B” rated or higher (Droutsa et al., 2016). In Greece, as in Spain, the deficiency derives from poor insulation (including windows) and inefficient heating systems. However, the interest of this paper is not energy efficiency per se; but the disclosure of EPC-information in advertisements and its spatial implications, as developed below.

4. Results: the spatial pattern of energy-performance information

Fig. 1 depicts the metropolitan distribution of listed apartments (continuous line) and the proportion of them exhibiting EPC-information. In the figure, data are grouped by metropolitan belts (i.e. locally called metropolitan “crowns”), but that from Barcelona municipality was regarded separately as the CBD. Listed apartments follow the same pattern as the population.

In general, there is some parallelism between the distribution of the number of apartments and the proportion including EPC-information (r = 0.3626 sig. = 0.00) nevertheless, some divergences are notorious. The municipality of Barcelona (with 15,251 offers) stands out in the first place, followed by the territory of the second “crown” (located 20 km from the metropolitan centre), which comprises the bulk of mature sub-centres such as Sabadell, Terrassa, Mataró, as well as its dynamic peripheries. However, the proportion of dwellings with energy information is far from being uniform across the metropolitan: Barcelona, with 21%, leads the territories with the highest proportion of energy-informed advertisements, followed by the third metropolitan “crown”.

\textsuperscript{4} Such a test allows identifying statistically different averages in continuous variables.
proportion of EPC-informed offers in the penultimate metropolitan aggregation. The municipalities of the Baix Llobregat and Garraf counties stand out for already mandatory for new housing.

The analysis was carried out starting from the 49,424 dwellings without any spatial information reaches up to 40.00% of the offered dwellings. Thus, it can be said that:

- Concerning real estate and architectural characteristics, EPC-informed dwellings, in relation to uninformed ones, are: more expensive both in the rental and selling markets; primarily offered for rent; have more bathrooms; better in terms of design/finishings quality; have a lift in a larger proportion and are newer. Furthermore, 17% was built after 2007 when the National Construction Code (CTE) came into force, strengthening the energy efficiency requirements, at the time that EPCs became mandatory for new completions.

Fig. 2 renders the two-dimensional distribution at the municipal level of the EPC-informed offers. There are municipalities in which such information reaches up to 40.00% of the offered dwellings. Thus, municipalities such as Masuefa, La Garriga (both with significant new housing completions) or Gavà stand out in this regard. In general, the coastal corridor formed by the C-32 motorway that articulates some municipalities of the Baix Llobregat and Garraf counties stands out for its high relative proportion of informed offers.

Conversely, dense municipalities with a large volume of residential offers located in the suburbs of Barcelona, such as Santa Coloma de Gramenet, Badalona, or Sant Boi, stand out for the low proportion of reported advertisements (8% for the first two cases and only 5% for the third). Surprisingly, some of the mature sub-centres, such as Terrassa, Sabadell or Mataró, with significant real estate dynamics, denote a relatively low proportion of dwellings disclosing EPC information (5%, 6%, and 9%, respectively). However, this trend cannot be extrapolated to other sub-centres, since others such as Granollers, Vilafortuna and Vilanova (these 2 latter located in the said C-32 corridor) have higher proportions (18% for the first two cases and 24% for the third).

In short, the presence of energy-performance information in property offers does not appear to be random. Broadly speaking, expensive dwellings located in more central, accessible, dense locations, and newer, and boasting better in quality disclose energy performance in a larger proportion. The same is true regarding the socioeconomic profile of their immediate residential surroundings, since the previous vectors are concomitant with the places where the better-educated people occupying better jobs live, presumably, with a higher income level. However, none of these conclusions can be conclusive without analysing the combined effect of all factors.

4.1. Factors correlated with the disclosure of energy-performance information

Table 2 contains the set of logistic models that allow us to explore the relationship between the probability that the offers disclose the energy-performance of dwellings and their architectural and locative attributes. These models are robust to problems of collinearity and are specified using variables significant at 95% confidence level.

MOD1 inmo-Arq is specified only with indicators from the property and architectural dimension. All the coefficients render the expected sign and suggest that the higher the dwelling’s price, the greater the likelihood of disclosing EPC-info. Noticeably the price is the best synthetic indicator of quality and location. The disclosing likelihood also increases if the home was built after 2007 (since as said homes built after that year do require to perform an EPC); but it is reduced if it was built before 1981 and when it is offered for sale. It is worth saying that before 1980 Spanish legislation did not include any requirement for thermal insulation (López-González et al., 2016), therefore, in the absence of energy-retrofitting, age is concomitant to energy inefficiency.

