Doctoral Dissertation

Doctoral Program in Urban and Architectural Management and Valuation

Spatial implications of Energy Performance Certificates on housing prices in the Barcelona Metropolitan Area

Author

Ai Chen

Supervisor

Prof. Carlos Marmolejo Duarte

Department of Architectural Technology (TA)

Universitat Politècnica de Catalunya (UPC)

Barcelona- España

SEPTEMBER, 2020

Declaration

I, Ai Chen, hereby declare that the contents and organization of this dissertation constitute my original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

“FOREVER YOUTHFUL, FOREVER WEEPING”

----《The Dharma Bums》

Jack Kerouac, 1958

CONTENT

LIST OF TABLES

LIST OF FIGURES

PREFACE

This document is submitted in fulfilment of the requirements for the doctoral program- Urban and Architectural Management and Valuation, organized by Centro de Política de Suelo y Valoraciones (CPSV) in the Escola Tècnica Superior d'Arquitectura de Barcelona (ETSAB) of Universitat Politècnica de Catalunya (UPC). This document is a part of the academic achievement in my four years' doctoral research (2016-2020) in which all the academic financial supports are from the project EnerValor (ref. BIA-2015-63606-R (MINECO/FEDER), supervised by Prof. Carlos Marmolejo. At the same time, my tuition fee and living expenses are offered by the Chinese Scholarship Council (CSC-No. 201506050024).

This document is a compendium of doctoral publications which meets the requirement of the doctoral thesis. It includes six publications where I am the first or second author. Besides, more publications I have participated or collaborated with other researchers did not collect as the main text in this compendium (more details in 1.5.1). As the main body of this document, these six publications have been published in academic journals and conference books as follows:

C3:The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample.

Published in 2018 conference book: XII Congreso Internacional Ciudad y Territorio Virtual: "Ciudades y Territorios Inteligentes which is indexed by Index Copernicus, Impact Factor of SJR is 0, the score transformation is 0.

J1: The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments and Implications for Public Policy and Private Markets.

Published in 2019 Journal of Sustainability which is indexed by WOS (SCI/SSCI), SCOPUS and Index Copernicus, Impact Factor of JCR is 2.576, equivalent to architecture Q1 and the score transformation is 4.

J4: La incidencia de las etiquetas energéticas EPC en el mercado plurifamiliar español: un análisis para Barcelona, Valencia y Alicante.

Publishde in 2019 Journal of Ciudad y Territorio, Estudios Territoriales which is indexed by WOS (ESCI), SCOPUS and Index Copernicus, Impact Factor of SJR is 0.133, equivalent to architecture Q3 and the score transformation is 2.

J2: The evolution of energy efficiency impact on housing prices: an analysis for Metropolitan Barcelona.

Published in 2019 Revista de la Construcción which is indexed by WOS (SCI), SCOPUS and Index Copernicus, Impact Factor of JCR is 0.430, equivalent to architecture Q1 and the score transformation is 4.

C4: How different are dwellings whose energy efficiency impacts price formation?

Published in 2019 IOP Conference Series: Materials Science and Engineering which is indexed by WOS(CPCI-S/CPCI-SSH), SCOPUS and Index Copernicus, Impact Factor of SJR is 0.198, equivalent to architecture Q2 and the score transformation is 3.

J3: Is the energy price premium spatially aggregated? A listing price analysis of the residential market in Barcelona.

Published in 2018 Journal of Technical Transactions which is indexed by Index Copernicus, Impact Factor of SJR is 0, the score transformation is 0.

In sum, the total scores are 12, exceeding the regulation of the << NORMATIVA PER A PRESENTAR LA TESI DOCTORAL COM A COMPENDI DE PUBLICACIONS>> that requires 8 scores for a collection of publications as the PhD thesis.

This dissertation consists of three parts. In the first part, I introduced and combing the research background and theoretical knowledge in details to have a better understanding of our research topic. It is helpful for readers to clear barriers about academic terms and the methodologies selected for each specific research when they reach the empirical studies in the second part. Finally, a general conclusion is listed in Part Three while some new academic activities and future researches are discussed here.

In addition, I have participated in some academic activities during the four years, such as to be the speaker in international conferences and seminars. In the school, I have participated in some teaching issues, such as to be an assistant in the master course "Urban Economy" and helped them to fulfil their master theses.

ABSTRACT

The concepts of “energy sustainability” and “environmentally friendly” arouse extensive attention and the discussion on how to utilize, save and regulate energy and reduce pollution has become a dominant issue. The building sector in Europe is responsible for 40% of total energy consumption and 38% of total CO_2 emissions, leading to economic, geopolitical and environmental concerns. For this reason, various countries and districts in Europe have begun to establish their building energy management systems to monitor, supervise and improve building energy efficiency. These include Energy Performance Certificates (EPCs), launched in 2003, the Building Research Establishment Environmental Assessment Method (BREEAM), which was launched in the UK in 1990, HQE in France, and Minergie in Switzerland.

An increasing number of studies have recognized the significant role that energy efficiency played in the residential market and the energy policies and the inner implication that promote or hinder the EPC program has aroused researchers’ concerns. Within this context, this PhD dissertation has tried to make contributions in this research field, especially paying more attention to Mediterranean Climatic zone that has not been well-discussed.

In general, this dissertation aims to explore the spatial implications of energy efficiency on housing price in Barcelona Metropolitan Area and furtherly detect the energy premium submarket in details as well as their policy implications. To well-fulfil this general objective, there are four specific objectives proposed: 1) To explore the possibility of selection biases when detecting the “green premium” in Barcelona residential market; 2) To explore the EPC impacts on housing price in different residential segmentations are uneven or not; 3) To explore the presence of spatial dependence (i.e. autocorrelation) when analyzing the impact of EPC on housing price; 4) To explore the presence of spatial heterogeneity when analyzing the impact of EPC on housing price.

As the second-largest area with a Mediterranean climate and having the most energy-efficient homes in Spain, Barcelona Metropolitan Area is a good example to analyze the energy efficiency's performance in the Mediterranean climatic zone. In our case, the selling asking price of apartments and other relative variables impacting on housing prices were collected in 2014 and 2016 respectively.

This dissertation has employed a series of Hedonic Price Models (HPMs) and spatial econometric models as well as other approaches or methods to fulfil the specific objectives. In the first empirical study, Heckman two-step model is applied to find if there is the existence of sample selection biases. Once there is selection bias, an instrument variable -"Inverse Mills Ratio" will be introduced into the HPM to correct such biases. Finally, a brief comparison between the estimation results of OLS and unbiased HPM is presented to see how the selection sample biases influence the results, positively or negatively. After correcting biases by sample selection, empirical study II employed a traditional HPM with a comprehensive system variable concerning structural quality, accessibility, neighbourhood and environment as well as the socio-economic aspect. Then, a two-step cluster analysis is used to identify the existence of real estate segmentation. According to various characteristics performance of segmentation, several HPMs are specified to explore how the energy efficiency impact on housing price locally. Empirical study III and IV introduce Spatial Error Model (SEM) and Geographically Weighted Regression (GWR) Model to solve the spatial implications where the former is for spatial dependence issue and the latter for spatial heterogeneity.

This dissertation has drawn a series of conclusion concerning each empirical study. Firstly, sample selection bias indeed exists and will lower the energy efficiency's impacts on housing price. In our case, the green premium will reach to an increase of 12% if an apartment improves its energy efficiency from rating G to rating A. From an ordinal EPC perspective, about 2% growth of housing price along with energy efficiency rating improvement gradually (i.e. step by step in the G to A Spanish EPC Scale). At the same time, we found that selection biases in Barcelona mainly happened surrounding the area with a higher housing price and more university-educated citizens. From a real estate segmentation perspective, there are several highlights of energy premium performance. Secondly, consumers are willing to pay more for those tangible characteristics (e.g. heating or air conditioning) rather than an intangible and composite indicator. Interestingly, the housing price in "new apartment" segmentation market does not sensitive at all to energy efficiency which supposed that the EPC implication has been captured by new buildings' structural quality. However, those cheapest apartments with a worst structural quality can enjoy considerable "energy premium" (reaching to 33%) if they renovated certificates from rating G to rating A. It is inferred that the poor people may regard this EPC label as one of the quality indicators for an apartment. It highlights that the spread and transparency of energy efficiency may fail to the public with a lower income/lower social class. Thirdly, empirical study III and IV confirmed the existence of spatial dependence and heterogeneity which contributed to the non-stationary distribution of energy premium.

In sum, there are many limitations to this dissertation but it has synthesized a comprehensive model to check the spatial implication of energy efficiency on housing prices. In the future how to improve this compositive model and apply it in other case study are our aims.

KEYWORDS: EPC; Hedonic housing price; Selection biases; Spatial dependence; Spatial heterogeneity; Real estate segmentation; Barcelona; Mediterranean Climate

RESUMEN

Los conceptos de “sostenibilidad energética” y “ambientalmente amigable” han ganado relevancia, y la discusión sobre cómo utilizar, ahorrar y regular la energía para reducir la contaminación, se ha convertido en un tema dominante. El sector de la construcción en Europa es responsable del 40% del consumo total de energía y del 38% de las emisiones totales de CO_2, lo que genera preocupaciones económicas, geopolíticas y medioambientales. Por esta razón, varios países y distritos de Europa han comenzado a establecer sistemas de gestión energética de edificios para controlar, supervisar y mejorar la eficiencia energética de las edificaciones. Entre ellos se incluyen los Certificados de Eficiencia Energética (*EPC*), lanzados en 2003, el Método de Evaluación Ambiental del *Building Research Establishment* (*BREEAM*), que se lanzó en el Reino Unido en 1990, la certificación de Alta Calidad Ambiental (*HQE*) en Francia y *Minergie* en Suiza.

Asimismo, una gran cantidad de estudios han reconocido la importancia de la eficiencia energética en el mercado residencial. Donde las implicaciones internas de las políticas energéticas que promueven o dificultan el programa de EPC, han despertado la preocupación de los investigadores. En este contexto, la presente tesis doctoral ha buscado contribuir en este campo de investigación, con especial atención a la Zona Climática Mediterránea que no ha sido bien discutida hasta el momento.

En general, El presente trabajo tiene como objetivo explorar las implicaciones espaciales de la eficiencia energética en el precio de la vivienda en el Área Metropolitana de Barcelona y detectar con más detalle el submercado de la prima energética, así como sus implicaciones políticas. Para cumplir con este objetivo general, se proponen cuatro objetivos específicos: 1)

evaluar los posibles sesgos de selección a la hora de detectar la “prima verde” en el mercado residencial de Barcelona; 2) analizar la desigualdad de los impactos del EPC en el precio de la vivienda en diferentes segmentaciones residenciales; 3) evaluar la dependencia espacial (es decir, autocorrelación) al analizar el impacto del EPC en el precio de la vivienda; 4) examinar la heterogeneidad espacial al analizar el impacto del EPC en el precio de la vivienda.

Como la segunda zona urbana más grande con clima mediterráneo y con las viviendas más eficientes energéticamente de España, el Área Metropolitana de Barcelona es un buen ejemplo para analizar el comportamiento de la eficiencia energética de esta región. En nuestro caso, el precio de venta de los apartamentos y otras variables relativas que impactan en los precios de la vivienda se recopilaron en 2014 y 2016 respectivamente.

Para esta investigación se han empleado una serie de Modelos de Precios Hedónicos (*HPM*) y modelos econométricos espaciales, así como otros enfoques o métodos para cumplir con los objetivos específicos. En estudio empírico I, se aplica el modelo de dos pasos de Heckman para determinar si existen sesgos en la selección de la muestra. Una vez que haya un sesgo de selección, se introducirá una variable de instrumento - "relación inversa de Mills" en el HPM para corregir dichos sesgos. Finalmente, se presenta una breve comparación entre los resultados de la estimación de OLS y *HPM* sin sesgo para ver cómo los sesgos de la muestra de selección influyen en los resultados, positiva o negativamente. Después de corregir los sesgos mediante la selección de la muestra, el estudio empírico II empleó un *HPM* tradicional con una variable de sistema integral en cuanto a calidad estructural, accesibilidad, vecindario y medio ambiente, así como el aspecto socioeconómico. Luego, se utiliza un análisis de conglomerados de dos pasos para identificar la existencia de segmentación inmobiliaria. De acuerdo con el desempeño de varias características de la segmentación, se especifican varios *HPM* para explorar cómo la eficiencia energética impacta en el precio de la vivienda a nivel local. Los estudios empíricos III y IV, introducen el Modelo de Error Espacial (*SEM*) y el Modelo de Regresión Ponderada

Geográficamente (*GWR*) para resolver las implicaciones espaciales, donde el primero es para el problema de la dependencia espacial y el segundo para la heterogeneidad espacial.

Cada uno de los estudios empíricos ha arrojado conclusiones particulares. En primer lugar, existe un sesgo de selección de la muestra que reducirá los impactos de la eficiencia energética en el precio de la vivienda. En nuestro caso, la prima verde alcanzará un aumento del 12% si un apartamento mejora su eficiencia energética de la calificación G a la calificación A. Desde una perspectiva EPC ordinal, alrededor del 2% de crecimiento del precio de la vivienda junto con la mejora de la calificación de eficiencia energética gradualmente (es decir, paso a paso en la escala EPC española de G a A). Al mismo tiempo, encontramos que los sesgos de selección en Barcelona ocurrieron principalmente en las zonas de mayor precio de vivienda y el mayor número de ciudadanos con educación universitaria. Desde una perspectiva de segmentación inmobiliaria, hay varios aspectos destacados del desempeño de la prima energética. En segundo lugar, los consumidores están dispuestos a pagar más por aspectos tangibles (por ejemplo, calefacción o aire acondicionado) que intangibles y compuestos. Curiosamente, el precio de la vivienda en el mercado de segmentación de "apartamentos nuevos" no es sensible en absoluto a la eficiencia energética, lo que supuso que la implicación del EPC se había reflejado en la calidad estructural de los nuevos edificios. Sin embargo, aquellos apartamentos más baratos y de menor calidad estructural son acreedores de una considerable “prima energética” (llegando al 33%) si renovaron los certificados de la calificación G a la calificación A. Se infiere que las personas de menos ingresos pueden considerar la etiqueta del EPC como un indicador de calidad para un apartamento, aunque se destaca que la difusión y transparencia de la certificación de la eficiencia energética puede presentar más fallas al público de las clases sociales más bajas. En tercer lugar, los estudios empíricos III y IV confirmaron la existencia de dependencia espacial y heterogeneidad que contribuyó a la distribución no estacionaria de la prima energética.

En resumen, aunque existe una gran cantidad de limitaciones en el estudio de este tema, el presente trabajo ha logrado sintetizar un modelo integral para verificar la implicación espacial de la eficiencia energética en los precios de la vivienda. Por lo que, en futuras investigaciones buscará mejorar este modelo y replicarlo en otros casos de estudio.

PALABRAS CLAVE: EPC; precios hedónicos de la vivienda; sesgos de selección; dependencia espacial; heterogeneidad espacial; Barcelona; clima mediterráneo

PART I

GENERAL INTRODUCTION

AND

THEORETICAL BASIS

CHAPTER 1

GENERAL INTRODUCTION

CHAPTER 1 CONTEXT OF RESEARCH

1.1 Introduction

1.1.1 Background of Research

For environmental and energy dependency reasons, improving energy efficiency in buildings is a major priority in the public agenda of industrialized countries (Olaussen, Oust, & Solstad, 2017). In the European Union, the Energy Performance of Buildings Directive (2002/91/EC), also known as EPBD, is the main policy instrument aimed to promote energy efficiency in the real estate market (Gonzalez Caceres & Diaz, 2018). The EPBD introduced Energy Performance Certificates (EPCs) to provide tenants and buyers with synthetic and third-party information regarding the efficiency of real estate to eliminate market asymmetries. Such a strategy is relevant since market failures, in the form of imperfect information and asymmetries, are suggested to be barriers in the diffusion of efficient buildings (Giraudet, 2018), producing an "energy gap" (i.e., a rate of adoption well below the social optimum) (Gillingham & Palmer, 2014). Therefore, the recast of the Directive in 2010 (2010/31/EU) made it mandatory to include EPC labels in the marketing of almost all new and existing buildings in order to inform prospective users.

As efficient buildings can save money in energy bills and reduce environmental impacts it is expected that informed tenants and buyers were willing to pay more for efficient real estate. Eventually, such willingness to pay for efficient buildings may capitalize into "market premiums", generating incentives for developers and owners to invest in energy efficiency (Bio Intelligence Service et al., 2013). In sum, the European Commission saw the EPC scheme as "a powerful tool to create a demand-driven market for energy-efficient buildings (European, 2008, p.5).

Among all the real estate markets, the residential one is a special case since, due to the size of its stock, it consumes much more energy than commercial properties (Chau & Zou, 2018). In the literature, there is extensive, yet in some case inconclusive, evidence regarding the existence of market premiums for efficient homes. According to the studies reviewed in the next section, home selling prices can vary up to 30.5% (for rating A, the most efficient one, in relation to rating G as the most inefficient) in the Danish case (Jensen et al., 2016) or as little as 5% (A/G) in the case of the Irish renting market (Hyland et al., 2013). However, there is evidence suggesting that EPC labels do not play any role in price discrimination in the Oslo market (Olaussen et al., 2017). Differences in climate and energy costs in relation to home prices and, perhaps, environmental concerns may be behind such divergences. As such, there are no reasons to believe that the impact of EPC labels is stationary across housing segments within the same city, where household budgets, personal tastes, and priorities, as well as home attributes and prices also vary in a significant manner. As a matter of fact, in the office market, there is evidence suggesting that "green labels" are contingent to characteristics of buildings in the determination of prices (Das & Wiley, 2014).

Although there are numerous studies on energy premium and its energy-efficient policy implications, few of them make their concentration on the spatial distribution of energy premium. As the literature review stated, housing price is mainly affected by its unique location which includes accessibility, neighbourhood's quality and socio-economic classes, etc. In turn, almost indicators that contribute to housing price have their spatial implications. To solve this spatial implication which always biases the estimation result of housing price, Spatial Error Model (SEM) and Spatial Lag Model (SLM) as well as Geographically Weighted Regression (GWR) Model are the most frequently used models and approaches when figuring out the spatial implication biases of energy premium (Bisello, et al., 2020; Bottero, et al., 2018; McCord et al., 2020; Taltavull, et al., 2017). In consideration of the complex spatial impact of energy efficiency, an advance spatial econometric model – Spatial Durbin Model (SDM) is also a good resolution if spatial dependence and spatial heterogeneity have an equivalent impact on energy premium (Morton, 2018).

1.1.2 "EnerVALUE" Project

This dissertation is within the competitive project "Does energy qualification on housing really matter? An analysis on EPCs comprehension, perceived confidence and impact on householder's preferences and residential values" (EnerVALUE), which is a four-year project (2016-2020) whose Principal Investigator is Prof. Carlos Marmolejo. As a comprehensive academic project, it has a complete set of research objectives, methodologies and operation procedures (see more details in Figure 1.1).

It has been more than two decades since the emergence of green labels in the building industry, and more than one since the EU established, by means of EPBD, the universal obligation to certify the energetic performance (EPC) of dwellings when transacted. Since then, the European real estate market has an institutionalized mark intended to give energetic transparency to real estate transactions, and mainly to promote the construction and rehabilitation of energy-efficient buildings. Nonetheless, the progress in reaching such a goal is distressingly slow, distancing the 20-20-20 objectives. Furthermore, the divergence of the transposition of the EPB Directive among the member states has produced a heterogeneous panorama and, in some countries, such as Spain, controversial discussions among energy experts and, apparently, distrust among households, all together menace the efficacy of EPBD. Unacceptably, in Spain it is completely unknown the impact of EPC classes on residential values, despite the fact that it is mandatory to have such a document when dwellings are marketed since 2013.

Figure 1. 1 Schematic design of the project EnerVALUE
Source: Proposal of the project "EnerVALUE"

To break down such immobility, scientific evidence is necessary on the impact of EPCs on the key aspects of residential dynamics. This project advances towards such knowledge using an integrated approach and 3 main objectives:

1）To study whether agents (i.e. construction companies, developers, realtors, investors and valuers) associated to the residential market fully understand the meaning and implications of EPCs, are confident on the provided information, and take them into consideration on their decision-making processes.

2）To study the same at end-user level regarding households, and assess the relative importance of EPCs on residential choice, and whether there is a WTP for dwellings certified as efficient.

3）To study whether the eventual WTP transforms into a market premium, and if such a premium depends on the dwelling size, climatic location, typology or market niche. Additionally, the spatial analysis of data will allow to study whether such hypothetical premiums/penalties produce “energetic submarkets” with possible negative effects on residential segregation.

Consequently, this proposal is not on a simply study of the complex residential market, but also takes into consideration the possible social repercussions of the market intervention.

1.2 Thesis Objectives

As stated previously in the introduction section, energy efficiency and energy performance systems play an important role in the residential market. To explore the significance of energy performance in the housing market, we choose “EPC ratings” as the key variable to analyze the impact of energy efficiency with quantitative measures.

Considering the work from “EnerVALUE” project, the general objective of this dissertation is to explore the spatial implications of energy performance certificates on housing price in Barcelona Metropolitan. It can be divided into four specific objectives:

(1) To explore the possibility of selection biases when detecting the “green premium” in Barcelona residential market.

(2) To explore the EPC impacts on housing price in different residential segmentations are uneven or not.

(3) To explore the presence of spatial dependence when analyzing the impact of EPC on housing price

(4) To explore the presence of spatial heterogeneity when analyzing the impact of EPC on housing price.

To solve these four specific objectives, several empirical studies are discussed the impacts of energy efficiency on housing price from various perspectives in Chapter 6-9.

1.3 Methodology

Figure 1.2 gives a brief introduction of the methodologies in this dissertation. The specific methods and models, such as the precise model for random selection issues or the pooled hedonic model for a two-year dataset, will be discussed in the following chapters.

1.3.1 Literature Review

Considering this dissertation is a collection of the publications, it is necessary to pay more attention to collect and introduce the relevant theories of housing price and spatial statistics as well as the corresponding literature review. In particular, it could show a general knowledge system of our topic and support to study the following empirical studies theoretically.

1.3.2 Models and Tools

This document has employed various technique methodologies. Firstly, at least five kinds of statistical methods/models are used, including the basic Hedonic model, Heckman two-step model, pooled hedonic model, spatial lag model as well as spatial error model. Then, several statistical and geographical software play considerable important roles when analyzing in the case study. For example, ArcGIS Pro supports the visualization of mapping and data management while the STATA or SPSS help to clean and revised the dataset and moreover, calculate the specified models.

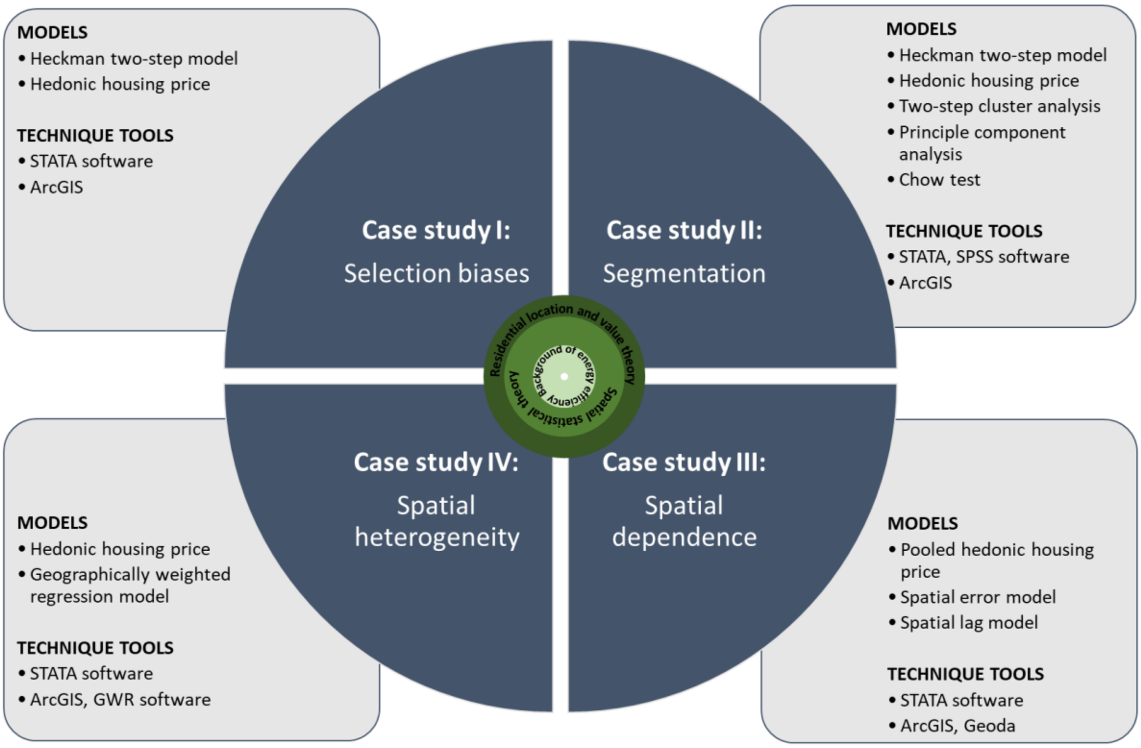


Figure 1. 2 Thesis's methodology frameworks
Source: Own elaboration

1.3.3 Quantitative Study/Case Study

In this document, there are four cases studies under the same framework of energy performance certificates in the housing market. Since these studies are analyzed in various periods, the specific numbers of samples in various empirical studies are a little bit different. In general, various synthetical methodologies including quantitative and qualitative measures are employed after considering the specific objective of each empirical case study.

1.4 Research Content

This dissertation consists of two main parts as well as the final discussion and conclusions. The Part I is the general introduction of the full document and the theoretical basis, including Chapter 1 to Chapter 4. Then Part II is composed of five publications which fulfil the four specific objectives of this dissertation as empirical studies. Finally, a general conclusion of this dissertation is summarized in Part III.

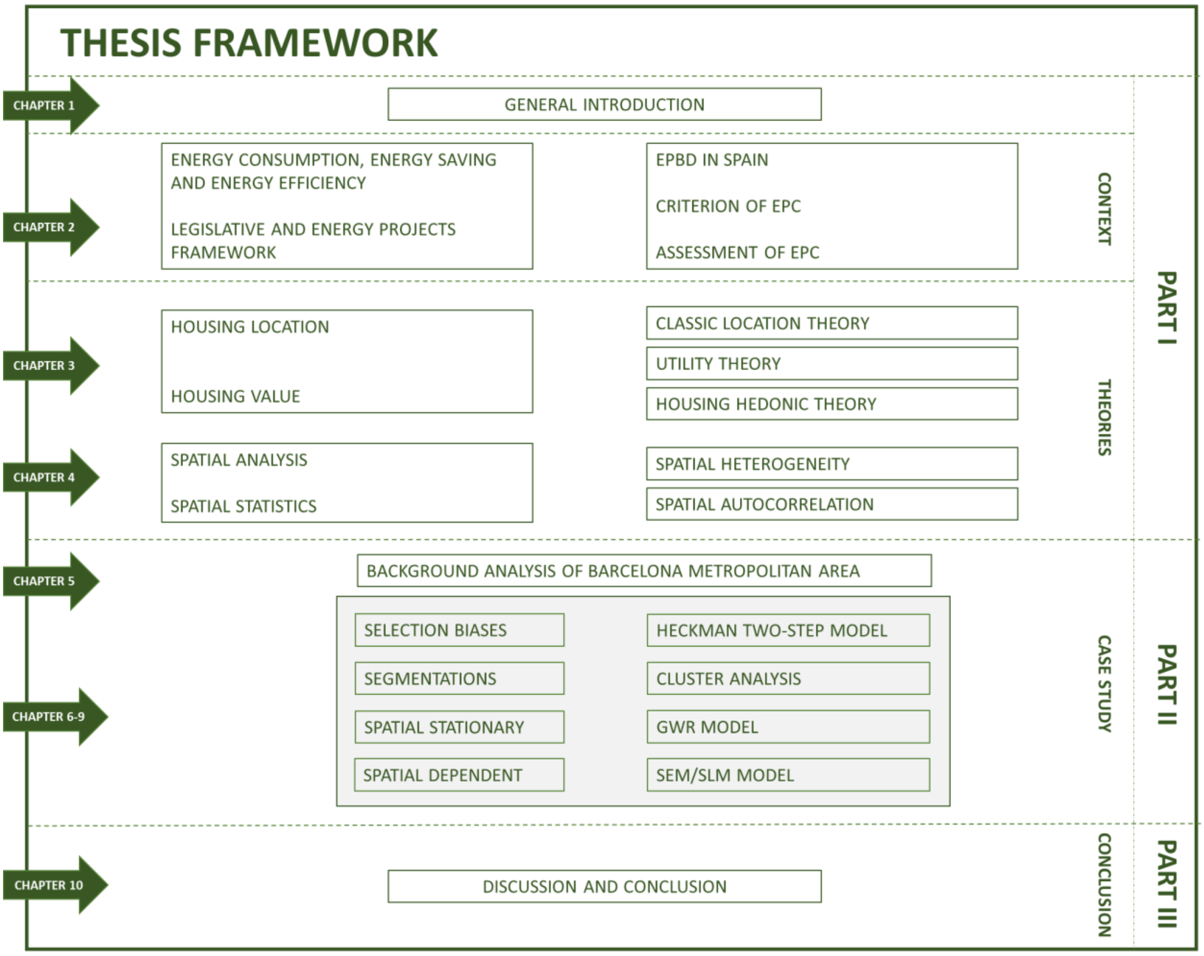


Figure 1. 3 Thesis's structure
Source: Own elaboration

In Chapter 1, it mainly introduces the background of this dissertation and the general as well as the specific objectives. To solve the objectives previously stated, a comprehensive framework of the methodology is proposed, conducting the following text in this document. In particular, the contributions of each publication are in details in this chapter since this document is a collection of publications as the doctoral thesis.

Chapter 2 concerns the background of energy consumption, energy-saving and energy efficiency which includes the literature review both in terms of legislative frameworks and relative energy projects. Also, in this chapter, Energy Performance Building Directives (EPBD) in Spain are introduced, including the criterion of EPC, the assessment of EPC process and the statement of energy efficiency program.

Chapter 3 brings a series of theories about the value and locations in the housing market. There is no doubt that supply and demand theory and utility theory will be introduced firstly which are the basis in almost researches concerning goods and humans. To better understand the determinants of housing price, residential location theories are explained with an evolution introduction from classic to newly theories. Then, the key role in our research- hedonic price theory is introduced and the components of hedonic price in the residential market are reviewed.

Chapter 4 is about the basic theories of spatial analysis and spatial statistics where two spatial characteristics are mentioned: spatial heterogeneity and spatial autocorrelation. In this part, the definition, basic theory and the classification of spatial implication are introduced. Especially, the methods and models of spatial analysis in urban area are listed.

After a brief introduction of functional BMA and corresponding literature review in relation to the specific objectives, four main empirical studies are introduced in Part II.

In Chapter 6, a traditional linear model is made to compare the housing price difference between those homes with a green label and those without. Then those dwellings with EPC label, considering our objective- the impacts of green homes, are analyzed by an Ordinal Least Square (OLS) model. Therefore, the first objective to address is coming: random selection biases. According to the literature review, the homes without green labels indeed have an impact on housing price. So, the hackman two-step model is used to avoid such selection bias. It concludes there will be some biases of estimation results when just analyzing those labelled-homes.

Subsequently, a cluster analysis is introduced in Chapter 7 to verify our second assumption: the existence of segmentation of green homes with specific and similar characteristics. In this chapter, green homes are divided into three clusters and search their own specific OLS expression on housing price. In order to address green homes' segmentation, a common hedonic model is applied to detect the different performances of EPC in various clusters.

Considering the two-years database and the conclusion of previous analysis-the existence of segmentation, a pooled data including green homes in 2014 and 2016 is used in Chapter 8 to explore the existence of spatial autocorrelation which could answer the third assumption: those factors impact on green homes are correlated with each other across the urban. In this section, Spatial Lag Model (SLM) and Spatial Error Model (SEM) are used to solve the problem of spatial autocorrelation.

According to the previous theoretical knowledge, spatial autocorrelation always happened along with the spatial heterogeneity. Therefore, in Chapter 9, the specific spatial statistical model - Geographically Weighted Regression (GWR) is employed to detect the existence of spatial heterogeneity and mainly to see how this spatial implication on housing price in functional BMA.

After four empirical studies employed, a general conclusion is summarized in Chapter 10. At the same time, the corresponding policy implications and future studies are discussed here.

1.5 Publications, Scores and Author Contributions

1.5.1 Publications List

There are 11 publications that I participated in during my four-year PhD academic period. All of them are framed according to "EnerVALUE" project, thereinto, five are journal articles, five are conference proceedings and one is book chapter. They are indexed by Web Of Science (WOS), SCOPUS or Index Copernicus. It is worth saying that I am the first author for three of them and the second author for five of them. Table 1.1 shows more details of each publication.

Table 1. 1 List of publications

CODE	YEAR	AUTHORS	PhD CANDIDATE AS FIRST AUTHOR	TITLE	JOURNAL/ CONFERENCE	INDEX
J1	2019	Carlos Marmolejo; **Ai Chen**	NO	The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments and Implications for Public Policy and Private Markets	Sustainability	WOS (SCI/SSCI) Scopus Index Copernicus
J2	2019	Carlos Marmolejo; **Ai Chen**	NO	The evolution of energy efficiency impact on housing prices: an analysis for Metropolitan Barcelona	Revista de la construccion	WOS (SCI) Scopus Index Copernicus
J3	2018	**Ai Chen**; Carlos Marmolejo	YES	Is the energy price premium spatially aggregated? A listing price analysis of the residential market in Barcelona	Technical Transitions	Index Copernicus
J4	2019	Carlos Marmolejo; **Ai Chen**	NO	La incidencia de las etiquetas energéticas EPC en el mercado plurifamiliar español: un análisis para Barcelona, Valencia y Alicante	Ciudad y Territorio Estudios Territoriales - CYTET	WOS (ESCI) Scopus Index Copernicus
J5	2019	Dell'Anna, F., Bravi, M., Marmolejo-Duarte, C., Bottero, M. C., & **Chen, A**.	NO	EPC Green Premium in Two Different European Climate Zones: A Comparative Study between Barcelona and Turin	Sustainability	WOS ((SCI/SSCI)) Scopus Index Copernicus
C1	2020	Carlos Marmolejo; Silvia Spairani; Consuelo del Moral; Luis Delgado; **Ai Chen**	NO	Is information symmetry sufficient in the promotion of energy efficient housing? Main results of the EnerValor project (Accepted)	The Euro-American Congress REHABEND 2020 on Construction Pathology, Rehabilitation Technology and Heritage Management	Scopus
C2	2019	Carlos Marmolejo; Consuelo del Moral; Luis Delgado ; Silvia Spairani Berrio; Joyce de Botton; Carlos Pérez; **Ai Chen**; Mateusz Gyurkovich	NO	Energy efficiency in the residential market and implications for architecture education in Spain	World Institute for Engineering and Technology Education (WIETE)	-
C3	2018	**Ai Chen**; Carlos Marmolejo	YES	The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases	CTV 2018: XII Congreso Internacional Ciudad y Territorio Virtual, Ciudades y Territorios Inteligentes	Index Copernicus
C4	2019	**Ai Chen**; Carlos Marmolejo	YES	How different are dwellings whose energy efficiency impacts price formation?	IOP Conference Series: Materials Science and Engineering	WOS (CPCI-S/CPCI-SSH) Scopus Index Copernicus
C5	2019	Carlos Marmolejo; **Ai Chen**	NO	How Relevant is Energy Efficiency in The Marketing of Homes? Evidence from Real Estate Agents in Spain	IOP Conference Series: Materials Science and Engineering	WOS (CPCI-S/CPCI-SSH) Scopus Index Copernicus
B1	2020	Carlos Marmolejo; **Ai Chen**; Mariana Bravi	NO	Spatial Implications of EPC Rankings Over Residential Prices	Springer Book Chapter: Green Energy and Technology-Values and Functions for Future Cities	WOS (BKCI-S/BKCI-SSH) Scopus

Notes: J denotes Journal Article; C denotes Conference Proceeding; B denotes Book chapter
Source: Own elaboration

1.5.2 Score according to The Thesis Submission Regulations by Articles

On the basis of the regulation, six of the mentioned publications are selected to constitute this dissertation. These publications have developed in this doctoral process. According to the << NORMATIVA PER A PRESENTAR LA TESI DOCTORAL COM A COMPENDI DE PUBLICACIONS>> by Programa de Doctorat Gestión y Valoración Urbana y Architectónica, the score associated with the quartile of the journals or conference proceedings which frame the main body of the thesis is calculated. Table 1.2 introduces the quartile and score of SJR in the field of architecture.

Table 1. 2 Quartile and scores in architecture field

YEAR	QUARTILE	SCORES IN ARQ
2018	Q1	> 0.261
	Q2	> 0.139
	Q3	> 0.104
	Q4	> 0.100
2019	Q1	> 0.251
	Q2	> 0.137
	Q3	> 0.104
	Q4	> 0.100

Source: Own elaboration based on SJR

According to the regulations, those publications not published on the "Architecture" Journal should be transformed their scores as Table 1.2 shown. Therefore, Table 1.3 shows the score transforming of these six publications in specialized conferece and journals.

In sum, these six publications could be transformed into 13 scores regarding the field of architecture, exceeding the requirement score of the regulation (i.e. 8 scores).

Table 1. 3 Articles in specialized conferece and journals

CODE	TITLE	AUTHOR	JOURNAL/CONFERENCE	YEAR	SCORES SJR	QUARTILE (EQUAL SJR ARQ)	SCORES	INDEX
C3	The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases	**Ai Chen;** Carlos Marmolejo	Conference: CTV 2018: XII Congreso Internacional Ciudad y Territorio Virtual, Ciudades y Territorios Inteligentes	2018	-	-	-	Index Copernicus
J1	The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments and Implications for Public Policy and Private Markets	Carlos Marmolejo; **Ai Chen**	Journal: Sustainability	2019	2.567	Q1	4	WOS (SCI/SSCI) Scopus Index Copernicus
J4	La incidencia de las etiquetas energéticas EPC en el mercado plurifamiliar español: un análisis para Barcelona, Valencia y Alicante	Carlos Marmolejo; **Ai Chen**	Journal: Ciudad y Territorio Estudios Territoriales - CYTET	2019	0.133	Q3	2	WOS (ESCI) Scopus Index Copernicus
J2	The evolution of energy efficiency impact on housing prices: an analysis for Metropolitan Barcelona	Carlos Marmolejo; **Ai Chen**	Journal: Revista de la construccion	2019	0.430	Q1	4	WOS (SCI) Scopus Index Copernicus
C4	How different are dwellings whose energy efficiency impacts price formation?	**Ai Chen;** Carlos Marmolejo	Conference: IOP Conference Series: Materials Science and Engineering	2019	0.198	Q2	3	WOS (CPCI-S/CPCI-SSH) Scopus Index Copernicus
J3	Is the energy price premium spatially aggregated? A listing price analysis of the residential market in Barcelona	**Ai Chen;** Carlos Marmolejo	Journal: Technical Transitions	2018	-	-	-	Index Copernicus

Source: Own elaboration based on JCR and SCOPUS

1.5.2 PhD Candidate Contributions

Supported by project “EnerVALUE”, numerous papers collaborated with a series of researchers have been published. Since the main body of this dissertation is a collection of six publications from the project “EnerVALUE”, three papers’ first author is Prof. Marmolejo who is the principal investigator of the project EnerVALUE and also the supervisor as my doctoral tutor.

As far as is concerned the Publications C3, C4 and J3, I proposed the ideas to explore the random selection biases and spatial implications when analysing the impact of energy efficiency on housing price. With the help of Prof. Marmolejo, I developed and designed the methodology as well as confirmed the model to be employed. Then I collected the data and depurated them by specific professional software. Subsequently, I analysed study data by application of statistical techniques. After Prof. Marmolejo revised my original draft, paper C3 and paper C4 were presented and published in two conferences: CTV 2018 and WMCAUS 2019, while the paper J3 was published in an academic Journal Technical Transaction.

While for the Publication J1, J2 and J4, Prof. Marmolejo is the first author where he formulated the research goals and aims within a comprehensive methodology. Then I am also responsible for the data collection and data depuration as well as the model calculation. Prof. Marmolejo fulfilled the original writing for these two publications after we discussed the estimation result.

These six publications are under supervised by Prof. Marmolejo who manages and takes charge of the research activity planning and execution. At the same time, he is also the principal investigator and leader who acquires the financial support for the project leading to this publication.

In order to identify clearly author contributions, Table 1.4 explain specifically what I have worked in these five publications.

Table 1. 4 PhD candidate contributions to published thesis

Code	Authors	Rank	Title of article	Conceptualization	Methodology	Software	Formal analysis	Data Collection	Data Analysis	Writing-Original draft preparation	Writing-Review and editing	Visualization
C3	Ai Chen; Carlos Marmolejo	1st	The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases	x	x	x	x	x	x	x	x	x
J1	Carlos Marmolejo; Ai Chen	2nd	The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments and Implications for Public Policy and Private Markets	-	-	x	x	x	x	-	-	x
J4	Carlos Marmolejo; Ai Chen	2nd	La incidencia de las etiquetas energéticas EPC en el mercado plurifamiliar español: un análisis para Barcelona, Valencia y Alicante	-	x	x	x	x	x	-	x	x
J2	Carlos Marmolejo; Ai Chen	2nd	The evolution of energy efficiency impact on housing prices: an analysis for Metropolitan Barcelona.	-	x	x	x	x	x	-	-	x
C4	Ai Chen; Carlos Marmolejo	1st	How different are dwellings whose energy efficiency impacts price formation?	x	x	x	x	x	x	x	x	x
J3	Ai Chen; Carlos Marmolejo	1st	Is the energy price premium spatially aggregated? A listing price analysis of the residential market in Barcelona	x	x	x	x	x	x	x	x	x

Note: the cross sign shows the work did by the PhD candidate, Ai Chen.
Source: Own elaboration

CHAPTER 2

ENERGY EFFICIENCY

AND

ENERGY PERFORMANCE

CERTIFICATES

CHAPTER 2 OVERVIEW OF ENERGY EFFICIENCY AND ENERGY PERFORMANCE CERTIFICATES

2.1 Overview of Energy Consumption and CO_2 Emissions

Energy resource plays a vital role in the development of the whole human society. With the prosperity of the world economy, the growth of the world's population and the improvement of citizens' living standards, the demand for energy around the world also gradually increase. It results in a huge amount of energy consumption and CO_2 emissions. At this stage, two main challenges regarding the energy utilization and consumption are: 1) the dramatical growth of primary energy consumption by the impact of economic modes and population pressures; 2) energy consumption imbalance across the world where industries of developed countries have turned to that of low-energy consumption and high output but counter stands in developing ones. Facing such challenges, the development of energy supply and consumption will direct to a more diversification, cleaner, higher-efficiency mode.

2.1.1 Primary Energy Supply

Total primary energy supply (TPES) is the total amount of primary energy that a country has at its disposal. It is made up of production +imports-exports- international marine bunkers-international aviation bunkers ± stock changes. For the world, it is defined as production + imports – exports ± stock changes (OECD, 2014).

Figure 2.1 shows the total energy supply increased from 5,519 Mtoe in 1972 to 13,972 Mtoe in 2017, which is a 250% growth. Regarding the year-to-year increase of such supply in the last decade, it fluctuated dramatically from 2007 to 2012. It illustrates the energy market was affected greatly by the global economic crisis which beginning in 2008.

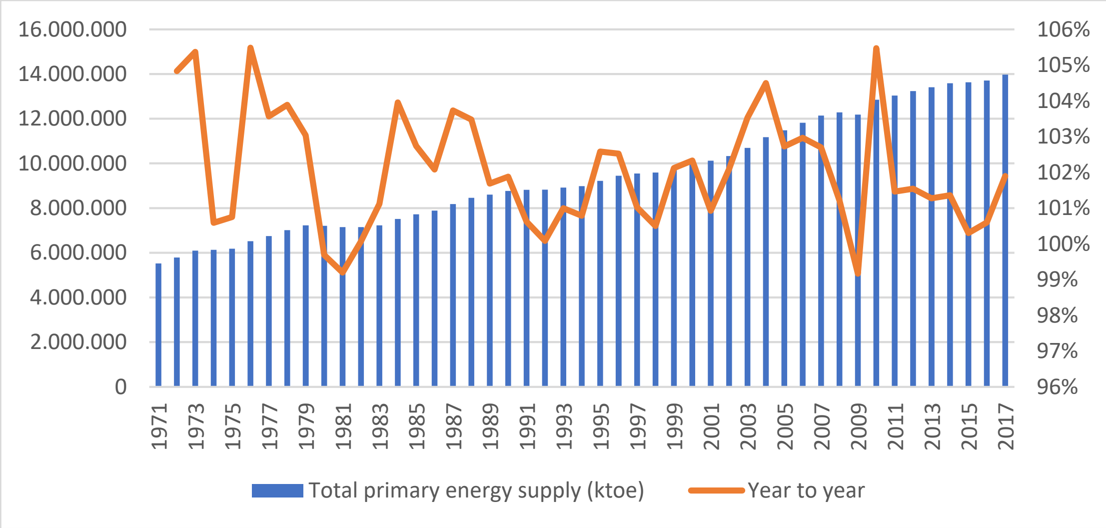


Figure 2. 1 Total primary energy supply of the world (1971-2017)
Source: IEA. Elaboration: author own

Regarding the status of TPES in the European Union-28 (see Figure 2.2), the total primary energy supply decreased to 1,619 Mtoe in 2017, which only accounts for 11.9% of the total world (about 17% in 2000). As previously stated, the industrial structure in developed countries has diverted to those fields with low-energy consumption and high-efficiency. It is also supposed those reductions are produced by the energy efficiency programs and projects in of EU.

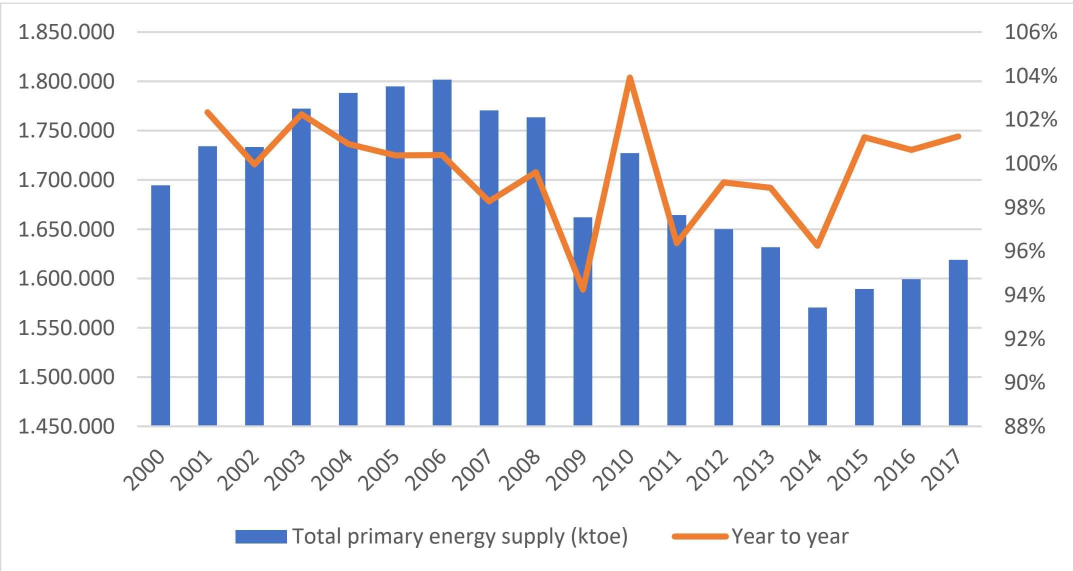


Figure 2. 2 Total primary energy supply of EU-28 (2000-2017)
Source: IEA. Elaboration: author own

Similarly, the year-to-year change of TPES in Spain, as can be seen in Figure 2.3, present the same trend. The total amount shows a small fluctuation in the last two decades. In 2017, Spain supplied about 126 Mtoe of primary energy to the market, accounting for 7.8% of the total TPES in EU-28. Under the context of energy reduction across the EU, this share of TPES in Spain keeps a relatively stable status, about 7.5%.

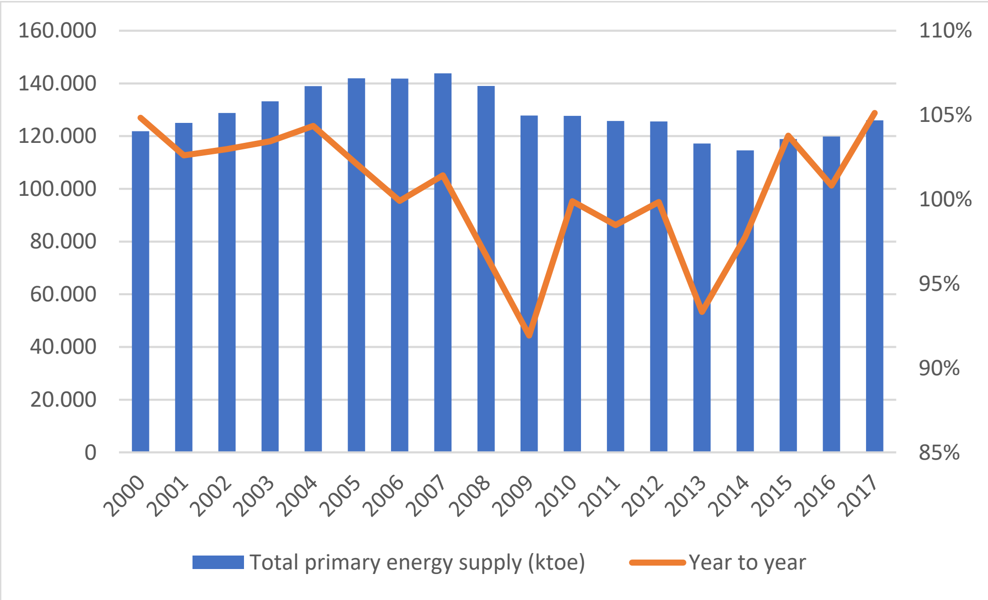


Figure 2. 3 Total primary energy supply of Spain (2000-2017)
Source: IEA. Elaboration: author own

2.1.2 Total Final Consumption

The Total Final Consumption (TFC) is defined as the sum of the consumption in the end-use sectors and for non-energy use. TFC can proxy the energy used directly by consumers.

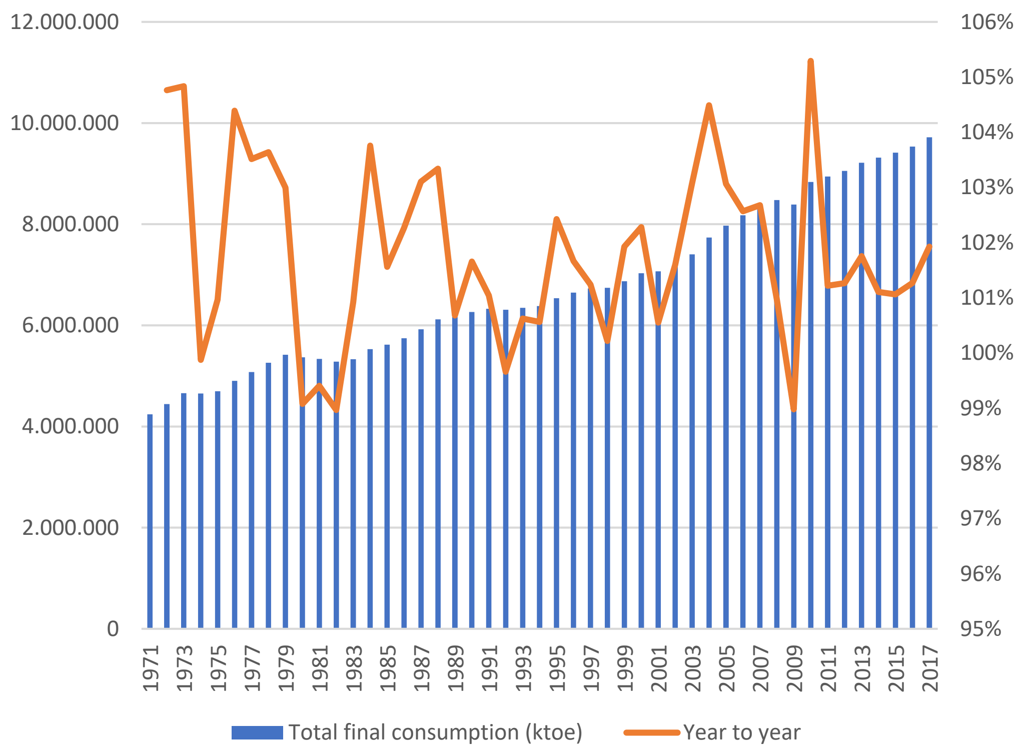


Figure 2. 4 Total final consumption of world (1971-2017)
Source: IEA. Elaboration: author own

As it can be seen in Figure 2.4, the world TFC has reached to 9,713 Mtoe in 2017, increasing more than double of that in 1971. In the last decade, the consumption of energy keeps a stable and mild growth trend. Similarly, the share of energy end-use of sectors fluctuates between 1% and 2% except in the residential sector (see Figure 2.5). In 2017, the most energy consumers are the transport sector and industrial sector which respectively accounted for 29% of TFC, followed by the residential sector and service sector with a 21% and 8% share of TFC respectively. According to the definitions of International Energy Agency (IEA), other sectors consists of agriculture/forestry, fishery, non-specified and non-energy use ones, which holds a stable share 13% of TFC.

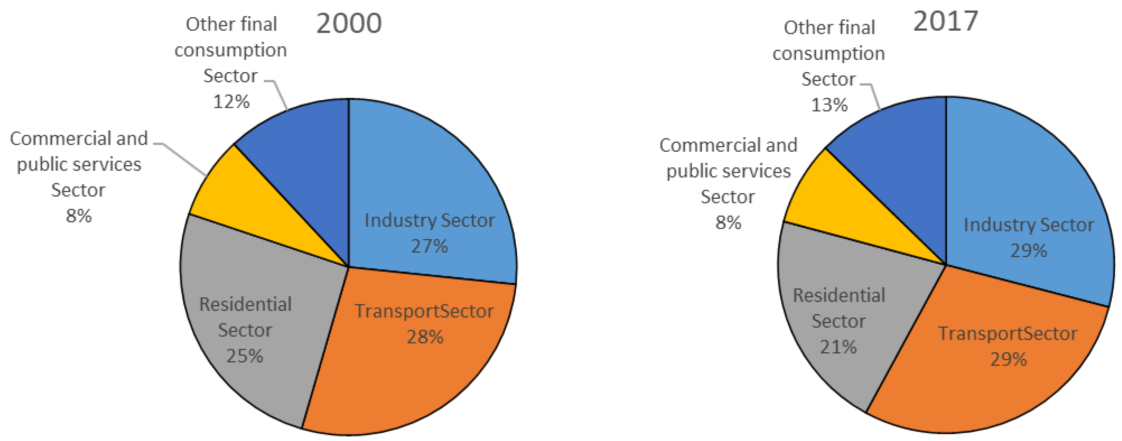


Figure 2. 5 Shares of world Total final consumption by sector (2010 and 2017)
Source: IEA. Elaboration: author own

In contrast, TFC across EU-28 fluctuated dramatically in the last decades (see in Figure 2.6). In 2014, it decreased down to the bottom with 7% reduction, compared with that of 1189 Mtoe in 2000. Although presenting growth after 2014, TFC is still lower than that at the beginning of the 21st century.

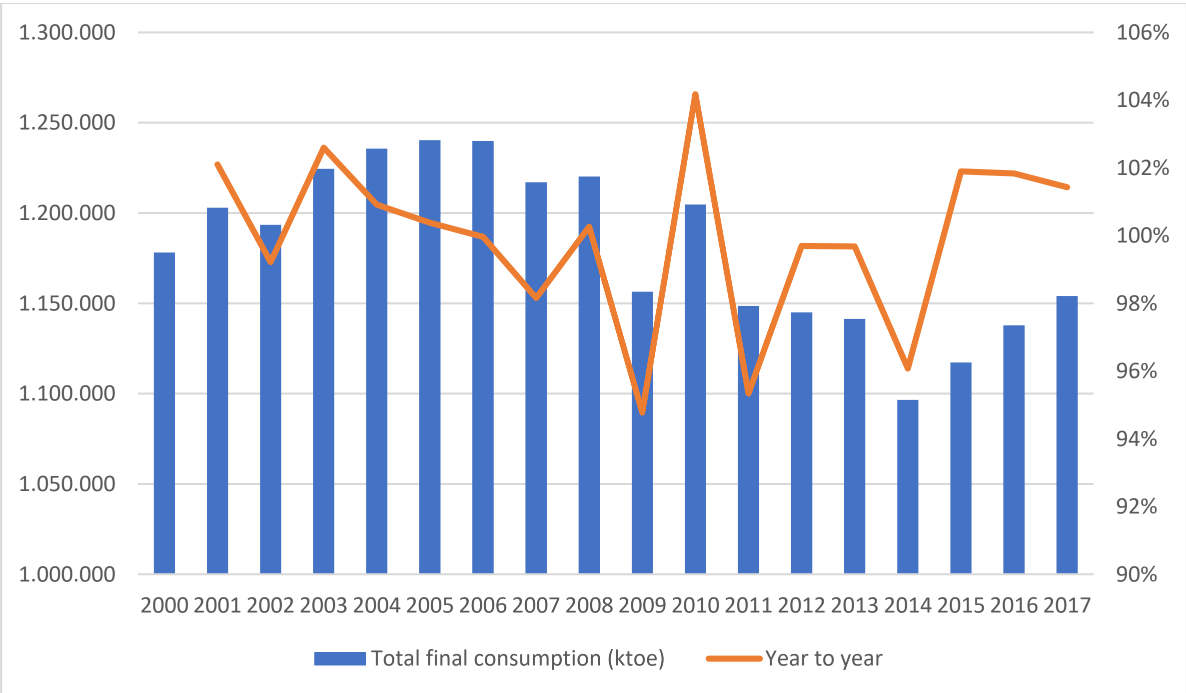


Figure 2. 6 Total final consumption of EU28 (2000-2017)
Source: IEA. Elaboration: author own

As Figure 2.7 shows, the industrial, transport and residential sectors held a relative balance shares, approximately a quarter of total consumption respectively in 2000 while the service sector and others accounted for 10% and 13% of TFC separately. However, the TFC of the industrial sector in 2017 decreased and accounted for 23% of total consumption. At the same time, service and transport sector consumed 2%-3% more energy. Notedly after a series of energy-saving and energy efficiency projects or programs in the residential sector, the consumption in this sector held the same share with 25%.

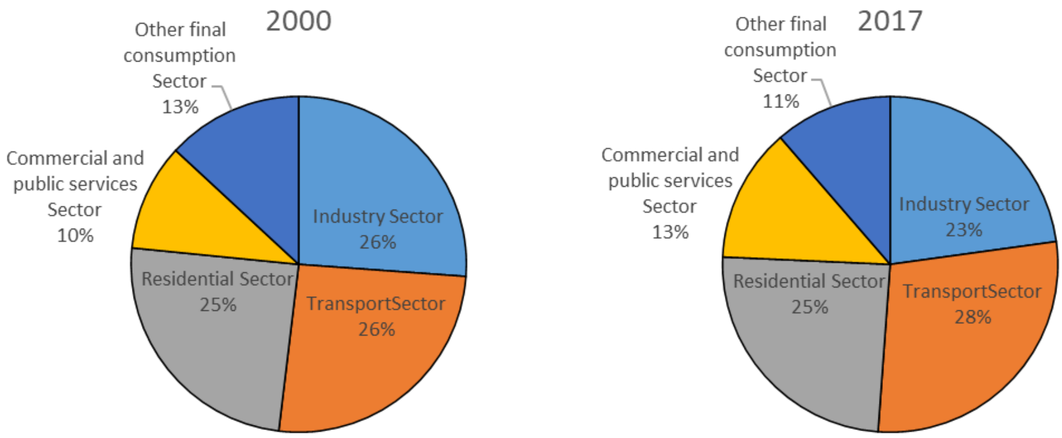


Figure 2. 7 Shares of EU28 total final consumption by sector (2010 and 2017)
Source: IEA. Elaboration: author own

Similarly, the TFC of Spain fell to the bottom in 2014 but shows a relative mild evolution in the last two decades. In 2017, the consumption reached to the 83 Mtoe, accounting for 7% of the total consumption of EU-28.

As can be seen in Figure 2.8, the structure of energy consumption in Spain is different from that in EU-20 and world. Transport sector accounted for 38% of the total consumption, which is 10% more than the average consumption in EU-28. On the contrary, the residential sector accounted for 18% of all consumption, less than that in EU-28.

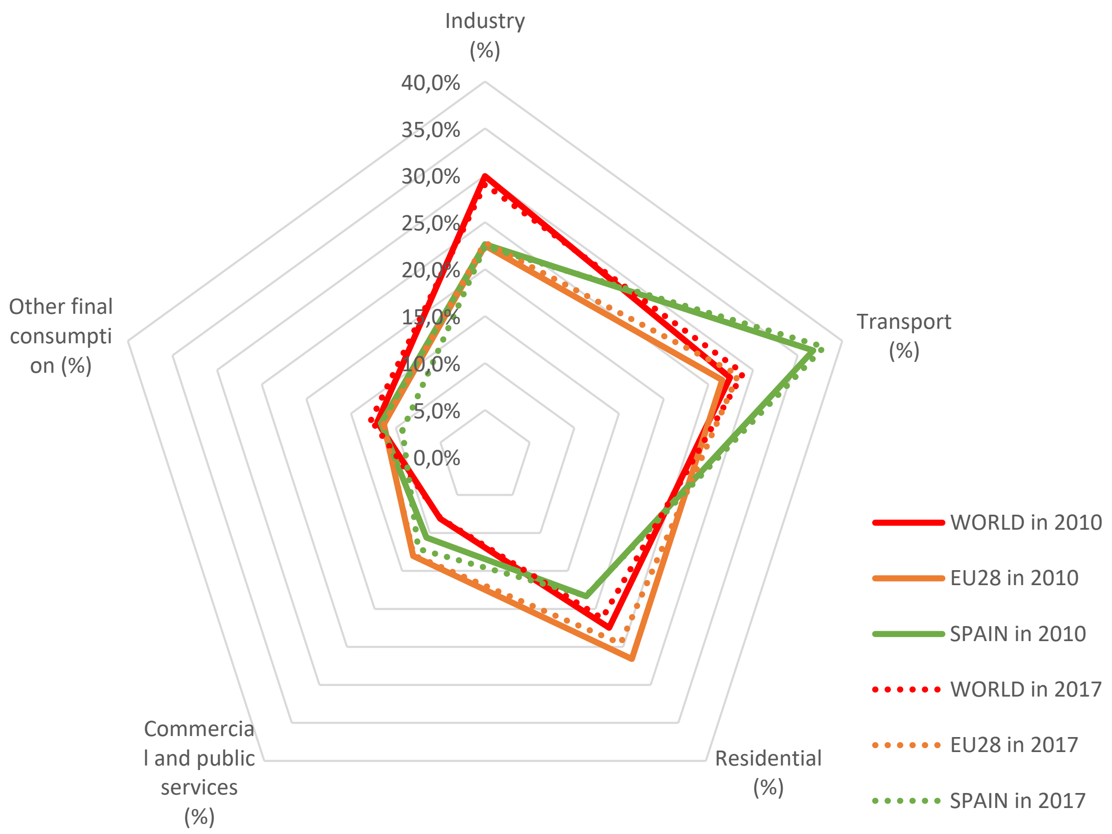


Figure 2. 8 Shares of total final consumption by sector (2010 and 2017)
Source: IEA. Elaboration: author own

Theoretically, a series of projects and programs related to energy saving and energy efficiency in Spain should bring in energy reductions. In order to explore what achievements concerning energy consumption reduction after executing projects and measures, Figure 2.9 illustrates the changes in TFC by sectors between 2010 and 2017. It indicates in 2017 the TFC in the industrial, transport and residential sector decreased by 10%, 6% and 10% respectively. Although it seems failed to reach our objective from the 20-20-20 goals framed within the Kyoto Protocol (i.e. 20% reduction of energy consumption, 20% increase of renewable energy, 20% reduction of CO_2 emissions), it still shows a certain achievement we have made.

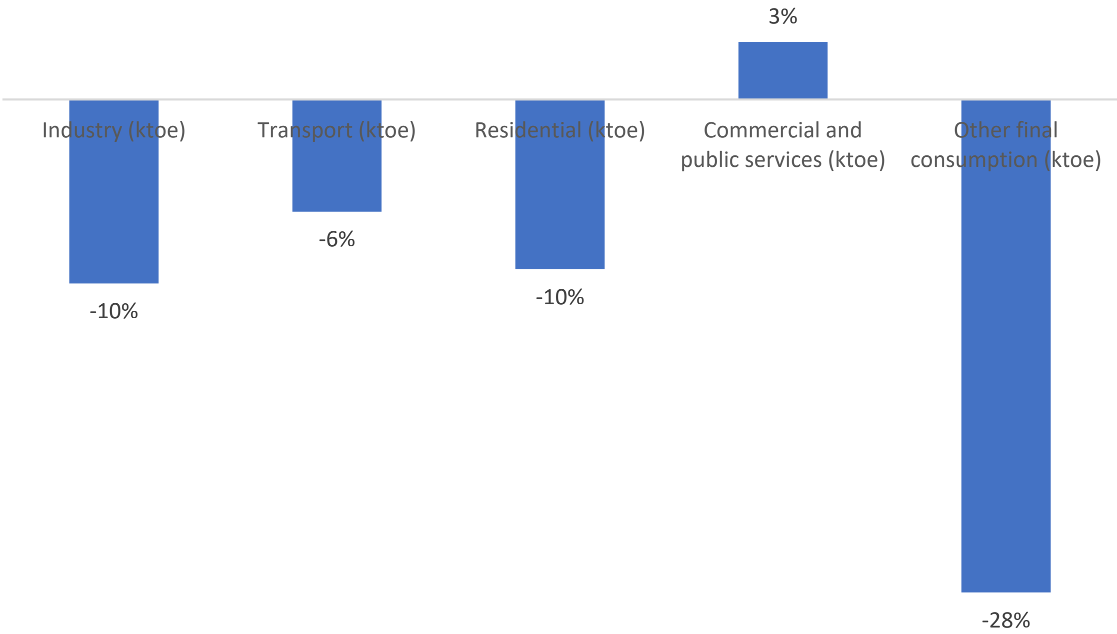


Figure 2. 9 Changes of the Spanish total final consumption by sector (2010 and 2017)
Source: IEA. Elaboration: author own

2.1.3 Total CO_2 Emissions

Carbon dioxide emissions are the culprit of greenhouse gases. In general, carbon dioxide emissions mainly come from the fuel combustion[1]. Considering that the energy supply and energy consumption have been increasing in the global context, carbon dioxide emissions also maintain a continuous increase. In contrast, carbon dioxide emissions in EU-28 and Spain have declined in the last 20 years (see in Figure 2.10). This is the benefit of reduced energy consumption and energy supply. It is worth noting that Spanish consumption in the past 20 years has fallen by 9%, which is far greater than the Eu-28's average of 4%. However, its carbon dioxide emissions have only dropped by 3% while the average reduction in EU-28 is 11%.

[1] CO_2 Emissions from fuel combustion only, including coal, oil, natural gas and other energy source. Emissions are calculated using IEA's energy balances and the 2006 IPCC Guidelines

Particularly, the total CO_2 emissions in EU-28 and Spain show a huge drop from 2008, which is supposed that the financial crisis from 2008 to 2015 resultes in the mainly reduction of economic activities across developed countries.

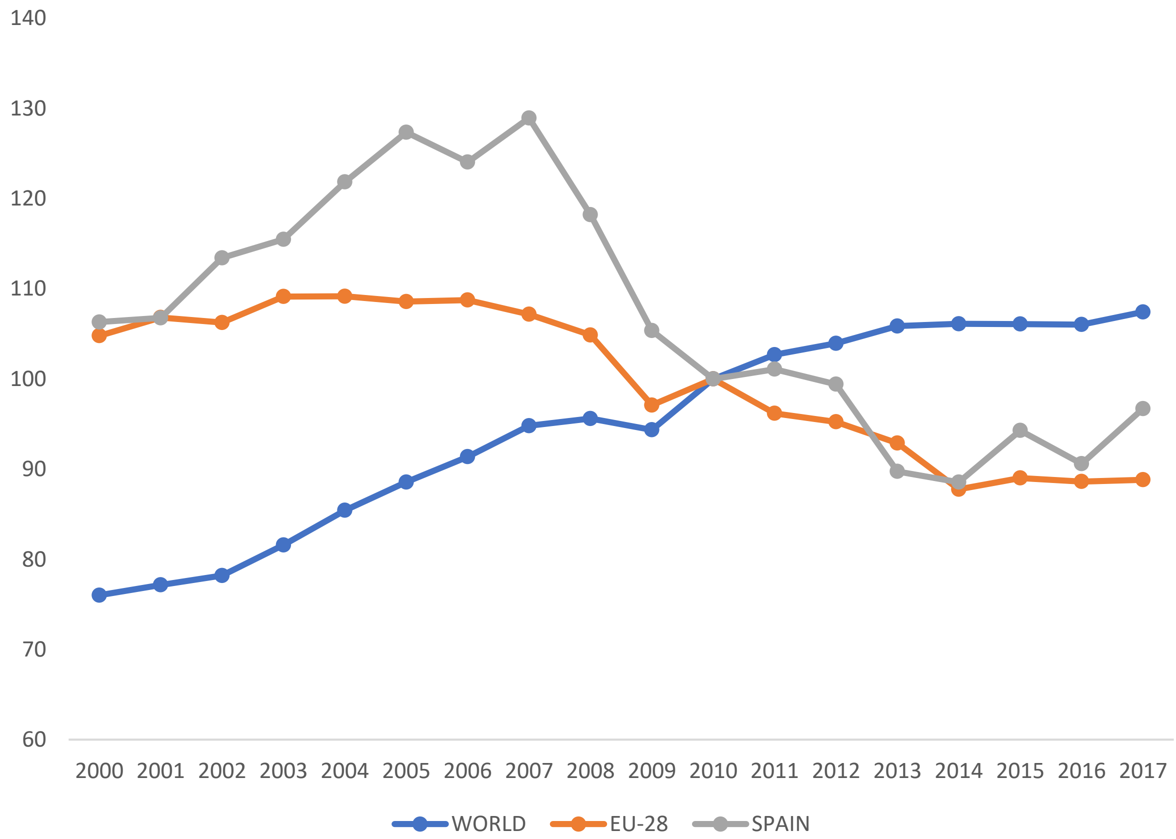
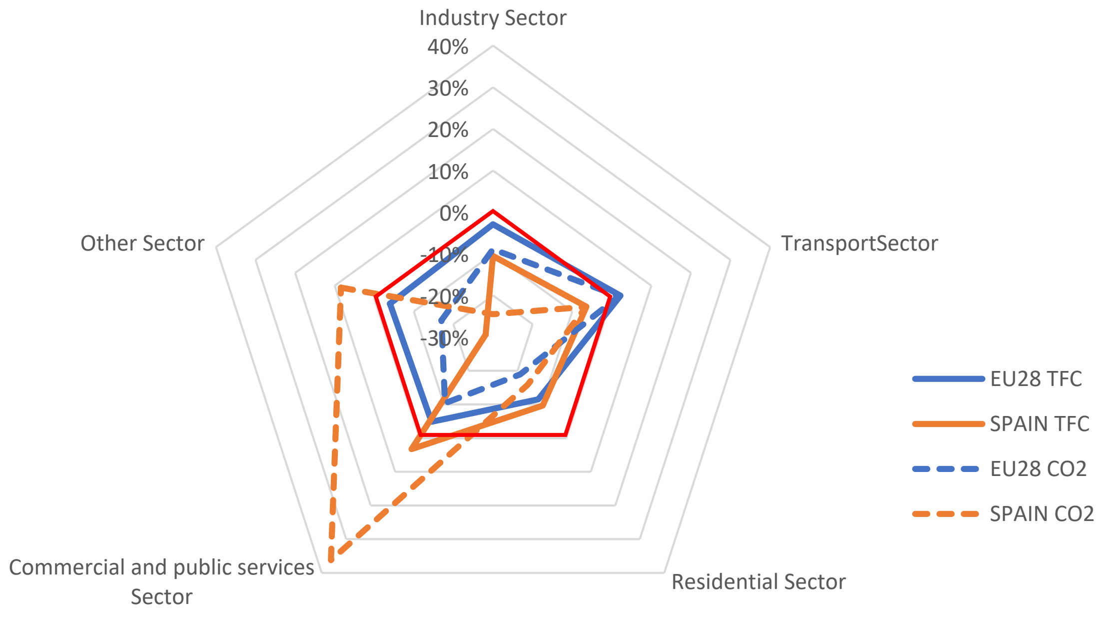


Figure 2. 10 Comparison of CO_2 emission index (Year 2010=100)
Source: IEA. Elaboration: author own

To explore why the decline in energy consumption in Spain does not bring in an equivalent reduction in carbon dioxide emissions, Figure 2.11 compares the changes of energy consumption and carbon dioxide emissions by sectors from 2010 to 2017 in EU-28 and Spain. From a global perspective of EU-28, the energy consumption in all sectors excluding Transport Sector has an average drop of 4%. At the same time, the performance of CO_2 emissions has a similar trend which brings in a reduction of 11%. It is to say, every 1% energy saving could bring in about 3% decrease in the CO_2 emissions. In contrast, the energy consumption and CO_2 emissions in Transport Sector have an increase of 2% from 2010 to 2017 which is supposed that personal and business activities began to increase and their communications are more frequent. Therefore energy consumptions in the transport show an increase under the context of overall reduction in energy consumption and CO_2 emission. In other hands, this overall drop also implies that meansures for energy saving across EU-28 have about triple benefits (i.e. triple reduction of CO_2 emissons), helping policy-makers to evaluate the achievement of specific energy policies in various sectors.

Concerning the energy saving and CO_2 emissions in Spain, it shows a totally different performance. As Figure 2.11 shows, a 9% of energy saving could bring in a 3% reduction in the CO_2 emissions, which is far lower than the same average level of EU-28. It is inferred that the implementation of energy saving in Spain is not as effective as expected, which highlights that it is necessary to inspect energy policies. In the industrial sector, there was a 2.4% reduction in CO_2 emissions as a 1% of energy consumption decreased. Similarly, there is a 1.6% reduction of CO_2 emissions with 1% decrease of energy consumption in the residential sector. It is worth to note that energy saving and CO_2 emissions in the commercial and public services sector have an contrast performance where the 3% growth of energy consumption will result in a 36% increase in CO_2 emissions. It demonstrates the energy polices in above-mentioned sectors have made great achievement and the corresponding researches are significant. In other words, it indicates that energy consumption in the commercial and public services sector should be paid more attention where an effective energy police may have a extra-benefits in relation to energy saving, energy economy and environment protection.



Reduction from 2010 to 2017	EU28 TFC	SPAIN TFC	EU28 CO_2 emissions	SPAIN CO_2 emissions
Total	-4%	-9%	-11%	-3%
Industry Sector	-3%	-10%	-9%	-24%
Transport Sector	2%	-6%	2%	-6%
Residential Sector	-12%	-10%	-19%	-16%
Commercial and public services Sector	-5%	3%	-10%	36%
Other Sector	-4%	-28%	-17%	8%

Figure 2. 11 The change of total final consumption and CO_2 emissions by sector (2010-2017)
Source: IEA. Elaboration: own elaboration

2.1.4 Residential Energy Consumption and Energy Price in Europe and Spain

From the perspective of the energy consumption by end-use in the residential sector, space heating, space cooling, water heating, cooking, lighting and electrical appliances as well as other energy uses consist of the final energy consumption of this sector.

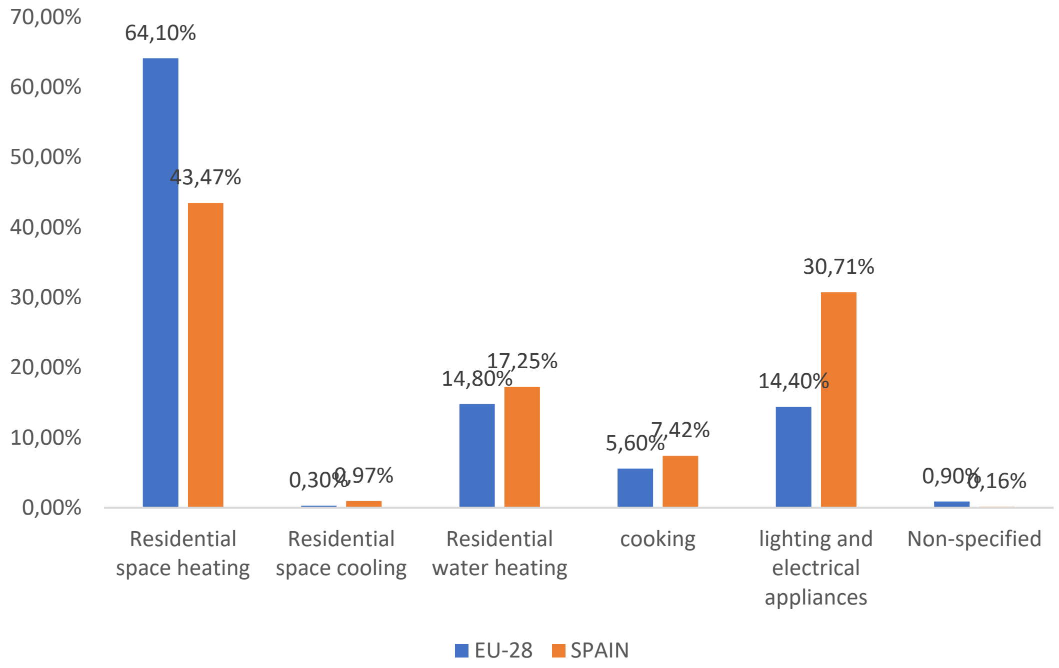


Figure 2. 12 Shares of the residential final consumption in EU28 and Spain (2017)
Source: Eurostat. Elaboration: author own

Figure 2.12 exhibits the share consumed in 2017 by the end use of the residential sector in EU-28 and Spain. Concerning to the 28 EU countries, space heating accounted for two-thirds of the total consumption of this sector, which is quite greater than the average of 43% in Spain. This is because of the Spanish Mediterranean climate that the temperature in winter is maintained from 2 °C to 10 °C all year round. In such case, the demand for heating is relatively small compared with other European countries (Figure 2. 13). The second most consumed sectors are water heating and lighting as well as the electrical appliances. The average consumptions of the 28 EU countries in these two end-uses are 14.8% and 14.4% respectively. Exagerately the consumed shares of such end-uses in Spain are more than the average in EU-28, where the consumption of lighting and electricity appliances exceeds more 2 times with 30.7% than that in EU-28. It suggests the improvement of energy efficiency of lighting and electricity appliances in the residential sector plays a vital role in the target of energy consumption reduction.

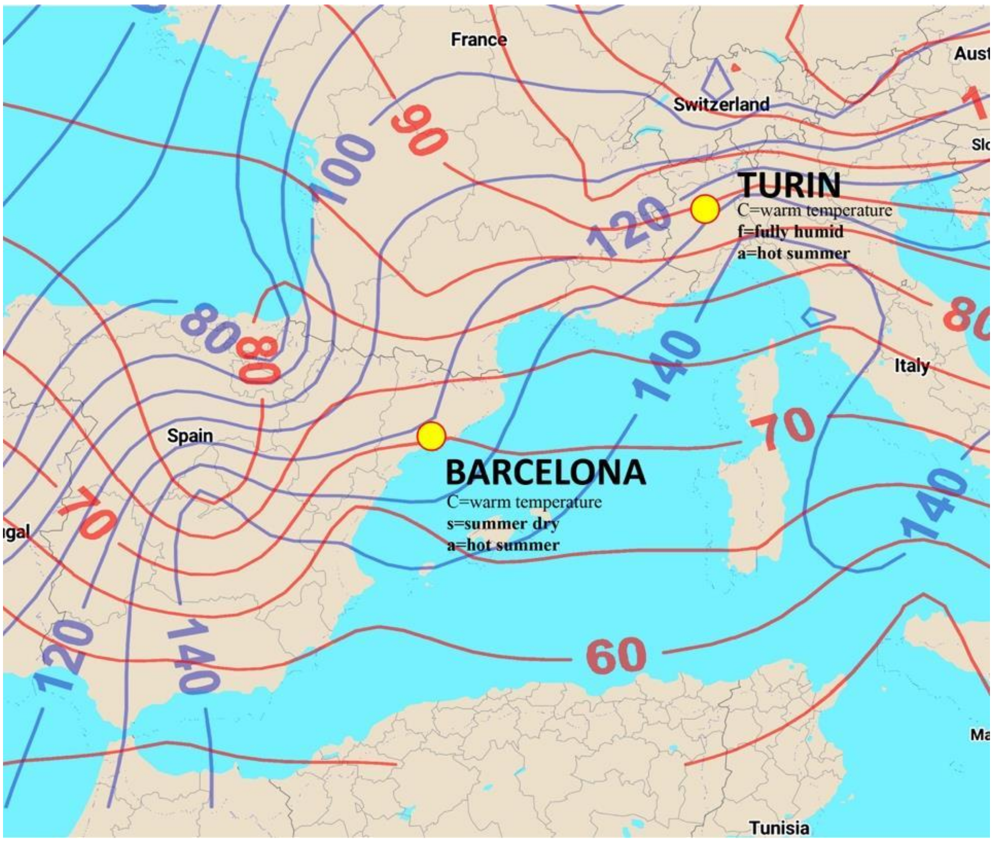


Figure 2. 13 European Heating Index (EHI) in red lines and the European Cooling Index (ECI) in blue lines
Source: Dell'Anna et al. (2019)

Considering the scarcity of energy and the increasing demand for energy around the world, the price of energy is also rising. The European statistics (Eurostat) confirms it and gives the EU-wide changes in energy prices. Figure 2.14 shows the evolution of energy prices EU-28 and Spain from 2008. It pointed out that the electricity price in Spain has been surpassing the average across the European continent since 2009. It is a similar trend to the increasing of natural gas costs. It means for Spanish households will pay more energy bills than others in Europe. However, the score of disposable income of household per capita in Spain is 96 which is less than the average score of 106 across the 28 EU countries. This implies two serious problems in energy consumption for the Spanish household:

- saving energy consumption and bearing uncomfortable living condition. If a household cannot afford additional energy bills, it is possible to reduce energy consumption. For example, they will in winter turn off the heating or reduce times to have a shower, in order to save electricity, gas or water. All these behaviours will give a deathblow to those households with elders, health conditioned or kids.

- keeping a comfortable living condition means households need to pay more money on energy expenditure, which will have an impact on other housing activities.

Whatever over-expenditures or lower comfort level, they may cause citizens' dissatisfaction and protests (e.g. protesting for rising electricity prices).

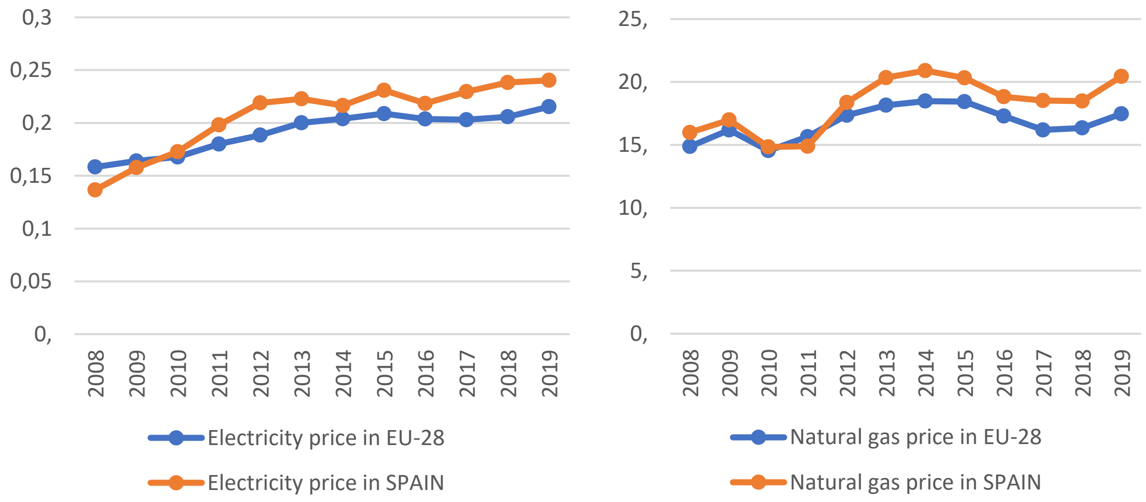


Figure 2. 14 Evolution of electricity price and natural gas price
(unit left: euro/KWh/household; right: euro/GJ/household)
Source: Eurostat. Elaboration: author own

2.2 Energy Efficiency Performance across Europe and Spain

2.2.1 Introduction

As stated previously in Sector 2.1, it is urgent to improve the efficiency of energy use, thereby reducing energy consumption and carbon dioxide emissions. Therefore, the EU in 2012, under the Energy Efficiency Directive 2012/27/EU[2], established energy efficiency target in 2020 by a reduction of 20% of TFC and the primary energy consumption. This Directive aims to reduce

[2] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance

energy consumption and the payment of energy bills, which in turn serves to protect the environment. At the same time, considering the instability caused by the fierce global competition for energy, the Directive also reduces EU member states' dependence on oil and natural gas, implying geopolitical concerns.

In order to achieve the 20-20-20 target, the EU requires each member country to transform EED 2012/27/EU complying with their specific national framework and to publish the annual report of the national energy efficiency action plan. In 2018, the European Union recast the Directive 2012/27/EU by the newer one 2018/2002/EU[3] which introduced new requirements and standards of energy efficiency. It is clearly stated that the energy target of 2030 is to reduce the consumption of the final energy and the primary energy by a decline with 32.5%.

This Energy Efficiency Directive establishes the basic energy efficiency goals of all sectors for the next two decades. Moreover, it provides the basic guideline framework for the transposition of relevant laws and regulations across EU countries.

Generally, the improvement of energy efficiency should run through the entire process from production to final consumption. As far as monetization is concerned, only when the benefits of savings can cover or even exceed the cost of energy efficiency improvement, can energy efficiency plans be promoted sustainably by stimulating the subjective initiative of various stakeholders. To date 2017, the relevant energy efficiency measures of the EU and Spain have made a great contribution to the reduction of energy consumption. However, as far as the goals of the Energy Efficiency Directive is concerned, more supports and help are needed to reach such reduction of 20% - 32.5%. Table 2.1 lists the relevant energy efficiency policies implemented by sectors, including the energy plan and various objectives.

[3] Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency.Text with EEA relevance.

Table 2. 1 Plans and projects regarding energy efficiency

Sector	Scale	Name of Plan/Projects/Program (Abbreviation)	Objective
Overall	EU	Energy Efficiency Directive (EED)	To reach the 20% energy efficiency target by a series of measures
	EU	National Energy and Climate Plan (NECP)	To meet the EU's energy and climate targets
	ES	Tax Measures for Energy Sustainability (Law 15/2012)	A tax reform in the electricity sector to internalize the environmental costs stemmed.
	ES	CLIMA Project	to reduce greenhouse gas (GHG) emissions and transform the production system towards a low-carbon model in Spain
Residential Sector	EU	Energy Performance of Buildings Directive (EPBD)	To boost the energy performance of buildings
	EU	Nearly Zero Energy of Building standard (NZEB)	To promote building in a nearly-zero energy consumption across the EU
	EU	NEARLY ZERO-ENERGY BUILDING STRATEGY (ZEBRA2020)	To deliver recommendations and strategies that accelerate the market uptake of NZEBs while having a deep understanding of local contexts. It creating a web tool-EU Building Stock Observatory (BSO)- to monitors the energy performance of buildings across Europe
	ES	Programa de Ayudas para la Rehabilitación Energética de Edificios Existentes (PAREER plan)	To undertake the energy rehabilitation of buildings in Spain
	ES	Programa de Ayudas para la Rehabilitación Energética de Edificios Existentes (PAREER-CRECE plan)	PAREER Plan Recast
	ES	State House Plan 2013-2017	To promote building renovation
	ES	State House Plan 2018-2021	To increase the pool of rented housing and to promote urban and rural rehabilitation and regeneration
	ES	Housing energy efficiency and sustainability improvement development program	To reduce annual energy demand for building and cooling, concerning the energy rating.