MOD2 inmo-Arq + Cal.E introduces with the expected sign, in addition to the aforementioned variables, two indicators of urban and environmental quality. Accordingly, the probability increases when the dwelling is close to natural parks or the sea, as well along with the

\[ V = \frac{12}{A_{\text{m}}^{1/2}} \] (1), where \( V \) is the unit price for sale, \( A \) is the unit price of rent and \( i \) is the yield. Such yield has been estimated, for each municipality, as:

\[ i = \frac{\text{recommended yield}}{100} \] (2). In (2) "Am" is the average monthly rent per sq. m and "Vm" is the average selling price for the same municipality.
increase of advanced services. In other words, coefficients suggest that both central locations and qualified environmental zones increase the probability that apartment advertisement include EPC-information. Thus, an environmental market niche may exist.

MOD3 Inmo-Arq + Cal_E + Acc goes further by including accessibility variables. So, the probability increases when the dwelling is located near a railway station and when travel-to-work increases. These results are complementary, the first reflects a pure transport indicator, the second is much more complex because it relates the infrastructure to the place of residence and work of the population, is, therefore, an indicator of mobility. The positive sign of the centrality indicator suggests that property dynamic zones such as the CBD and the subcenters increase the likelihood to disclose such information. Consistently, the probability is also related to population density (people per urbanised sq. km).

Finally, MOD4 Inmo-Arq + Cal_E + Acc + Soc incorporates vectors related to the socioeconomic characteristics of the population. The multivariate analysis confirms that areas populated with not only middle-income people but, mainly, the high-income population, is precisely where residential offers contain more energy-performance information.

Overall, results suggest that energy-informational asymmetry depicts uneven geography throughout the city. Thus, the information opacity is accentuated in areas with the worst dwellings (cheaper and built without any thermal protection), dominated by a population with low income, separated by a pedestrian distance from transport stations, in non-central places. In short, the population that could obtain the most benefit from the energy-performance of buildings information is, in the light of these results, the most uninformed.

The fit of the aforementioned models is, nonetheless, far from being satisfactory, the best of them hits 84.8% of predictions, but only has a Nagelkerke R2 of 2.3%. It is possible, therefore, that the patterns of the informational presence are spatially autocorrelated: that is, the probability that a dwelling discloses this information depends not only on the previously studied factors, but also on the fact that in its vicinity there are other dwellings in the same information circumstances. To prove this conjecture, Moran’s I indicator has been computed. The result allows us to reject the null hypothesis of spatial independence, although with a small value (Moran’s I = 0.036).

Given such a poor result, the local version of the indicator has been then calculated, considering a 100-dwelling-neighbourhood. The maps in Fig. 3 detail that in half of the cases the spatial autocorrelation on the local scale is statistically significant and that there are even areas where the Local Moran’s I exceeds the value of 0.7 signalling important spatial relationships. An example of them is precisely the C-32 corridor that at a municipal level stood out as an area with a high rate of EPC-informed advertisements. Some nuclear areas of metropolitan centralities, including the municipality of Barcelona, are in the same situation.

To take into account this spatial trend in the logistic analysis, MOD5 Inmo-ArqCal_E + Acc + SocESP has been constructed. This model is specified following MOD4, but incorporates local Moran’s I as a spatial control factor. As is shown in Table 3, the signs of the coefficients are maintained, and except for the variables related to the proximity to the natural parks, the railway stations, and the marketing regime, the coefficients remain stable. However, the spatial autocorrelation emerges, with an Odd-ratio of 19.07, as the main explanatory factor of the probability that an offer complies with the obligation to report the energy efficiency of homes. This finding faithfully reflects the spatial mechanisms of housing choice and marketing supported in local-based property agents that are necessarily bounded in space, and ratifies the importance of taking into consideration locally embedded factors in studying the spatial diffusion of energy policies.