Sector	Scale	Name of Plan/Projects/Program (Abbreviation)	Objective
Service Sector	ES	Energy Refurbishment of buildings and infrastructures at central state administration	To promote the actions that reduce CO_2 emission in existing buildings and infrastructure of the state
	ES	Efficiency programme for municipal street lighting.	To reform the outdoor lighting installations under energy-efficiency designs by a line of financing too for local entities.
Transport Sector	ES	MOVELE project	The pilot project MOVELE is an IDAE project designed to demonstrate the technical, financial and energy viability of electric vehicles in Spain.
	ES	Movilidad con Vehículos de Energías Alternativas (MOVEA)	To promote mobility using alternative energy vehicles)
	ES	Programa de Incentivos al Vehiculo eficiente since 2013 (PIVE)	To encourage the acquisition of newer, greener, more efficient and safer vehicles since 2013
	ES	Los Planes de Impulso al Medio Ambiente (PIMAs)	The Environmental Promotion Plans, known as PIMAs, is a tool for the implementation of measures to combat climate change at the national level. The different PIMAs proposed additionally carry other environmental benefits along with a positive effect on economic development and the promotion of employment, including different targets: 1) PIMA Frio; 2) PIMA Residuos; 3)Pima Adapta; 4) PIMA Tierra; 5) PIMA Empresa; 6) PIMA Transporte; 7) PIMA Aire; 8) PIMA Sol
	ES	Rail system energy efficiency programme	To incentivize and promote the performance of actions in the railway sector reducing carbon dioxide emissions
	ES	Programme on modal shift and more efficient use of transport.	To promote a change in the mobility of people and goods towards more efficient modes as well as make better use of transport models, reducing final energy consumption and CO_2 emission in the transport sector.
Industrial Sector	ES	Efficiency programme for SMEs and large companies in the industrial sector	To reduce CO_2 emission in the industrial sector
	ES	Programme to promote industrial competitiveness	To promote energy and resource-efficient technologies

Source: Own elaboration

Under the Energy Efficiency Directive 2012/27/EU and 2018/2002/EU, the EU required that the member states establish a 10-year integrated national energy and climate plan (NECP) for the period from 2021 to 2030. It aims to meet the EU's energy and climate targets for 2030 and intend to address the following six issues:

- Energy efficiency
- Renewables
- Greenhouse gas
- Emissions reductions
- Interconnections
- Research and innovation

ENCP requires sufficient collaboration among various government departments and a progress report every two years. According to the plan submitted by Spain in January 2020, it sets goals for decarbonization, energy efficiency, energy security, internal energy market and related energy performance investment, innovation and competitiveness. Afterwards, it explains the goals of the above-mentioned dimensions in details by various policies and measures. Finally, it reports an analysis of such mentioned-dimensions' comprehensive impacts on the aspects of the economy and society. This report points out that Spanish emission reduction targets between 2020 and 2030 are 24.7% and 39.5% respectively, higher than the basic required reduction of 20% and 32.5% from the Energy Efficiency Directive. As far as the residential sector is concerned, the main measures are 1) to improve thermal envelope over 1,200,000 households during these ten years and 2) to tighten thermal comfort[4] up for 300,000 households

[4] Here mainly the renovation of thermal installation for heating and domestic hot water

per year. Once these measures are approached completely, it will bring in an energy saving of 18% of the total predicted consumption.

To support such approaches and measures implementation, Fiscal Measures for Energy Sustainability (Law 15/2012) was established in 2013, which has brought in the tax reform with a view to internalize energy costs and then promote energy efficiency in Spain by incentives' measures.

In sum, the EU has made great achievements to reduce energy consumptions and carbon dioxide emissions throughout implementing an integrated framework of energy efficiency directives in all sectors. Considering a huge number of existing homes consumed a quarter of total energy, an introduction of plans and policies in relation to energy efficiency in the residential sector is explained as follows.

2.2.2 Legislative Framework of Energy Performance of Buildings Sector

Energy saving in the residential sector plays a key role in the target of the EU's energy and environment. Simultaneously, the higher energy-efficiency buildings bring in benefits to citizens by tightening thermal comfort up as well as other welfare. Figure 2.14 shows the evolution of the legislative framework of the energy performance of building section across EU as well as Spain. More details of corresponding documents will be explained as follows.

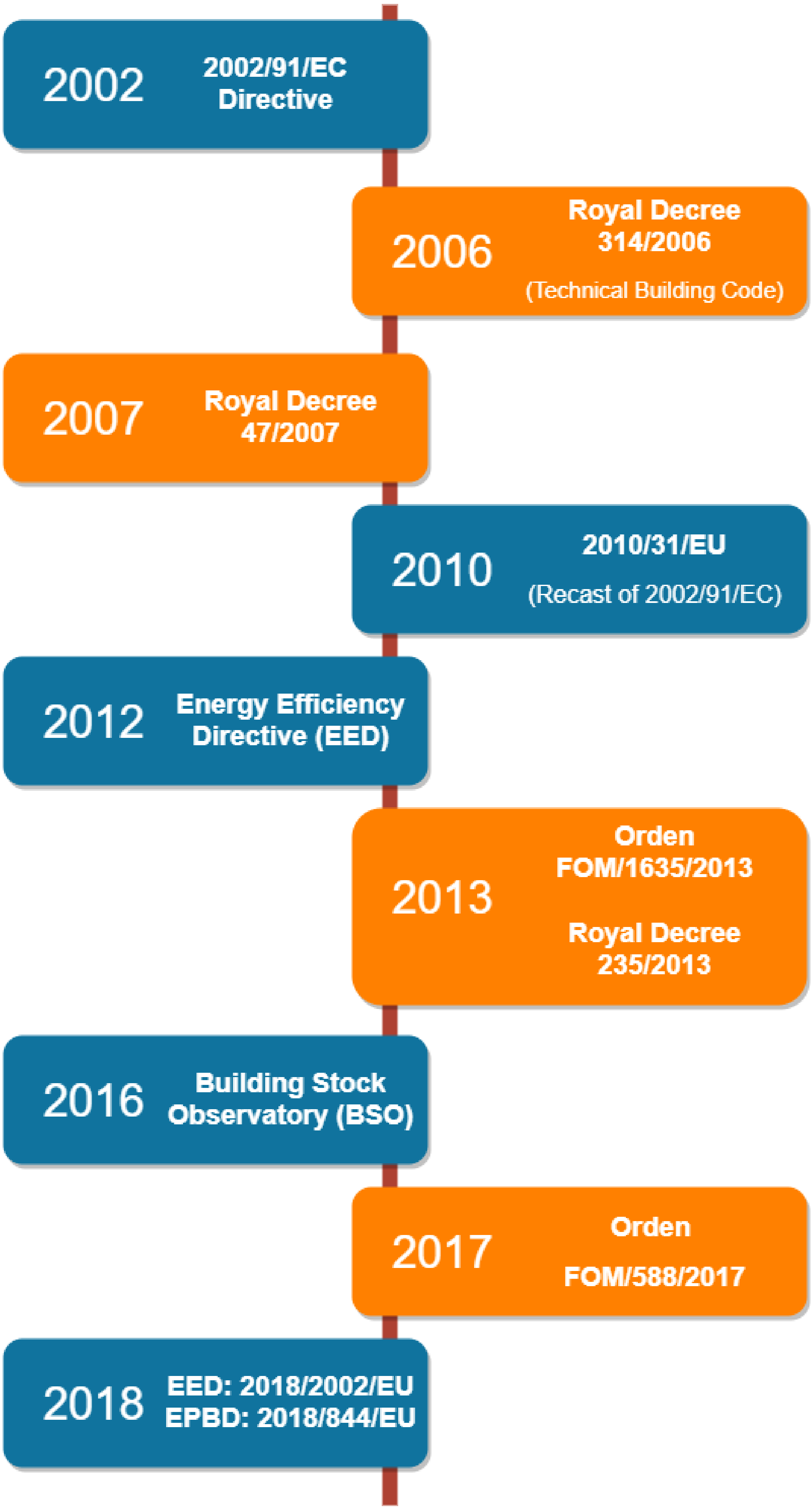


Figure 2. 15 Evolution of energy efficiency legislation
Source: Own elaboration

Energy Performance of Building Directive (EPBD) was introduced in 2002, which is the first time in the framework of European legislation. The objective of EPBD (2002/91/EC)[5] is to promote the improvement of the energy performance of buildings with the Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. As a pioneer of energy efficiency in the residential sector, this directive firstly established the following aspects:

1) A general framework for a methodology to calculate the energy performance of buildings with a holistic view.
2) Minimum requirements on the energy performance of new buildings and of large existing buildings under major renovation.
3) Energy certification of buildings
4) An inspection system for that equipment in buildings (e.g. air-conditioning system and heating installation)

It is worth noting that "Energy Performance Certificate (EPC) of a Buildings" here was put forward for the first time. It is a certificate regarding buildings' energy efficiency recognized by the Member State or a legal person designated by it.

In order to comply with the local law and regulation in Spain, the Technical Building Code (CTE) was approved by Royal Decree (RD) 314/2006[6]. This code is a regulatory framework that confirms the basic quality requirements of buildings (e.g. facilities of buildings). It established the basic standards of the safety and the habitability:

- Structural safety
- Fire prevention safety

---

[5] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.

[6] REAL DECRETO 314/2006, de 17 de marzo, por el que se aprueba el Código Técnico de la Edificación

- utilization safety
- hygiene, health and protection of the environment
- Protection against noise
- Energy-saving and thermal insulation.

CTE is the guideline in the design, construction, maintenance and conservation of buildings and facilities. CTE aims to respond to the demand of society regarding the improvement of buildings' quality by a relatively flexible way which is not just a prescriptive construction regulation.

After an important discussion of the EPC system (Backhaus, Tigchelaar, & de Best-Waldhober, 2011), they pointed that it was very urgent to improve the EPC system and provide the access and useful information regarding buildings' energy efficiency. Therefore, the recast EPBD (2010/31/EU)[7] explained a series of additional requirements to improve the EPC system. The revision of EPBD shows several improvements regards as:

1) An independent control system was mandated to confirm the high quality of EPC (Art.18).
2) A requirement for experts/ technicians regarding EPC assessment was established, including the education requirements, mandatory exams, and continuous professional training.
3) A series calculation method of EPC can be chosen based on the specific situation.
4) A penalty system was introduced to avoid some illegal issues (i.e. non EPC label disclosure since the real estate advertisement).

[7] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

5) A mandatory display of the energy label in the advertisement was required which promotes the EPC scheme into citizens' vision.
6) Additional information on improvement measures and energy consumption as well as carbon dioxide emission are mandatory and recommendation.

To update the additional energy-efficiency information from the revision EPBD (2010/31/EU) into Spanish legislative framework again, the RD 235/2013[8] establishes the obligation to provide buyers or users the energy performance certificate. This certificate includes the mandatory energy-efficient information as the revision EPBD stated and also meets the minimum energy-efficient requirements according to CTE which was revised in the same year by Orden FOM/1635/2013[9]. This Orden mainly concerns "Energy Saving" (DB-HE) which constitutes the first phase of approach towards the objective achieving of revision EPBD (2010) -Nearly Zero Energy of Buildings (NZEB). This is the first time in the Spanish legislative framework that exhibiting energy performance rating on the advertisement is mandatory when properties are sold or rented. At the same time, it approves the basic procedure for the energy performance certificates of buildings in accordance with the NZEB requirement.

After several years of the EPC system promotion, the EU Building Stock Observatory (BSO) was established in 2016. It aims to provide the information concerning the energy performance of the building sector and to monitor the implementation of various energy-efficient measures by a collection of data, offering the suggestions to policy-makers. This BSO database consists of 250 indicators which are classified into 10 thematic areas as regards:

1) Building stock characteristics
2) Building shell performance

[8] Real Decreto 235/2013, de 5 de abril, por el que se aprueba el procedimiento básico para la certificación de la eficiencia energética de los edificios
[9] Orden FOM/1635/2013, de 10 de septiembre, por la que se actualiza el Documento Básico DB-HE «Ahorro de Energía», del Código Técnico de la Edificación, aprobado por Real Decreto 314/2006, de 17 de marzo

3) Technical building system

4) Nearly Zero-Energy Buildings

5) Building renovation

6) Energy consumption

7) Certification

8) Financing

9) Energy poverty

10) Energy market

In 2017, CTE recast by the revision Orden FOM/588/2017[10] with adding new information and requirement regarding the document of "Energy saving" and "Health" respectively. This Orden modified and updated some specific technical codes and requirement. Finally, this order completes the incorporation of buildings' energy efficiency of EPBD (2010/31/EU) into Spanish law.

Then, the Energy Efficiency Directive extended and updated the framework beyond 2020 by the new directive (2018/2002/EU). Similarly, EPBD recast again in 2019 by a new directive (2018/844/EU)[11] which brings new factors and release a strong signal to modernize the technological improvements of buildings and to enhance buildings' renovation. The key points in the building sector[12] of the revision EPBD (2018/844/EU) are:

1) A general and long-term national plan for buildings' renovation should be established for each Member States under the basic framework of the EU.

[10] Orden FOM/588/2017, de 15 de junio, por la que se modifican el Documento Básico DB-HE "Ahorro de energía" y el Documento Básico DB-HS "Salubridad", del Código Técnico de la Edificación, aprobado por Real Decreto 314/2006, de 17 de marzo.

[11] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (Text with EEA relevance)

[12] In additional residential sector, it also includes the construction sector and servicer for building sector.

2) Each Member States must set “cost-optimal minimum energy performance requirements” for buildings.
3) All new buildings[13] must be nearly zero-energy buildings from December 2020.
4) Disclosure of EPC must be issued when buildings are sold or rented and also a procedure of inspection scheme for thermal appliances (e.g. heating and conditioning system) must be established with clear standards and steps.

In sum, energy-efficient measures on buildings sector play a vital role in the energy-saving because this sector in Europe is the most consumed sector which accounted for 40% of the total energy consumption and 36% of total carbon dioxide emissions.

2.2.3 Energy Performance of Buildings Implementation in Spain

To promote the implementation of the energy performance of buildings in Spain, several national policies and plans related to building energy efficiency have appeared (see Table 2.2).

CLIMA[14] project was established in 2011 by the Carbon Fund for a Sustainable Economy (FES-CO_2) to reduce the greenhouse gas (GHG) emissions in Spain. This indicates the production system in Spain is transforming towards a low-carbon one. As an integrated project, measures to reduce energy consumptions and carbon dioxide emissions were applied in all sectors[15].

Program for Energy Rehabilitation of Existing Buildings (PAREER)[16] is an aid program to undertake the energy rehabilitation of buildings. Its objective is to reduce final energy consumptions and carbon dioxide emissions by improving energy efficiency. It consists of two sub-programs: PAREER CRECE (2015-2016) and PAREER II (2016-2018) program. This

[13] New public buildings have been required with a nearly zero-energy status since December 2018.
[14] More details in https://www.miteco.gob.es/en/cambio-climatico/temas/proyectos-clima/que-es-un-proyecto-clima/
[15] Sectors here includes Transport; Residential commercial and institutional; Agricultura; Industrial; Waste; and Fluorated gases.
[16] More details in https://www.idae.es/ayudas-y-financiacion/para-rehabilitacion-de-edificios-programa-pareer/segunda-convocatoria-del

program provides a sum of 200 million and 204 million financial aid respectively to improve the energy efficiency of the envelope, installation and lighting, and substitution renewable energy (e.g. solar, biomass, geothermal energy).

State House Plan (SHP)[17] aims to promote building renovation and urban regeneration and renewal wherein the first phase between 2013 and 2017, improvement actions to reduce the energy demand were encourage by financial subsidy[18]. In the second phase (2018-2021), the main objective is the integral retrofitting in the poverty urban areas with a maximum subsidy of 12,000 euros per household. It pays more attention to the most vulnerable population who need more thermal comfort in their living place. In particular, the "Housing Energy Efficiency and Sustainability Improvement Development Program" as a part of the state plan, is figured on reducing annual energy demand for building heating and cooling to tighten up energy efficiency (e.g. energy rating).

Table 2.2 shows energy saving in the building sector from 2014 to 2017 including the cumulative energy saving and the completed proportion of the energy reduction's target in 2020. In general, the cumulative energy saving and the completed proportion account for about 22% of all the saving during the four years. That is to say, the Government should make more efforts to reach the 24.5% reduction between 2017 and 2020 in accordance with the NECP's objective. However, it is worth noting that energy saving in the State House Plan (2014-2017) has exceeded more than three times on the expectation in 2020. It means such measures in this plan have made great achievements on energy-saving, bringing unexpected benefits. Moreover, it proves how important energy efficiency and what benefit we can get from energy efficiency improvement in the building sector.

[17] More details in https://www.iea.org/policies/7635-state-housing-plan-2018-2021?country=Spain&qs=SPAIN&sector=Residential

[18] 2,000 euros for 30% reduction; 5,000 euros for 50% reduction

Table 2. 2 Energy efficiency policies and plans in the building sector (unit: million euros)

Policies/Plans	Total cumulative energy saving (2014-2017)	Energy-saving (2017)	Total cumulative expected savings (2020)	Completed (%)
PAREER plan (aid for the energy renovation of existing buildings)	6.33	-	39.89	15.9%
PAREER-CRECE plan	12.26	-	61.44	20.0%
JESSICA fund	8.04		46.51	17.3%
Communication campaigns	51.46	19.72	102.92	50.0%
PIMA Sol (plan promoting improved energy efficiency in hotels)	0.80	-	5.60	14.3%
Programmes implemented by the Autonomous Communities (MENAE)	344.74	31.14	1555.80	22.2%
2014-2020 ERDF funds. Integrated Sustainable Urban Development (DUSI) multiregional section	20.88	10.44	93.95	22.2%
2013-2017 State plan to promote building renovation (3R)	42.12	0.54	11.93	353.1%
Introduction of environmental criteria and criteria for efficient distribution to the central government for urban public transport	44.44	14.95	222.40	20.0%
MULTIREGIONAL SECTION (IDAE): central government buildings	4.15	4.15	16.60	25.0%
Total (Building sector)	535.21	80.94	2157.03	24.8%
Total (All sectors)	2221.18	436.28	10922.76	20.3%

Source: Own elaboration

2.3 Co-Benefits of Building Energy Efficiency

Considering the serious energy consumption and huge emissions of CO_2 in the residential market, it is imperative to improve the Building Energy Efficiency (BEE). As the strict and energy-efficient building standards in Europe, BEE in the new residential market has made great achievement. However, it is necessary to pay more attention to the existing residential market since there are a large number of low energy-efficient dwellings whose total energy consumption is far more than that in the new residential market. In consideration of the balance of cost and benefit for BEE improvement, this section mainly discusses the potential direct and indirect benefits for BEE before making the corresponding energy policies. These benefits have impacts on not only whether the energy measures are implemented or not, but also socio-economic and environmental aspects in a long term.

Generally the direct benefit brought by BEE improvement could be realized through building energy efficient reformation. That is to say, the reduction of energy consumption and of CO_2 emissions from BEE improvement are the direct benefits[19]. In other words, all other benefits generated during and after the process of energy reformation can be called "co-benefit"[20].

Concerning the definition of co-benefit, Ferreira et al. (2017) summarized the previous opinions (Ürge-Vorsatz et al., 2014) and proposed a more explicit definition that co-benefit comes from 1) a direct energy policy or action, or 2) the impacts from BEE improvement in relation to socio-economic and environmental perspectives.

2.3.1 Content of Co-benefits of Building Energy Efficiency

In fact, we usually concentrate on energy saving (i.e. direct benefits) when analyzing what the BEE improvement could bring in. This will cause the underestimation with respect to housing

[19] Actually the cost is also a direct impact produced by BEE but it refers as the direct penalty.
[20] Co-benefits is also called "Multiple benefits" or "Non-energy benefits"

price and the effectiveness of such improvement measures (Ürge-Vorsatz et al., 2009). It is worth to say that those co-benefits have a better performance with respect to the living condition for owners or tenants (Wyon, 1994) as well as the socio-economic for all society (Jochem & Madlener, 2003).

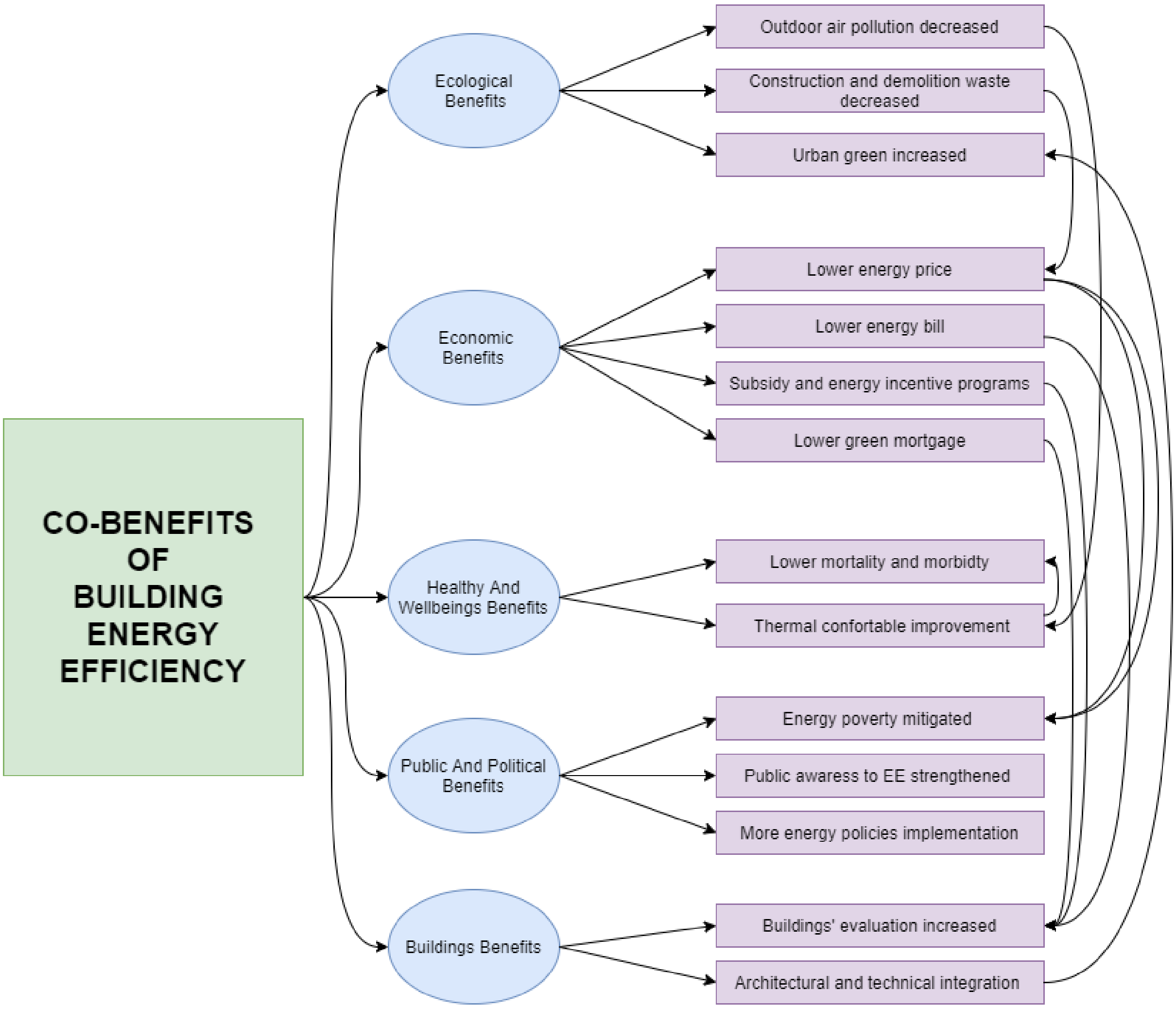


Figure 2. 16 Content of co-benefits for building energy efficiency

Source: Dell'Anna, 2020. Elaboration: author own

Figure 2.16 depicts the content of co-benefits for BEE where five dimensions are consisted of the full range of co-benefits: 1) Ecological benefit; 2) Economic benefits; 3) Healthy and wellbeings benefits; 4) Public and political benefits; 5) Buildings benefits.

Ecological Benefit

Ecological benefits mainly consist of the decrease concerning outdoor air population and construction and demolition waste as well as the increase of urban green. The reason why the first two formers decrease is that the energy-saving and decrease CO_2 emissions will lessen the release of noxious gas while more construction activities are implemented within a sustainable approach (e.g. urban renewal) instead of new constructions. As the building technology advanced, a better energy-efficient roof or walls could be reformed by installing vegetation or plants, which increase the urban green space to some extent.

Economic Benefits

Economic benefits are composed of the less expenditure in relation to energy price, energy bill and residential mortgage, and new jobs creation as well as more subsidies and incentive concerning the BEE. Noted that the improvement of energy efficiency means reducation of enery consumption and demand, which causes the energy price's drop. Furtherly, this downward of energy price plus the less amount of energy consumption both result in the decrease of household energy bill (i.e utility bill). From the standpoint of a consumer, we can ask for either more subsidies/energy-incenives from government or a mortgege with a lower interest rate from banks for BEE.

Healthy and Wellbeings Benefits

Healthy and wellbeing benefits mainly focus on the comfortable improvement for human beings which includes a better thermal comfortable space and noise-isolation as well as high air quality. Furtherly, mortality and morbidity, mainly resulting from the bad environmental condition in relation to the indoor and outdoor, will be reduced.

Buildings Benefits

Concerning the buildings benefits, it could be identify into physical improvement and the monetary performance. In order to have a higher energy-efficient building, the corresponding technologies will be employed in relation to the physical characteristics of the property, for example, the envelop and installation (more details in Section 2.4.2). As the main objective of this dissertation, how the impact of energy efficiency on housing prices will be dicussed in the following chapters.

Public and Political Benefits

According to the co-benefits above-mentioned, more and more citizens will realize that BEE is a valuable investment, drivig them to improve their dwelling's energy efficiency. Furtherly, more energy policies will be implemented well if the improvement of BEE is a voluterring behavior.Finally, the numbers of high-energy efficiency buildings in the residetial market will scale up, alleviating the happening of energy poverty.

2.4 Energy Performance Certificates (EPCs)

In the introduction of energy consumption by end-use in Spanish residential sector, lighting and electrical appliances, as well as the space heating, consumed energy more than 70% of the total final consumption. Therefore, it is crucial to establish an integrated assessment system on buildings energy efficiency by inspecting buildings quality and their installations.

As above-mentioned, it has passed almost ten years since Energy Performance Certificates was put forward by EPBD (2010/31/EU). To transpose the EU's framework of energy efficiency in the building sector complying with Spanish legislation, several directives and technical codes, as well as the procedure to assess energy efficiency in buildings, recast and finally an integrated energy efficiency project was established.

In this section, Energy Performance Certificates (EPCs) is introduced in accordance with the contents, key standards and the ratings. Finally, the procedure to request a certificate will be exhibited.

2.4.1 Introduction

2.4.1.1 Definitions related to EPC

Energy Performance Rating is a range that professional technicians calculate the real energy consumption and carbon dioxide emissions of buildings by tools to satisfy the energy demand of buildings and the thermal comfort needs by households. As Figure 2.17 shows, this rating consists, in Spain, of seven classes where the G corresponds to the least efficient building while the A indicates the most energy-efficient building. Commonly, the former coloured by red and the latter by green. For the medium ratings, they are gradually coloured between red and green. Notedly, this rating for new buildings consists of four classes from D to A (most efficiency).

Energy Performance Certification is the procedure that an energy efficiency rating is awarded to a building in the form of an energy efficiency certificates and label.

Energy Performance Certificates is a document consisting of basic information of buildings, the quality assessment of buildings and the energy efficiency label as well as the suggested measures for energy efficiency improvement.

Energy Performance Label is the mark indicating the level of energy efficiency rating certificated by the buildings.

Figure 2. 17 Energy Performance Certificate of existing buildings
Source: ICAEN

According to Figure 2.16 shown, the simplified energy performance certificate consists of three parts:

- General information of the building: the location, type, normative constructed and the cadastral reference

- Label information of the building: two scales of energy efficiency concerning the energy consumption and carbon dioxide emission as well as their detailed number of consumptions and emissions.

- Registration information: registration ID and the expiration date (10 years)

2.4.1.2 Limitation to EPC ratings

Due to differences in energy demands and energy consumptions by various climatic conditions, the specific climatic zone should be taken into consideration when assessing the energy performance of a building (European Commission, 2016). Therefore, a classification of the climatic zone is introduced by CTE-DB-HE. Those zones are defined for calculation purposes of energy demand and performed by capital letters (A-E) and numbers (1-4). The former corresponds to the climatic severity of the winter as well as the number for the summer. The bigger of the letters and numbers, the more severe the climatic conditions. In Spain, there are 16 climatic zones in the main peninsula and four zones for the Canary Islands. In order to simplify the classification of the climatic zone, each province is assigned to one climatic zone by the altitude of its capital city. More details of climatic zones are in Appendix I.

As above-mentioned, different energy demand leads to different energy consumption and carbon dioxide emission. In such case, climatic zones should be into consideration when establishing standards for each energy-efficient rating. Table 2.3 shows the upper limits of energy demand, Energy Primary no renewable (EPnr) consumption and carbon dioxide emissions regarding varies climatic zones in Catalonia. For example, a building in Barcelona with the emission of carbon dioxide less than 6.1 $kgCO_2/m^2$.year can be certified as “A” rank but in Tarragona, it should be less than 3.6 $kgCO_2/m^2$.year for the most energy efficiency label.

Table 2. 3 Limits of EPC classes by climatic zones in Catalonia

Upper limits of EPC classes	Demand (kWh/m².year)		Consumption of EPnr (kWh/m².year)				CO_2 Emissions ($kgCO_2/m^2$.year)			
	Cal.	Ref.	Cal.	Ref.	DHW	Total	Cal.	Ref.	DHW	Total
Zone B3 (Tarragona)										
A	4.6	5.5	6.7	5.6	5.6	15.6	1.9	1.4	1.4	3.6
B	10.7	8.9	15.5	9.1	6.6	29.6	3.7	2.2	1.6	6.8
C	19.2	13.9	27.9	14.1	8	50	6.2	3.5	1.9	11.5
D	32.2	21.3	46.7	21.7	10	80.1	10	5.3	2.4	18.5
E	64.3	26.3	127.3	26.9	19.6	173.7	30.2	6.6	4.7	41.5
F	70.1	32.4	138.8	33	21.3	189.4	35.4	8.1	5.5	46.9
Zone C2 (BCN)										
A	7.7	2.1	11.2	2.1	9.6	26.8	3.3	0.5	2.3	6.1
B	17.9	3.9	26	4	11.3	43.4	6.2	1	2.7	9.9
C	32.4	6.6	46.9	6.7	13.8	67.3	10.5	1.7	3.3	15.3
D	54.2	10.6	78.5	10.8	17.3	103.5	16.8	2.6	4.2	23.5
E	99.8	12.8	179.6	13	20.3	212.9	40.9	3.2	4.9	49
F	108.8	15.7	210.1	16	22.1	240.5	47.9	3.9	5.7	57.3
Zone D2 (Gerona)										
A	11.7	2.1	16.9	2.1	7.7	35.3	4.9	0.5	1.9	7.9
B	27	3.9	39.2	4	9	57.2	9.3	1	2.2	12.9
C	48.7	6.6	70.7	6.7	10.9	88.7	15.8	1.7	2.6	20
D	81.6	10.6	118.3	10.8	13.8	136.3	25.3	2.6	3.3	30.7
E	144.1	12.8	250.8	13	20.9	284.7	54.8	3.2	5.1	63
F	157.1	15.7	293.4	16	22.8	333.1	64.1	3.9	5.9	73.7
Zone D3 (Lleida)										
A	11.7	5.5	16.9	5.6	5.6	37.1	4.9	1.4	1.3	8.4
B	27	8.9	39.2	9.1	6.5	60.1	9.3	2.2	1.6	13.6
C	48.7	13.9	70.7	14.1	7.9	93.2	15.8	3.5	1.9	21.1
D	81.6	21.3	118.3	21.7	10	143.3	25.3	5.3	2.4	32.4
E	144.1	26.3	250.8	26.9	20.4	298.1	54.8	6.6	4.9	66.3
F	157.1	32.4	293.4	33	22.3	336.8	64.1	8.1	5.8	79.6

Source: IDEA. Elaboration: author own

2.4.1.3 Certifiable real estate

It is mandatory to register an energy efficiency certificates by requirements of EPBD and RD since 2013. For various types of buildings, there are small differences among them.

- New buildings: all new buildings should be under the EPC process by a higher technical requirement. Unlike above-mentioned in Table 2.3, the least energy efficiency of a new building should be ranked at least in "E" rating since 2017.
- Existing buildings: owners should apply the certificates and exhibit the energy label when a building is selling or renting.
- Public buildings: it is mandatory for a public building with a useful surface area more than 500 m.sq and that with a useful area more than 250 m.sq that frequently used by the public or under a lease.[21]

In addition, some buildings are exempted to register a certificate for energy efficiency. It includes:

- Protected buildings and monuments
- Building for religious activities
- Provisional buildings used less than two years
- Non-residential industrial, military and agricultural buildings with a lower energy demand
- A building used less than four months or its energy consumption accounts for less than 25% of predicted energy consumption per year
- Buildings obtained by a donation or a succession

[21] Surface area > 500 m.sq mandatory since 1st June 2013; Surface area > 250 m.sq mandatory since 9th June 2015; Surface área > 250 m.sq under a lease mandatory since 31st December 2015

- Other local without conditioning or the purpose of buying is to renovate or demolish

2.4.1.4 Assessment tool of EPC

There are various tools to assess the energy efficiency of building in accordance with the types and end-use of buildings, under the requirement of CTE (see in Table 2.4). Generally, more than 90% of EPC in Catalonia are calculated by CE3X which eases the process of EPC and offers sufficient default data related to the local situation of energy efficiency. The detailed indicators of CE3X will be introduced in the following apart.

Table 2. 4 Tools for EPC assessment by typology and the use of buildings

Procedure	Typology of Building	Use of Building	Tools
General	New and existing buildings	Dwellings and Public	HULC, CYPETHERM, SG SAVE
Simplified	New and existing buildings	Dwellings and Public	CE3X
		Dwellings	CERMA
	Existing buildings	Dwellings and Public	CE3

Source: Own elaboration

2.4.1.5 Validity of EPC

This certificate has a maximum validity of 10 years. After expiring, it should be renewed when sold or rented (including to a new tenant). For the public buildings larger than 250 m.sq, it is mandatory to update its certificates if occupied frequently by the public.

In sum, energy performance certification is to show buildings' energy efficiency by a simple straightforward manner to the public. A standard of limits to each rating of EPC was established in accordance with the climatic zone which has an impact on energy demand and consumption. The relative documents also clearly point out mandatory contents and suggested tools.

2.4.2 Procedure of Energy Performance Certification

After a basic understanding of EPC, the procedure of EPC will be explained here. As Figure 2.18 shown, this procedure is consisting of three steps:

Step 1: Delegation and Authorization

Generally, the owner of a building or the developer of a project should apply an Energy Performance Certificate. After confirming that this mandatory of a certificate is necessary for their properties, these two stockholders should delegate and authorize professional technicians who are in the professional list that Instituto Catalán de Energía (ICAEN) provides to inspect the building's quality and assess the energy efficiency of buildings.

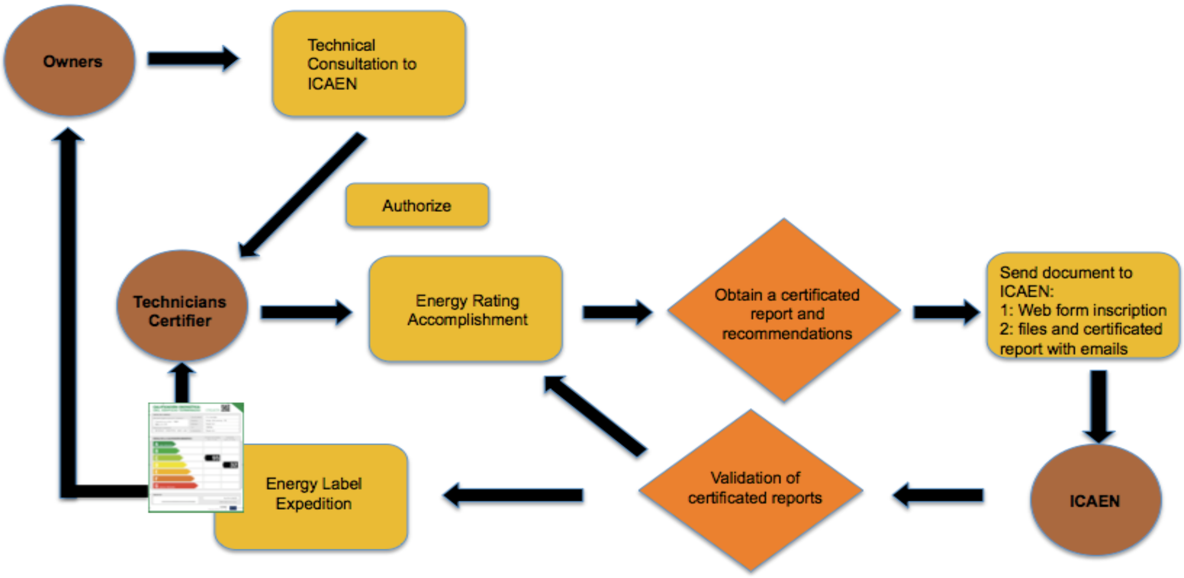


Figure 2. 18 Procedure of Energy Performance Certification
Source: ICAEN

Step 2: Assessment of EPC

In this step, technicians should collect a building's data, inspect the quality of buildings and then calculate the energy rating by tools. Finally, they will propose some measures for better energy efficiency and suggestions in the economic aspect in accordance with the energy bill, after getting the energy efficiency certificate.

- Data collection and quality inspection. Technicians should inspect a building's quality after a series of basic information of buildings has been collected. It takes generally 1-3 hours to do this operation and the data collected include but do not limit to the regarding:
  - Cadastral reference and construction year of the building

- General information and the surface area precisely
- Location, direction and the shadow of this building
- Envelope system and type of holes
- Installation of heating, cooling, DHW, etc.
- Other specific information

- Data calculation. This operation generally spends 3-6 hours by the recommended tool. It includes:
    - Identification of the building
    - Normative chosen in accordance with the building’s construction year.
    - Description of the building’s energy characteristics including all the specific technical terms which will be explained in the following.
- Improvement measures. The certificates in relation to the building’s quality are produced and then technicians propose suggestions to improve building’s energy efficiency according to the result from data calculation. At the same time, an economic report will be analyzed in line with the energy bill of a household.

Figure 2.19 depicts a tree of data collected as an example and explained clearly what the exact indicator should be calculated to make a certificate.

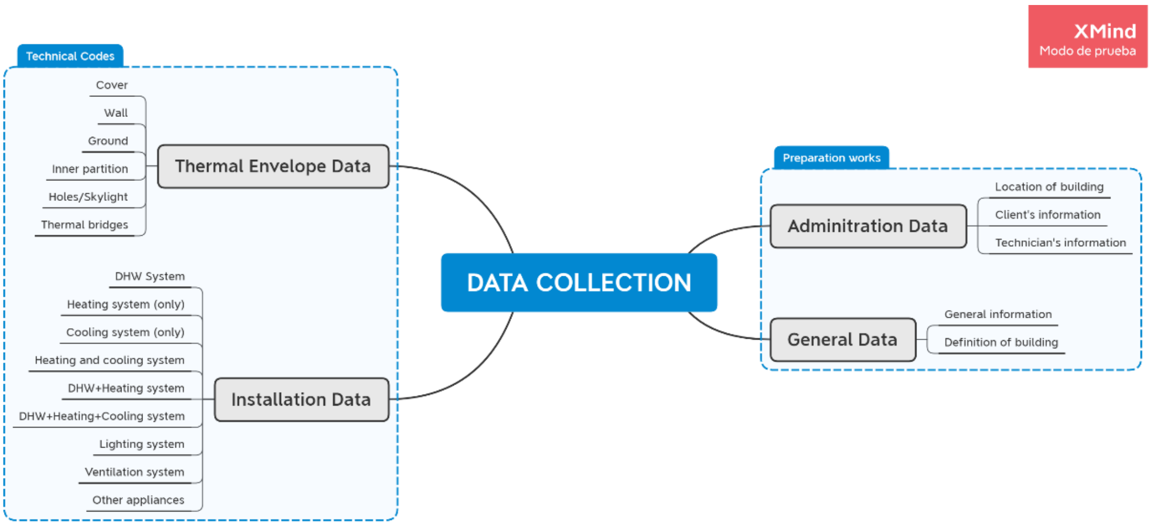


Figure 2. 19 Data structure for EPC assessment
Source: Own elaboration

Step 3: Auditing, register and presenting a certificate

With the final document of this certification, technicians submit them to ICAEN by a digital way (i.e. web-form inscription and emails). Subsequently, ICAEN will check and audit these digital documents and control the technics and administration. In case, there is some error for a certificate, ICAEN will request the corresponding technician to revise this procedure and correct faults. Next, the corrected certificate is registered and open to the public. Finally, the technician will present the completed document of this certification to corresponding applicants.

Final Document of EPC

The final document of EPC consists of 5 sections (more details in Appendix II). The first one is a resume of the total document which provides the basic information of buildings and technician's data as well as the most important energy efficiency labels in the consumptions of EPnr and emissions of carbon dioxide. The second one includes all technical codes above-mentioned to assess the energy performance of buildings. The third is a series of description of energy certificates in relation to the installation. In detail, it identifies the consists of such EPnr consumption and CO_2 emission by heating, cooling, DHW and lighting installations. The final two sections are suggested measures for energy efficiency improvement and the economic analysis.

2.4.3 Status of Energy-Efficient Performance in Catalonia

As the most energy efficiency Autonomous Community, certificated buildings in Catalonia has increased 1.5 times from 675,000 in April 2017 to 1,040,000 in June 2020. It implies homes with an average growth of 9,500 monthly registered energy performance certificates during these four years. Seven years have passed, since the first mandatory of EPC registration for existing buildings. Thanks to the efforts from the government and relative departments promoting and supervising the process of EPC, we have gotten an abundant knowledge of energy efficiency and a huge number of certificated buildings with relative indicators in details. A series of descriptive statistics of EPC information is helpful to understand the local green market well. Considering the general objective of this thesis, the following statistical analysis is based on multi-familiar homes with an energy label.

Shares of EPC rating

Figure 2.20 shows the distribution of EPC (calculated by CO_2 emissionS) for multi-familiar homes which accumulates until 2nd June 2020. Certificated home with an "E" label accounts for 58.43% of the total certificated home. The "G" and "F" are followed with a proportion of 16.61% and 12.7% respectively. In the multi-familiar residential sector, high-medium green home (A+B+C+D) only accounts for 12.26%. In relation to the existing homes, the distribution is similar to this Figure 2.19 shown, which indicates there is a great potential for energy saving by improvement and renovation.

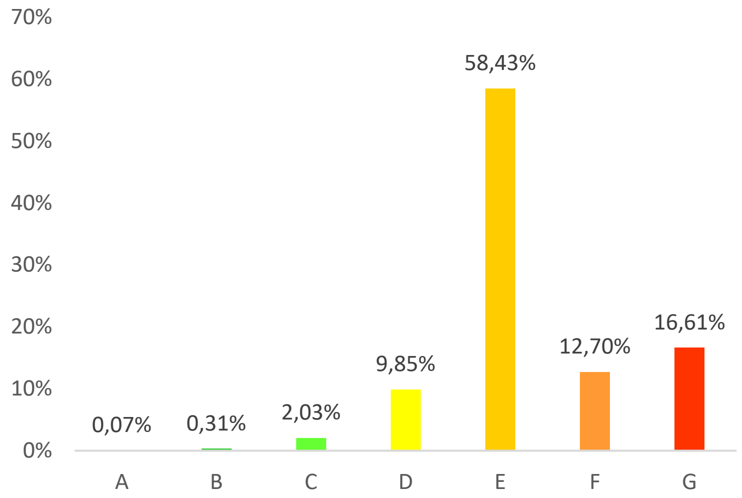


Figure 2. 20 Distribution of EPC specified by CO_2 emission for multi-familiar homes
Source: ICAEN. Own elaboration

Motivation of EPC registration

Concerning the motivation of EPC registration in Figure 2.21, the proportion of renting and selling are around equal, accounting to 51% and 45% respectively. It implies the mandatory of EPC registration required by EBPD and RDs has made great achievements. Expectedly, people who have transactions in the residential rental market are more willing to register EPC. In the future, how to promote the purpose of the renovation is what should be considered, especially for the rental market.

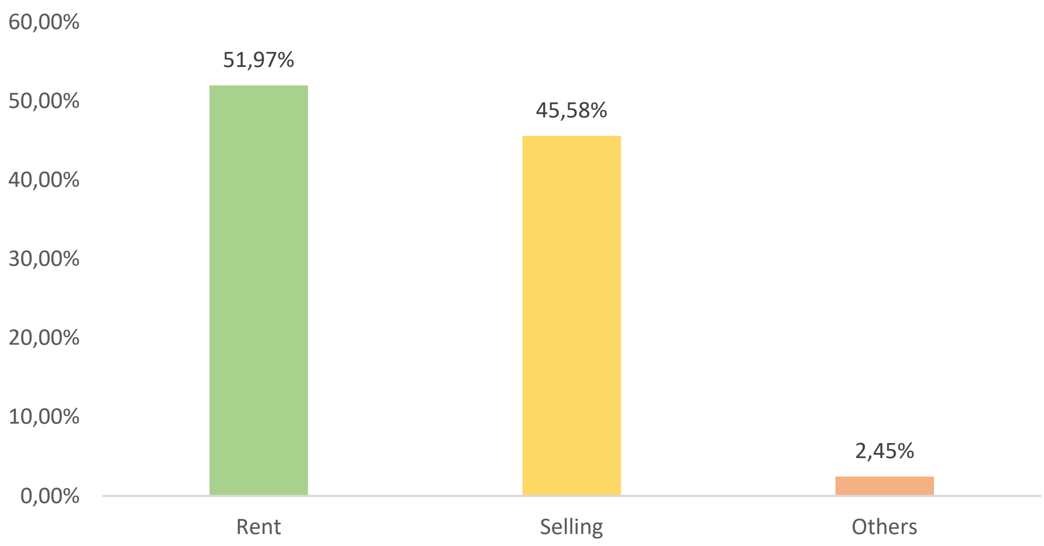


Figure 2. 21 Motivation of EPC registration for multi-familiar homes
Source: ICAEN. Own elaboration

Shares of the building normative for each EPC rating

With the development of building technology, technical codes (CTE) request a stricter on energy efficiency. According to the performance of existing multi-familiar homes, there are five commonly used normative.

- Before 1979: no specific regulations and code on the thermal envelope of buildings
- NBE-CT-79 (1981-1989): requirements on thermal transmittance of the envelope
- NRE-AT-81 (1989-2007): Improvement of previous regulations in Catalonia
- CTE-2006 (2007-2014): requirement on materials and techniques or energy-saving and solar system
- CTE-2003 (2014-present): requirement on sustainable energy consumption from a renewable source

Figure 2.22 depicts the distribution of certificated homes by different normative regulations. Obviously, the proportion of medium-low[22] energy efficiency has a drop along with a stricter

[22] Medium-Low consists of ranking “E”, “F”, “G”

regulation while that of greener homes (certificated with A/B/C/D) increases. In particular, those medium-low energy efficiency homes constructed as the guide of NBE-CT-79 AND NRE-AT-87 accounts for more than 70% of total existing multi-familiar homes. In order to meet the goal of NZEB in 2030, more efforts should be made in the existing residential sector to promote the buildings' renovation.

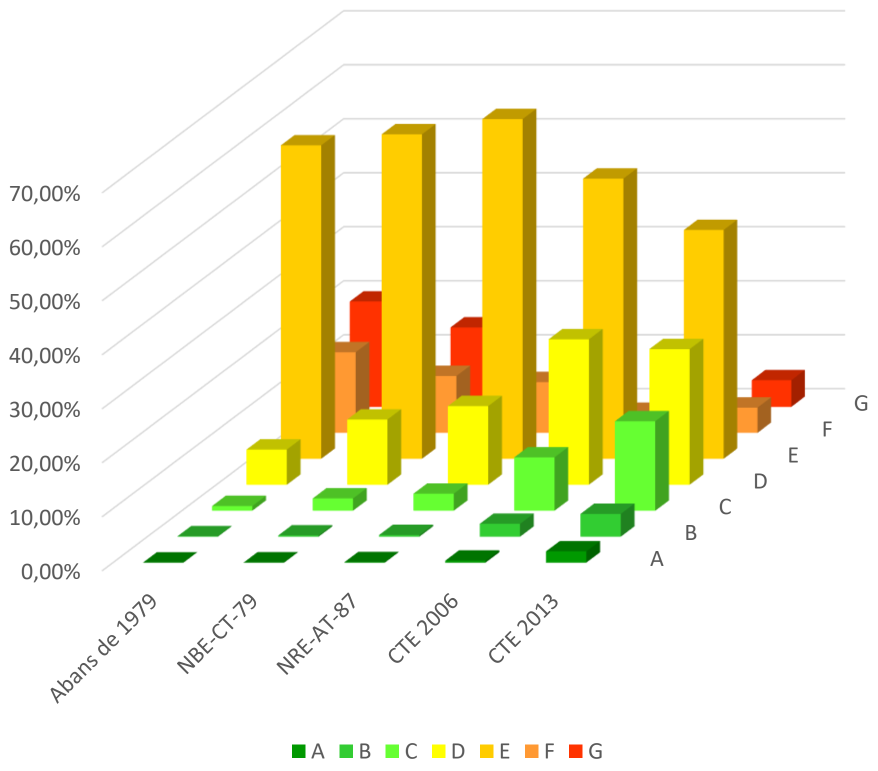


Figure 2. 22 Distribution of EPC for multi-familiar homes by normative
Source: ICAEN. Own elaboration

CHAPTER 3

VALUE AND LOCATION THEORIES IN HOUSING MARKET

CHAPTER 3 THEORY OF VALUE AND LOCATION IN THE HOUSING MARKET

The studies of commodity value and urban location, form a theoretic perspective, have raised a considerable attention in the past century. The goods in the residential market (i.e. houses), however, is different with the general commodity, which characteristics are 1) the high risk of investments; 2) house durability; 3) heterogeneity of residential location; 4) house immovability. Consequently, transforming and applying such theories to the housing market plays a vital role to understand the nature and formation of housing well.

According to the theory of real estate economics, the housing market is composed of ***housing stock*** and ***housing service***. Housing stocks are multi-dimension and expressed as "QUANTITY" which is regarded detailly as the floor area, the number of rooms and the storey, etc. while "QUALITY" includes

1) the physical characteristics, such as architectural style, structure and inner equipment, etc.
2) environmental characteristics, such as green areas, pollution, noises, etc.

Conceptually, housing service (i.e. flow of services) is defined as the household's utility or public service from the locations and quality which is integrated and determined by all the attributes and characteristics from houses. For instance, the possibility for a better education due to the housing policy for the school district, or the living convenience because of the closer to a shopping mall. In general, the housing stock is the basis of the corresponding services. That is, the certain level of the housing stock is the determinant of which level of services household obtain.

In order to understand well the value formation in the housing market, this chapter initially introduces two most common theories with respect to housing price formation and then the evolution of location theory, which reveal the basic structure of housing price across urban space. In particular, Hedonic Price (HP) theory, the most used housing price theory, is presented with a comprehensive view in this chapter.

3.1 Supply and Demand Theory supply

3.1.1 Demand Theory in Residential Market

Residential demand refers to the number of houses that consumers are willing and affordable to buy at a certain level within a given period. The standard demand function in the residential market is equated as following

$$D = f(I, P, P, T, N) \tag{3.1}$$

Where D denotes the housing demand

I denotes the affordability of consumers

P denotes the housing price

P denotes the housing service

T denotes the consumers' preference to houses

N denotes the number of potential consumers for houses

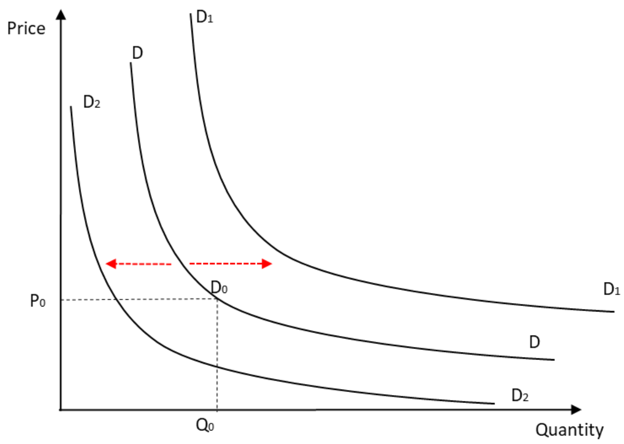


Figure 3. 1 Residential demand function

Elaboration: author own

D-D is the demand function and X-axis is housing price and the Y-axis is numbers of houses or housing services. D_0 is a given residential demand at Time=0 while P_0 and Q_0 are the corresponding price and quantity.

Typically, the factors which impact on demand are consist of as follows.

3.1.1.1. Income and welfare

As can be seen in equation (3.1), residential demand is subject to the household affordability. In general, such affordability includes the basic household income, other income and savings. If household income rises, ceteris paribus, the demand will increase. Namely, as shown in Figure 3.1, the demand function will move to the right curve as D_1-D_1. Vice versa, the demand decreases resulting in the function expression as D_2-D_2. Aa a matter of factor, household saving, that is the accumulated income, plays a key role in making decisions to change their demand. At least, the impact of such household saving, to some extent, exceeds that of the monthly or yearly income when consumers are considering to change their residential demand.

In sum, the change of current income have an influence on consumer's residential demand but the transforming such demand into behaviours is subject to household's accumulated deposit.

3.1.1.2. Housing prices

Doubtlessly, housing price is the most determinant in the housing demand. Unlike the positive impact of incomes on the residential demand, an increase in housing prices will lead to a fall of housing demand (see Figure 3.1 from D_0-D_0 to D_2-D_2). It, therefore, can be said that the housing price is the first threshold for demand adjustment. In other words, the high housing price will suppress housing demand, resulting in the growth of consumption on other commodities. Conversely, lower housing price will stimulate the residential market, where consumers release numerous housing demand and flood into the market. Finally, the demand and price again step into a volatile period until the temporary equilibrium emerging.

3.1.1.3. Population and household Structures

Population and household structures are also important elements impacting on housing demand. As the main object of this demand, the composition of the family determines what the type of house they want, resulting in shaping their preference for housing. Moreover, such composition is not always stable and transforms by the improvement of family’s other living requirement, causing furtherly the change of the residential demand. For instance,

1) An educational family with two generations prefers to buy a house close to a high-quality school and also requires at least 2 bedrooms.
2) A young family without children is willing to live in the areas with well-developed transportation and close to CBD/commercial entertainment centre. The requirement of the inner structure or distribution for a house is not what they care more about.
3) A family with high income or prestigious one is likely to live in a luxury house in the suburb and quiet areas. Commonly they have a time-flexible job and cars, indicating the requirement of convenient public transportation, especially metros do not take into consideration.

As a matter of fact, this preference of demand is dynamic and transformed when some changes happened on their family composition. For instance, the educational family may move to a bigger house in a quiet area (e.g. periphery area) since their children are leaving for an university-educated. Similarly, when the young couples have a baby, they may seek for home as the educational family has. Therefore, family composition not only plays a key role in the consumer’s preference demand but also increases the number of potential consumers.

3.1.2 Supply Theory in Residential Market

The similar definition with the demand, housing supply refers to the number of houses that producers are willing and affordable to sell at a certain level within a given period. The standard supply function in the residential market is equated as following:

$$H = f(L, N, K, M, P) \tag{3.2}$$

Where H denotes the housing supply

L denotes the residential land which has not been developed

N denotes labour when developing

K denotes the capitalization

M denotes the materials when producing

P denotes the housing price

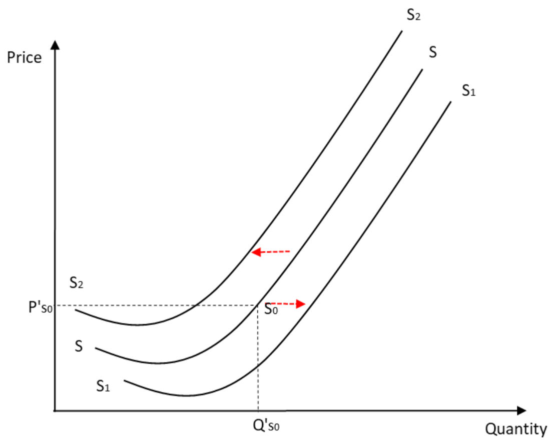


Figure 3. 2 Residential supply function
Elaboration: author own

Typically, the factors which impact on supply are consist of as follows.

3.1.2.1. Housing prices

Housing price is not only the most direct factor in determining housing demand but also the key factor in their supply. Supposed that the construction cost is fixed, the developer's profit, therefore, is subject to the selling prices. This has a major impact on a developer's decision with aspect to the housing supply. Generally, if the housing price cannot afford for the corresponding cost, the developer may directly cut off this supply. Particularly, once the "Abnormal Profit[23]" occurs, other developers will enter into this "super" market to earn the profit by increasing production and supply.

3.1.2.2. Available residential land

As known, the supply of land, in terms of long-run is inelastic due to the scarcity of land. In relation to the residential land, this supply is not completely inelastic but still lack sufficient elastic. Typically, the supply of residential land will rise if agricultural modernization is well-developed in a city. In detail, the intensive economy by agricultural modernization will enhance the production yield per unit area. Supposed that the food consumption in a city is certain, the higher the agricultural modernization means the more land saving which could convert into the residential land. In sum, in a given period, the supply of residential land is fixed, which determines that the willing to supply is not absolutely controlled by developers but more regulated and conducted by urban policies and plans.

3.1.2.3. Capital investment and interest rate

Due to the huge investment in the initial stage of development, developers prefer to seek monetary support from banks or other financial institutions, in addition to their funds. Therefore, the local monetary policy plays a key role in the supply behaviours from developers. If the loan interest is too high, the financial cost that developers need to bear will increase.

[23] Abnormal profit, also called excess profit, supernormal rprofit or pure profit, is "profit of a firm over and above what provides its owners with a normal (market equilibrium) return to capital" (Deardorff, n.d.).

Once this additional cost could not pass on to the selling price, the profit of developers relatively shows a fall-drop, even at a loss. This will discourage the developers' investment behaviours, which may reflect in downsizing the scale of development and reducing the housing supply. Conversely, the lower load interest brings financial saving and beneficial profit, stimulating developers to supply more housing.

3.1.2.4. Capacity of building materials supply and construction technology

Undoubtedly, the supply of building materials that is the physical basis of a house is quite important. Likewise, the advanced construction techniques, the latest materials and the more professional management teams could effectively help to reduce the construction cost, improve the efficiency, obtain more profits and furtherly promote the supply behaviours.

3.1.3 Market Mechanism Equilibrium

The residential market equilibrium refers to a state where supply and demand have reached stability. As far as housing prices are concerned, the price of housing supply is equal to that of demand. With respect to the overall market, it means the same number of houses on demand and supply.

As Figure 3.3 shown, S is the supply function and the D for the demand function. This intersection E is the equilibrium point where the corresponding P_0 and Q_0 is the equilibrium housing price and number.

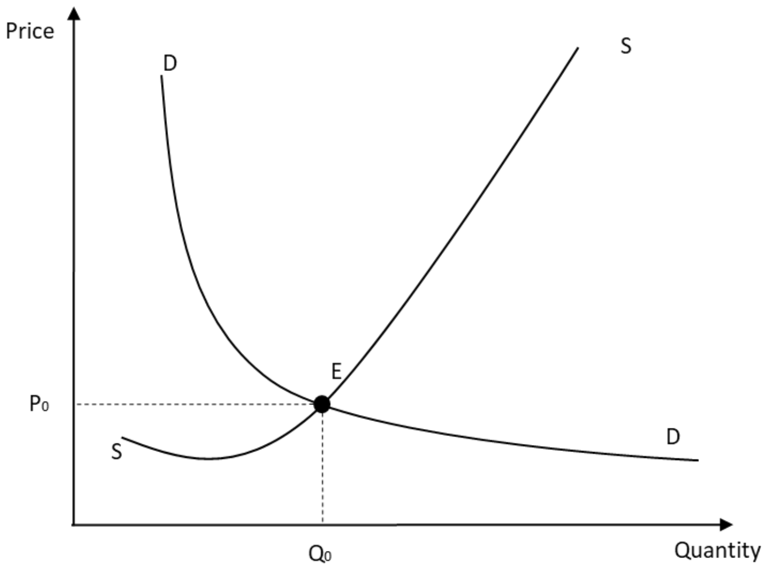


Figure 3. 3 Equilibrium in demand and supply
Elaboration: author own

The market mechanism of the residential market actually is the interaction among those factors[24] that constitute the residential market and its key point is the housing price which reflects the benefit and cost for stockholders by monetary expression and conducts their making-decision. As can be seen in Figure 3.4, the housing price shows an increase when the market demand exceeds its supply. At this period, the additional profit has a “fatal” attraction to those developers to speed up their production behaviour, leading to a rise of supply and finally there will be a dynamic balance between the demand and supply. Considering there is a certain time lag from housing project development to selling in the market, the temporary equilibrium is broken immediately when the considerable lagged-household persistently enter the residential market. Consequently, demand falls short of supply, resulting in the redundant houses and then forming a buyer’s market where buyers have more choice to make the decision and the bargaining initiative is by buyer’s side. At the same time, this abundant stock market may stimulate the competition among the developers and sellers, leading to a fall on selling prices or a reduction of the housing supply. Then this market reaches again an equilibrium state.

[24] Including stakeholders, housing price, modes of demand and supply, etc.

As already noted, the equilibrium market is a dynamic loop without an absolute balance-state between supply and demand. Under the adjustment of the "invisible hand" in the market, two relative equilibrium sates are expressed as 1) supply slightly exceeds demand and 2) demand slightly exceeds supply. Almost every moment, the relationship between supply and demand is transforming each other.

Figure 3. 4 Market mechanism
Source: Own elaboration

3.2 Utility Theory

Utility theory also called as Consumer Behaviour theory which aims to research how consumer assigns their income between goods and services to meet their maximum satisfaction. According to the utility theory employed in the housing market, it holds that the housing price consumers are willing to pay (WTP) is determined by the consumer's satisfaction that the house brings in. Supposed that two houses with the same cost of construction materials and labour located one in the city centre and other in the urban periphery. Although the locational costs are different to some extent, the gap of their WTPs probably exceeds this cost difference. The time saving and life convenience bringing from the house located in the city centre may be able to explain such situation that consumers are willing to pay more to satisfy their requirement for a better life.

Typically, utility theory holds that the more satisfaction consumers have when they consume goods or services, the higher their utilities are， which express in the housing market as their willingness to pay for a house. In addition to such satisfaction from the physical characteristics of the house, their utility performances also rely on consumer's subjective feelings.

In theoretical assumption, consumer's behaviour requires 1) consumers are completely rational which expresses that they understand well with their choice and their goals are to meet their maximum satisfaction; 2) the market should be dominated by consumers where consumer's demand is the most predominant determinant for the housing price and their making-decisions are independent without any impacts from outside; 3) utility is derived from the consumption process, rather than other aspects

However, how to measure quantitatively such utility is a puzzle. To date, there are two domain theories to address the utility into quantity.

3.2.1 Cardinal Utility Theory/ Marginal Utility Theory

Cardinal Utility Theory (CUT), also called Marginal Utility Theory (MUT), is a concept commonly used in Western economics in the 19th and early 20th century. It holds that the utility is measurable and can be summed up. Its unit of measurement is expressed as the size of the utility, denoting in bases (e.g. 1,2,3……).

The marginal utility refers to the increase of utility that consumers get by one more unit of consumption within a certain period. The most significant is that the marginal utility of goods is always diminishing with the accumulated usage (i.e. the law of diminishing marginal utility). Marshall (1890) also pointed out that money should be under this diminishing law. The marginal utility is equated as the following:

$$MU = \frac{\Delta U}{\Delta Q} = (U_i - U_j)/(Q_i - Q_j) \tag{3.3}$$

Where MU denotes marginal utility while ΔU and ΔQ are the differentiations of utility and quantity when consuming goods or services with i and j unit. Figure 3.5 shows that the function curve of total utility and marginal utility where the former is a unimodal type and the latter is a decrease gradually type.

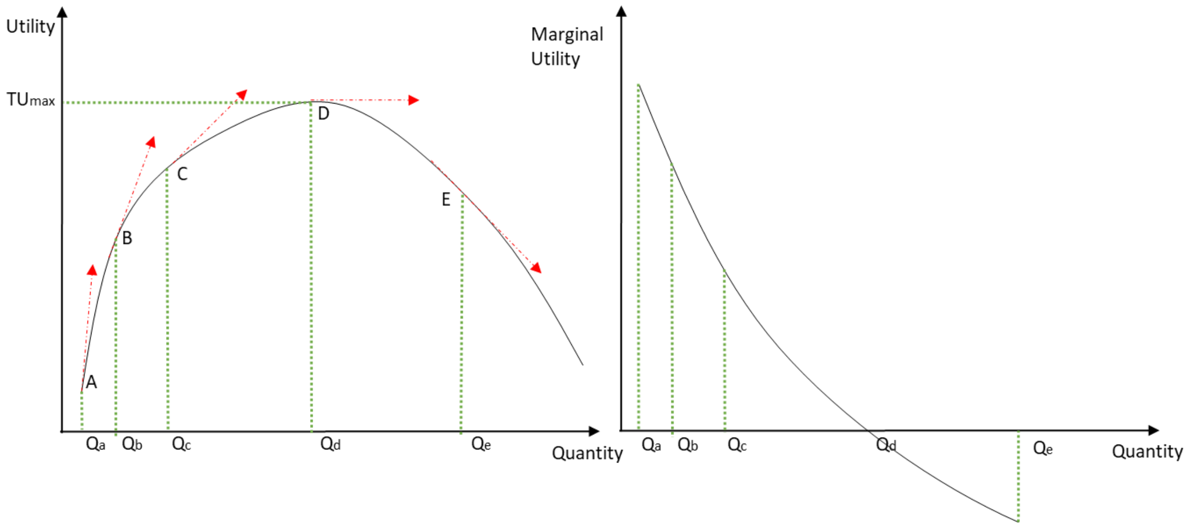


Figure 3. 5 Function of total utility and the marginal utility
Elaboration: author own

It is obvious that the utility curve reaches the peak D point with the consumption and then falls down although consumption still rises. In the growth stage (A-D), the accumulated utility grows but the marginal one (dotted line with red arrow) decreases gradually. When reaching the maximum total utility, in contrary, the marginal utility drop to zero.

What makes this diminishing law is that the use of the same object is always the strangest stimulus or freshness for consumers at the beginning of use. Then this stimulus decreases with the consumption accumulated, leading to a reduction of consumers desires.

3.2.2 Ordinal Utility Theory

Ordinal utility theory (OUT) is proposed and developed by Hicks & Allen (1934). It is one of the basic theories in consumer's behaviour theory and also is for making up the shortcomings of MUT where it is difficult to quantify the real utilities standing by the consumer's side.

In practice, OUT is the commonly used method to explore the disciplines of consumer's behaviour with respect to the making-decision in the residential market. Considering the difficulties to identify consumer's utility by detailed numbers, Hicks proposed that using the ordinal level to compare utilities among various goods or services is better. Supposed that one house located in the periphery areas with a quiet and high-quality environment while the other located in the areas in the CBD with a completed transport network. For the elderly who is retired, it is impossible to have detail numbers to decide the utilities in relation to these two houses. Based on his preference in living condition, however, it is relatively simple to say the one located in the periphery is better than that in the CBD. That is to say, the utility of houses in the former area is larger than that in the latter one for a retired person.

Hypothesis for OUT are 1) a consumer has a certain order for his preference on production; 2) this order should be coherent without any difficulties in decisions; 3) the quantity of goods or services is always more than the number of consumers.

In order to explain this theory, Hicks applied the Indifference Curve (IC) method to define consumer's utility. This curve is to indicate the utility is the same whatever quantity combination between two commodities and its function is shown as following:

$$U = f(X\ , Y) \tag{3.4}$$

Where U is a constant and expressed as a certain level of consumer's utility. X and Y denote the consumed numbers of commodity-X and commodity-Y respectively.

As shown in Figure 3.6, IC and IC' are the indifference curves with various utility-level where point A, B, C are expressed the combined consumption pattern between X and Y commodities. A and B are in the same curve indicates whatever the detailed consumption between X and Y, consumer's utility keeps the same while the C point in the IC' curve represents a different utility for consumers. As can be seen obviously, this curve is with a negative slope from the upper left to the lower right, indicating commodities' substitutability where the consumption for commodity X decreases, in order to meet the same utility, another commodity Y will be consumed.

In sum, if the combined consumption is in the same curve, they have the same utility, bringing the same satisfaction.

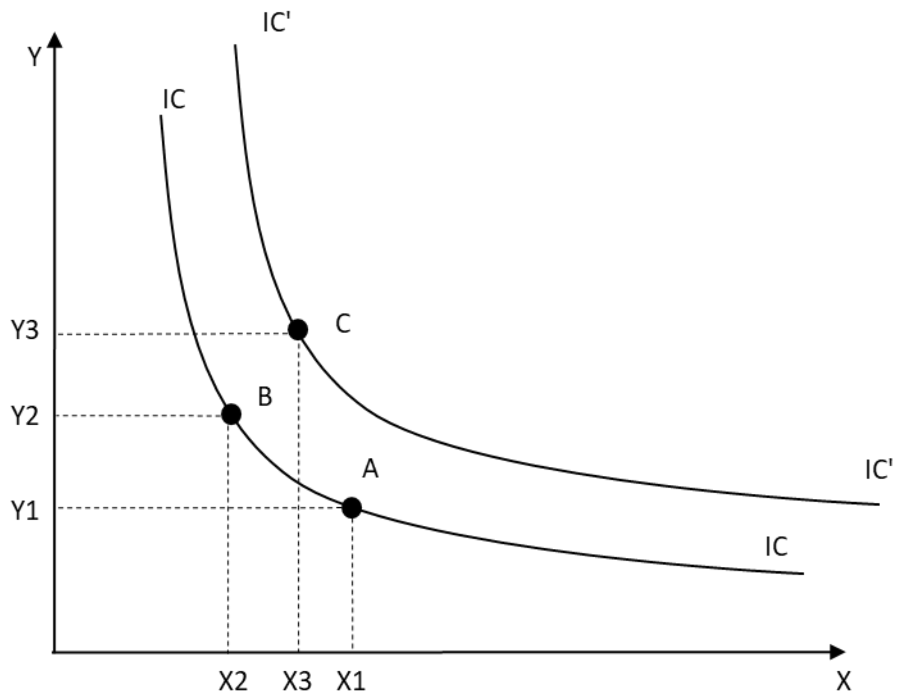


Figure 3. 6 Indifference curve for consumers' utility
Elaboration: author own

Since consumer's preference is infinity, those Indifference Curves for a consumer form consumer's preference system. Typically, it is impossible for a given consumer that the indifference curve has intersections. The curve far away from the origin represents a higher utility.

3.3 Residential Location Theory

Generally, when talking about which determinants are formed the housing price, we always mention "Location- Location- Location" (K. Jones & Simmons, 1990; Kiel & Zabel, 2008; Rousseau & Fried, 2001). Location refers to the spatial place occupied by objects or economic activities and the economic geographical relationship between the spatial place and its surrounding objects.

Location theory was first proposed by Von Thünen in 1826. He established primarily the agricultural location theory based on a background of the agricultural economic society. The differential land rent theory conducted by Von Thünen plays a vital role in the location choices in urban land use and the formation of housing price. He thought 1) prices for the same agricultural products increase with the distance between the place of production and the market after considering the additional transport fee; 2) different agricultural products will compete for the same land. Therefore, he proposed an urban land pattern where the CBD is the centre, surrounding by different agricultural belts. Subsequently, Weber proposed an improved location theory for industrial cities (Weber, 1909). He confirmed the location choices by exploring the relationship between transport cost, labour cost, factors of aggregation and dispersion and the industrial location. With the development of economy and society and the rapid growth of business activities, Christaller proposed a “Central place theory” in 1933 and explained the law of distribution in terms of commercial activities. He defined two limits: the upper (outside) is the maximum radius of the commodity and services while the lower is the radius for the normal profit.

Residential location theory is later than agricultural and industrial ones but it is almost in sync with the commercial one. Next, this section mainly introduces the development of residential location theory, dividing into three stages roughly: 1) Classical residential location theory; 2) utility-residential location theory; 3) New residential location theory.

3.3.1 Classic Location Theory

3.3.1.1. Concentric zone model theory

In 1925, Burgess firstly proposed the concentric zone model theory based on the residential market in Chicago. He studied Chicago's urban land use and concluded that a city could be divided into six zones where the residential location is composed of four zones.

Figure 3. 7 Concentric zone model
Elaboration: author own

Low-Class Residential Zone (also called Zone of Transition)

This is the closest zone to CBD. At the beginning of urban development, there was a large number of high-income families in order to obtain its accessibility and convenience for life. As time passed, the living conformability in this zone cannot meet these rich families' requirement due to the limits to floor areas or nuisance of noise and air pollution. Consequently, rich families gradually moved out and low-medium income families migrate in this zone due to its possible low rent.

Medium-Class Residential Zone (also called Working-Class residential zone)

Although the Transition Zone shoulders a certain living requirement, the Medium-Class Residential Zone is the real and gathering area including low-income and medium-income families. These families living here pay more attention to the less commuting time and better accessibility, instead of dwelling quality and living comfortably.

High-Class Residential Zone

This zone is gathering with those high-income families since its environmental quality and locational benefits are better than that in Medium-Class Residential Zone. It usually consists of single-family dwellings, of exclusive "restricted districts" and of high-income apartment buildings.

Commuter Zone

This is actually an additional area for high-income families, located in urban's periphery with a better environment (e.g. fresh air quality). Considering the high rate of car ownership, it seems that the general accessibility does not affect particularly for their commuting travel due to more completed transportation facilities, such as highway and train centre.

Burgess believes that the distribution of residential location is a concentric structure where CBD is the centre and other residential zones are surrounding with it. The deteriorating living environment and poor physical quality of house lead that the rich escape to the outskirt of the city for a comfortable life while the poor flood within the centre area for better accessibility for works. In other words, the quality of dwellings and household income increased gradually from the centre to the urban fringe. Therefore, this theory is also referred to as a dynamic filtering process in residential areas.

This concentric zone model provides a good theoretical basis for the development of following location models. The shortcomings of this theory, however, are also evident: 1) it is supposed that a city is a homogeneous plain and there is no cost to move in or move out; 2) industries are dispersions across urban space; 3) the situation where CBD is gathering with poor or low-income families and the riches always live in the suburb happened exclusively in the USA; 4) this model is only applicable to a monocentric city, rather than those with multi-centres structure. In practice, it is almost impossible to meet these strict hypotheses of the concentric zone model theory when studying the choice of residential location.

3.3.1.2. Sector model theory

In order to improve these shortcomings previously stated, Hoyt proposed a sector model theory in 1939 based on Burgess's concentric zone model theory and further considering the impacts of transportation on urban residential location. This model is composed of five sectors where CBD is still in the centre but industrial, commercial and residential zones distribute as a sector rather than a concentric model. In this model, residential zones are similar to the concentric model did within three zones.

Figure 3. 8 Sector model theory
Elaboration: author own

Hoyt collected the rent information block-by-block in 142 American cities and classified them into five rent zones: 1) less than 10 dollars; 2) between 10-19.99 dollars; 3) 20-29.99 dollars; 4) 30-49.99 dollars; 5) equal and more than 50 dollars. As shown in Figure 3.9, Hoyt found that the highest rent in a city is often located in one or more areas. As the highest centre, rent gradually decreases in all directions. In contrary to the concentric model, Hoyt has not found any rent shows an evident reduction from the city centre to urban fringe according to the results of 142 cities collected. He believed that residential zones expanded autonomously by a path with the minimum space friction and time friction. For instance, residential zones are distributed along with a perfect transportation route (e.g. highways, railways, etc.) or aggregated surrounding a high-quality landscape (e.g. coastlines, national parks, etc.) or closed to a commercial or prestigious area.

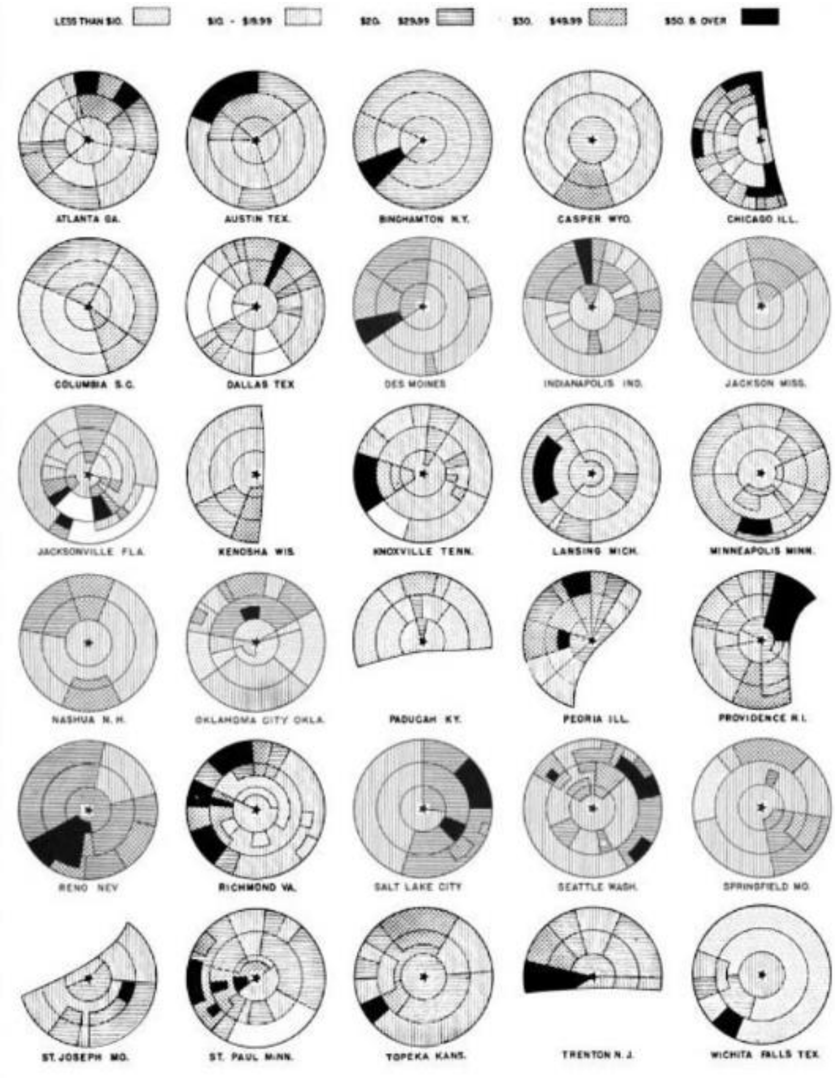


Figure 3. 9 Theoretical patterns of distribution of rent areas in 20 American cities
Source: Administration & Hoyt, 1939, p77

3.3.1.3. Multiple nuclei model theory

The two previously stated theories supposed based on monocentric city. However, urban structures have become more complex with the development of society and economy, leading to the emergence of multi-centric cities. In 1945, Harris & Ullman proposed this Multiple Nuclei Model Theory and explaining the factors contributing to the formation of multi-centric cities which includes 1) specific and professional facilities for some certain activities; 2) benefits brought by agglomeration economy; 3) the negative interaction among different sectors; 4) forced to move out since benefits are less its land rent.

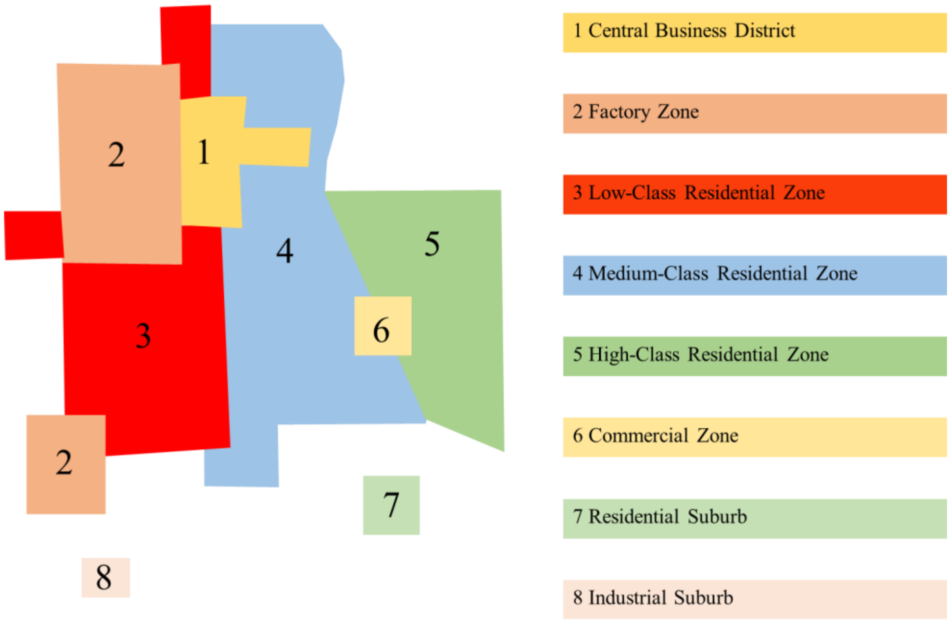


Figure 3. 10 Multiple nuclei model theory
Elaboration: author own

Figure 3.10 shows a general example of multiple nuclei model where the low-income residential is still located in the city's inner and formed within a rectangle or polygon shape rather than zonal and sectoral distributions. Similar to concentric and sector model, low-income is surrounding with CBD and light manufacturing zone since most of them are workers who primarily consider commuting cost. In terms of medium and high-income families, they are willing to live relatively far away from CBD. As the results from Harris and Ullman's study indicated, it is possible to emerge the polarization of locational distributions between the medium- and high-income families and the low-income ones, conforming to the studies of the theory of segregation and discrimination to a certain extent.

3.3.2 Utility Theory-Based Residential Location Choice

The inner core of the early classic residential location theory is to identify such zones by means of family income, occupation, etc., but lack of researches on specific elements and influence mechanisms affecting residential location choice. Therefore, the universality of these theories is often called into questions. In order to study the inherent laws of the distribution of residential locations, the utility theory is introduced to guide the development of locational theory.

3.3.2.1. William Alonso: exchange theory of the residential location

Alonso proposed the exchange theory of residential location in 1964 based on the maximum of economic utility between commuting fee and living cost. This theory assumes that 1) all commuters have the same commuting efficiency whatever vehicle they choose; 2) urban residences are distributed homogeneously across the whole space; 3) other factors (e.g. living density, neighbour quality, etc.) do not affect the choice of residential location. In case of a given income level, residents assign their preferences between commuting fee and living cost, resulting in the maximum economic utility. The basic equation of this theory is as follows:

$$Y = P_Z \times Z + P(t) \times G + K(t) \tag{3.5}$$

Where Y denotes the household income; P_Z denote the price of the other goods while Z is the quantity of the other goods. $P(t)$ is the land price per square meters at the distance t to the CBD; G denotes the square meters of residential land; $K(t)$ denotes the commuting fee between the CBD and t location.

As can be seen in equation 3.5, commuting fee and live cost are determined by the distances between the workplace and CBD. The more expenditure on transport, the less left for rent. If families move out to the periphery area for a better living environment, the saving rent will cover its incremental commuting fee. Residents will balance their preferences to transportation and rents for a maximum economic utility.

3.3.2.2. Alan Evans: aggragation factors in the residential location

In order to update the cognition of residential location theory, Evans improved Alonso's Exchange theory in 1985. In addition to aggregation factors, he emphasized psychological needs play a vital role in the choice of residential location, which includes followings:

- Social communication needs. People are willing to contact and live with groups that are similar or better than theirs, resulting in an agglomeration gradually across urban space. This spillover of aggregation effect will attract more similar families gathering together. Briefly, there are considerable obstacles when the lower class want to elevate to a higher one.
- Differential demands. More similar demand they have, the more likely the making-decision on the residential location are same. For instance, families are willing to live in an educational area when they have children.
- High-quality living experience. Families constantly adjust their living places in order to live in neighbourhoods with better environment sand life-friendly.

3.3.2.3. Others residential location theory

Similarly, Brown & Moore (1970) supported Evan's conclusions and emphasized consumer's psychological need is the primary impact on residential location choice. Quigley (1973) agreed with them and believed the condition that families are motived to change their living-places is that the effectiveness or utility of a new residential area is greater than it has now. subsequently, Simmons (1974) and Smith (1979) et al. have established relative residential location choice model where the farmer expresses the utility level by defining zonal attraction while the latter by consumer's expectations for the destination area.

3.3.3 New Residential Locational Theory

After considering the utility theory, the choice of residential location evolved from the initial income-focus model into a mixed one with consumer's preference. However, the hypothesis of economic man could not reflect those factors impacting on residential locational choices (e.g. household type, neighbourhood environment, etc) (Smith, 1937). Accordingly, researchers have begun to pay more attention to these aspects with respect to socioeconomic and cultural factors, for a better understanding and description residents' locational choice.

After a comprehensive review of the pioneers' works with respect to the land value theories, Roca (1988) began to explore the structure of urban value in Barcelona city. In this work, he discussed the rent of accessibility, urban externalities and the social hierarchy. Particularly, the impact value of these three rent above-mentioned are highlighted. On the other hand, he also introduced and compare two alternative theories: the local equilibrium and the real estate market segments which are most important when analyzing the urban value. More details are dicussed in the following parts.

Gabriel & Rosenthal (1989) firstly applied the Multi-nominal Logit model (MNL) to analyze the socio-economic, demographic and racial characteristics of 2,500 American families in which 800 of them are the black ones and the others are the white. They indicated that the differences in racial characteristics play a considerable role when choosing the residential location. That is to say, the racial stratification will lead to a residential agglomeration across urban space. In particular, those socioeconomic and demographic factors which are very important for the white families to choose the residential area do not make sense for the black. They are more willing to live in integrated and multi-racial areas located in the city interior. Instead, some studies suggested that different races are willing to separate with each other (Guo & Bhat, 2007; Pinjari, Bhat, & Hensher, 2009; Pinjari, Pendyala, Bhat, & Waddell, 2011; Waddell, 2006). Sermons (Sermons, 2000) found that almost families in San Francisco Bay metropolitan area have the racial avoidance behaviours, especially among Asian, Hispanic and the black households. Similarly, De Palma et al. (2005, 2007) suggested foreigners in France preferred to live together which leads a negative opinion from the local.

In terms of employment in the studies of residential location choice, it is expressed in different forms such as unemployment rate and job density. Andrew & Meen (2006) used the data from London and South East England to illustrate what factors impacting on residents' moving and location decision. They found the unemployment rate shows a negative impact when employing an MNL model. Habib & Miller (2009) found a loss aversion attitude on unemployment when presenting a reference-dependent model for residential location choice in the Great Toronto Area (GTA). Dujardin et al. (2008)demonstrated that there was an interacted relationship between the unemployment rate and residential segregation in Brussels. An area with a high employment rate may attract more people to live here for job opportunities, vice versa. As such, the gap of employment rate among various areas results in residential segregations, which in return exacerbates employment market deteriorates. Wu et al. (2013) demonstrated that a 1-unit increase in job density will bring in the possibility of a household choosing this zone by 4.9%. However, more studies suggested that the factors related to employment have not impacted on residential location choice (De Palma et al., 2005, 2007; Pinjari et al., 2009, 2011). Bürgle (2006) argued that in Great Zurich area, job density in the model of residential location choice is not significant. Instead, population density and household types play an important role in the model of residential location choice (J. H. Kim, Pagliara, & Preston, 2005; Waddell, 2006; Zolfaghari, Sivakumar, & Polak, 2012).