5. Discussion and conclusions

Almost two decades ago, the Energy Performance of Buildings Directive (EPBD) introduced a synthetic and legible indicator of the energy efficiency of buildings. As a result, energy performance certifications (EPC) became universally applied in the EU property market. The main objective of such energy labels is to give transparency to the opacity of the energy attributes, and therefore, to foster informed real estate decisions. Such a policy relies on a free market to create a virtuous circle in which, the demand, better informed, manifests through its willingness to pay, its preference for the most efficient buildings, given...
potential energy savings and environmental preservation. At the same time, developers can recover the extra capital expenditure of building with efficient technologies.

Nevertheless, to properly work the aforementioned “circle” requires the omnipresence of energy-performance information as a primary requisite. In Spain, almost 3 years after Royal-Decree 235/2013 made it mandatory to exhibit EPC-label in property advertisement only 15% of listed apartments in metropolitan Barcelona meets such obligation. This paper insight into the spatial implications of this informational “obscurity”, departing from the hypothesis that the spatial distribution of energy efficiency information is not random; but forms patterns correlated with the characteristics of the offered dwellings, as well as with the urban and socioeconomic locative attributes.

In total, have been analysed about 49 thousand offers for sale and rental of apartments located in the 184 municipalities functionally linked to Barcelona. This information comes from Habitaclia, which is one of the most important real estate web listings in Catalonia, and has been supplemented with climatic, census, land use, public and private

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**Table 1**

Average housing attributes are classified according to the presence/absence of EPC-info.

| Real estate and architectural features | Sub sample without energy information | Sub sample with energy information | ANOVA Test |
|---------------------------------------|--------------------------------------|----------------------------------|------------|
|                                       | Mean (41,913 (36,428 Sale; 5485 Rent)) | Mean (7511 (6244 Sale; 1267 Rent)) | F (Sig.)   |
| Sale price (Euro/sq m)                | 2402 (1498)                         | 2648 (1740)                      | 136.683 –  |
| Rent price (Euro/sq m)                | 12.8 (6.2)                          | 14.8 (8.0)                       | 94.411 –   |
| Sale offer (%)                        | 87% (34%)                           | 83% (37%)                        | 77 –       |
| Number of rooms                       | 2.90 (1.02)                         | 2.88 (1.05)                      | 2.69 0.10  |
| Number of bathrooms                   | 1.40 (0.6)                          | 1.43 (0.7)                       | 18.851 –   |
| Floor number                          | 2.0 (2.1)                           | 2.1 (2.2)                        | 95.403 –   |
| High quality real estate (%)          | 4.8% (21.4%)                        | 5.9% (0.9)                       | 17.364 –   |
| Lift                                  | 32% (1)                             | 38% (1)                          | 29.974 –   |
| Construction year                     | 1969 (25)                           | 1970 (26)                        | 7.265 0.01 |
| EPC rating “A”                        | nd nd                               | 3% (0)                           | nd nd      |
| EPC rating “B”                        | nd nd                               | 2% (0)                           | nd nd      |
| EPC rating “C”                        | nd nd                               | 4% (0)                           | nd nd      |
| EPC rating “D”                        | nd nd                               | 11% (0)                          | nd nd      |
| EPC rating “E”                        | nd nd                               | 50% (1)                          | nd nd      |
| EPC rating “F”                        | nd nd                               | 12% (0)                          | nd nd      |
| EPC rating “G”                        | nd nd                               | 10% (0)                          | nd nd      |
| Built before 1981 (%)                 | 74% (44%)                           | 72% (45%)                        | nd nd      |
| Built after 2007 (%)                  | 10% (55%)                           | 17% (70%)                        | nd nd      |
| Urban and environmental quality       |                                     |                                  |            |
| Distance to the sea (km)              | 7.2 (7.9)                           | 5.8 (6.7)                        | 209.951    |
| Environmental noise problems (%)      | 38% (11%)                           | 39% (12%)                        | 65.715     |
| Environmental pollution problems (%)  | 22% (12%)                           | 23% (12%)                        | 31.8 –     |
| Dirty streets (%)                     | 37% (13%)                           | 37% (13%)                        | 14.025 –   |
| Untidy streets (%)                    | 1.3% (1.9%)                         | 1.4% (2%)                        | 8.384 0.00 |
| Manufacturing premises (%)            | 10.1 (16.9)                         | 8.8 (15.3)                       | 39.265     |
| Buildings in poor condition (%)       | 10% (11%)                           | 11% (12%)                        | 31.108     |
| Buildings in good condition (%)       | 86% (16%)                           | 84% (17%)                        | 47.978     |
| Average age real estate stock (years) | 57 (20)                             | 59 (21)                          | 98.27      |
| Municipal employment density (jobs/sq km) | 3170 (3154)                      | 3993 (3450)                      | 421.501    |
| Accessibilty                          |                                     |                                  |            |
| Near urban railway station (%)        | 36% (48%)                           | 43% (50%)                        | 139.813 –  |
| Near suburban railway station (%)     | 11% (5.9)                           | 12.4% (33.0%)                    | 5.569 0.02 |
| Distance to railway station (km)      | 1.0 (1.6)                           | 0.8 (1.4)                        | 74.354 –   |
| Distance to Metropolitan Centre (km)  | 16.7 (13.5)                         | 14.9 (14.2)                      | 109.406 –  |
| Time home to work (min)               | 23.6 (4.4)                          | 24.2 (4.2)                       | 106.089 –  |
| Centrality (dummy – 1 if CBD or Subcentre) | 59% (49%)                       | 62% (49%)                        | 27.392     |
| Highway/Freeway access (%)            | 88% (32%)                           | 89% (31%)                        | 5.176 0.02 |
| Socioeconomic context                |                                     |                                  |            |
| Delinquency opinion (%)               | 27.6% (17.4%)                       | 28.3% (18%)                      | 9.863 0.00 |
| Pop without primary studies (%)       | 14.3% (6.0%)                        | 13.8% (6%)                       | 39.624 –   |
| Pop with primary studies (%)          | 24.2% (6.2%)                        | 23.5% (6%)                       | 76.699 –   |
| Pop with secondary studies (%)        | 46.6% (5.8%)                        | 45.9% (6%)                       | 84.682 –   |
| Pop with university studies (%)       | 14.9% (10.7%)                       | 16.7% (11%)                      | 182.848 –  |
| Med-income population. (Princ. component) | 0.36 (0.52)                      | 0.38 (0.54)                      | 4.87 0.03  |
| Socioeconomic diversity (H)          | 1.98 (0.10)                         | 1.97 (0.1)                       | 22.826 –   |
| Pop with European citizenship (%)     | 95% (4%)                            | 94% (4%)                         | 58.134 –   |
| Diversity of dwelling typology (H)   | 1.71 (0.3)                          | 1.72 (0.3)                       | 4.781 0.03 |
| CatSiquepPot votes (%)                | 10.5% (3%)                          | 10.1% (2.4%)                     | 89.234 –   |
| Polular Party votes (%)               | 9.4% (3.4%)                         | 9.2% (2.8%)                      | 14.941 –   |
| PSC votes (%)                         | 14.0% (4.0%)                        | 13.5% (3.8%)                     | 129.634 –  |
| JxC votes (%)                         | 34.3% (9.2%)                        | 35.2% (8.6%)                     | 67.35 –    |
| C’s votes (%)                         | 20.1% (3.9%)                        | 19.6% (3.8%)                     | 97.049 –   |
| CUP votes (%)                         | 8.0% (1.9%)                         | 8.5% (1.9%)                      | 422.04 –   |