3.4 Housing Hedonic Theory

3.4.1 Introduction of Hedonic Price

Broadly, the methods for housing price evaluation are divided into two dimensions: 1) traditional methods include a comparative method, contractor's method, residual method, profit method and investment method (Roca Cladera, 1990; Roca Cladera, Moix Bergadà, & Biere Arenas, 2017b, 2017a); 2) advanced method include Hedonic Price Method (HPM), Artificial Neural Network (ANN), case-based reasoning and spatial analysis method. Therefore, HPM is the most commonly used technique in housing price analysis. In history, the first scholar proposed "hedonic" term is Court (1939) who analyzed the relationship between price and the demand of individual's pleasures. That is to say, the "hedonic", at that time has been considered as characteristics for different commodities. Then in 1966, Lancaster firstly discussed the term "hedonic utility" according to the consumer's demand theory. He believed that consumer's utilities come from commodities' characteristics rather than commodities themselves. In other words, what consumers are willing to buy is a combined of attributes of commodities. Unfortunately, Lancaster did not study furtherly about its theory. In this occasion, Rosen in 1974 proposed firstly the Hedonic Price Theory which demonstrated that the sum of implicit prices for each attribute is equal to consumer's WTP under an equilibrium market. He implied that a commodity's price could be regressed on its bundle of attributes but he did not establish any specific function forms since the model result suggested that the price formation is not a linear form. Consequently, Freeman III (1979) proposed a housing price function as following, including structural, neighborhood and environmental attributes.

$$P_{tot} = P(\sum_{i=1}^{n} S_i + \sum_{i=1}^{m} N_i + \sum_{i=1}^{q} E_i) \qquad (3.6)$$

Where P_{tot} demotes the total price of a house, S_i, N_i, E_i delegate the of ith attribute of Structural, Neighborhood and Environmental characteristics.

As shown in Eq. (3.6), it can be seen that the truth of HPM is "Housing price is equal to the specific price of each attribute of a house".

According to stated previously, the equilibrium market basically does not exist, i.e. evaluating housing prices by HPM infringes the theory's assumption. Freeman III (1993) pointed out that the HP estimation results may bring variance error rather than systematical biases if equilibrium market assumption broke down. Follain & Jimenez (1985) argued that the HP estimation results do not reflect consumers' WTP since it is subjected to the homogenous preference assumption and market adjustment mechanism. Xiao (2017) indicated the housing price collection was made in a certain period which reflects the current state of the real estate stock market. Therefore, the accuracy and validity of HP estimation result are suspicious which may mask the potential relationship between factors affecting prices and prices.

HPM is very sensitive to the specification of formulas and until now, there is not enough theoretical support to guide such formula selection. Xiao (2017) summarized the four most commonly used formula forms, considering various types of data sets.

- Linear specification

$$\mathrm{P} = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \varepsilon \tag{3.7}$$

Where P denotes the housing price; β_0 indicates the constant term and ε is a vector of random error term; β_i represents the marginal changes of a unit price of the ith characteristic X_i of a house[25].

- Semi-log specification

$$\mathrm{Ln(P)} = \mathrm{Ln}(\beta_0) + \sum_{i=1}^{n} \beta_i X_i + \varepsilon \tag{3.8}$$

Where P, β_0, ε denotes the same as stated previously. β_i here represents the rate at which the price increase at a certain level, given the characteristics X_i of a house,

- log-log specification

$$\mathrm{Ln(P)} = \mathrm{Ln}(\beta_0) + \sum_{i=1}^{n} \beta_i Ln(X_i) + \varepsilon \tag{3.9}$$

Where β_i indicates how many per cent of the price P increases at a certain level if the ith characteristic X_i changes by 1%.

- Box-Cox transform.

[25] The X attributes affecting housing price will be explained in the section 3.4.2

$$P(\theta) = \beta_0 + \sum_{i=1}^{n} \beta_i X_i^{(\lambda_i)} + \varepsilon \qquad (3.10)$$

Where

$$P(\theta) = \frac{P(\theta)-1}{\theta}, \quad \theta \neq 0$$

$$= \mathrm{Ln(P)}, \quad \theta = 0$$

$$X^{(\lambda_i)} = \frac{X^{(\lambda_i)}}{\lambda_i}, \quad \lambda_i \neq 0$$

$$= \mathrm{Ln}(\mathrm{X}_i), \quad \lambda_i = 0$$

Summarized that the Box-Cox model will be transformed into the basic linear form if the θ and λ_i are equal to 1; to the log-log form if the θ and λ_i are equal to 0; to semi-log form, if the θ is equal to 0 and λ_i are equal to 1.

The semi-log form is the most prevalent specification in housing price evaluation, especially for the data set including dummy variables (i.e. 0 and 1), although the homoscedastic error term may happen in this form (Diewert, 2003).

To date, there is still a lot of researches trying to find the most suitable function form. Regarding various sample sets, a unique and universal function form seems impossible. In this absence of theoretical background, HP has become the most commonly applied value model theory in econometrics and moreover, it no longer depends on consumer's utility maximization law to some extent (Xiao, Orford, & Webster, 2016).

3.4.2 Components of Hedonic Price in Residential Market

As stated previously, one of the hypotheses of HPM is that housing price consists of the WTP of a bundle of house's attributes. According to numerous empirical studies of HPM, these attributes can be divided into the following four main dimensions:

1) Structural attributes: it is the physical attributes of a house or this building, such as housing size, numbers of bedrooms/bathrooms, age of the house, the presence of a swimming pool, etc.
2) Locational attributes: it includes attributes of accessibility, such as the distance to the nearest train station.
3) Neighbourhood sociodemographic attributes, it consists of the nature or characteristics of the neighbourhood, for example, the household income level or the educational degree of neighbours.
4) Environmental attributes: it consists of a collection of attributes describing the quality and services with respect to the environment, such as annoyance of noise and pollution, the proximity to the green area, etc.

Actually, there is not a clear requirement for the selection of HP attributes and even the detailed contents of such dimensions stated are still flexible in different empirical studies. In the following sub-sections, there is a brief literature review for HP attributes.

3.4.2.1 Structural attributes

Structural attributes represent a bundle of physical attributes of the house and building. Since structural attributes are the most basic elements to form a house, almost all hedonic housing price studies involve such attributes (Atkinson & Crocker, 1992; Cheshire & Sheppard, 1995; Follain & Jimenez, 1985; Kain & Quigley, 1970; Mahan, Polasky, & Adams, 2000; S. Sirmans, Macpherson, & Zietz, 2005).

Housing physical attributes

Mok et al. (1995) applied a hedonic price model to estimate the housing price of private properties in Hong Kong and they found that *gross floor area (GFA)* and its *age of construction* (AGE) show negative impacts on housing prices. Although under their expectation GFA should be in a positive impact on the total selling price for an apartment, the marginal impact of GFA is quite low as compared to other housing attributes which may result from a pricing strategy that selling price per square foot for bigger flats is slightly lower than that of a smaller flat. Haider & Miller (2000) introduced the *numbers of bedrooms, washrooms* and *architectural type of a flat* as its structural attributes to detect its impacts on housing price based on the residential sold prices during 1995 in the Greater Toronto Area. This result indicated that such structural attributes have made a positive contribution to sold price for residential properties. Kim et al. (2003) agreed with their physical attributes selection to analyze the formation of housing price which derives from respondent estimates. Wang et al. (2005) argued that individual structural attributes seem less important than a set of immeasurable integrated building and dwelling concerning characteristics which, however, have played a negligible role on housing price. Schovelin & Roca (2016) applied an optimized design model to evaluate a new apartment building's price based on the principle of the maximization commercial profit. They introduced physical, legal, architectural and economic restrictions when applying HPM and finally made use of the HPM and optimized model into practice.

Building physical attributes

Garcia Pozo (2009) analyzed the housing market in Malaga, one of the main Spanish tourist destinations with an active housing market. He introduced a collection of physical building's attributes (e.g. *the presence of natural light, the quality of the inner conservation and the caretaker in the building*) to define the presence of sub-market, in addition to dwelling's structural traits. This result suggested that the residential market in Malaga could be divided into effective sub-markets based on structural and location criteria. Bhatti & Church (2004) and Wang & Li (2006) have studied the impacts of *building's design and space* on household's preferences where the former paid attention to the *garden* and the latter focus on *outdoor space*. Moghimi & Jusan (2015) concluded residents' conceptions are affected by various structural housing traits. In addition to such mentioned, Sirmans et al. (2006) researched the impacts of a *swimming po*ol and *garage* on housing price by HPM. They found that the presence of swimming pool plays an important role in housing price and varies significantly by the geographical location while the garage shows an inverse representation. On the contrary, Kohlhase (1991) argued that the significances of structural attributes are dynamic and determined by time and their locations.

3.4.2.2 Locational attributes

In addition to structural attributes, a housing unit also consists of a set of locational attributes which has been regarded as the second fundamental element with respect to housing price. As stated in Section 3.3, we have discussed in details about how the location theories impacting on the residential market. In the early period, "location" is the most determinant when choosing a residential area. Here, this "location" is expressed as the distance between a housing unit and CBD. However, the emergence of multi-centric cities with the development of urban broke down the laws of location theories where the monocentric city is the fundamental hypothesis. As such, using distance to CBD to illustrate a housing unit's location cannot express the implicit meaning of its location in a complex urban structure. In this paper, when talking about location attributes in hedonic housing price studies, we often use "accessibility" term which includes more information to depict a housing unit's location. To date, a precise definition of "accessibility" is still suspending but considerable studies have tried to give the implications of "accessibility" and how to measure such accessibility when analyzing the housing price formation (see Table 3.1 and Table 3.2).

Accessibility Definition

Hansen (1959) has defined that accessibility is a "potential of opportunities for interaction", which is a generalization of the population -over-distance relationship or "population potential" developed by Stewart (1947). In order to understand well and more details about accessibility, Ingram (1971) utilized the dataset including 466 enumeration areas in the city of Hamilton, Ontario to measure their accessibility. He has distinguished relative accessibility and integral accessibility where the former was defined as the degree to which two places on the same surface are connected while he later was defined as that interconnection for a given place with all others across urban space. Agreed with the conclusion from Ingram, Dalvi & Martin (1976) have furtherly improved the "integral accessibility" which indicates the inherent characteristic of a place with respect to overcoming some form of spatially operating source of friction. In the same year, Burns & Golob (1976) defined that accessibility denotes the ease with which any land-use activity can be reached from a location using a particular transport system, similar to the definition by Karlqvist (1972) and Black & Conroy (1977). In addition to the associated with the transport system, the availability of satisfactory for potential destinations with respect to a given need (Jones, 1981; Koenig, 1978; Weibull, 1980).

Table 3. 1 Literature review of the definition of accessibility

Author	Year	Definition
Hansen	1959	"Potential of opportunities for interaction"
Ingram	1971	"For this purpose, a measurement-theoretic framework is suggested where accessibility is considered as a property of configurations of opportunities for spatial interaction."
Dalvi and Martin	1976	"Integral accessibility: accessibility indicates the inherent characteristic (or advantage) of a place with respect to overcoming some form of spatially operating source of friction."
Burns and Golob	1976	"Accessibility denotes the ease with which any land-use activity can be reached from a location using a particular transportation system."
Koenig	1978	"The concept of accessibility usually associates both an appreciation of the quality of transport conditions and an appreciation of the availability of satisfactory potential destinations with respect to a given need (e.g. looking for an employment place, shopping, leisure, ...)"
Weibull	1980	"Accessibility is considered as a property of configurations of opportunities for spatial interaction."

Jones	1981	"Accessibility is seen as being concerned with the opportunity available to an individual or type of person at a given location to take part in a particular activity or set of activities."
Des Rosiers et al.	1999, 2000	"The ability of individuals to travel and to participate in activities at different locations in an environment."

Source: Own elaboration

***Accessibility Measurement*[26]**

Ball (1973) have summarized a set of empirical studies on the determinants of relative housing price where Wabe (1971) found that numerous variables forming housing price (e.g. house type, environmental variables, etc.) could be regarded as a function of distance from the city centre and Evans (1973) has pointed out that variables related to distance could explain almost three-quarters of the asking price. Roca (1988) reviewed the accessibility theories and indicated the rent of accessibility in Barcelona city, which aims to exlore the structure of urban value. Many studies supposed and strengthened such conclusion (Li et al. 2019). However, more measures of accessibility other than Euclidean distance have been paid attention in many studies on property value (Ben-Akiva & Lerman, 1977; Hoch & Waddell, 2010). Longley et al. (2005) have concluded that the distance metric in housing price formation is potentially dependent on a set of elements including physical factors, socio-economic factors and administrative geographies. Zhou et al. (2018) and Yu et al. (2012) both analyzed the accessibility measures based on various transport models (e.g. by walking, by car) wherein the former uses travel time and the latter by creating driving time buffers. In addition, Lu et al. (2014) introduced non-Euclidean distance (non-ED) metrics when exploring the housing prices in London market. They compared the estimation results between ED and non-ED metrics by a mixed GWR[27]-HP model and concluded that those non-ED metrics could help HP model

[26] Halden et al. (2000) have summarized the 3 main types of accessibility measurements, including simple measures, opportunities measures and value measures.
[27] GWR here denotes Geographically weighted regression Model

with better fitness and reveal additional and useful insight into the nature of factors forming housing price in the local real estate market. Shen & Karimi (2017) applied a network-based Mixed-scale Hedonic Model (MHM) to reveal the interactions between the spatial layouts and land-use system through various street networks affect housing prices. They emphasized and confirmed the necessity of using the non-ED metric when describing price variation in Shanghai City. Similarly, Wu et al. (2018) preferred to use the hierarchical[28] values for accessibility variables, rather than ED metrics when identifying the spatial features of housing prices in Wuhan, China.

In sum, the previous studies on property value with respect to the location or accessibility dimension are categorized by two approaches. The first approach applies the distance between a housing unit and the nearest CBD while the second one measures accessibility as a function of facilities and residential locational factors. However, there are two main shortcomings that Song & Sohn (2007) suggested:

1) The first approach is inaccurate and incomplete since it does not take the neighbourhood services into account and can't capture overall implicit accessibility.

2) The second approach is less appropriate because those impacts from neighbourhood factors and facilities next to the neighbourhood boundaries are often ignored.

Therefore, Song & Sohn (2007) applied Geographical Information System (GIS) technique which considers establishing accessibility index which considers the numbers and size of properties as well as the distance between a property and census unit. This is the guiding ideology in this thesis when calculating accessibility variables.

[28] Hierarchical value is calculated based on kernel density which considers the interaction between spatial units and specific parameters of factors as different weights.

3.4.2.3 Neighborhood sociodemographic attributes

In fact, those factors which are categorized to dimension "Neighborhood" have played more and more important roles in the formation of the properties value. Kiel & Zabel (2008) proposed the 3L Approach[29] to explore determination of house price by HP method in American and indicated that the concept of "Neighborhood" is multifaceted: 1) local surrounding, such as the maintenance of their blocks[30]; 2) neighbour's demographical and socioeconomic characteristics, such as the household income; 3) a broader and general aspect in the neighborhood, such as the crime rate and school quality.

Chin & Foong (2006) analyzed the formation of housing price in Singapore based on the transaction information from 2000 and 2003. They have introduced nine neighbourhood variables to estimate housing price, including proportion of private properties in zone, proportion of residents in managerial and professional sector in the zone, proportion household in a zone which are owner-occupiers, proportion of residents in a zone which are non-Chinese, number of Good Class Bungalow Areas in the zone, Industrial land area in zone, commercial gross floor area in zone, average primary school intake take-up rate and average secondary school's performance based on mean L1B5[31]. They concluded that the neighborhood's prestige shows a higher impact on housing price, comparing with other attributes.

Clark & Herrin (2000) have brought in numerous variables with respect to neighbourhood quality (e.g. median household income, school quality, the radical diversity, etc.) when analyzing the sold HP within Fresno County in California over the period 1990-1994. Their

---

[29] 3L Approach is the abbreviation of "Location, Location, Location", indicating that prices are determined by the Metropolitan Statistical Area (MSA), town, and street where the house is located

[30] In most hedonic studies, such factors related to urban quality are assigned to "Environmental Attributes"

[31] L1B5 denotes as the abbreviation of first language and best five subjects. It is an indicator to evaluate the educational performance in Singapore.

findings suggested that residents in this county paid more attention to the quality of local schools when buying a new home.

Bayer et al. (2007) indicated that the HP estimation result may be biased if the target household sorting across boundaries among neighbourhoods. As such, they introduced neighbourhood's fixed effects variables into the model, resulting in that the impacts of household income and neighbourhood's average level of education on housing rent per month reduce by 25% and 60% respectively.

Can (1992) proposed a drift indicator "Neighborhood Quality" which integrated with a set of characteristics of socio-economic and public services.

Cervero & Duncan (2004) demonstrated that racial diversity (i.e. racial mix[32]) has a negative impact when using HPM to explore the land value variation within many California communities.

However, Dubin (1992) has pointed that neighbourhood variables in most of the hedonic estimations did not make sense to housing price variation, which may result from the multicentric of city structure or the measurement problems with respect to neighbourhood quality.

A community's crime rate, arts and recreational opportunities, as well as school quality, are important to explain the variation of housing price (Clark & Herrin, 2000; Gibbons & Machin, 2008; Haurin & Brasington, 1996; Pope, 2008; Wen et al., 2014)

Harris (1999) accessed the marginal price of racial aversion by employing a hedonic price analysis and provided evidence of lower property values in neighbourhoods with a relatively

[32] Racial Mix: Normalized entropy = $\{-\sum_k[(p_i)(\ln p_i)]\}\ /\ (\ln k)$, where p_i =proportion of total population in racial category i for 5-mile radius of parcel (where racial categories are: White; African American; Asian American; Other; and $k = 4$ means the number of racial categories).

high proportion of black residents. He indicated that 1) property value decreased by 16% at least when the black accounted for 10% of the total population; 2) the presence of racial proxy hypothesis (i.e. socioeconomic status) promotes resident's living preference with prestige and well-educated neighbours. Finally, he concluded that the type of dwellings' tenure (rent vs owner-occupied) and the percentage of the black in a given neighbourhood should be taken into account when determining which factor, the black race or their social classes, results in a decline property value.

Lynch & Rasmussen (2001) estimated the impact of crime on house selling price in Jacksonville, FL. They concluded the cost of crime did not play an important role in housing price across the whole urban space but in high crime-rate areas, homes are discounted greatly. Similarly, Bowes & Ihlanfeldt (2001) introduced the density of total crimes in the census tract to assess the impact on housing price in Atlanta. Instead of such an insignificant impact of crime, they found that the housing price has shown a 5.6% drop for one additional crime per acre.

Generally, "Neighborhood" attributes are comprehensive and multi-dimensions, which brings in more implicit information and more related to resident's characteristics. For example, Roca (1988) precisely lies with the effect of socio-professional stratification on the formation of land value.

Given the positive and regulating capabilities of diversity in the urban system, Echavarria Ochoa & Roca Cladera (2014) introduced an integrated set of variables related to the land use, the distribution of employment, the income level of the population, tansport accessibility and etc. to assess the distribution of housing prices. In the region of Barcelona, they found that the diversity of employment environment, diversity of economic activities and diversity of land use have considerable impact on the ciucumstance of the regions of Barcelona directly and further indirectly impact on the housing price.

3.4.2.4 Environmental attributes

Luttik (2000) analyzed almost 3000 home transaction in eight regions of the Netherlands and found housing price increase maximally up to 28% for a home with a garden facing the water. They concluded that an attractive environmental landscape, such as closer to water bodies or open space, could bring in an additional housing price premium.

Kong et al. (2007) used GIS and landscape metrics in determining HPM variables in Jinan City. The results confirmed their expectation that the urban green space amenities could be capitalized as a part of housing price.

Chasco & Gallo (2013) explained how the air quality and noise annoyance affect properties value in the centre of Madrid and estimated the marginal price of such two environmental factors by HPM. They introduced four objective ad subjective variables with respect to air pollution and noise annoyance. Interestingly, these two objective variables showed significantly positive impacts on housing price. In other words, the serious environment (severe air pollution and increased noise annoyance) actually result in a marginal price growth which is totally inverse than resident’s subjective opinion.

Jim & Chen (2006) discussed the impacts of environmental elements on housing price in Guangdong, including green space view, proximity to wooded areas and water bodies, exposure to traffic noise, etc. They suggested that the semi-log HPM provided a stronger explanatory power and a more reliable estimation. The first two elements mentioned have positive impacts on property value, contributing notably at 7.1% and 12.3%, respectively. However, exposure to traffic noise did not affect housing price which is supposed that resident’s tolerance of the noise annoyance in Guangzhou is high due to the compact city structure.

Brasington & Hite (2005) argued that the environmental hazard seems a limited impact on housing price when estimating hedonic housing prices in urban areas in Ohio. They indicated that that the 10% closer the distance between a housing unit and a polluted site, the 0.3% reduction of housing price presented. Similarly, Rehdanz & Maddison (2008) found the differences in perceived air and noise pollution are not capitalized into housing price variation.

3.5 Location Equilibrium and Market Failure

3.5.1 Locational Equilibrium and Segregation

3.5.1.1 Prices adjust to achieve locational equilibrium

Locational equilibrium in the real estate market refers to no more changes across urban space, that is, there is no driving force to promote residents’ relocation. Taking the residential market as an example, buyers prefer to have the home with better environment and neighbourhood when comparing two homes charging the same price. Once there are more than two competitors, the winner who is willing to pay more for this target house will get the initiative. Theoretically, the residential market could be reached a locational equilibrium when other competitors find their “ideal homes” and do not have any desire to relocate.

However, this is impossible to happen “Locational Equilibrium” as mentioned above. Residents will have continuous motivation to find a better home than what they currently own if the price across urban space is stationary. In this case, the housing market will never reach market equilibrium. Therefore, the “invisible hand” of the real estate market will adjust this balance by property prices. In other words, you need to pay more rent or housing price if the residential location or the surrounding facilities are better. In this way, competitors who cannot afford the extra housing price will start looking for a home that satisfies their requirement with an acceptable price. Under this dynamic development process, each house may charge various prices to match its value, including special geographic location, surrounding environment, etc. Eventually, a dynamic equilibrium will be formed by the various housing price performances. In fact, this mentioned housing price variation is an integrated concept which capitalizes the characteristics of the location, neighbourhood as well as the environment (more details in Section 3.4.2).

3.5.1.2 Self-reinforcing effects generate extreme outcomes

The self-reinforcing effect in residential market refers that changes of the house itself will lead to other changes. In short, firstly hypothesized that all residential quality is evenly distributed across space. When a large number of high-quality houses are gathered, the self-reinforcing effect occurs. This extreme result may be the spillover of housing price expectation or the enhancement of attractiveness to high-income households or high-prestige constructors continue to develop residential projects in the same area or high-value commercial brands settle in, etc. All these reasons will result in the agglomeration effect in this area, which performances like the consolidation of social classes or the sharing of knowledge.

In any case, the impact of the self-reinforcing effect is multi-dimensional and diversified in the real estate market, which should be observed in a combination with multiple aspects of knowledge.

3.5.2 Market Failure

3.5.2.1 Externalities cause inefficiency

Firstly, we should clarify what is an externality. Ideally, the cost and benefit of a housing transaction process will exclusively involve buyers and sellers. If the cost and benefit in this process are borne or accepted by other third parties, the behaviour will lead to the externality emergence. When the transaction cost is borne by a third party, we call this situation "external diseconomy", otherwise, the benefit is accepted by a third party bringing "external economy".

As far as urban development is concerned, almost every behaviour will be accompanied by external economic and dis-economic results. Generally, they do not appear solely in the transaction process. The third-party regarding the real estate market may derive from the aspect of society, environment or even neighbourhood. For instance, the beneficiary (i.e. homeowners) have a better living experience after the house is renovated or furnished. Furtherly, the owners could ask for an additional charge when selling the house to cover the cost of the renovation. The external economy at this time is also reflected in the neighbour who is the third party that enjoys the spillover of a housing price premium. However, this refurbishment behaviour also results in an increased cost for those households who plan to buy properties in the same region. We usually do not declare theoretically that certain behaviour is the purely external economy or diseconomy but firstly identify who is the subject of the analysis.

Since externalities exist, the equilibrium of the market will also be broken, i.e., the market is inefficient. In other words, those third parties who enjoy the benefits resulting from the external economy will continue to chase similar behaviour, and even strengthen it for self-profit. On the contrary, those who are damaged by such external dis-economic behaviour may look for measures to avoid the loss. In the above example, neighbours who are the beneficiary may also adopt the same renovation behaviours to strengthen such economic effects. However, the tenants who are living in the same region may move to another neighbourhood to avoid the rent increase. At this time, the dynamic equilibrium of the market itself is broken, leading to an inefficient market.

In general, the solution to externalities is mainly to internalized externalities. As far as the housing market is concerned, tax regulation and subsidy policies (e.g. mortgage) could effectively reduce the interference of externalities on the equilibrium market.

3.5.2.2 Imperfectly competition

First of all, perfect competition means that there are no restrictions on entering and exiting a market. The market will eventually become balanced and reach a state of zero economic profit as new participations constantly join and drop out. According to the definition of economics, economic profit refers to the difference of the total income minus economic cost which includes the basic cost of input and the corresponding opportunity cost. As such, the zero economic profit refers that there is no excess benefit in real estate market, just leaving the normal accounting profit. In the case of the residential market, a large number of competitors floods into this profitable area for a transaction until the excel profits have been divided up, keeping a stable and equilibrium statement.

However, the perfect competition market, as we know, is impossible in the housing market. In addition to the requirement “without excess profit”, there should be more three characteristics for perfect competition: 1) the existence of a large number of buyers and sellers who have complete elasticity of demand and supply for housing; 2) Homogeneity of productions. It requires that the houses are the same, including the tangible characteristics (e.g. structural quality) and intangible characteristics (e.g. locations). This is to avoid the emergence of monopoly benefits due to the differentiation productions, i.e. the houses should be completely replaceable with each other in the perfect market; 3) information completeness. It refers that all information in the entire housing market can be mastered at no cost by both parties, particularly transaction information on prices of supply and demand), helping those stakeholders make their own optimal decisions and obtain maximum economic benefits.

3.5.2.3 The residential market of "Lemon"

Akerlof (1970) firstly proposed a problem "the market of lemon" and tried to reveal the market an dpricing effects of information asymmetries between buyers and sellers. He made an example of the car selling in a second-hand car-selling market and hypothesized there were high-quality and low-quality cars. Supposed that buyers could not identify the difference of cars' quality, buyers were willing to pay the average price between better cars and worse cars. Nevertheless, sellers knew all the information about their production-cars, especially which one is the "Peach"[33]. Under the premise that the price buyer is willing to pay (WTP) is fixed, the transaction will be made when the seller's car is a "**Lemon**". Instead, the seller will close this transaction if the selling car is a "Peach". This paper explained a reality that why sellers could sell low-quality goods to the buyers is because the asymmetry of the information held by both parties in the market. In contrast to the "good money drives out bad money" conluded by the competitive mechanism in the tranditional market, an adverse-selection characteristics resulting from information asymmetry are produced. That is to say in the car-selling market above-described, no high-quality cars are willing to enter this transaction. Thus a huge number of low-quality cars begins to flood the market, which gradually results in a cutting-WTP from the buyer's perspective. Finally, there won't be any transaction in such market with a pool of worst cars.

Based on Akerlof's classic adverse selection market, Levin (2001) furtherly solve the question – "do greater information asymmetries reduce the gainsfrom trade?". He confirmed better information the seller have cause the "buyer's curse", resulting in a lower demand from buyers or furthermore a change of supply mode. The effectiveness of market depends on the relationship between such demand and supply modes. Particularly, strengthering buyer's

[33] Here peach denotes the a high-quality car while lemon, a low-qulity car.

information acquisition absolutely improves the market condition when the consumer's demand is downward sloping.

Subsequently, some researchers began to discuss the "Lemon problem" in real estate market. Chee (2012) detailly discussed the possibility that the Akerlof's adverse selection market occur, when analyzing which indicator in Hongkong real estate market reveals more dwelling's information to buyers. He pointed out that market failure may be the inevitable outcome if buyers do know anything about the production they want to buy. However, when a buyer is willing to purchase a property, some basic information about this real estate, such as the location, accessibility or neigborhood quality, are easy to obtain or inspect. Therefore, talking about the "Lemon problem" in real estate market should be more careful.

Concerning the asymmetric information in the office market, Lützkendorf & Speer (2005) indicated that adverse selection is applicable to the ransaction marke for properties. They found even though the tenant has checked and inspected the office before moving in, the bad experiences in relation to office service or the detailed quality also may happen. That is to say before signing the contract, all the faults are intangible. Since managers are regarded as suppliers of information in the office market, the lack of manager-related information is fatal which mainly contributes the information asymmetry occurs. Agreeably, Palm (2015) analyzed the existence of "Lemon problem" in Malmö CBD office market and confirmed the market for advertisement of office properties have adverse selection issue.

In order to explore what measures could help to solve the "Lemon problem" in the residential market, Daughety & Reinganum (2008) proposed that when quality is exogenous, economic models of such communication take two alternative forms: 1) disclore of quality through a credible direct claim; or 2) signalling of quality via producer actions that influence buyers' beliefs about quality. they indicated that mandatory disclosure play a significant role in the information symmetric which means all the information are disclosed with a benefit to consumers, because the price falls to the full information line from the price signalling line. The study of Benjamin et al. (2006, 2007) suggested that signals of quality play an important role in the real estate market when information asymmetry occurs.

In fact, some studies and organizations have proposed various building information system[34] with an overall data pool for building information, from which certain information could be obtained without any obstacles. However, almost such tools are available for new or sigle-ownership buildings. In order to reveal the quality of existing multi-ownership buildings, an Building Classification System (BCS) by Chau et al. (2004) and Building Health and Hygiene Index (BHHI) by Ho et al. (2004) are proposed sequentially. Furtherly, Ho and Yau (2004) developed another index Building Safety and Conditions Index (BSCI) for evaluating a building's safety performance according to the experiences of study about BHHI.

Concerning the improvement of building energy efficiency and environmental protection, numerous studies have concluded that market-based incenives are both efficient and effective tools avoiding an energy-efficient lemon market (Dennis, 2006; Jaffe, et al., 2002; Qian & Chan, 2007, 2008).

Chegut et al. (2014) pointed out that building certification in the commercial real estate market could help the corresponding stakeholders (i.e. building developers, investors and tenants) have a better intermediation process, generally depending on the relationship between a property's quality and efficiency. This process may avoid the ineffective investment occurred to the "Lemon" properties.

[34] Including Building Information System (BIS) by Lützkendorf and Speer (2005), BREEAM, GBTool, LEED, EPC (Larsson, 2004)

Sedlacek & Maier (2012) argued that the uncertainty about the building's quality for investors and the deceptive or concealment behaviors by developers may result in a prisoners' dilmma trap. They analyzed the corresponding obstacles for a green residential market and indicated that Green Building Councils (GBC) could act as a third party to reduce and even avoid the happening of information asymmetry in the real estate market.

Qian et al. (2013) have discussed the information asymmetry plays a significant role in the promotion of Building Energy Efficiency (BEE) which furtherly cuttailed the developers' benefits. They also suggested some policy recommendations to induce the developers into the BEE market by reducing transaction costs and enhancing information transparency.

Generally, housing quality including BEE is a multi-dimensional conception, which brings in a complicated theoretical and practical consideration. Thus, how to employ measures in relation the "signals" or volunteer disclosure of quality should be evaluated in details.

CHAPTER 4

SPATIAL STATISTICS THEORIES

CHAPTER 4 THEORY OF SPATIAL ANALYSIS AND SPATIAL STATISTICS

As the main theoretical basis of this dissertation, this chapter is to introduce firstly spatial statistics and its theories where the definition of key term/index and theoretical basis are explained. Then two important spatial issues: spatial autocorrelation and spatial heterogeneity is explained in details. Finally, a literature review of spatial impacts on urban studies is listed and the development of spatial analysis is discussed.

4.1 Introduction

4.1.1 Theory Evolution

Spatial analysis has existed for a long time in history, and its development has become more mature with the advancement of science and technology. Murayama & Thapa (2011) pointed out there are four original current disciplines of spatial analysis: 1) quantitative geography which began in the United States in the 1950s; 2) regional science which is based on regional economics was founded by Isard (1956); 3) Spatial statistics which is based on statistics was proposed in the early 1990s (Anselin, 1988; Ripley, 1984); 4) computational geometry which was led by information scientists was developed from 1970s. Nonetheless, it is very difficult to define spatial analysis due to the complexity, variability, and multidisciplinary nature of spatial questions. Instead of defining this concept, Bailey gave a conceptual description of spatial statistics:

"A general ability to manipulate spatial data into different forms and extract additional meaning as a result."

(Bailey, 1994, p15)

"In broad terms, one might define spatial analysis as the quantitative study of phenomena that are located in space."

(Bailey & Gatrell, 1995, p7)

Actually, a vital concept -Tobler First Law (TFL) - was proposed by Tobler at the end of the second phase.

"………all attribute values on a geographic surface are related to each other, but closer values are more strongly related than are more distant ones."

(Tobler, 1970)

This concept established the theoretical basis for the development of spatial analysis. Then in 1973, Ord & Cliff argued for the spatial autocorrelation which was ignored in the beginning two phases. Their work was focus on the statistical estimation and test methods that try to solve the spatial dependency problem. Subsequently, Ripley (1981) integrated and proposed a comprehensive explanation of spatial statistics. This work discussed systematically the process of spatial statistics, including spatial sampling, smoothing and interpolation, regional and lattice data, etc. Similarly, Anselin (1988) enabled the concepts of spatial effects: spatial dependency and differences based on the theory from Moran (1950).

All in all, spatial statistics is a branch of classic statistic, which considers the specific location of elements. Therefore, considerable terms and basic concepts in classic statistics need to be re-defined in accordance with the characteristics of spatial location.

4.1.2 Theoretical Basis of Spatial Statistics

4.1.2.1 Spatial probability

As a description of the possibility of something happening, "Probability" in classic statistics is a multiplier by the probabilities of specific independent cases. However, in the spatial statistic field, it should be a joint probability in accordance with the TFL. As Tobler said, a closer distance brings a higher correlation. It means the distance enforce an additional possibility to some extent despite the probability of an independent case happening.

4.1.2.2 Probability density

Probability is the ratio of the probability area between a possible range divide by its length. Generally, the distribution is normal in accordance with the probability theories. In the spatial area, this density could be regarded as the ration of the volume where the centre is a case's location and a circular area is the scale range

4.1.2.3 Uncertainty

Uncertainty is passable across the geography. That is to say this data's uncertainty results in the same uncertainty of estimation results. This uncertainty may come from the measurement, or the observer itself or uncompleted data collected. Therefore, it is necessary to explore the reason for such uncertainty and to study how this uncertainty impacts on results.

4.1.2.4 Statistical inference

Statistical inference is one of the most important tools in an analysis of spatial data. In Classic statistics, this inference can analyze data's performance by a small sample and then deduce the possible results for a sample population popular. However, there is not an independent possibility for spatial statistics due to the TFL and neither the process of sampling because of the limitation of data collected. In such case, spatial statistics commonly analyze in an overall and then verify for the partial.

4.1.3 Hypothesis and Pattern in Spatial Statistics

4.1.3.1 Null hypothesis in spatial statistics

The null hypothesis is a pre-established assumption when performing a statistical test. Firstly, it is necessary to assume for results a numerical interval which is generally consistent with a certain probability distribution. Then the estimation results will be compared with the predicted one. If the estimation deviates from the predicted range, it means that there is a small possibility to meet this pre-assumption. This is to say the null hypothesis is rejected by this estimation result.

In spatial statistics, the null hypothesis refers to the spatial position in a certain area with a completely random distribution. In this sense, the objective for spatial analysis is to explore the reasons resulting in the null hypothesis rejection.

4.1.3.2 Distribution pattern in spatial statistics

In classic statistics, distribution patterns are identified based on the characteristics of traditional distribution functions and models. This identification is the most important process for statistical analysis. For spatial data, not only the characteristics of the distribution of factors in numbers are identified but also the spatial distribution should be paid more attention, which may bias the final estimation results. In a narrow sense, spatial statistics is exploring spatial distribution patterns. Generally, spatial distribution patterns focus on cross-sectional data where locations are fixed in the given period[35].

Spatial distribution pattern consists of random and non-random patterns. In the former, it could be identified as normal distributions randomly or evenly. For the latter one, it is also could be regarded as the Poisson pattern which consists of aggregation or dispersion.

4.2 Spatial Relationship

The most difference between spatial statistics and classic one is the integrated process which links the spatial information and relationship together when analyzing. Therefore, it is necessary to conceptualize spatial relationship before analyzing spatial data. In a narrow sense, spatial location is usually represented by distance. It means units such as meters or minutes by car are usually used when describing the spatial relationship between two objects. Nevertheless, this relationship depends on the perspective of observers and state of data in a broad view. In this section, the six spatial relationships used mainly for urban analysis are introduced.

4.2.1 Inverse Distance/Inverse Distance Squared

This spatial relationship is expressed as an impedance or distance attenuation. According to TFL, any element will affect other. It is to say a closer distance, a higher impact. This inverse distance is classified by Euclidean Distance (ED) and Manhattan Distance (MD). The former is generally suitable for modelling continuous data (e.g. temperature changes, space humidity) and the latter is used for spatial data with a fixed location.

[35] The panel data includes spatial and temporal information. This temporal-spatial data doesn't discuss here.

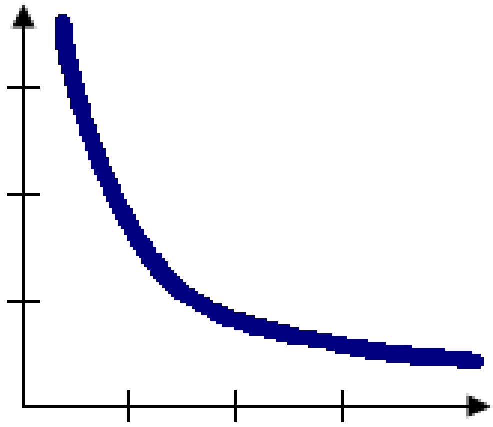


Figure 4. 1 Inverse distance

Similarly, inverse distance squared is expressed as a steeper and more attenuation curve which means neighbours' impact changes dramatically along with the distance (Figure 4.1). Theoretically, do not use the power more than 3.

4.2.2 Fixed Distance

This spatial relationship is the expressed by a fixed distance. that is to say, the impacts in a fixed scale range are the same whatever the distances between two neighbourhoods. The neighbours do not affect each other if they are not on the same scale. Therefore, its spatial matrix is a standard matrix consisting of 0 and 1 (Figure 4.2).

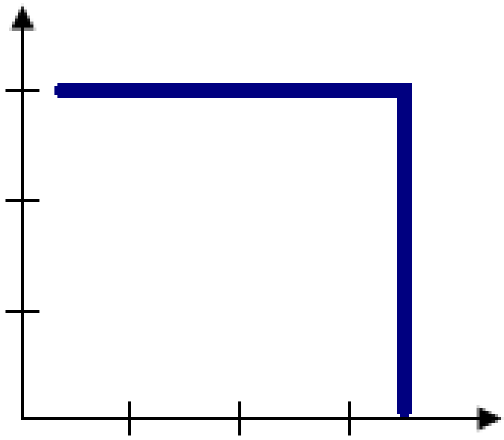


Figure 4. 2 Fixed distance

4.2.3 Zone of Indifference

Actually, this is a mixed relationship consisting of the two above-mentioned ones. It means impacts are the same in a beginning fixed scale and then the impacts attenuate along with distance. Theoretically, a threshold and a form of attenuation curve should be set in accordance with the specific objective (Figure 4.3).

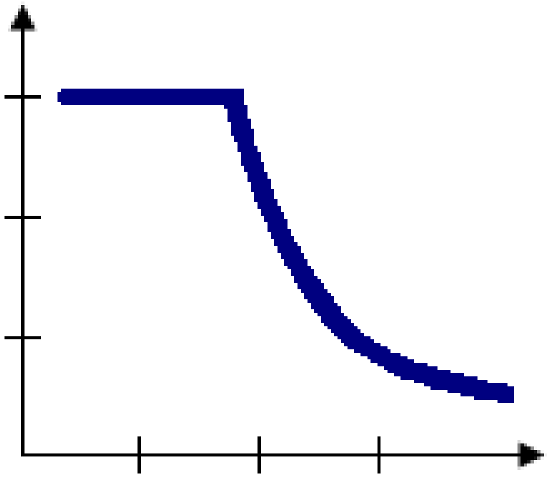
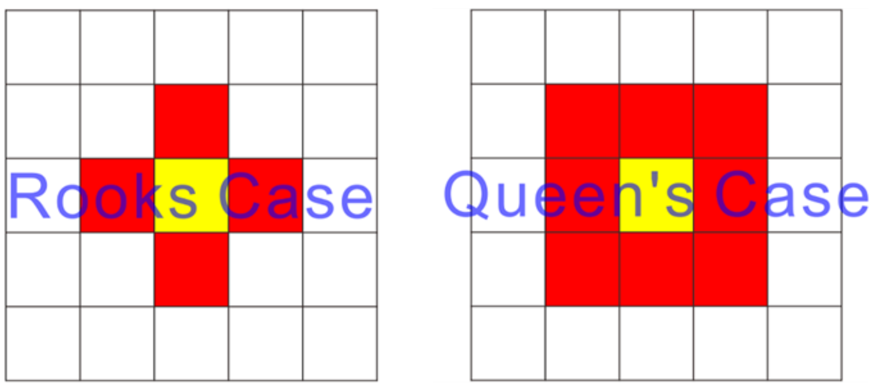


Figure 4. 3 Zone of indifference

4.2.4 Polygon continuity

Commonly, the possible forms for polygon data are cross, cut, separate, include, etc. To figure and ease their relationship, the concept of polygon continuity consisting of Rook's case and Queen's case is proposed (Figure 4.4). The former is for the polygon shared with the line while the latter is for that shared with line or angles.



(a) *(b)*

Figure 4. 4 Polygon continuity
(a Rook's case; (b) Queen's case

4.2.5 K-Nearest Neighbours

This relationship means the cases in a given range are neighbours. The difference between fixed distance and K-Nearest Neighbours (KNNs) (Figure 4.5) is the threshold for the former is the distance in meters while the latter one is the number of neighbours. It is an adjustive method to calculate the spatial relationship. The advantage of this relationship is to confirm at least one neighbour, especially for those data are sprawled across the study area.

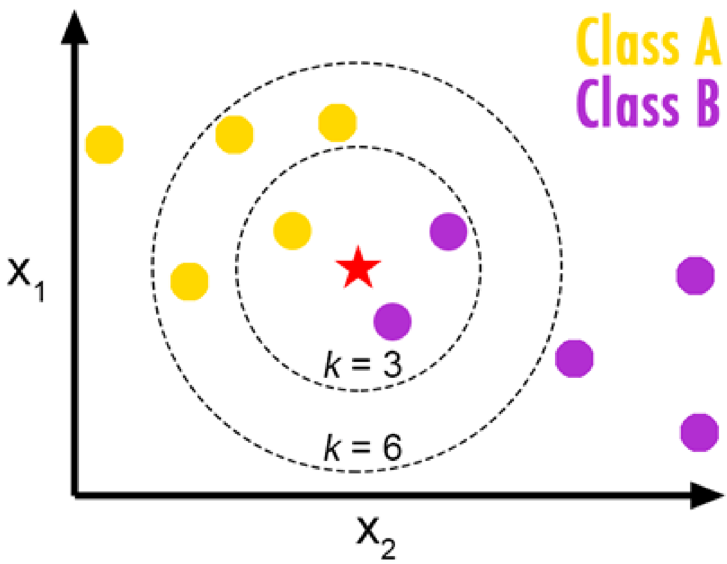


Figure 4. 5 K-nearest neighbours

4.2.6 Delaunay triangulation (naturally adjacent features)

This spatial relationship is depicted by a triangulation net for point data (Figure 4.6). Firstly, a Voronoi triangle should be built by original point data and then those adjacent polygons are regarded as neighbours. Similar to KNNs, this relationship also can guarantee at least one neighbour and moreover, better for those cases super far away.

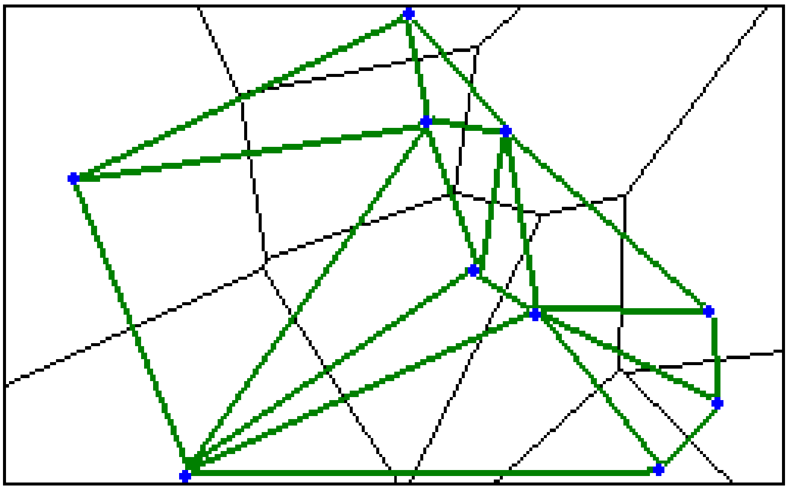


Figure 4. 6 Delaunay triangulation

4.3 Spatial Characteristics and Methods

As stated previously, the understanding of the impact of spatial relationships was limited by science and technology before the 1990s. With the rapid development of computational technology and geographic science, researchers have paid more attention to identify characteristics of spatial data firstly and moreover began to explore the methods to solve spatial intrinsically problems. To date, there are two main approaches to deal with spatial data. The first method is data-driven which is to explore primarily the potential distribution of spatial data and further to compare with the classic statistical distribution in accordance with the null hypothesis (i.e. observations across space are homogeneous). Nevertheless, this kind of homogeneous distribution across space seems impossible with respect to reality (Jiang, 2018). In other words, the probability of an event occurring in adjacent places may not be independent, which may lead to failure or estimations biases when using the data-driven approach. The other method is model-driven, beginning with theoretical specification and then verifying by data. The most character for this approach is the spatial data is estimated with particular techniques related to “space” (e.g. the choice of the spatial matrix).

Regardless of which approach used, understanding characteristics of the data is prior for spatial analysis. In this respect, spatial dependency and spatial heterogeneity were introduced and relative measures to solve these spatial issues were also established. An introduction of spatial dependency and heterogeneity will be presented, including their defines and statistical methods.

4.3.1 Spatial Autocorrelation

Spatial autocorrelation was captured by Tobler's first law of geography which implies the distance is a key tool to present the relationship between neighbours. Spatial autocorrelation is defined as the correlation between feature values of a single variable in different locations, referring to the proximity of features in geographic space (Tobler, 1970). In statistics, the independent probability is the theoretical basis but this spatial proximity leads to a dependent relationship between the observation and its neighbours. Spatial autocorrelation statistics aims to identify the level of interdependence and measure its characteristics (Fortin et al., 1990). Spatial autocorrelation is classified as positive or negative where the former has similar characteristics together and the latter, inverse.

4.3.2 Spatial Heterogeneity

Unlike the similar aggregation of spatial autocorrelation, spatial heterogeneity represents the differences between the global and local distribution which resulted from various locations. In practice, “global” here is expressed as an average while the “local” shows the performance in a given or smaller region from the whole sample scale. Generally, the appearance of spatial autocorrelation is accompanying with the spatial heterogeneity and even is produced by the elements behave heterogeneously across space (Darmofal, 2015a). In this sense, the ignorance of such heterogeneity may lead to a misspecification spatial model and moreover produce a biased estimation result. Therefore, it is necessary to consider spatial heterogeneity.

4.3.3 Statistical Methods

The most commonly used measures for spatial autocorrelation are Moran’s I statistic (Moran, 1950), Geary’s C statistic (Geary, 1954), and Anselin Local Moran’s I (Anselin, 1995). The first two are mainly to explore the global spatial autocorrelation whereas their local version (e.g. LISA) aims to study such correlation in details. Concerning spatial heterogeneity, Monte Carlo test provide a convince diagnostical result to explore such non-stationary impact. Thus, this section introduces the four above-mentioned methods and their theories.

4.3.3.1 Moran's I terms

To identify this spatial correlation, Professor Patrick Moran in 1950 published a work which first proposed an integrated index -Moran's I (1950). This index is known as the first signpost of spatial statistics and commonly used in spatial statistical algorithms. Two main advantages using Global Moran's I are: 1) the best method to explore whether there are some characteristics of distribution for spatial data; 2) applied in almost spatial analysis when exploring the suitable distance.

The principle of Moran's I is a multiplier of factor's attribute and their spatial relationship, which helps to determine the spatial distribution pattern. Moran's I is defined as the following equation:

$$I = \frac{n}{S_0} \frac{\Sigma_i \Sigma_j \omega_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\Sigma_j (x_i - \bar{x})^2} \tag{4.1}$$

where

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} \omega_{i,j}$$

the z-value, as the determination of spatial autocorrelation, is listed as regards

$$z_I = \frac{I - E[I]}{\sqrt{V[I]}} \tag{4.2}$$

Then, the expected value and variance of I_i are given by

$$E[I] = -1/(n-1) \tag{4.3}$$

and

$$V[I] = E[I^2] - E[I]^2 \tag{4.4}$$

Where the n is the total number of spatial units; i and j indicate the specific unit; x is the variable's attribute; $\bar{x}$ is the mean of x; ω_{ij} is a spatial matrix and S_0 is the sum of all ω_{ij}.

For Moran's I, the first and foremost thing is to confirm the spatial matrix by calculating the spatial relationship for all spatial units. To ease the computation, this spatial relationship is represented as a sparse matrix. Then deviations are calculated by the specific spatial unit subtracting the total average, helping to measure the degree of data's dispersion. Next, an overall degree of deviations is calculated by the multiplier between deviations and spatial weights divide the sum of squared deviations. Finally, a general score to identify the spatial correlation is produced by multiplying the overall degree of deviations and the total weight coefficients.

The range of Moran's I should be from -1 to +1, after standardizing the spatial matrix. This index provides an overall result to show the spatial distribution pattern of all the sample.

- If Moran's I is more than zero, it means positive spatial correlation. The value is larger, the spatial correlation is higher. This is to say the value of between the target spatial unit and its neighbours has a similar performance: High-Hight or Low-Low.

- If Moran's I is less than zero, it means negative spatial correlation. The value is smaller, the spatial difference is larger. In contrast to the positive correlation, the negative performance is polarization: High-Low o Low-High.

- If Moran's I is equal to zero, it means the data is randomly distributed.

4.3.3.2 Geary's C

In addition to Moran's I, Geary's C statistic was proposed subsequently by Robert Charles Geary in 1954. Similar to Moran's I, this measure is a test to determine if observations are aggregated with the same characteristics in a global sense. Geary's C is defined as

$$C = \frac{(n-1)}{2S_0}\frac{\Sigma_i\Sigma_j\omega_{ij}\left(x_i-x_j\right)^2}{\Sigma_j(x_i-\bar{x})^2} \tag{4.5}$$

Where the n is the total number of spatial units; i and j indicate the specific unit; x is the variable's attribute; $\bar{x}$ is the mean of x; ω_{ij} is a spatial matrix with zeros on the diagonal (i.e., $\omega_{ii} = 0$.) and S_0 is the sum of all ω_{ij}.

The value of Geary's C smaller than 1 demonstrates a positive autocorrelation, whilst values greater than 1 corresponds to a negative spatial autocorrelation (Sokal and Oden 1978). The most difference between Moran's I and Geary's C is that the former shows a deviation comparison between an observation and the mean of all sample while the latter pays more attention to local deviation (i.e. neighbour's deviation).

4.3.3.3 Local Indicators of Spatial Association (LISA)

As above-stated, global Moran's I and Geary's C provide a general description of spatial pattern for the whole sample. However, researchers have realized that the spatial distribution unlikely always show a stationary status, especially for a huge number of spatial units (Ord & Getis, 1995). To explore individual local clusters within a region or search for heterogeneous regional patterns, Getis & Ord (1992) developed a local spatial autocorrelation statistic Gi(d) introducing a distance parameter d to a weight coefficient ω_{ij} to measure spatial proximity of spatial objects. Subsequently, Anselin (1995) proposed a new concept -Local Indicators of Spatial Association (LISA) - to describe the local performance of spatial correlation. LISA is defined as the statistic following two requirements:

- the LISA for each observation indicates the extent of significant spatial clustering of similar values around that observation
- the sum of LISAs for all observations is proportional to a global indicator of spatial association

The local Moran statistic for an observation i is defined as the following equation:

$$I_i = z_i \sum_j \omega_{ij} z_j \tag{4.6}$$

Similar to global Moran's I, z_i and z_j are in deviations from the mean in the spatial unit i and j. The sum of j is the neighbours around i, defined by the specific spatial matrix. That is to say, the final local Moran's I for i is an average of the sum of neighbourhoods' standard deviations.

In contrast with global Moran's I, LISA provide a set of indicators for each individual observation, including Local I Index, Z-score, P-value and Cluster Type. The meanings of the beginning indicators are the same as global Moran's I. Furthermore, the spatial patterns are performed for each observation. Figure xx shows the possible patterns by a four-quadrant map.

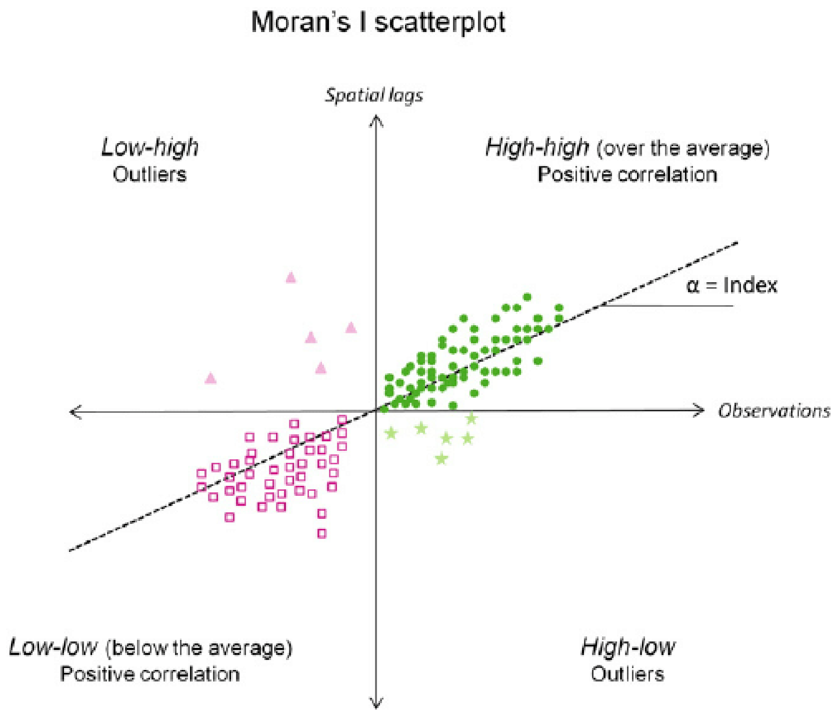


Figure 4. 7 LISA four-quadrant map

In the map, the X-axis represents the value of observation and the Y-axis, as the spatial lags, is actually the value of neighbours. In detail, the first quadrant is the High-Hight clusters where the value of the observation and its neighbours are high. That is to say, the high-value observation is surrounding by high-value neighbours. Similarly, the third quadrant represents low-value observation is surrounding by low-value neighbours. For the second and fourth quadrant, observation is surrounding by the neighbours who show converse performances on value (High vs Low). To some extent, it could help recognize outliers.

Although local Moran's I could provide the detailed indicators for each observation, Anselin suggests it is necessary to test the spatial correlation firstly by global Moran's I and then by local index. Considering the issues of pretesting and multiple comparisons caused by the two-pronged strategy, an adjustment of the significance levels has to do to mitigate such effects (Anselin, 1995).

4.4 Spatial Models

Spatial attributes, the most characteristics for spatial data, consists of various, complex, multiscale information across space. Especially in urban studies, almost elements are linked to their location and moreover, the location may play a vital role in the implicit performance of elements. Therefore, it is inevitable to carry out spatial modelling on the characteristics of spatial data.

4.4.1 Overview of Ordinary Least Square Model

Before introducing the spatial model, a back review of Ordinary Least Square (OLS) is necessary. OLS is a type of linear least squares methods, aiming to estimate the unknown parameters in a linear regression model by introducing a series of independent variables and minimizing the deviation between the observed value and predicted value. OLS is defined as the following equation:

$$y = X\beta + \varepsilon_i \quad (4.7)$$

Where y is the $n \times 1$ vectors of the dependent variable and ε_i is the errors for the various observations. X is a matrix of regressors which consists of a series of independent variables and β is the corresponding coefficients for each independent variable.

As the most basic model in statistics, OLS has widely used in various urban studies and subsequently, more complex models and methods, based on OLS, are proposed to solve realistic problems. Considering the spatial attribute of the interest objects in urban studies are common, it is very important to apply the linear regression into spatial analysis. In this section, four models to solve the characteristics of spatial data (i.e. spatial autocorrelation and spatial heterogeneity) are introduced.

4.4.2 Spatial Lag Model

Typically, researchers prefer to estimate parameters to an ideal status (e.g. normal distribution) by means of transforming the form of data. Nevertheless, the existence of spatial dependency indeed has broken the specification of traditional models where independence and homogeneity are required for data. Ord (1975) firstly pointed out that the spatial lag model could be applied to avoid such unexpected influences if this potential dependent relationship is spread through neighbours' continuity and correlation. Considering this spatial dependence may spread anywhere, he specified the hypothesis for SLM where this dependence relationship does not exist in the error term with a normal distribution. In this occasion, a spatial lag model is defined as follows.

$$y = \rho \cdot W_y + X\beta + \varepsilon \quad (4.8)$$

Where y is the dependent variable with a $n \times 1$ vector and X, β, ε are the same meaning as Section 3.4.1 explained. The parameter, ρ, is the estimation of spatial autocorrelation if there is indeed a spatial lag dependence. W_y is the spatial matrix which represents the detailed spatial relationships.

As can be seen in the equation's specification, this spatial matrix is established by the target value (i.e. dependent variable) between the interested observation and surrounding neighbours. Theoretically, the ignorance of spatial dependence will bias the estimation of ρ. Pure SLM is also expressed as spatial autoregression model (SAR). It captures the spatial dependent relationship including the external effect and spatial interaction. Considering the characteristics of a spatial relationship, two popular estimation methods for SLM are presented as regards.

4.4.2.1 Maximum Likelihood Estimation-Spatial Lag (MLE-SL)

MLE is recommended to solve the spatial dependence if there is spatial diffusions in accordance with the diagnostic results of OLS. Smirnov & Anselin (2001) pointed out the most difficulty in MLE-SL is to evaluate the parameter ρ for each observation. Concerning to ease this computational problem, Ord (1975) has suggested to use eigenvalues of the spatially weighted matrix W which is calculated exclusively once. The most advantage of MLE-SL is the satisfaction of consistency, asymptotic efficiency and asymptotic normality by using the eigenvalue of the spatial weighted matrix. However, MLE for the spatial lag model is limited to employees in a large number sample. The precision of ML estimation results falls down as the number of sample increases (Bell & Bockstael, 2000). As a result, a quasi-maximum likelihood estimator (QMLE) was proposed for the spatial lag model with a large number of observations (Lee, 2004).

4.4.2.2 Instrumental Variable Estimation-Spatial Lag (IV- SL)

The instrumental variable method is used widely to solve the endogeneity issue resulting in asymptotically biased estimates (Reiersøl, 1945). This method aims to introduce an instrumental variable in relation to that endogenous variables to control and correct the biased estimation results. Concerning to spatial analysis, the spatial interdependence is an endogenous issue which is always ignored in researches. As a result, such ignorance spatial information may be integrated into a special omitted variable, thereby increasing the deviation of estimation results (Betz et al. 2017).

4.4.3 Spatial Error Model

Darmofal (2015b) has demonstrated that the spatial model should be established on the error term if the OLS diagnostic results indicate the existence of spatial error dependence. Spatial error dependence is expressed as the correlation between the factors of neighbours that having an impact on dependent variables but excluding in the spatial model. In order to address such "error" impacts on estimation, Spatial Error Model (SEM) was proposed and defined as:

$$y = X\beta + \varepsilon$$

$$\varepsilon = \lambda W_{\varepsilon} + \xi$$

Where y, X, β, ε are explained in Section 4.4.1. W_{ε} is a spatially lagged error term with spatially weighted matrix W and λ is the spatial autoregressive parameter for the spatial error term. Noted this autoregressive parameter λ is not consistent, resulting in a bias estimation result. In the above equation, ξ is assumed to be independent normally distributed

In contrast to spatial lag estimation, the dependence resulting from error term spatially pays more biases to standard errors of the regression rather than the estimation coefficients. This may furtherly cause the final estimation results with some mis-inferences: 1) the regression coefficients are invalid as the standard error has been estimated biasedly; 2) the significance test for the regression does not make sense resulting from the biased variances and standard error. In this sense, two approaches, ML and Generalized Least Squares (GLS) are recommended to address this spatial error issue. As already stated, the ML approach is the most used and popular method to solve the spatial dependence problems. Here GLS will be introduced briefly. Magnus (1978) developed the ML approach to the estimation of GLS in the error covariance matrix and then Anselin & Bera (1998) confirm this method is useful to address the spatial error issue.

4.4.4 Geographically Weighted Regression Model

According to Tobler's first law of geography, the closer the distance is, the more correlated across space. Generally, spatial autocorrelation and heterogeneity are mutually related. Once one of such spatial characteristics is discovered, the alternative one should be considered into analysis to avoid biases. Spatial heterogeneity is also expressed as spatial non-stationary which has attracted huge attention from researchers in various fields. To date, the most used widely model to address spatial heterogeneity is Geographically Weighted Regression (GWR) model. Practically, GWR is a modelling technique for spatial statistics and aims to explore the changes in spatial relationship among variables. Brunsdon et al. (1996) firstly proposed the GWR model which was defined basically as following

$$y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{n} \beta_j(u_i, v_i)\, X_{ij} + \varepsilon_i \qquad (4.9)$$

Where (u_i, v_i) denotes the coordinates of the i point in the space and $\beta_j(u_i, v_i)$ is a spatial location function at i point.

Although it seems that there are more omitted variables than the collected ones in accordance with the equation, the employing of GWR model is still predominated in discussing spatial heterogeneity (Fotheringham et al. 2003, p.66). To avoid such impact derived from omitted information, Fotheringham et al. (2003) have calibrated this model by assuming the coefficients are deterministic functions of spatial location rather than those are randomly distributed. The spatial location function and spatial matrix are as following:

$$\beta = \begin{bmatrix} \beta_0(u_1, v_1) & \beta_1(u_1, v_1) & \dots & \beta_k(u_1, v_1) \\ \beta_0(u_2, v_2) & \beta_1(u_2, v_2) & \dots & \beta_k(u_2, v_2) \\ \vdots & \vdots & \vdots & \vdots \\ \beta_0(u_n, v_n) & \beta_1(u_n, v_n) & \dots & \beta_k(u_n, v_n) \end{bmatrix} \tag{4.10}$$

and

$$W(i) = \begin{bmatrix} w_{i1} & 0 & \dots & 0 \\ 0 & w_{i2} & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & w_{in} \end{bmatrix} \tag{4.11}$$

Where β consists of a $(n \times k)$ vector for local parameters and w_{in} is the weight given to data point n in the calibration of the model for location i.

As spatial heterogeneity stated in Section 4.3.2, the performances of variables in the different spatial unit are not analogous. In such case, the GWR model provides a good place for each region to explore independently their specific model. The identification of spatial relationship is the key to building a spatial weighted matrix. Concerning to GWR model, the distance between observations is responsible for the shape of spatial clusters. Consequently, spatial relationship related to "distance" is the optimal choice when establishing the spatial matrix.

As stated in Section 4.2, there are several alternative weights matrices have been proposed, i.e., Gaussian kernel function, Bi-square kernel function and K-nearest neighbour kernel function where the Gaussian kernel function is the widely used for spatial matrix. It is expressed as the form

$$w_{ij=} exp\left[-1/2\left(d_{ij} \;/\; b\right)^2\right] \tag{4.12}$$

Where d_{ij} is the distance between points i and j while the b denotes the bandwidth, reflecting the distance-decay of a spatial weight matrix. As Figure 4.8 shown, the weight is the maximum when a data point shares the same location with a regression point. Simultaneously the weight declines as the distance increases between the data point and the regression point. In contrast to the general weight matrix, the GWR model provides a set of sub-regional weight matrices to explore the differences across space.

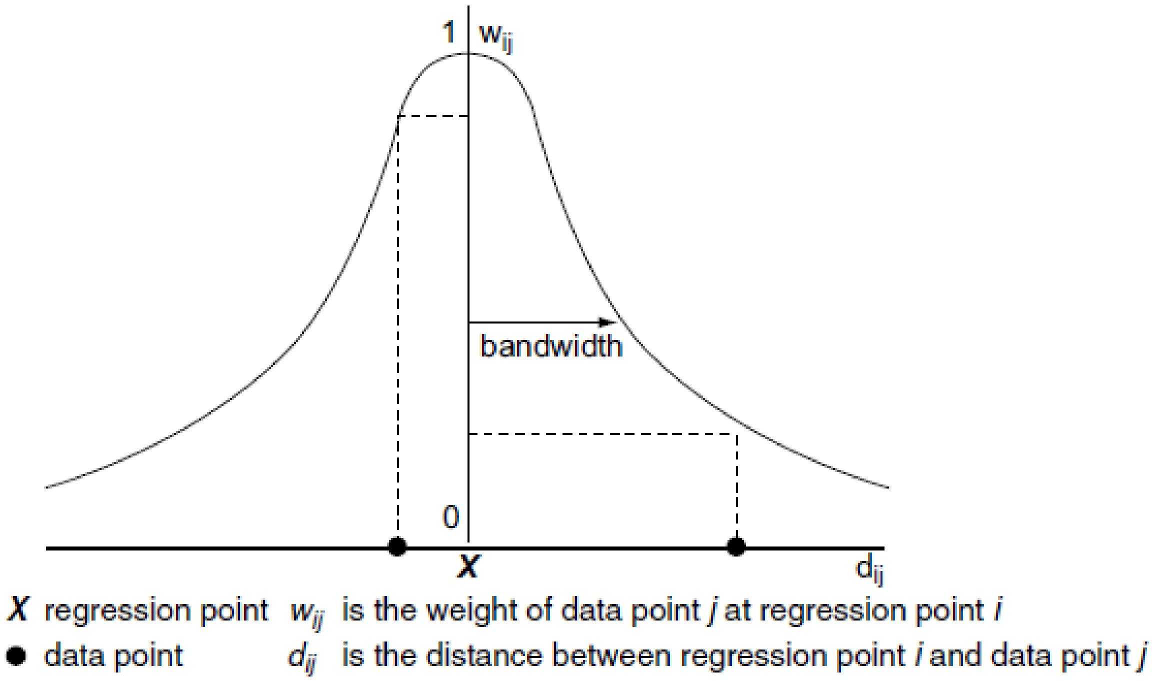


Figure 4. 8 Description of Gaussian kernel function
Source: Fotheringham et al. (2003)

Actually, estimation results of GWR are not sensitive to the choice of weighted function. Instead, how to confirm the best bandwidth, b, is the key process when employing the GWR model. As can be seen in the above figure, the larger bandwidth brings a smoother spatially scale, vice versa. There are three main methods to explore the optimum bandwidth: Cross-Validation (CV) criterion, Generalized Cross-Validation (GCV) criterion, Corrected Akaike Information Criterion (AICc) and Bayesian Information Criterion (BIC) where AIC is the most widely used criterion to find the best bandwidth. The AIC and AICc are formulated as:

$$AIC = -2n \log L + 2k \tag{4.13}$$

$$AIC_c = -2n \log L + 2k + \frac{2k(k+1)}{n-k-1} \tag{4.14}$$

Where $\log L$ is the maximized log-likelihood and k is the number of parameters in the model. Theoretically, AIC is a measure of the overfitting model by adding a large number of covariates but this criterion in a large sample may bring in some errors. Thus, for the small size of the sample, researchers prefer to use AICc to obtain a better bandwidth (Lee & Ghosh, 2009). In sum, the AIC and AICc converge to the same value if the sample size is larger enough, indicating nothing to lose when using AICc.

It should be noted that the spatial autocorrelation's biases have been moved out with the geographical weighted in the local model if the Moran's I for the residual of GWR is not significant (Charlton & Fotheringham, 2009).

4.4.5 Model Choice

As stated in Section 4.3.3, a set of statistical methods or tests can address whether the existence of spatial autocorrelation and spatial heterogeneity. It seems, nevertheless, impossible to obtain a corresponding result when employing mentioned-above spatial models. To have a better understanding of how to choose the best model for specific spatial data, Figure 4.9 shows the choice process into two parts.

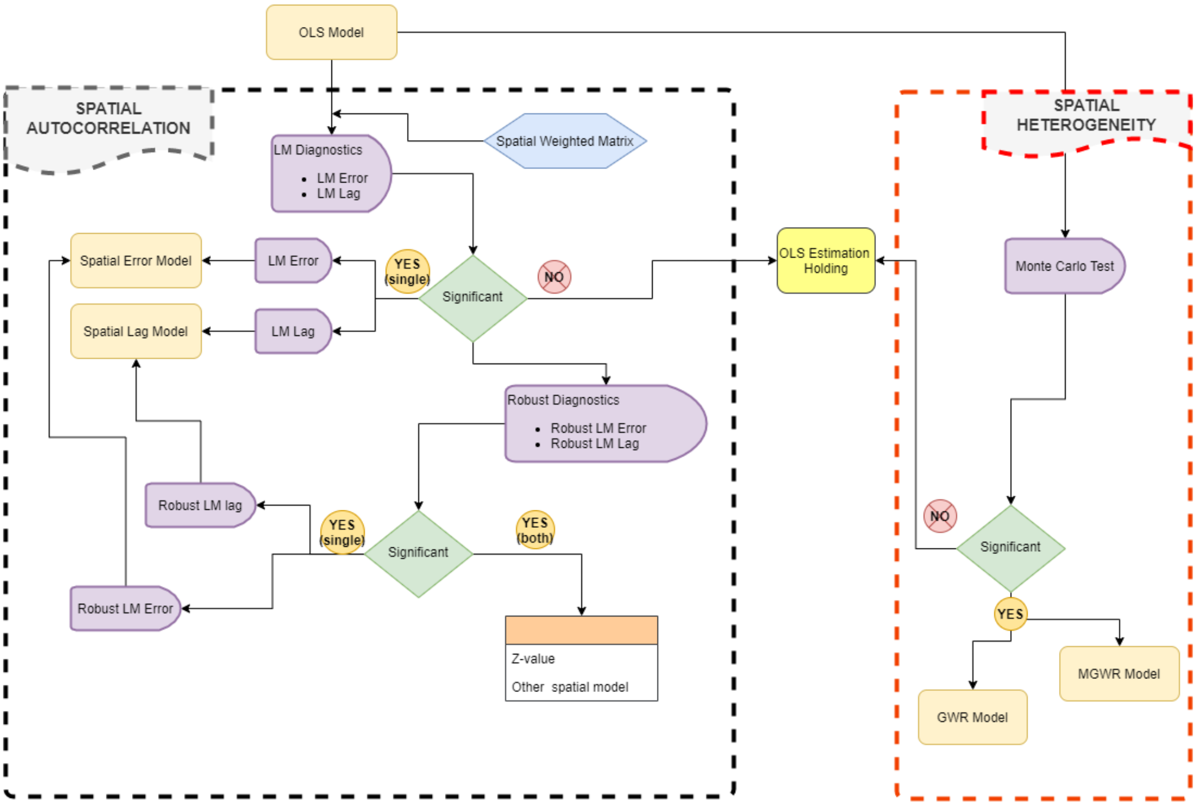


Figure 4. 9 Process of spatial model choice
Source: Own elaboration

Firstly, an OLS model is produced which provides a basic framework for the following spatial analysis. Then a Lagrange Maximum (LM) Diagnostic is conducted in accordance with the specification of the above OLS model to explore the spatial autocorrelation. This diagnostic comprises four tests: two classic LM tests and two robust LM tests for spatial lag and error dependences.

- Classic LM diagnostics should be primarily paid more attention.
  - If the two classic tests are not significant, OLS estimation results are holding. i.e., there is not a spatial dependence issue for this spatial data.
  - If the significance is exclusively in one test, it indicates there is a corresponding spatial characteristic. i.e. Spatial lag model should be employed when the LM lag test is significant exclusively.
  - If both of them are significant, a further check-in will be required in the robust tests.

- Robust LM diagnostic, for simple model, is the key to identify which type of model is suitable for this spatial data. Similar to the process in classic LM diagnostics, if just one robust test is significant, a corresponding spatial model is available. Moreover, if both of the robust tests are significant, there are two approaches to identify the optimal model.
  - Z-value is larger, the corresponding spatial dependence is larger. i.e. the test with a larger z-value shows better fitness for such spatial model.
  - A complex model (e.g. Spatial Durbin Model) should be applied to discuss the interacted impact derived from spatial lag and spatial error.
- A Monte Carlo test of GWR model is employed to explore the existence of spatial heterogeneity where an overall review of spatial heterogeneity and specific performances of spatial heterogeneity for each variable is available. Considering not all the variables show heterogeneous across space, those variables homogeneous and heterogeneous are integrated into a Multiscale-GWR model (MGWR) which will minimize the spatial impacts derived from non-stationary distribution.

PART II

EMPIRICAL STUDIES

CHAPTER 5

GENERAL INTRODUCTION

OF

EMPIRICAL STUDIES

CHAPTER 5 GENERAL INTRODUCTION OF CASE STUDY AND LITERATURE REVIEW

This chapter mainly presents the description of the case study and the data materials in Section 5.1 while the literature review in relation to our specific objectives in Section 5.2.

5.1 Case Study and Data Materials

In order to depict a profile of our research object, a brief introduction of functional BMA is explained and data source, as well as the introduction of key variables, are described in details.

5.1.1 Introduction of Barcelona Metropolitan Area

All the case studies in this dissertation are mainly concentrated in the functional Barcelona Metropolitan Area (BMA) which proposed by Roca et al. (2001a, 2001b, 2009, 2011). Highlighting that the tendency of metropolitan structures towards polycentrism, they proposed a new method to delimit the metropolitan area considering the subsystems of the metropolitan area. The functional BMA consists of 184 municipalities[36] with the land area of 3,760 square kilometres as the second metropolitan area in Spain. As of 2019, the total habitants has been reached about 6.8 million.

[36] The list of 184 Municipalities are in *Appendix III*

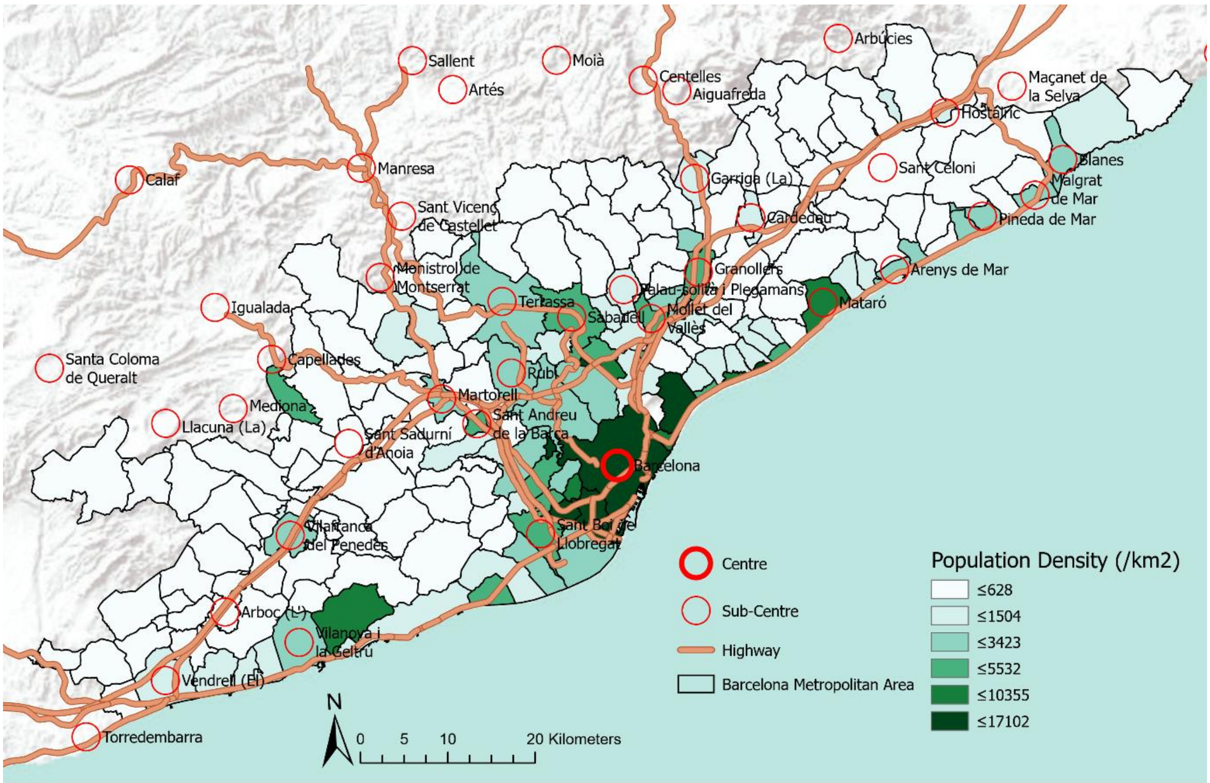


Figure 5. 1 Delimitation of the functional Barcelona Metropolitan Area
Source: Own elaboration

5.1.2 Data Source

Table 5.1 shows the general information of observations in each case study, including the data collected year and the number of samples. Data refers to November 2014 and April 2016, it is to say, almost 1 year and three years after the RD 235/2013 has made it mandatory to include EPC label information in real estate advertising.

Table 5. 1 General information of observations in case studies

Topic of Case study	**Number of Chapter**	**Collected year**	**Number of observations (EPC labelled dwellings)**
Random selection biases	Chapter 6	2014	4248
Cluster/Segmentation Analysis	Chapter 7	2014	3479
Spatial dependence issue	Chapter 8	2014 and 2016	6492
Spatial heterogeneity issue	Chapter 9	2016	4436

Source: Own elaboration

The original dataset comprises 35,116 flats and includes architectonic structural attributes as well as geo-locations. Nonetheless, such an obligation in the sample only about 15% of the offers do include energy information. It is worth saying, that autonomous community Catalonia is one of the regions in Spain with a higher proportion of certified houses.

Selling listing prices for apartments coming from Habitaclia is the main source of information. Habitaclia is one of the leading web-based real estate listings in Catalonia. In order to control all the location attributes that might influence apartments' listing price (i.e. environmental quality, accessibility and socioeconomic structure of neighbourhoods), a comprehensive GIS has been built departing from the following complementary sources of information:

- ***Dwelling and population census INE (2001):*** It includes socioeconomic information of resident population, the perception of noise annoyance at census tract level as well as employment information and journey to workflows at the municipal level. Data from the last 2011 census has been discarded since it is based in a survey that is not representative in statistical terms at the census tract level.
- ***Metropolitan Transport of Barcelona (2005):*** Street cartography has been used to identify the main transport axis as well as train and metro stations that have been conveniently digitalized. Departing from such information, the precise distance among census tracts has been calculated using TransCAD.
- ***Cadastral database (2013):*** The information of built-up density and area allocated from a selection of land use has been retrieved at the census tract level.
- ***Digital Elevation Models (2018):*** The climate zone and EPC zones are recalculated based on Digital Terriain Model (DTM-25).
- ***Self digitalization by ArcGIS Pro:*** Considerable variables are calculated by ArcGIS Pro based on basic variables required from above-mentioned data source. More details in the Section 5.1.3.

5.1.3 Data Description

Considering the sample numbers are different in each specific case study, this section shows the description of variables with relation to the collected dimensions. In particular, some key variables which help to understand the status quo of BMA are depicted by maps.

5.1.3.1 Structural and building variables

As can be seen in Table 5.2, almost apartment's quality variables are derived from the Habitaclia, including all the structural and building's characteristics. Considering our research target, we just depurated cases that are selling within a multi-familiar type (i.e. apartment, Attic, duplex, studio, Loft, flat as well as ground floor). Particularly, our target variables, the rating of EPC and the real number of CO_2 emission for each observation, are required from Habitaclia.

Structural characteristics of apartments

In relation to the structural variables of dwellings, it includes the size of apartments, the number of bedrooms and bathrooms, the number of the floor that apartment located, construction year as well as the presence of storage room and laundry, etc. Noted that the dummy variables of the presence of air conditioning and heating are the most important variables since they are correlated with the EPC rating for each apartment.

In order to understand well of the characteristics of apartments are selling, four dummy variables in relation to the general quality of the apartment and the kitchen are produced by exacting key quality words from seller's statement. They are the high quality of kitchen, high quality of the apartment, good design of the kitchen and the apartment reformed or not.

Table 5. 2 Description of variables in structural and building dimensions

ID	Variables	Definition/Content	Unit	Equation	Source
1	Code_property	code of apartments			Habitaclia
2	Longitude_X	longitude of apartments			Habitaclia
3	Latitud_Y	latitude of apartments			Habitaclia
4	municipality	code of municipality			Habitaclia
5	Type_property	type of apartments: **Apartment / Attic** / House / Townhouse / Semi-Detached House / Chalet / **Duplex / Studio / Loft** / Masia / **Flat / Ground floor** / Tower / Triplex			Habitaclia
6	Type_operation	type of operation: **selling** or rent			Habitaclia
7	Total_price	total price of apartments	euros		Habitaclia
8	Unity_price	unity price of apartments	euros/m^2	Total_price/Superfice	Habitaclia
9	Superfice	floor area of apartments	m^2		Habitaclia
10	square superficie	square of floor area	m^2 x m^2		own calculation
11	Num_bedroom	number of bedrooms			Habitaclia
12	Num_bathroom	number of bathrooms			Habitaclia
13	Num_Toilet	number of Toilets			Habitaclia
14	Num_floor	number of floors			Habitaclia
15	Year_construction	construction year of buildings	year		Habitaclia
16	Age_building	age of building		Year_collected - Year_construction	own calculation
17	Inverse_Age_Building	inverse of a building's age: to increase significantly the difference of the impacts between the new and old apartments.		1/Age_building	own calculation
18	Y_B_81	construction year before 1981 (including 1981)			own calculation
19	Y_82_06	construction year between 1982 and 2006			own calculation
20	Y_A_07	construction year after 2007 (including 2007)			own calculation
21	Superfice_terrace	superficeber of terraces	m^2		Habitaclia
22	Superfice_garden	superficeber of public gardens	m^2		Habitaclia

ID	Variables	Definition/Content	Unit	Equation	Source
23	Superfice_livingroom	superficeber of livingrooms	m^2		Habitaclia
24	Dum_office	the presence of office in apartments			Habitaclia
25	Dum_roof	the presence of roof in apartments			Habitaclia
26	Dum_storageroom	the presence of storageroom in apartments			Habitaclia
27	Dum_laundry	the presence of laundry in apartments			Habitaclia
28	Dum_swimmingpool_persona l	the presence of private swimming pool			Habitaclia
29	Dum_swimmingpool_Public	the presence of public swimming pool			Habitaclia
30	Dum_garden_Public	the presence of public garden			Habitaclia
31	Dum_furnished	the presence of furnished			Habitaclia
32	Dum_lift	the presence of lift in buildings			Habitaclia
33	Dum_airconditioning	the presence of air conditioning in apartments			Habitaclia
34	Dum_heating	the presence of heating in apartments			Habitaclia
35	Dum_chimeny	the presence of chimeny in apartments			Habitaclia
36	EPC_emission	EPC ranks by CO_2 emission: A is the most efficient rank while the G, inefficient.			Habitaclia
37	Value_emission	the detail number of CO_2 emission per year	kg CO_2/ m^2* year		Habitaclia
40	Quality_kitchen_high	high quality of kitchen			own calculation
41	Design_kitchen	good design of kitchen			own calculation
42	Quality_inmobility_high	high quality of the whole dwelling			own calculation
43	Reformed_inmobility	whether the dwelling has been reformed			own calculation

Source: Own elaboration

Source: own elaboratio

Figure 5.2 shows the average floor area of dwellings across the functional BMA. In Barcelona city, the dwellings are sized less than 100 square meters, excepting the richest zone - Sarrià-Sant Gervasi. Similarly, the size of dwellings is smaller in subcenters (e.g. Sant Cugat and Sabadell) than their periphery areas.

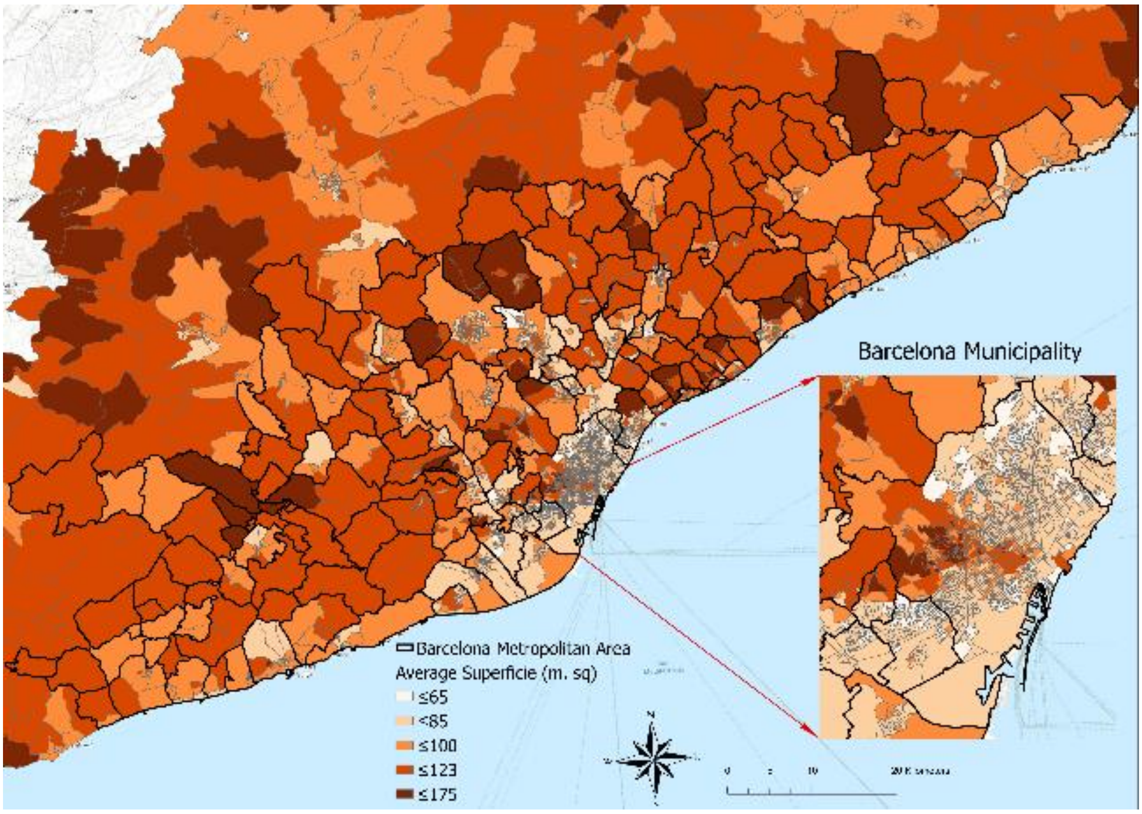


Figure 5. 2 Average floor area of dwellings
Source: Census 2001. Elaboration: author own.