Note: In gray are the characteristics that are significantly different to less than 99% of confidence and more than 90%.
Source: own elaboration.
transport networks data to give a clear picture of the urban, environmental and socio-economic conditions of the dwellings environment. Such datasets have been analysed using conventional and spatial multivariate statistical procedures.

The results allow us to reject the null hypothesis of spatial independence, since they suggest that there is a local concomitance regarding the EPC disclosure. That is, the probability that an offer discloses EPC-information depends on the presence of such information in neighbouring offers. This autocorrelation is the main explanatory factor of spatial irregularities in information asymmetry. This type of spatial trend had already been reported by Chegut et al. (2014) for BREEAM certificates in the London office market. These authors refer to it as “gentrification” (sic) process whereby buildings that are certified late receive market prizes in their rents which are lower than the rents of their neighbouring buildings certified early. Also, it is plenty coherent with most of the studies review in section 2.

Beyond spatial autocorrelation, results suggest that the presence/absence of EPC-information is related to the characteristics of dwellings and their location. Thus, the probability that an offer discloses information of its energy rating positively depends on the price of the dwelling, that is to say, on the best indicator of architectural and urban quality that exists, on its marketing regime (being higher in the case of dwellings that are rented), on its year of construction (being higher in the case of new dwellings), on its location (being higher in the best and more central areas) and on the level of income of the population (being higher where affluent people lives). These results contrast with those of Brounen & Kok (Brounen and Kok, 2011) discussed in the second section of this paper.