Facilities or services characteristics of buildings

In addition, there are numerous variables with respect to the services or facilities of the building or the block. For example, the public swimming pool, public garden and the presence of lift are the most common facilities offered by the buildings.

Figure 5.3 shows the average construction year of buildings, indicating the "oldest" homes mainly locate in the centre of Barcelona (e.g. Raval and Gotico zone). In contrast, the relatively new dwellings located along the coastline and surrounding subcenters. It highlights that the quality of residential buildings maybe has made contributions to several housing-submarkets in relation to housing price.

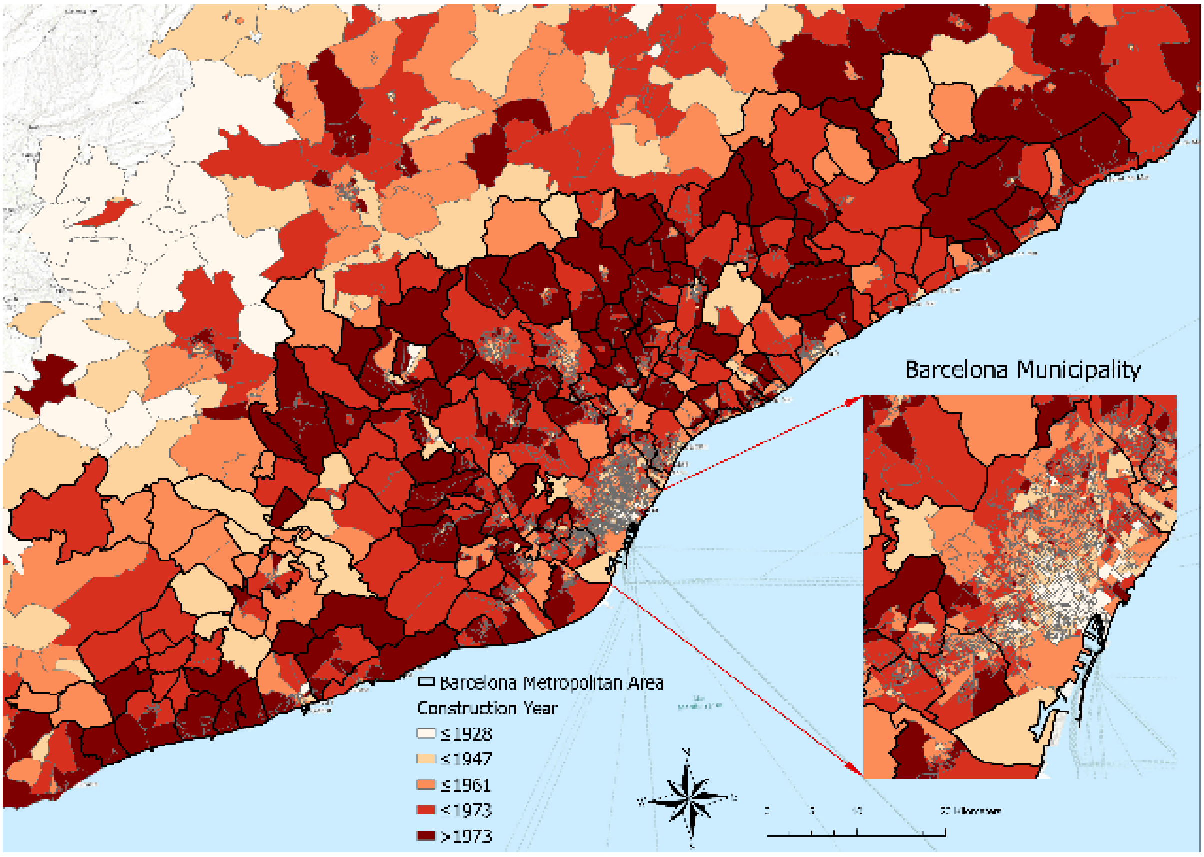


Figure 5. 3 Average construction year
Source: Census 2001. Elaboration: author own

5.2.3.2 Socio-demographical and transport variables

In this section, variables in relation to the demographical aspect are collected from INE 2001 (more details in Table 5.3).

Population and employment

It includes the total population of each municipality of BMA in the year 1991, 2001 and 2006 as well as the total working population collected from Census 2001. As can be seen in Figure 5.4, Barcelona is the most employed city where there are 645, 682 people having jobs, accounting for about 10% of BMA's working people. Concerning the ratio of jobs to working people in Figure 5.5, it illustrates that in BMA almost municipalities have a good employment

Table 5. 3 Demographical and transport variables at the municipal level

ID	Variables	Definition	Unit	Equation	Source
1	COD_MUN	Code of Municipality			INE
2	POB_91	the population of municipality in 1991	people		INE
3	POB_01	the population of municipality in 2001	people		INE
4	POB_06	the population of municipality in 2006	people		INE
5	POR_01	the population living in the municipality that have works in 2001	people		INE
6	LTL1991_M	the number of households with professional occupations in 1991	jobs		INE
7	LTL_2001	the number of jobs with professional occupations in 2001 (Lugares de trabajo localizado)	jobs		INE
8	DLTL_MUN	the density of jobs in 2001	jobs/km^2	LTL_2001/CLC00_Total	
9	RW	resident workers: the people who are living in this mun also work in the same mun	people		
10	FLE	flows entrance: the people coming to this mun	people		
11	FLS	flows salida: the people leaving from this mun	people		
12	SUP_URB_90	artificial surfaces in 1990	km^2	CLC90_total	
13	SUP_URB_00	artificial surfaces in 2000	km^2	CLC00_total	
14	Job_ratio_01	the ration of jobs to the number of people working	jobs/people	LTL_2001/POR_01	
15	Autocontención_01	the ratio of people working in the residential areas to the total people who having jobs	%	RW/POR_01	
16	Nodalidad_01	flow mobolity	ratio	FLE/FLS	
17	Dist_CBD		km		
18	Dist_sub_center	subcenter: the control municipality in proto consolidado; the distance between the controal municipality and other municipalities in the same proto consolidado	km		Own calculation by ArcGIS
19	Elevation_Mean	The average altitude	m		IGN: MDT25
20	dum_acces_viappal	if in this municipality there is a highway ramp or highway enlace, assigned 1			Own calculation
21	Dum_proteg_int	whether homes in the protegida area			Own calculation
22	Dum_proteg_200m	whether homes in the protegida area buffer in 200 meters			Own calculation
23	Dum_Sea_200m	whether homes in the coastal line buffer in 200 meters			Own calculation
24	Dum_train_station_400m	whether the homes access to the nearest urban train station in 400 meters			Own calculation
25	Dum_Subtrain_station_800m	whether the homes access to the nearest sub-urban train station in 800 meters			Own calculation
26	Dum_train_station	whether the homes access to the nearest train station			Own calculation
27	Dist_highway	distances betwee homes and the nearest highway	km		Own calculation
28	Dist_train_station	distances betwee homes and the nearest train station	km		Own calculation
29	desplaz_pond_minu	the commuting time			INE
30	centrality index	centrality index			

Source: own elaboration

environment since majorities job rations of them are more than 1 and less than 2. It is easy for working people finding a job meanwhile there is not too much-idled workforce.

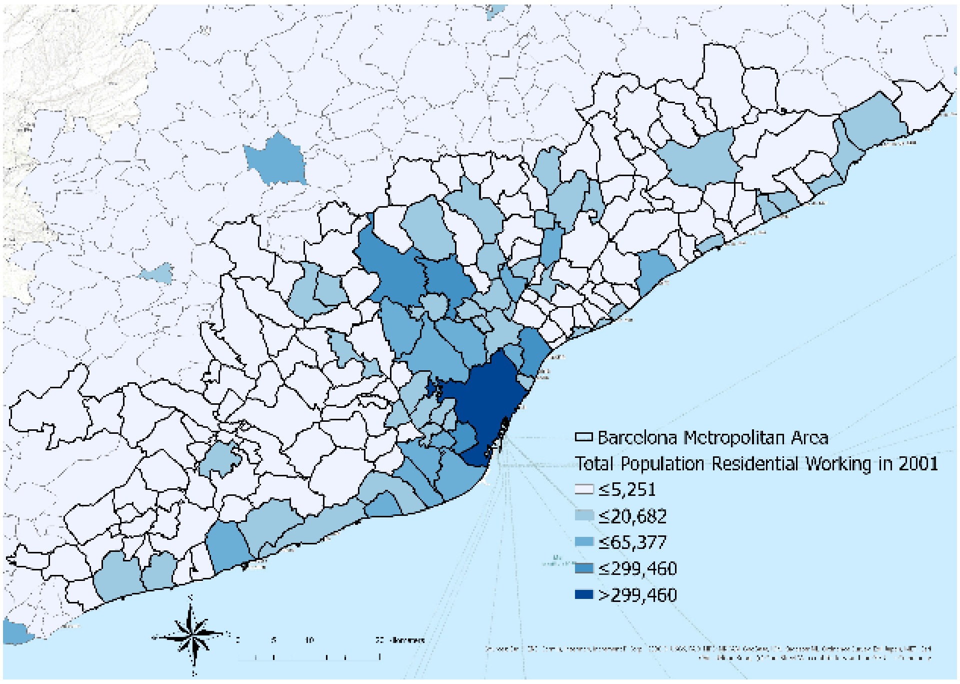


Figure 5. 4 Total working population in the municipality of residence
Source: Census 2001. Elaboration: author own

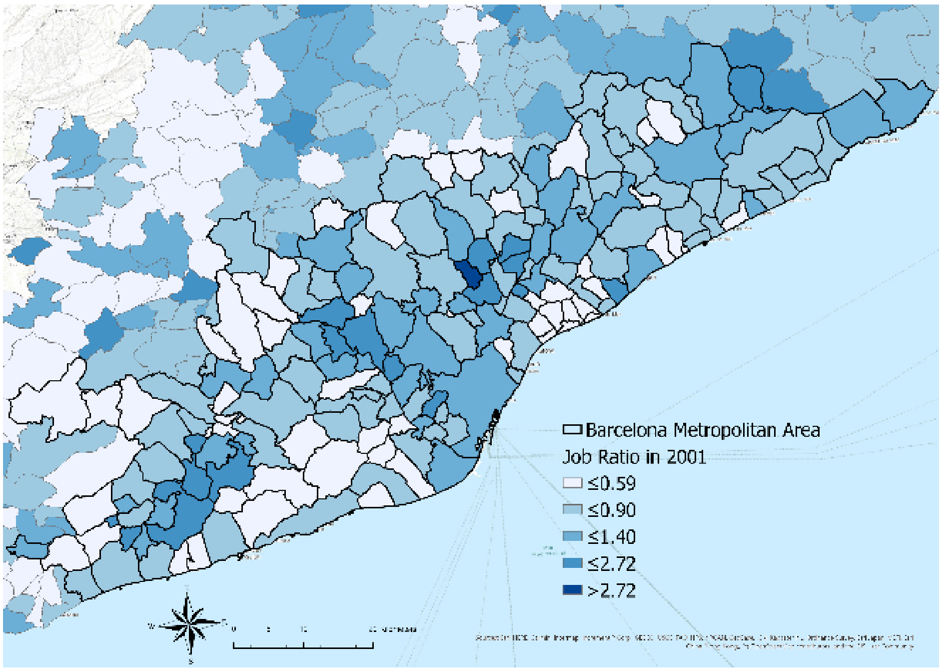


Figure 5. 5 Job ratio
Source: Census 2001. Elaboration: author own

Accessibility

There are numerous variables with respect to accessibility. For example, the distance to CBD, the accessibility to the nearest train station. In addition to these variables calculated by the distance, Figure 5.6 and Figure 5.7 show the performance of commuting time and centrality index in BMA where the former is collected by INE investigation and the latter one is calculated by Marmolejo & Cerda (2017). Regarding the commuting time, the average commuting time across the whole BMA is around 24 minutes. As expected, the people living in the centre area spend less than 20 minutes for work. In contrast, it takes more time (about 40 minutes) to work for the people living in San Adrián del Besós and Villirana area. It is beneficial from Barcelona's quite complete and convenient transportation system, supporting people working in the city but living in the outskirt where rent/housing price is lower.

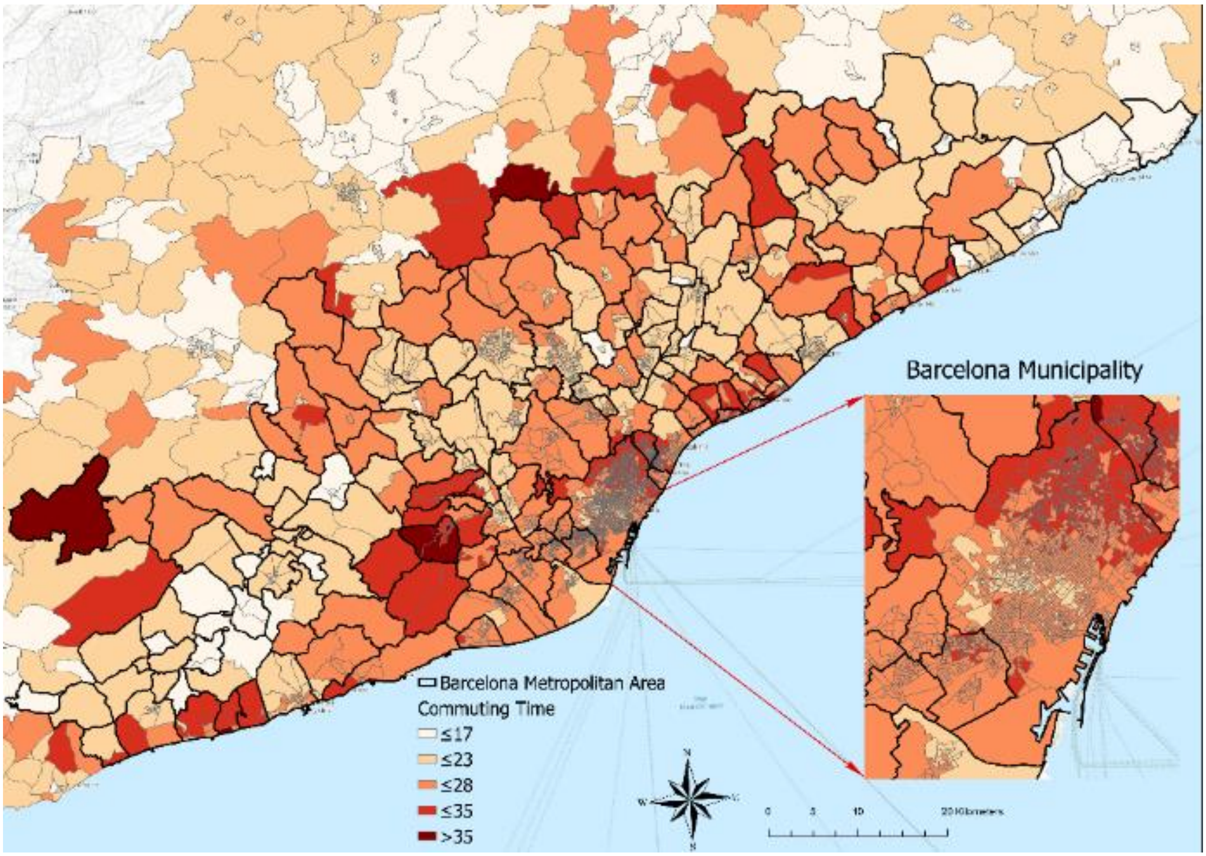


Figure 5. 6 Commuting time
Source: Census 2001. Elaboration: author own

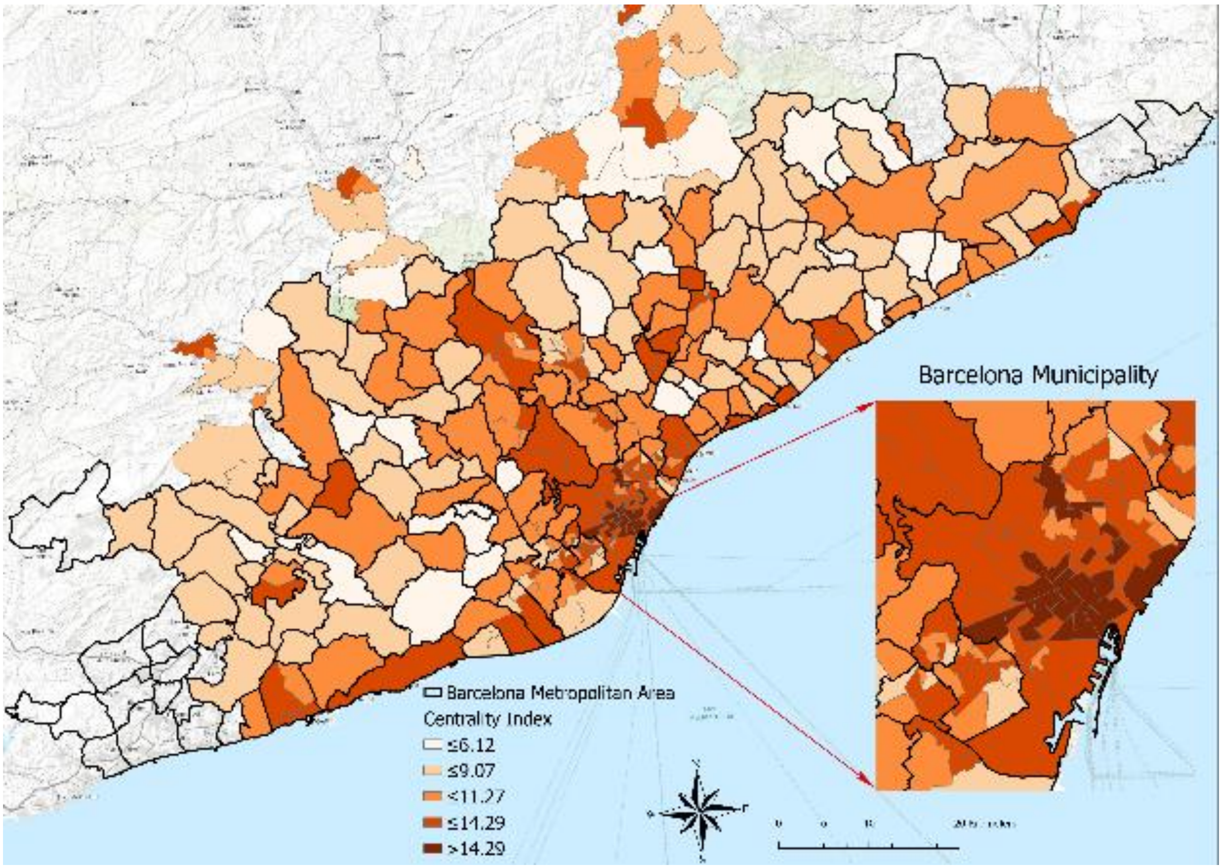


Figure 5. 7 Centrality index
Source: Daily Mobility Survey (EMQ 2006)[37]. Elaboration: Marmolejo & Cerda (2017)

5.2.3.3 Socio-economy variables

In this socio-economic dimension, there are two main aspects for variables: 1) professions and social class as well as the income and 2) the survey data in relation to citizens opinion that investigated face to face from Census 2001. More details in Table 5.4 for the explanation of each variable.

[37] https://www.bcn.cat/estadistica/angles/dades/anuaris/anuari12/cap15/C1510050.htm

Table 5. 4 Socio-economic variables

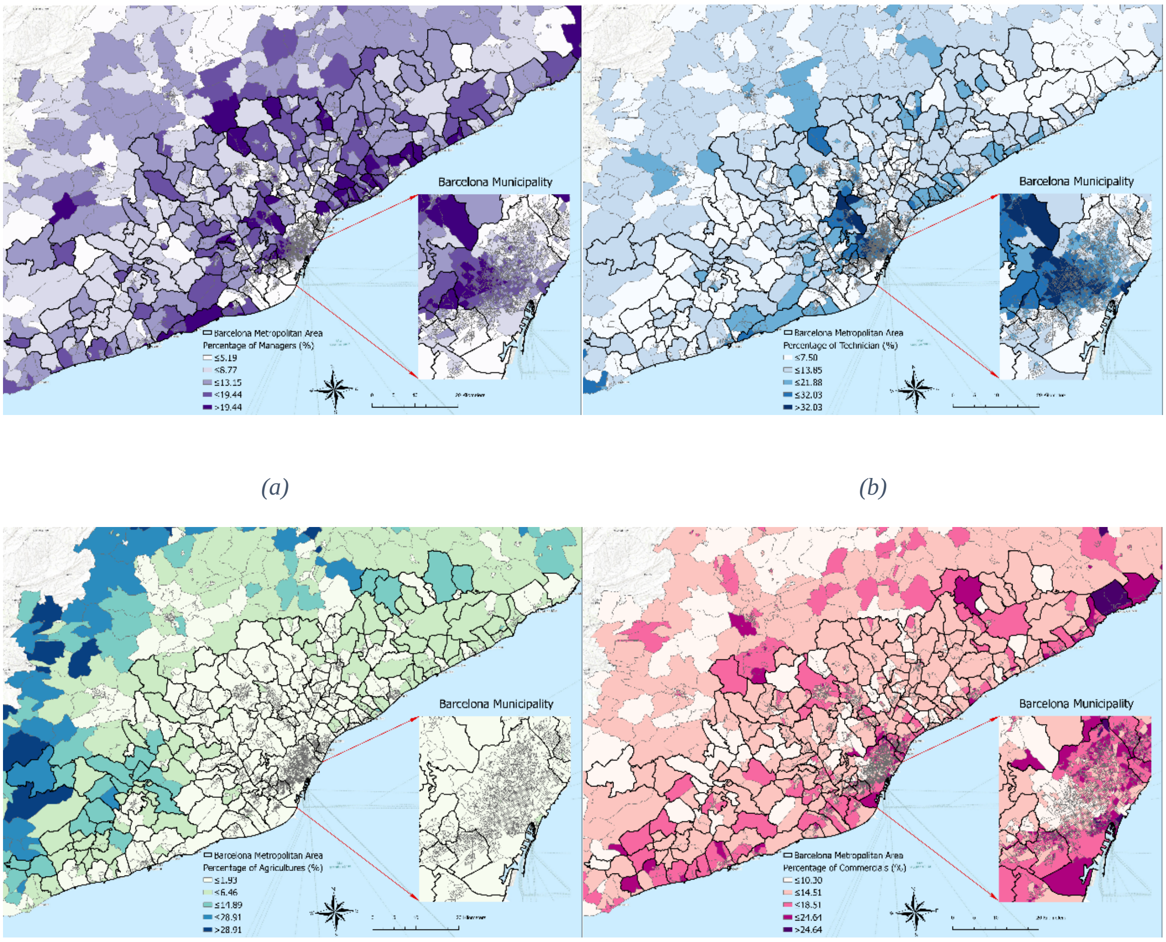
ID	Variables	Definition	Unit	Equation	Source
1	CODSECC	code of tract seccion			
2	pr_directivo	the proportion of the managers in companies and public administrations	%	the population of specific occupations/ the total population of occupations	INE
3	pr_tecnico_prof	the proportion of scientific and intellectual technicians and professionals	%		INE
4	pr_tecnico_apoyo	the proportion of technicians and support professionals	%		INE
5	pr_empl_admin	the proportion of administrative employees	%		INE
6	pr_restaur_comerc	the proportion of the workers of catering services,persional, protection and sellers of shops	%		INE
7	pr_agro_calificado	the proportion of the skilled workers in agriculture and fishing	%		INE
8	pr_artesano	the proportion of the craftsman and skilled workers of the manufacturing	%		INE
9	pr_operador_inst	the proportion of the facility and machinery operators and assemblers	%		INE
10	pro_no_calif	the proportion of the unskilled workers	%		INE
11	Income	Household income	euros		INE
12	F_renta_alta_PCA	high-income group		they are calculated by FACTOR ANALYSIS from variable "pr_directivo" to "pro_no_calif"	own calculated
13	F_renta_medalta_PCA	high-medium income group			own calculated
14	F_renta_medbaja_PCA	medium-low income group			own calculated
15	IND_pr	the proportion of the industrial services	%	(The activities of extractive industries+manufacturing industries + production and distribution of electricity, gas and water)/ the total activities	own calculated
16	FIRE_pr	the proportion of the high-value services	%	(The activities of financial intermediation+real estate ren rental activities, business services + extraterritorial agencies)/ the total activities	own calculated
17	edif_ruin_pr	the proportion of the ruin buildings	%		INE
18	edif_malo_pr	the proportion of the bad buildings	%		INE
19	edif_deficient_pr	the proportion of the deficient buildings	%		INE
20	edif_bueno_pr	the proportion of the good quality buildings	%		INE

ID	Variables	Definition	Unit	Equation	Source
21	Doorman_pr	the proportion of doorman	%	the number of buildings with doorman/ the total buildings	INE
22	opin_ruido_si_pr	the proportion of citizens' opinion if they think there is a noise problem	%		INE
23	opin_contam_si_pr	the proportion of citizens' opinion if they think there is a contamination problem	%		INE
24	opin_calle_suicia_pr	the proportion of citizens' opinion if they think the street is dirty	%		INE
25	opin_mala_comunic_pr	the proportion of citizens' opinion if they think communication is bad	%		INE
26	opin_pocazonaverde_pr	the proportion of citizens' opinion if they think there is a lack of green area	%		INE
27	opin_delincuencia_pr	the proportion of citizens' opinion if they think there is a delinquent problem	%		INE
28	opin_falta_aseo_pr	the proportion of citizens' opinion if they think there is a lack of WC	%		INE
29	local_salud_pr	the proportion of the number of locals of the health equipment (outpatient, health centre, hospital)	%	the number of locals in specific equipment/ the total number of locals	INE
30	local_edu_pr	the proportion of the number of locals of the educated equipment (school, university, nursery, college)	%		INE
31	local_social_pr	the proportion of the number of locals of the social welfare equipment (old peoples home, social services centre, day centre)	%		INE
32	local_cult_pr	the proportion of the number of locals of the culture or sporting equipment (theatre, cinema, museum, exhibition hall, sports centre)	%		INE
33	local_comerc_pr	the proportion of the number of locals of the commercial equipment	%		INE
34	local_oficinas_pr	the proportion of the number of locals of the office (also includes the rest of the services)	%		INE
35	local_indust_pr	the proportion of the number of locals of the industrial equipment	%		INE
36	local_agrar_pr	the proportion of the number of locals of the agrarian equipment	%		INE
37	dens_loc_100hab	ratio of the locals to population	locals/ People	LOCAL_TOTAL/(POB_TOTAL X 100)	own calculated
38	dens_loc_sup	the density of locals	locals/km^2	LOCAL_TOTAL/Sup_km^2	own calculated
39	dens_pob_sup	the density of population	people/km^2	POB_TOTAL/Sup_km^2	own calculated
40	estud_sin_pr	the proportion of people uneducated	%	the population with different educations/ the total number of residents	INE
41	estud_primer_pr	the proportion of people holding primary education			INE
42	estud_segund_pr	the proportion of people holding secondary education			INE
43	estud_tercer_pr	the proportion of people holding higher education			INE

ID	Variables	Definition	Unit	Equation	Source
44	resi_euro_pr	the proportion of the residents whose birthplace is Europe	%	the people where they were birth/ the total following five numbers	INE
45	resi_africa_pr	the proportion of the residents whose birthplace is Africa	%		INE
46	resi_america_pr	the proportion of the residents whose birthplace is American	%		INE
47	resi_asia_pr	the proportion of the residents whose birthplace is Asia	%		INE
48	resi_oceania_pr	the proportion of the residents whose birthplace is Ocean	%		INE

Source: own elaboration

Figure 5.8 shows a brief profile of the profession in BMA where managers and technicians prefer to live in the outskirt of the city. In particular, the managers prefer the villa in Sarrià-Sant Gervasi while technicians aggregate together surrounding the area of Sant Cugut del Vallès. For the relatively lower social class (e.g, merchants), they are willing to live in the city but far away along the line of Diagonal which often charges for a higher housing price. It helps them to save the commuting fee and time as well as enjoy the recreational activities expediently. Similar to Peasantry, they are living far away from the city centre since they need farmland to produce agricultural productions.



(a) *(b)*

(c) *(d)*

Figure 5. 8 Profile of professions
(a): the proportion of managers; (b) the proportion of technicians;
(c) the proportion of peasantry; (d) the proportion of merchants
Source: Census 2001. Elaboration: author own

Education level largely determines your career choice, which in turn affects the final income level. Similar to the basic distribution of prestigious professions in Figure 5.8 (a) and (b), the three groups, better-educated people, high-income household and the people with high reputation job, coincide with each other in the area of Sarrià-Sant Gervasi and Sant Cugat del Vallès (Figure 5.9 and 5.10). It suggested that the residential market maybe has been separated into segmentations in relation to housing price, neighbourhoods and environment status. Therefore, these zones and groups should be paid more attention to when analyzing housing studies.

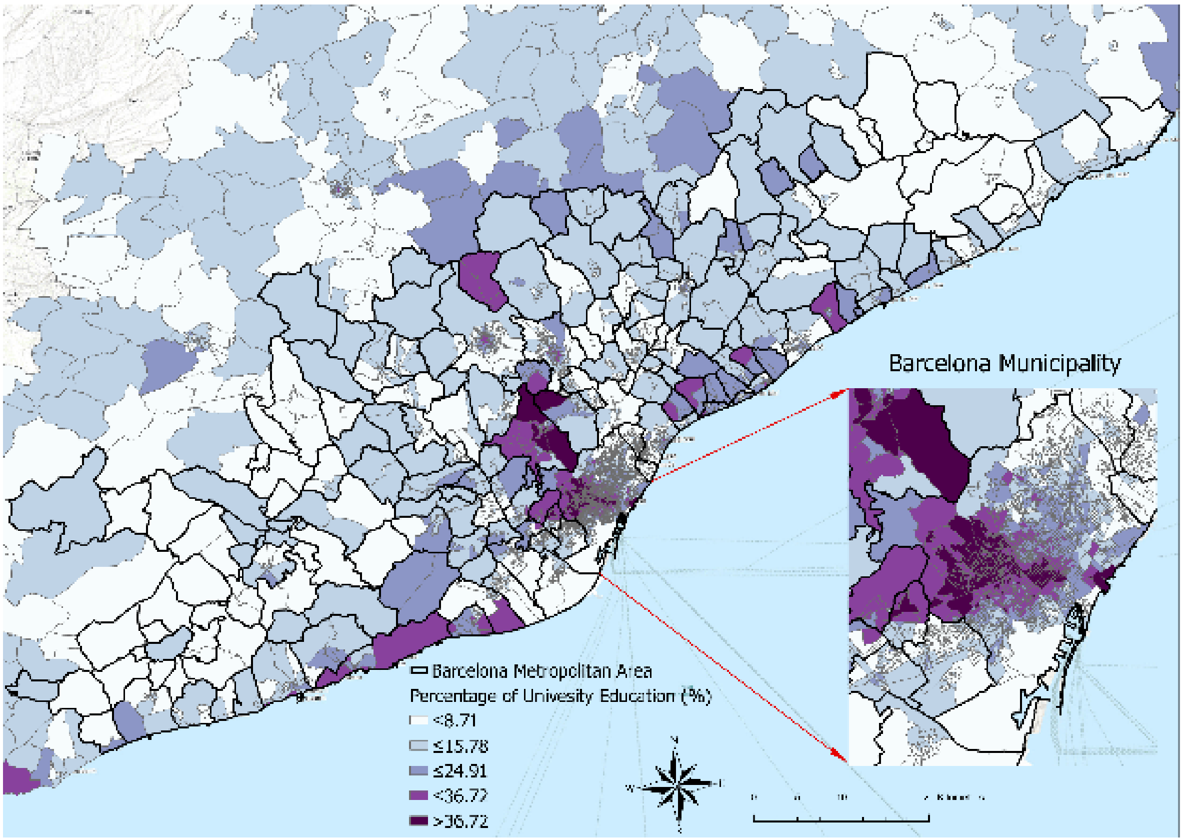


Figure 5. 9 Proportion of university-educated people
Source: Census 2001. Elaboration: author own

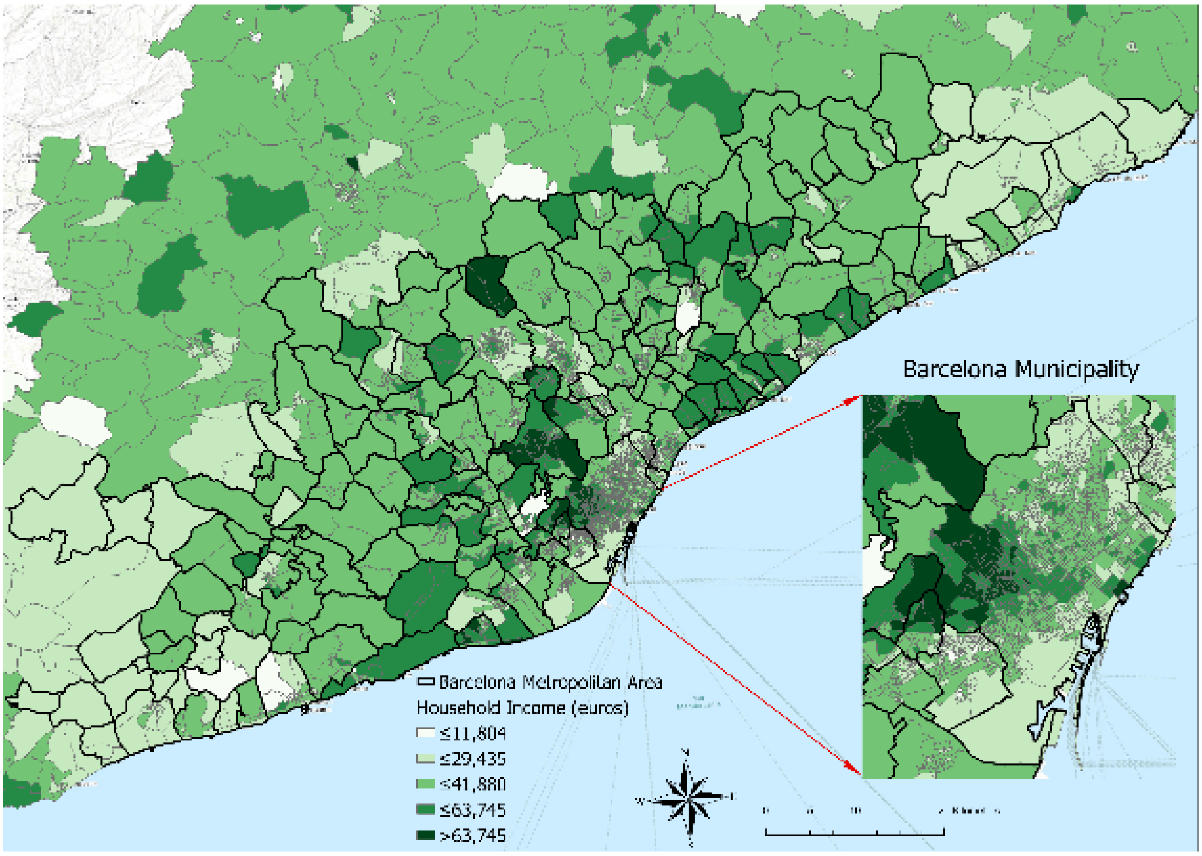
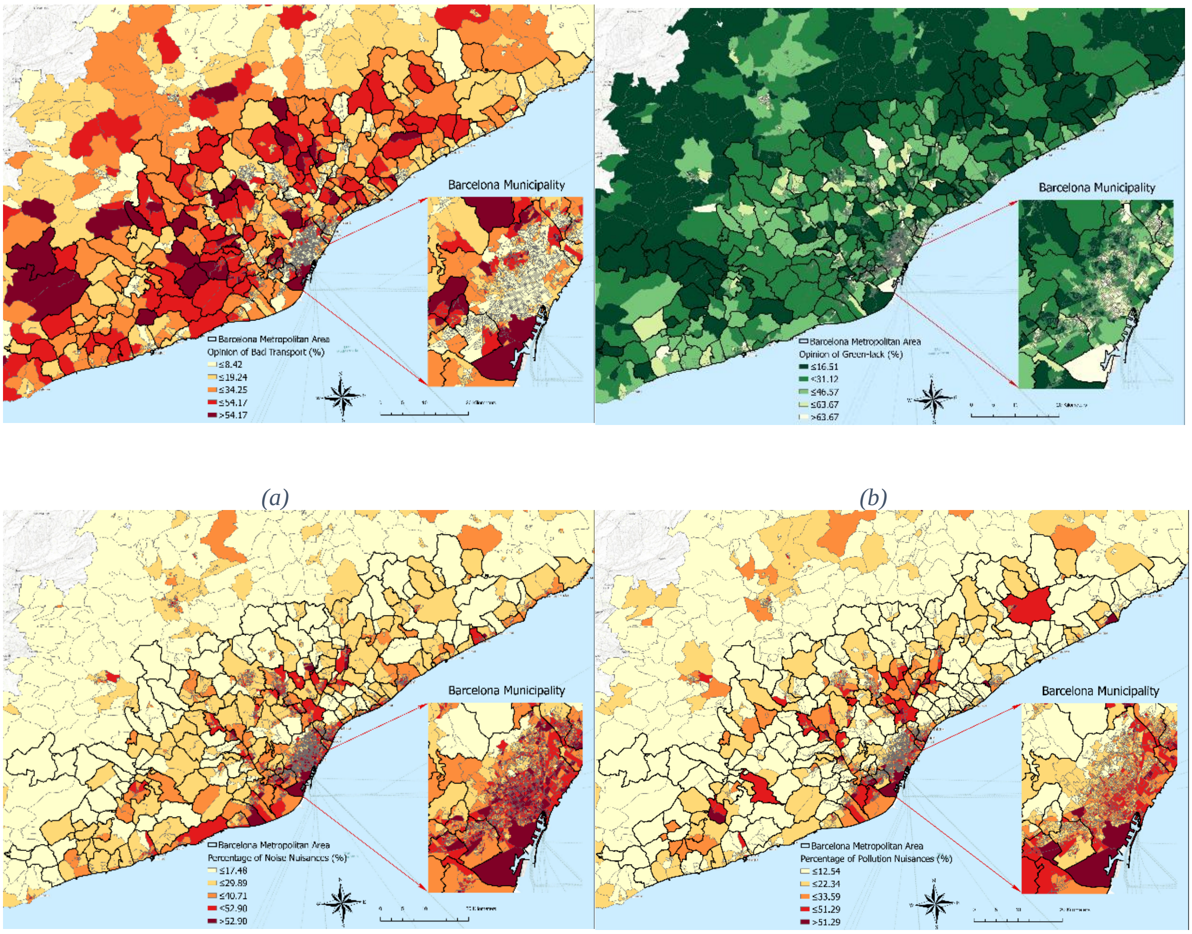


Figure 5. 10 Average annual household income
Source: 2016 Experimental INE dataset based on taxpayers' self declarations. Elaboration: author own

These variables in relation to residents' opinion to social environment play a considerable role in housing study because such variables could reveal residents' living preference. Furthermore, a comprehensive consumer's preference profile could help policy-makers better formulate the corresponding regulations and policies.

Figure 5.11 depicts a general consumer's preference to the social environment, including opinion to bad transport, opinion to green-lack, opinion to noise nuisance as well as the pollution nuisance. It is worth to note that citizens who live in the southwest Sants - Montjuïc district are dissatisfied heavily with the local social environment regardless of the accessibility and living environment. The similar situation also occurs surrounding the area of San Adrián del Besós and Cerdanyola del Vallès as well as the Villirana. Compared with the performance of household income stated previously, it is easy to conclude that these areas are hated by the local citizens are also along with an unprosperous economy, resulting in an inefficient residential market. Therefore, more attention should be paid to these areas when discussing the results in the following chapters.



(a) *(b)*

(c) *(d)*

Figure 5. 11 Proportion of resident's opinion to the queality of the residential environment
(a): opinion to bad transport; (b) opinion to green-lack; (c) opinion to noise nuisances; (d) opinion to pollution nuisance
Source: Census 2001. Elaboration: author own

5.2 Literature Review

In order to foster energy-efficient buildings, the European Commission issued the Energy Performance of Buildings Directive (EPBD 2002/91/EC), recast in 2010/31/UE. The main hypothesis of such communitarian policy is that building users (i.e. buyers and tenants) should elicit in preferential conditions efficient buildings when they are informed on energy consumption and CO_2 emissions. So, individuals may be willing to pay more for taking advantage of energy savings and environmental preservation. In doing so, the Directive obligates real estate owners willing to sell or lease properties to get an Energy Performance Certificate (EPC) and include the derived energy rank in the advertising of the property. In sum, by breaking down energy information asymmetries, the EU tries to promote the construction of efficient buildings and the energy retrofit of existing ones (Encinas et al. 2018).

5.2.1 The Impact of Energy Ratings on Prices

The positive relationship between the green labels introduced before the EPC scheme (e.g. BREEAM-Building Research Establishment Environmental Assessment Method, HQE-High Quality Environmental standard, LEED-Leadership in Energy and Environmental Design, Green Mark, Energy Star and Minergie) and both rental and sales prices are well studied in the literature and stands in contrast with the relatively reduced number of studies focused on the EPC scheme. These papers share a common methodology (based on the hedonic analyzes of marginal prices) and the same information sources (in the absence of transaction prices, they refer mainly listing data).

The reform of the EPBD (2010/31/EU) and Directive 2012/27/31 set the current framework for the transposition of energy certification into the Member States. Within this context, the pioneering study by Brounen & Kok (2011) analyzed the impact of these new “green labels” on residential prices in the Netherlands; although the data used comes from the period in which the buyer could exempt the seller from providing the EPC. The results of this study found a positive correlation between the best-rated dwellings and sales prices verified in real estate transactions. Such authors, like almost all others whose work has been summarised in Table 5.5, assume that energy ratings constitute a categorical measure of energy efficiency. Therefore, considering the intermediate rate “D” as the basis for comparison, they found that the marginal price moves from +10% for rate “A” to –5% for rate “G”, i.e., “market premiums” are formed above the reference situation, while below such threshold market penalties or “brown discounts” (i.e., price reductions) emerge. The study conducted by Hyland et al. (2013), in different Irish cities, was the first to simultaneously compare the impact of EPCs on the rental and sale listing prices. In general, they found that the impact of energy labelling is higher in the sale market than in the rental market. For example, a dwelling for sale ranked as “A” (in relation to “D”) has a market premium of +9.30%, and only a premium of +1.80% if it is in the rental market, holding everything else equal. Similarly, the “brown discount” for a home rated as class “F” or “G” (in relation to “D”) is significantly larger (–10.60%) than another one on the rental market (–3.20%). The larger impact of green labels on sales prices in relation to rental prices is a finding that had already been reported by previous work based on other certification schemes. Examples of such research are the work regarding LEED offices in the US (+31.40% for sale and only +9.20% for rent) (Fuerst & McAllister, 2011); LEED offices (+11.10% for sale and only +5.80% for rent) and Energy Star (+13.00% for sale and only + 2.10% for rent) (Eichholtz et al. 2010). The unequal impact of energy labels on rental and sale prices has an impact on yields, for example, Fuerst & McAllister (2011) demonstrated the inverse relationship between yields and energy ratings of the BREEAM scheme for the English office market. It seems, therefore, that investors do value efficient buildings as a result of better marketability, lower vacancy rates, and lower depreciation (Cajias & Piazolo, 2013; Wiley et al., 2010); in relation to office tenants for whom the savings in energy bills are marginal in relation to operating expenses (e.g., salaries).