In short, energy opacity is precisely obscuring areas where low-quality dwellings are preeminent, that according to its year of construction were built when no thermal isolation was required by law. This situation is further aggravated by the fact that they are inhabited by the

### Table 2

Logistic models to explain the probability that property advertisements disclose EPC-information.

| Dimension                              | MOD1 Inmo-Arq | MOD2 Inmo-Arq + Cal_E | MOD3 Inmo-Arq + Cal_E + Acc | MOD4 Inmo-Arq + Cal_E + Acc + Soc |
|----------------------------------------|---------------|------------------------|-----------------------------|-----------------------------------|
| R square of Nagelkerke (%)             | .012          | .023                   | .022                        | .023                              |
| Hosmer & Lemershow test (sig.)         | .002          | .000                   | .439                        | .999                              |
| N                                      | 49,424        | 27,000                 | 32,000                      | 27,000                            |

| Dimension                              | MOD1 Inmo-Arq | MOD2 Inmo-Arq + Cal_E | MOD3 Inmo-Arq + Cal_E + Acc | MOD4 Inmo-Arq + Cal_E + Acc + Soc |
|----------------------------------------|---------------|------------------------|-----------------------------|-----------------------------------|
| Real estate and architectural features |               |                        |                             |                                  |
| Constant                               | -1.73         | 1397                   | -1.86                       | 1059                              |
| Sale price eq (Euro/sq m)              | 0.00          | 177                    | 0.00                        | 26                                |
| Dwelling on sale                       | -0.25         | 52                     | -0.18                       | 26                                |
| Built before 1981                      | -0.18         | 7                      | -0.17                       | 31                                |
| Built after 2007                        | 0.14          | 45                     | 0.13                        | 38                                |
| Urban and environmental quality        |               |                        |                             |                                  |
| Less than 200 m of a natural park      | 0.42          | 27                     | 0.00                        | 27                                |
| Distance to the sea (km)               | 0.02          | 122                    | 0.44                        | 158                               |
| Municipal advanced services (%)        | 0.04          | 158                    | 0.42                        | 27                                |
| Accessibility                          |               |                        |                             |                                  |
| Near urban or suburban railway station | 0.16          | 35                     | 0.14                        | 23                                |
| Time to work (min)                     | 0.01          | 14                     | 0.01                        | 7                                 |
| Centrality (dummy = 1 if CBD or Subcentre) | 0.11         | 14                     | 0.07                        | 6                                 |
| Population density (pop/km2 urb)      | 0.00          | 23                     | 0.00                        | 22                                |
| Socioeconomic context                  |               |                        |                             |                                  |
| High-income population (principal component) | 0.08        | 25                     | 0.08                        | 1.08                              |
| Medium-income population (principal component) | 0.10        | 13                     | 0.10                        | 1.10                              |

Note: Success rate in predictions for model 4: 84.8%.
Source: own elaboration.
Furthermore, according to the work of Marmolejo & Chen, the market premium for an energy rating one; while non-EPC-disclosed apartment less wealthy population, which is precisely what could benefit the most from knowing the economic implications of buying or renting a ther- mally inefficient dwelling, as discussed by Fuerst et al. (2015). On the other hand, the fact that the dwellings that are sold are energetically more opaque concerning those that are rented has important implications. Since the empirical evidence reviewed in the second section suggests that real estate differentiation operates primarily in the buying and selling market, which is, in our Spanish case, the most uninformed. Furthermore, according to the work of Marmolejo & Chen (Marmolejo-Duarte and Chen, 2019) such low-income energy-inefficient neighbourhoods exhibit the largest impact of EPC ratings on housing prices. Furthermore, non-disclosure of EPC-info might have also repercussions for the selling side. Taylor (1999) shows that while market prices can be boosted by not disclosing inconvenient housing attributes, buyers are reluctant to choose homes with incomplete information of relevant attributes. In that line, using data from the selling market in the Netherlands, Aydin et al. (2019) have found that EPC-informed homes sell faster than non-energy-informed ones. Taking into consideration that in Spain home sellers are primarily households, this issue might be also impacting households willing to sell their own-occupied homes located at energy-information dark low-income neighbourhoods.

Beyond the spatial implications of EPC disclosure analysed here, it is important to discuss the very small proportion of energy-informed listings from the micro-foundations perspective. Marmolejo (2016) using a hedonic model for Metropolitan Barcelona indicates that undisclosed EPC information may imply incentives in the case of inefficient homes. According to his model, the market premium for an “A” rated apartment is 5.11% concerning a “G” rated one; while non-EPC-disclosed apartments are sold only 1.85% cheaper than EPC-disclosed ones. Such author also shows that such incentive is 8.7 larger than the fine the owners can get for non including EPC information in advertisements. Complementary, he compares the market premium for efficient homes versus the extra capital required to achieve such performance. As an average, he finds that each EPC rating has a market premium of Euro 16/sq.m while extra investment for the same dwelling typology/local- range from Euro 22 to 25/sq.m. according to the passive/active measures introduced. In a further study Marmolejo et al. (Marmolejo-Duarte et al., 2020b) surveying Spanish real estate agents, conclude that EPC labels exert a small, even negligible effect, over housing marketing (i.e. price-fixing/negotiation and speed-to-market). Such research also reveals that most of the buyers and tenants are informed on the energy performance of the home during the contract signature. That is after having visited the property when the leasing or purchasing decision is already done, this trend is remarkably present in low-income neigh- bourhoods where sellers wait until the last moment to pay for an EPC. All in all, suggest that at the moment to which this paper refers, the incen- tives to improve the energy performance of homes were unclear, while undisclosed strategies for inefficient homes may be cost-benefit convenient despite the sanctions in place.

These findings are clear messages for law enforcement agencies, but also call into question the important commitment that the EPBD policy has given to the free market as a supplier of energy-efficient homes. Also, this paper contributes to stress the relevance of spatial dependence on energy policy issues. In the same strain are the works of Gallaher et al. (2021) who explore the role that tree trimming operations plays over grid readability; Caragliu (2021) whose work on firm productivity related to energy-intensive industries highlights the relevance of spatial dependence and a-spatial proximity; as well as the work of Schulz & Rode (Schulz and Rode, 2021) showing that local context conditions influence the adoption rate of green transportation technology.

In short, if in Denmark the certification began to exert the expected effects on dwellings elicitation when it became effective (Jensen et al.,

![Spatial autocorrelation](image)

Table 3
Logistic Model controlling the local spatial autocorrelation.

| Dimension                          | Variable                  | B  | Wald | Sig. | Exp (B) |
|-----------------------------------|---------------------------|----|------|------|---------|
| Urban and environmental quality   | Municipal advanced services (%) | 0.28 | 9    | 0.00 | 1.32    |
|                                   | Distance to the sea (km)  | 0.02 | 68   | 0.00 | 0.98    |
| Accessibility                     | Near urban or suburban railway station | 0.18 | 38   | 0.00 | 1.20    |
|                                   | Time to work (min)        | 0.01 | 7    | 0.01 | 1.01    |
|                                   | Centrality (dummy = 1 if CBD or Subcentre) | 0.06 | 4    | 0.04 | 1.07    |
| Socioeconomic context             | High income population (princ. component) | 0.06 | 13   | 0.00 | 1.06    |
|                                   | Medium income population (p. component) | 0.00 | 17   | 0.00 | 1.00    |
| Spatial autocorrelation           | Local Moran’s I           | 2.95 | 2785 | 0.00 | 19.07   |

Note: The success rate of predictions for model 5 is: 88.1%. Source: own elaboration.

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2016) universal, there is no reason to think that in Spain when that time comes, the Energy Performance Certifications will no longer be seen as a mere bureaucratic procedure. Nor should we forget the Dutch experience where a public trust towards EPC was correlated with the voluntary adoption rate before the reform of the EPBD universalised these labels (Brounen and Kok, 2011).

Limitations of the study

This paper uses all the listed apartments in a given moment, however, neighbouring previously listed apartments may exert an influence over the EPC disclosure of present ones. Unfortunately, it was not possible to retrieve historical listings, therefore further research is required to explore the implications from a cross-longitudinal perspective.

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CRediT authorship contribution statement

Carlos Marmolejo-Duarte: Conceptualization, Methodology, Formal analysis, Writing – original draft, statistical analysis, draft preparation. Belen Oneca-Pérez: Writing – original draft, Data curation, Writing – review & editing, results interpretation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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