From Table 5.5, the work of the Bio Intelligence Service et al. (2013) stands out. This organization was commissioned directly by the European Commission as part of the studies aimed at assessing the effectiveness of the EPBD. It shows the impact of EPC in several countries, with the novelty that the energy rating has been taken as continuous and not categorical. Yet again, the impact of EPC is sharper in selling prices than in rental prices. From this study, it should be noted that EPC ratings seem to have a larger impact on hinterlands (e.g.,

Table 5. 5 Selected studies on EPC marginal prices

Study cases	Market	Scale Type as interpreted by EPC ratings	Marginal impact of EPCs on: Sale	Marginal impact of EPCs on: Rent	From energy rating X to Y (X/Y)	Type of prices	Authorship
Netherlands	Residential	Categorical	10.00%		A/D	Closing	Brounen & Kok (2011)
			5.50%		B/D		
			2.00%		C/D		
			–0.50%		E/D		
			–2.50%		F/D		
			–5.00%		G/D		
Ireland	Residential	Categorical	9.30%	1.80%	A/D	Listing	Hyland et al. (2013)
			5.50%	3.90%	B/D		
				–1.90%	E/D		
			–10.60%	–3.20%	F, G/D		
Vienna	Residential	Continuous	Between 10% & 11%	Between 5% & 6%	step	Listing	Bio Intelligence Service et al. (2013)
Lower Austria			Between 5% & 6%	4.40%	step		
Brussels (Flandes)			4.30%	3.20%	step		
Brussels (Capital)			2.90%	2.60%	step		
Brussels (Wallonia)			5.40%	1.50%	step		
Lille			3.20%	nd	step		
Marseille			4.30%	nd	step		
Ireland (cities)			1.70%	1.40%	step		
Ireland (not cities)			3.80%	1.40%	step		
Oxford (United Kingdom)			0.40%	–4.00%	step		
United Kingdom	Residential	Categorical	5.00%		A,B/D	Closing	Fuerst et al. (2015)
			1.80%		C/D		
			–1.00%		F, E/D		
			–7.00%		G/D		
Denmark	Residential before 1st July 2010		2.40%		A, B, C/D, E, F, G		
	Residential after 1st July 2010	Categorical	10.10%		A, B, C/D, E, F, G	Closing	Jensen et al. (2016)
			6.20%		A, B/D		
			5.10%		C/D		
			–5.40%		E/D		
			–12.90%		F/D		
			–24.30%		G/D		

Source: Own elaboration

Belgium and Ireland, with Austria as an exception) than in capital cities. According to the authors, this differential impact is explained by the fact that savings in energy bills are more important, in relation to the base price, in dwellings in smaller urban areas (where housing is cheaper) than in capital cities. Moreover, a higher energy rating does not always imply a market premium. In the Oxford rental market apparently, there is a penalty for the best-rated dwellings (–4.00% per EPC class). However, the authors acknowledge the enormous deficiencies of their analysis since in this city, the older, better located and high-priced mansions do rank low in the efficiency ladder. In general, the very poor control of urban characteristics (e.g., accessibility, quality of urbanization and neighbourhood effect affecting residential values as studied since Cladera (1988)) is a deficiency of such work and can bias the coefficients of their models.

Finally, from Table 5.5, it is also worth mentioning the work by Jensen et al. (2016)has found that a clear increase of the energy rating premium in Denmark as the inclusion of the EPC label became mandatory in 2010. Denmark was the first country to introduce, in 1997, an “A”–“G” energy label for buildings, well before the first EPBD came into force; nonetheless, according to such authors, only in 2011 did Danish real estate agents begin to claim that properties with higher EPC rating were the easiest properties to sell.

However, the positive impact on prices reviewed before contrasts with the outcomes of opinion-based research. Murphy (2014) surveyed in the Netherlands in order to identify the impact of EPC information on price negotiation in the context of home purchasing. Her results suggest that “a higher EPC fails to have a direct influence during negotiation and decision making” (p. 666). In the same line, Parkinson et al. (2013) have found no correlation between EPC ratings and rental values while surveying commercial office occupants in the UK. Their findings suggest that facilities’ aesthetics are the main driver of rents. Compatible evidence can be found in the study of Pascual et al. (2017) based on surveys applied to real estate agents in eight countries. According to their results, EPC ratings exert a negligible impact on housing prices, this conclusion is especially valid in the case of Spain where only 15% of the surveyed agents confirmed the existence of a premium for efficient flats. Departing from such contradictory evidence, that is: on the one hand a positive market premium for efficient properties suggested by hedonic models; and on the other hand, no strong evidence on EPC impact on prices and rents coming from demand and agents' surveys, Olaussen et al. (2017)have carried out an interesting quasi-natural experiment in order to identify whether omitted variables in model specifications can lead to spurious results. Their study, based on Oslo's residential market, consists of analyzing the price of homes sold before and after July 2010 when it became mandatory to include the EPC labels in advertisements, so as to identify whether such labels did actually produce a price increase in the case of efficient homes. In doing so, they assigned the EPC class to each home in the pre-2010 sample according to the class the same home had in the post-2010 sample. Their hedonic results show similar market premiums and penalties on EPC ratings for the pre and post 2010 samples, allowing them to conclude that "price premium of the energy labels clearly captures something else rather than an effect caused by the labels themselves" (p. 251). Nonetheless, such authors warn that even though EPC rating does not matter in Norway, they could matter in other countries, possibly where trust and honesty in the building industry are lacking. All in all, it is necessary to carefully incorporate control variables, as is done in this paper, in order to reduce the risk of omitting relevant attributes.

So far, there is a great divergence, yet inconclusive evidence, regarding the impact of EPCs on residential values across Europe, perhaps explained by the important differences in terms of income, energy costs, construction regulations/traditions, climate, and environmental concerns. Furthermore, the way the EPBD has been transposed across the countries has resulted in divergent calculation methods, often supported by previous national regulations, making it difficult to assess cross-border comparisons (Garcia-Hooghuis & Neila, 2013). In this context of Spain, there are two pioneering works in the study of the hedonic agenda of the EPC ratings. De Ayala et al. (2016)base their study on opinion-values declared by a sample of non-specialist respondents from 5 cities (Madrid, Bilbao, Seville, Vitoria and Malaga). In their study energy rating is produced by their estimation. They determine 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. On the other hand, Marmolejo (2016) uses listing selling prices in Barcelona, finding a marked premium of +5.11% from the G to A rates, or of +9.62% if it is accepted that buyers perceive the rating scale to be nominal. Both studies need revisiting, the former not only because it analyzes opinion values but also because it makes little control of micro-locational and structural factors that have a paramount influence on values, and their omission can bias the coefficients; and the latter because precisely these micro-locational factors make the variable "EPC rating" become statistically significant in the models, and therefore suggests a heterogeneous impact of this factor in the real estate market. Further EPC research in Spain includes: the work by Bian & Fabra (2020) regarding the incentives that owners have to deliver EPC information; the work by González (2018) on the shortcomings in the EPC scheme based on in-depth interviews to energy certifiers; and Taltavull et al. (2019) on the hedonic agenda of EPCs in Alicante. Therefore, this paper aims to explore this aspect in greater detail.

5.2.2 Sample Selection Biases Issue in Housing Price Studies

Regarding sample selection biases, a number of studies has indicated that selection bias does matter to housing prices and residential analysis (Bergström & van Ham, 2010; Gatzlaff & Haurin, 1998; Hill, 2011; Jud & Seaks, 1994). They proposed that a necessary selection biased correction should implement before any hedonic price models and calculations. They indicated the missing test for sample selection biases might have an inverse impact on estimation results or the conclusion. For this reason, Heckman two-step method was put forward by Heckman (1976) and developed by following relative studies (Heckman, 1977, 1990 (a), 1990 (b);

Heckman & Robb, 1986; Puhani, 2000). They suggested that the biases can be estimated by a procedure where a proxy variable could be produced and the Heckman two-step model is the best choice to solve the selection biases. Gordon & Winkler (2017) applied a corrected-biased model to explore the impacts of the price percentage discount in housing prices in North Alabama. They found a discount impact 2.98% was made after correcting sample selection biases. The same conclusions were suggested using the Heckman two-step model by Seko & Sumita (2007)and García & Hernández (2008). They indicated that the impact of the tenure choice is negative when properties were transacted. However, few studies show attention to the sample selection biases when analyzing the relationship between EPC and housing prices. Brounen & Kok (2011)found that homes with a "green" label sell at a premium of 3.6% relative to otherwise comparable dwellings with non-green labels using Heckman two-step method. Hyland et al. (2013) employed the hackman two-step model to detect the presence of sample selection biases but interestingly found that self-selection was not significant. In such case, this paper is to explore the presence of selection biases and to correct these biases by the Heckman two-step model, as an initial analysis of hedonic housing prices.

5.2.3 The Impact of the EPC Rating may Differ between Market Segmentations

The studies researching the impact of EPC ratings among segments depart from univariate segmentation using variables such as area, age or typology of homes. In Sweden, Cerin et al. (2014) have made a particular study in which the sale price of housing has been correlated directly with the energy consumption stated in the very EP certificate. The coefficient of energy consumption in their hedonic model, built on the entire housing sample, appears with a contradictory sign (Bx = 0.06, p = 0.000, where "x" is the log of consumption in kWh/year/sq. m. and "Y" the log of the price per sq. m.): that is, the higher the consumption in kWh/year/sq. m., the higher the price of housing, with everything else being equal. However, they conclude exactly the opposite when the sample is segmented, that is, the higher the energy consumption the lower the price. This conclusion is especially valid for the quartile of cheaper housing, which indicates that households with tight budgets that can only access the cheaper housing seem to value energy-bill savings from efficient dwellings. In contrast, those who can afford the purchase of dwellings with unit prices in the upper quartile seem to attribute zero importance to the EPC rating. Likewise, these authors find a market premium for dwellings built before 1960, since in general these houses have less quality and therefore those rehabilitated (with a better rating) are distinguished among houses of equal age. In the same sense, in Ireland, the impact of an EPC step on a 2-room apartment equals an increase of 2.3%, whereas in the 3-room and 4–5-room apartments this increase is lower and stands at 1.70% and 1.60% respectively (Hyland et al., 2013). Fuerst et al. (2015) have found that the greatest impact of the EPC on the English residential market occurs in townhouses and that the impact on apartments is larger than that on detached houses. This situation might imply several things, among others that the potential consumption savings are more important for the cheaper houses occupied by people of lower-income levels, conclusions that are convergent, with the results of Cerin et al. (2014). However, the previous results are contradictory to the results of Salvi et al. (2008) who studied the impact of the Minergie certification in Switzerland and found a larger impact in the single-family dwellings in relation to apartments. They argue that this finding is compatible with larger energy savings produced by larger energy demand in single-family dwellings.

So far, the studies reviewed performed univariate segmentation, neglecting the fact that market segments are made of the combination of multiple attributes regarding architectural and locative features and therefore it is necessary to consider them simultaneously as is done in Chapter 7.

5.2.4 Spatial Implication of Energy efficiency

Although energy efficiency has become a hot topic in the past 15 years, most of the studies pay attention to hedonic price for energy efficiency as stated in Section 5.2.1. Concerning the spatial aspects of energy efficiency are mainly carried out from the spatial and temporal differentiation as well as spatial correlation.

Morton et al. (2018) employed Spatial Durbin Model (SDM) to explore the diffusion of domestic energy efficiency policies (i.e. Green Deal Assessment (GDAs)) in Britain. They aim to confirm the importance of socioeconomic, contextual, and local policy conditions in shaping the spatially heterogeneous response to national policy. The results suggested that the presence of young families, university-educated residents, detached homes and large households positively affects the uptake of energy efficiency assessments whereas property market activities, personal income, the presence of self-employed residents, and the energy efficiency rating has a dampening effect. This work makes a good example of how transitions towards a low-carbon society can progress in a spatially uneven manner, supporting policy-makers to design and evaluate policies. Similarly, Balta-Ozkan et al. (2015) indicated that demographic structure shows a spatial non-stationary, furtherly impacting the executive of energy efficiency improvement.

Based on a comprehensive dataset of property list price advertised in Bolzano in 2018, Bisello et al. (2020) estimated that the influence of energy rating on housing price by a spatial econometric model. After finding a spatial autocorrelation, they introduced the Spatial Lag Model (SLM) to identify the exogenous effect of the prices of nearby properties on the price of each apartment. The results suggested that EPC ratings have impacts on housing price significantly with a premium of 6.5%, 5.5% and 3% for apartments with rating A, B, C after correcting the spatial autocorrelation biases from their neighbourhoods. Although they did not apply other spatial models to explore the energy premium's spatial implication, SDM for spatial autocorrelation and GWR for spatial heterogeneity were mentioned for the possible further research.

Taltavull et al. (2017) proposed a Generalized Least Squares model by a time-space recursive functional form[38] (STAR GLS) to evaluate the diffusion effect of house prices spatially by submarket and assessment upon the pricing effect of green characteristics in Bucharest, Romania. Results suggested that the spatial diffusion positively contributes to housing price by 0.46% due to the effects from their neighbouring properties but the unobserved spatial component reduces the diffusion effect equivalent to 0.22% of the price increase. In all, the total spatial effect is 0.24% positively. Interestingly, energy efficiency in this spatial model shows a negative impact, even if in a stricter confidence level, it will be insignificant on housing price. They inferred that a green property could be related spatially with unobserved variables thereby capturing some opportunity cost arising from retrofitting. That is to say energy premium have a decrease of 4.9% in the area where there is a large number of the refurnished green property.

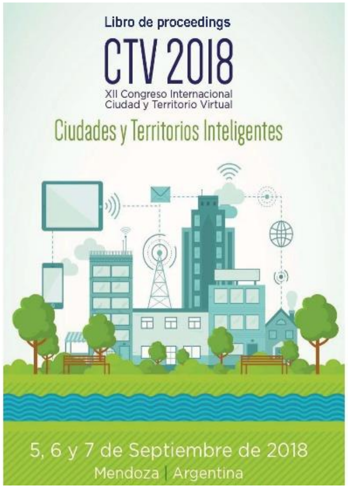
Bottero et al. (2018)compared the energy premium in Turin's residential market by three HPMs and four spatial models (i.e. linear and non-linear SAM and SLM) to test omitted spatial variables affecting the model's estimation result. However, this work mainly emphasized the necessity to check the consistency among the spatial and econometric approaches rather than the spatial distribution of energy premium.

McCord et al. (2020) used a cross-sectional housing price dataset of the Belfast Metropolitan area to explore the spatial analysis. In order to evaluate whether spatial effects exist between EPCs and housing price, several spatial tests, including GWR and SLM models are developed to account for spatial dependency and spatial heterogeneity. GWR results suggested that the

[38] Developed by Anselin (1999)

spatial variation indeed exists across Belfast but the influences are various according to different structural quality classification. Furtherly, SLM results revealed the spatial aggregation and clustering in relation to energy premium in Belfast.

In sum, there are still few studies using spatial econometric models to explore the impact of energy efficiency on housing price. Although there is a lack of theoretical support, on the other hand, this is also the main research direction for our future studies.



CHAPTER 6

The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases

Chen Ai & Marmolejo Duarte Carlos

CHAPTER 6 SAMPLE SELECTION BIASES IN MARGINAL PRICE OF HOUSING ENERGY EFFICIENCY

6.1 Overview

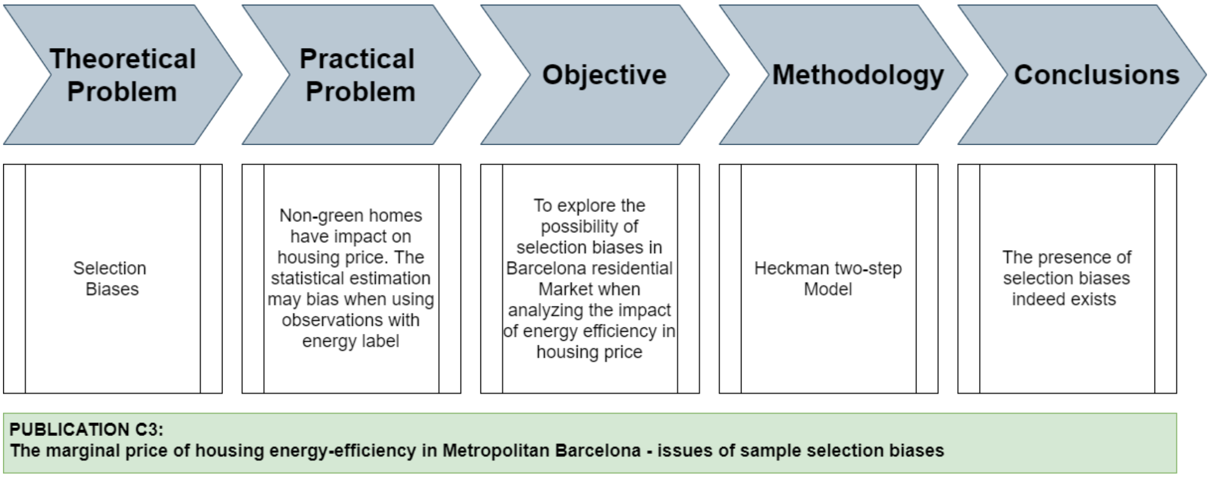


Figure 6. 1 Chapter 6's structure
Source: Own elaboration

This chapter is derived from the paper "The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases" published on the proceeding book CTV 2018. This chapter aims to explore the presence of selection biases and to correct these biases by the Heckman two-step model, as an initial procedure before a hedonic housing prices analysis (Figure 6.1). Section 6.2 illustrates a general introduction to the methodology and Heckman two-step model in detail as well as a brief description of the data. In relation to the impact of energy efficiency on housing price, Section 6.3 discusses the estimation results from Heckman two-step model within three aspect:1) whether there are the sample selection biases; 2) how to correct such biases if the selection biases indeed exist; 3) depicting the distribution of instrument variable "Inverse Mills Ratio" (IMR) and try to find if there is any relationship with other variables. Section 6.3 draws the conclusion.

6.2 Methodology, Model and Data

After having delimited the case study, the method has consisted in 4 steps:

1) First, a sample depuration procedure will be made by eliminating cases which prices were +/- standard deviation above or below-average price and using Mahalanobis distance.
2) Second, a Probit model will be elaborated which can be regarded as the selection equation model of Heckman two-step model. In this model, the dependent variable is a binary one where the energy-labelled dwellings are equal to 1 and otherwise is 0. Subsequently, a new variable - "Inverse Mills Ratio" (IMR) will be produced which represents the existence of sample selection biases if the P-value of IMR is less than 0.05 (confidence level =95%).
3) Third, a four-equation OLS hedonic price model will be built into 2 groups where the difference is the expressive forms of energy label in dwellings. Noted the IMR variable will be applied in these two groups to correct impacts of sample selection biases.
4) Finally, estimation results from the former four equations will be analyzed to identify the corrected impacts of sample selection biases, and a coefficient-estimated distribution of energy label and related variables also will be made as maps by ArcGIS.

6.2.1 Heckman Two-Step Model

Often, dwellings without energy-labels, according to previous literature, fail to estimate in the study to explore the impacts of energy label on housing prices. However, such dwellings influence the local housing prices and housing prices of energy-label equipped dwellings, in turn, will be affected by the condition of local real estate markets. That is to say, those cases we used are non-random ones and this ignorance may lead to bias in our estimation.

In order to identify and eliminate this bias, an econometric model called the Heckman two-step model was made by Heckman (1976). He pointed that the maximum likelihood estimation of a nonlinear model (e.g. Probit model) produced consistency, asymptotically normal estimator and the usual standard error and test statistics are valid if the selection is entirely a function of the exogenous variables. Heckman two-step model is made of 2 equations:

6.3.1.1 Selection equation - Probit model

Using all n cases, estimate a Probit model of a series related buildings and economic characteristics and factors on the presence of an energy label for a dwelling. Then IMR is produced to identify the existence of sample selection biases.

$$Dum_{EPC_i} = \beta_i + \sum_{s=1}^{n} \beta_{is}\, SD_{is} + \sum_{k=1}^{n} \beta_{ik}\, SB_{ik} + \sum_{m=1}^{n} \beta_{im}\, A_{im}$$

$$+ \textstyle\sum_{f=1}^{n} \beta_{if}\, E_{if} + \sum_{a=1}^{n} \beta_{a}\, S_{ia} + \varepsilon_i \qquad \textbf{(6.1)}$$

In equation (6.1), the existence of EPC of an apartment i depends on a set of variables related to SD structural attributes of dwellings; SB structural attributes of buildings; A accessibility indicators; E environmental quality indicator; S socioeconomic hierarchy indicator while ε is a vector representing the random error.

In the SD and SB dimensions, there are covariates and factors related to physical structural features (e.g. dwelling's and building's quality) and facilities (e.g. lift, heating as well as an air conditioner). It is worth saying, heating and air conditioner, as well as the presence of reform of dwellings, are correlated to energy efficiency since in Spanish regulation and law of energy efficiency in buildings EPC is made of some items related to such facilities. This dimension also includes the EPC ranks that are mandatory to be noted in the advertisement of properties as it has been sold.

The A dimension includes accessibility indicators, such as centrality index, the average time to work. It is worth saying that centrality index is an integrated variable which includes information of time-density, the density of activities, distance travelled by people making activities in a given zone by using DP2 methodology (Espina, 2009; Trapero, 1977).

The E dimension includes the perception of the presence of green areas and the percentage of different functional facilities (e.g. health facility, social services, cultural premises). It is supposed that higher proportion of such facilities proportion in a city or local districts will contribute to a higher housing price premium due providing to a satisfactory living environment.

In the S dimension, education and income level and are key factors. It includes the percentage of residents holding a university degree living around each of the analyzed apartments. In order to depict a wider picture of the socioeconomic structure of the city a Principal Component Analysis (PCA) has been computed departing from the professional categories (e.g. managers, clerks, blue-collar workers, etc.) of employed people living around each of the apartments. The resulting PC represents proxies for the high and low-income population. Socioeconomic indicators are relevant for price formation and EPC rank market premium since income and education are correlated with purchasing power, social prestige and environmental concerns (Banfi, et al. 2008; Himmelberg, et al. 2005).

Noted that in this model, a new variable, IMR, is produced by the model calculation. It is the ratio of the probability density of function over the cumulative distribution function of a distribution. This is usually applied to explore the presence of sample selection bias. The coefficient of inverse mills ration in Probit model can explain the presence of selection bias if the P-value is less than 0.05 (based on confidence level 95%)

6.3.1.2 Outcome equation – HP model

Hedonic price model is made by Rosen (1974). This method assumes that the price paid for the asset from housing buyers is equal to the total utility they extract from it, being this a composite utility coming from the marginal attribute of the dwelling (e.g. area, quality, location, etc.). It is possible to calculate such marginal utility expressed in monetary terms by a regression model.

In the literature, little advice can be found on the functional form that hedonic modes shall adopt (Can, 1992; Epple, et al., 2014; Malpezzi, 2008; Sheppard, 1999).

Nonetheless, the semi-log function has been intensively used in the context of real estate price analysis. Marmolejo & Gonzalez (2009) summarized the advantages of the semi-log function:

1) It helps to normalize the price and residual distributions which is fundamental for OLS regression analysis;
2) Coefficients can be read as semi-elasticity (i.e. coefficients express marginal price variation in per cent terms for each unit of change), making it possible to directly compare the importance of the attributes with the results of other studies.

Four models are established by using the samples equipped with EPC label information as following:

$$MOD1\colon \ln(P)_1 = \beta_{i1} + \sum_{s=1}^{n} \beta_{is}\, SD_{is} + \sum_{k=1}^{n} \beta_{ik}\, SB_{ik} + \sum_{m=1}^{n} \beta_{im}\, A_{im} + \sum_{f=1}^{n} \beta_{if}\, E_{if} + \sum_{a=1}^{n} \beta_{a}\, S_{ia}$$

$$+\beta_{n1} EPC_{in} + \varepsilon_i \qquad (6.2)$$

$$MOD2\colon \ln(P)_2 = \beta_{i2} + \sum_{s=1}^{n} \beta_{is}\, SD_{is} + \sum_{k=1}^{n} \beta_{ik}\, SB_{ik} + \sum_{m=1}^{n} \beta_{im}\, A_{im} + \sum_{f=1}^{n} \beta_{if}\, E_{if} + \sum_{a=1}^{n} \beta_{a}\, S_{ia}$$

$$+\beta_{n2} EPC_{in} + IMR + \varepsilon_i \qquad (6.3)$$

$$MOD3\colon \ln(P)_3 = \beta_{i3} + \sum_{s=1}^{n} \beta_{is}\, SD_{is} + \sum_{k=1}^{n} \beta_{ik}\, SB_{ik} + \sum_{m=1}^{n} \beta_{im}\, A_{im} + \sum_{f=1}^{n} \beta_{if}\, E_{if} + \sum_{a=1}^{n} \beta_{a}\, S_{ia}$$

$$+\beta_{n3} EPC_{io} + \varepsilon_i \qquad (6.4)$$

$$MOD4\colon \ln(P)_4 = \beta_{i4} + \sum_{s=1}^{n} \beta_{is}\, SD_{is} + \sum_{k=1}^{n} \beta_{ik}\, SB_{ik} + \sum_{m=1}^{n} \beta_{im}\, A_{im} + \sum_{f=1}^{n} \beta_{if}\, E_{if} + \sum_{a=1}^{n} \beta_{a}\, S_{ia}$$

$$+\beta_{n4} EPC_{io} + IMR + \varepsilon_i \qquad (6.5)$$

Where:

EPC_{in} indicates the nominal EPC level in an apartment i (seven variables assigned 1 if it is in existence). EPC_{io} indicates the ordinal EPC level in an apartment i (variable assigned as A=7, B=6, C=5, D=4, E=3, F=2, G=1). IMR means the Inverse Mills Ratio, the corrected variable of selection biases where it comes from the previous Probit model.

6.2.2 Data Description

Selling listing prices for apartments coming from Habitaclia is the main source of information. Habitaclia is one of the leading web-based real estate listings in Catalonia. The original dataset comprises 35,116 flats and includes architectonic structural attributes as well as geo-locations. Data refers to November 2014, it is to say, almost 1 year after the RD 235/2013 has made it mandatory to include EPC label information in real estate advertising. Nonetheless, such an obligation in the sample only 15% of the offers do include energy information. It is worth saying, that autonomous community Catalonia is one of the regions in Spain with a higher proportion of certified houses.

All the contextual information has been incorporated into each of the analyzed flats using a spatial query departing from a buffer of 300 meters of radius around each dwelling. In order to eliminate extreme cases a twofold approach has been used: 1) first all the cases with price values located beyond +/- Std. Dev from the average valued have been removed, 2) second, the remaining cases have been depurated using the Mahalanobis Distance.

This latter procedure allows to remove the cases whose price is not explained by the covariates but rather by other unmeasured aspects, such as landscaping or specific insulation against noise pollution (F. Li, et al. 2005). After filtering invalid cases, an effective sample with 4,248 labelled dwellings has been made.

Table 6.1 shows the statistical description of attributes for the 4,248 cases database. According to such data, the average selling price for apartments is 211,396 Euro (implying a unitary price of 2,197 Euro/sq. m.), the area of an average apartment is 89 sq. m, and has 1.36 bathrooms. Regarding the facilities of condominium, 6% of apartments are equipped with a swimming pool and 48% with lift; 33% of the listed apartments have air conditioners and 46% heating systems. The area of terraces and balconies in very dense and hot Mediterranean cities is pretty well appreciated by housing demand.

Regarding EPC rank the average class is 2.72, where the most efficient class in Spain is A=7 and the worst is G=1, only 15.77% of the sample is ranked as class A, B or C. All in all, it depicts a housing stock where thermal energy efficiency has a large room for improvement.

Table 6. 1 Descriptive statistics for the depurated sample

Dimensions	Variables	N	Minimum	Maximum	Mean	Std. Deviation
Structural Characteristics of Dwelling	Price (Euro)	4,248	22,800	8,000,000	211,396	251,925
	Unit price (Euro/sq.m)	4,248	304	15,385	2,197	1,352
	Area (sq.m)	4,248	25	600	89	39
	Number of bathrooms	4,248	0	6	1.36	0.60
	Number of rooms	4,248	0	15	2.95	0.96
	Ratio bathrooms/rooms	4,248	0	3	0.49	0.23
	Energy Rating (ordinal)	4,248	1	7	2.72	1.29
	Level of the apartment in the building	4,248	0	18	2.26	1.83
	Balcony or terrace areas (sq.m)	4,248	0	256	10.77	16.67
	Living room area (sq.m)	4,248	0	100	12.61	11.13
	Air conditioner (dummy)	4,248	0	1	0.33	0.47
	Heating (dummy)	4,248	0	1	0.46	0.50
	Quality/retrofit (dummy)	4,248	0	1	0.11	0.31
	Penthouse (dummy)	4,248	0	1	0.04	0.20
	Duplex/triplex (dummy)	4,248	0	1	0.05	0.22
Structural Characteristics of Building	Communal swimming pool (dummy)	4,248	0	1	0.06	0.24
	Communal garden (dummy)	4,248	0	1	0.10	0.30
	Elevator (dummy)	4,248	0	1	0.48	0.50
Accessibility Indicators	Built density (area floor ratio)	4,248	0.19	5.90	2.08	1.37
	Time-density	4,248	324	1,154,882	136,251	171,947

Dimensions	Variables	N	Minimum	Maximum	Mean	Std. Deviation
	Centrality index	4,248	2.52	20.53	11.59	2.54
	Land use diversity (of the context)	4,248	0.35	1.64	1.04	0.22
	Diversity of activities (of the context)	4,248	0.00	1.92	1.32	0.27
	Average time to work (minutes)	4,248	7.95	37.01	23.31	4.48
	Land use diversity at street level	4,248	0.00	90.10	12.93	14.16
Environmental Quality indicators	Average age of buildings (of the context)	4,248	21.17	124.35	55.65	16.29
	Perception of the presence of green areas	4,248	12.45	97.89	64.00	14.00
	% Health facilities (of the context)	4,248	0.00	41.88	2.08	2.96
	% Educational premises (of the context)	4,248	0.00	93.00	2.17	3.08
	% Social services premises (of the context)	4,248	0.00	68.47	1.84	4.30
	% Cultural premises (of the context)	4,248	0.00	95.15	1.64	3.87
	% Premises for trade (of the context)	4,248	0.00	89.93	40.75	13.55
	% Premises for offices (of the context)	4,248	0.00	100.00	16.52	14.12
	% Industrial premises (of the context)	4,248	0.00	97.01	8.88	11.26
Indicators of Social Hierarchy	% People holding a university degree (of the context)	4,248	2.34	68.73	21.78	14.38
	% buildings with porter services (of the context)	4,248	0.00	84.67	8.34	10.59
	CP low socioeconomic level	4,248	-1.97	7.42	0.03	0.96
	CP high socioeconomic level	4,248	-3.26	7.16	-0.21	0.85

Source: Own elaboration

6.3 Results and Discussion

6.3.1 The Presence of Sample Selection Biases

Table 6.2 shows the estimation results of the selection model where the dependent variable is the presence of EPC information when transacting in the market. It is a dummy variable where dwellings equipped EPC label is equal to 1, otherwise 0.

In Table 6.2, the appliances (e.g. air conditioning and heating) and facilities in buildings (e.g. lift and public swimming pool) do matter to the presence of EPC, but their impacts are negative. It is deduced that 1) the insulation function in energy-efficient dwellings is better than those unequipped ones, especially considering the Mediterranean climate in the MBA; 2) more than 50% of dwellings with a lift are out of the green label which may bias the impact inversely; 3) Noted Here the p-value of IMR is close to 0.000, indicating selection biases in this sample indeed exist. Subsequently, this corrected variable, IMR, will be introduced into the following hedonic models to detect and correct those selection biases.

Table 6. 2 Estimation results of selection model (Probit model)

	Coef.	Std. Err.	z	P>z	[95% Conf.Interval]	
Dependent Variable: Dum_EPC						
Constant	-1.12	0.094	-11.850	0.000	-1.304	-0.934
Unit price (Euro/sq.m)	0.00	0.000	2.520	0.012	0.000	0.000
Area (sq.m)	0.00	0.000	0.780	0.433	0.000	0.001
Level of the apartment in the building	0.03	0.005	5.390	0.000	0.016	0.034
Balcony or terrace areas (sq.m)	0.00	0.000	-0.950	0.341	-0.001	0.000
Living room area (sq.m)	0.00	0.001	-3.530	0.000	-0.004	-0.001
Air conditioner (dummy)	-0.03	0.022	-1.590	0.112	-0.078	0.008
Heating (dummy)	-0.28	0.023	-12.380	0.000	-0.326	-0.237
Quality/retrofit (dummy)	-0.04	0.028	-1.320	0.186	-0.091	0.018
grand terrace	0.00	0.000	0.200	0.843	-0.001	0.001
Communal swimming pool (dummy)	-0.11	0.043	-2.500	0.012	-0.192	-0.023
Communal garden (dummy)	0.02	0.034	0.570	0.567	-0.048	0.087
Elevator (dummy)	-0.18	0.021	-8.540	0.000	-0.224	-0.140
Built density (area floor ratio)	-0.02	0.011	-1.850	0.064	-0.041	0.001

	Coef.	Std. Err.	z	P>z	[95% Conf.Interval]	
Centrality index	0.00	0.005	0.520	0.602	-0.008	0.013
Perception of the presence of green areas	0.00	0.001	0.860	0.392	-0.001	0.002
% People holding university degree (of the context)	0.01	0.002	3.830	0.000	0.003	0.010
% buildings with porter services (of the context)	-0.01	0.001	-4.400	0.000	-0.009	-0.003
CP low socioeconomic level	0.01	0.019	0.580	0.559	-0.026	0.048
CP high socioeconomic level	-0.16	0.035	-4.540	0.000	-0.226	-0.090
IMR	-1.19	0.151	-7.900	0.000	-1.489	-0.897
rho	-1.00					
sigma	1.19					

Note: Dependent variables is the dummy of EPC in dwellings. Coefficients (Coef.), Standard Error (Std.Err.), Confidence (Conf.). The grey variables mean they could not represent the effect of variables on the presence of EPC.

Source: own elaboration

6.3.2 Corrected Samples Selection Biases

Table 6.3 shows the estimation results of various hedonic models where column 1 (MOD1) and column 3 (MOD3) are the ordinary least squares (OLS) models separated by the nominal and ordinal EPC variables. The other two columns are the results of the Heckman two-step model by IMR variables corrected the samples selection biases. Noted that variables show significance at a confidence of 95% and ranking G is the control group.

After correcting sample selection biases by IMR, the R square increases from 0.65 to 0.72. That is to say, the model with the same controlled variables can explain more 7% cases in the whole sample, which can strengthen the persuasion and results' accuracy. It is worth noting that IMR (-0.408 in MOD2 and -0.410 in MOD4) shows a negative impact on housing prices where the fewer selection biases, the higher housing prices premium.

Table 6. 3 Estimation results of HPM

		MOD1 (OLS Model)	MOD2 (Heckman two-step Model)	MOD3 (OLS Model)	MOD4 (Heckman two-step Model)
	R square	0.654	0.721	0.653	0.721
	R square adjusted	0.652	0.720	0.651	0.720
	Sigma	0.2859	0.3661	0.2862	0.3660
	(Constant)	10.236***	10.861***	10.229***	10.840***
		(0.05)	(0.151)	(0.05)	(0.152)
	IMR		-0.408***		-0.410***
			(0.094)		(0.094)
Structural characteristics of dwellings	**Area (sq.m)**	0.018***	0.011***	0.018***	0.011***
		(0.001)	(0.000)	(0.001)	(0.000)
	Air conditioner	0.101***	0.146***	0.101***	0.146***
		(0.013)	(0.017)	(0.013)	(0.017)
	Number of bathrooms	0.064***	0.128***	0.062***	0.129***
		(0.012)	(0.013)	(0.012)	(0.013)
	Heating	0.044***	0.182***	0.046***	0.184***
		(0.013)	(0.031)	(0.013)	(0.031)
	Quality/retrofit indicator	0.042**	0.066***	0.043**	0.066**
		(0.017)	(0.021)	(0.017)	(0.021)
	Area^2	0.000***	0.000***	0.002***	0.003***
		(0.000)	(0.000)	(0.000)	(0.000)
Structural characteristics of buildings	**Lift*floor level**	0.012***	0.022***	0.013***	0.022***
		(0.002)	(0.003)	(0.002)	(0.003)
	Communal swimming pool	0.134***	0.293***	0.136***	0.294***
		(0.026)	(0.029)	(0.026)	(0.029)
Accessibility	**Floor/area ratio**	0.038***	0.052***	0.038***	0.052***
		(0.006)	(0.007)	(0.006)	(0.007)
	Centrality indicator	0.01***	0.025***	0.01***	0.025***
		(0.003)	(0.004)	(0.003)	(0.004)
Socio hierarchy	**% people holding university**	0.005***	-0.007***	0.005***	0.007***
		(0.001)	(0.001)	(0.001)	(0.001)
	CP high socioeconomic level	0.061***	0.101***	0.061***	0.101***
		(0.014)	(0.019)	(0.014)	(0.019)
	% buildings with porter services	0.004***	0.003***	0.005***	0.003***

		MOD1 (OLS Model)	MOD2 (Heckman two-step Model)	MOD3 (OLS Model)	MOD4 (Heckman two-step Model)
		(0.001)	(0.001)	(0.001)	(0.001)
Energy rating	**A**	0.096***	0.126***		
		(0.034)	(0.037)		
	C	-0.027	0.071**		
		(0.026)	(0.029)		
	D	0.039*	0.058***		
		(0.019)	(0.022)		
	E	0.022	0.036**		
		(0.013)	(0.015)		
	F	0.011	0.007		
		(0.017)	(0.020)		
	Ord_EPCs			0.009*	0.020***
				(0.004)	(0.005)

Notes: Dependent variable is ln (total price); *** significance at 99%, ** significance at 95%, *significance at 90%; The grey variables mean they could not represent the effect of variables on the presence of EPC.

Source: own elaboration

The majority variables shows an increasing premium on housing prices after biases corrected, especially the impact of the presence of heating and public swimming pool on housing prices, around 15% premium growth. The same conclusion we have concluded from the previous selection model where such appliance and facilities in buildings highly contributed to the presence of EPC.

Regarding energy efficiency information, the energy-efficient premium on housing prices increases from 9.6% to 12.6% when dwellings are improved from ranking G to ranking A or from 0.9% to 2% with energy ranking after corrected sample selection biases. More nominal EPC variables (e.g. ranking C and ranking E) show the significant impacts on housing prices after corrected sample selection biases. It is to say that sample selection biases may not only influence on estimation results but also the model specification.

6.3.3 Selection Biases Impacts Across Urban

As previous stated, IMR shows the impact of selected biases in the whole sample: the larger coefficients of IMR, the higher impacts of unobserved cases. Figure 6.1 (a) shows the distribution of IMR. The impacts of sample selected biases are higher along the coastline, such as Sitges, Barcelona and Maresme zones while such impacts are lower in far away from MBA centre (in red colour). In Figure 6.1 (b), it shows a similar distribution of total housing prices compared with that of IMR's impact. Dwellings with high housing prices located in areas where EPC premium is affected highly by sample selection biases. The same conclusion to the distributions of the proportion of people holding a university degree (Figure 6.1 (c)). Generally, selection biases more likely happen to dwellings with high prices and surrounded by a higher proportion university education neighbourhood.

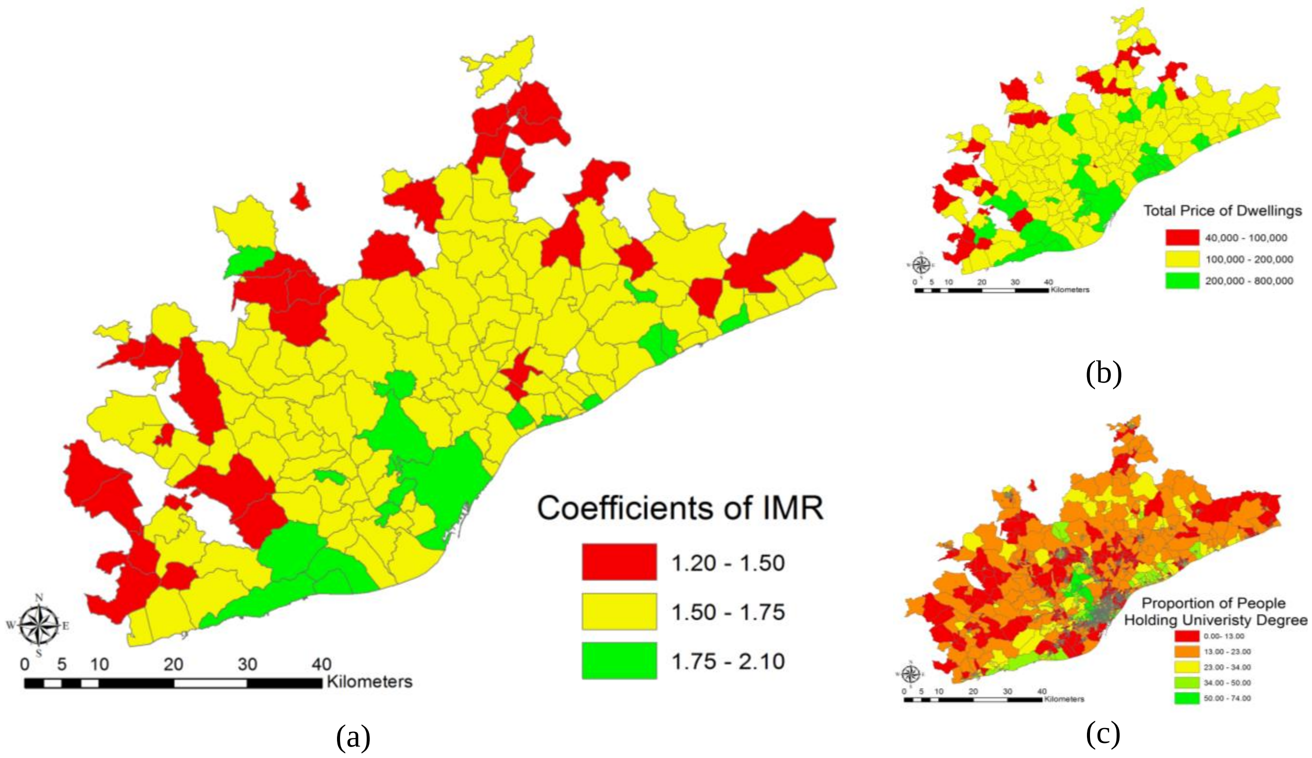
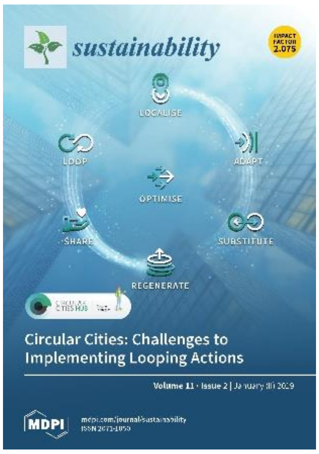


Figure 6. 2 Spatial distribution of residential variables
(a) Coefficients of IMR; (b) Total price of dwellings; (c) Proportion of people holding a university degree
Source: Own elaboration

6.4 Conclusions

The process of Energy Performance Certificates has made a great achievement after it was introduced by EPBD in 2002. In order to enhance the public awareness on energy efficiency and promote EPCs difussion in the residential market, it is mandatory to offer EPCs information when transacting in the real estate market from 2010. Therefore, numerous studies on housing prices impacted by EPCs are investigated but a few studies concerning the selection biases when taking into consideration. In such case, we applied the Heckman two-step method to detect the presence of selection biases and corrected these biases in the Hedonic model using IMR.

Our results suggest that selection biases indeed exist and have an impact on housing prices regarding energy efficient label. This premium increases from 9.6% to 12.6% when houses improve energy ranking from G to A, or from 0.9% to 2% with every ranking increasing. That is to say, correcting the impact of selection biases brings a 3% increase on housing prices from G to A or 1.1% with energy ranking. Simultaneously, we find that selection biases more likely happen to dwellings with high prices and surrounded by a higher proportion university education neighbourhood.



CHAPTER 7

The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments and Implications for Public Policy and Private Markets

+

La incidencia de las etiquetas energéticas EPC en el mercado plurifamiliar español: un análisis para Barcelona, Valencia y Alicante

Marmolejo Duarte Carlos & Chen Ai

CHAPTER 7 THE UNEVEN PRICE IMPACT OF ENERGY EFFICIENCY ON HOUSING SEGMENTATION

7.1 Overview

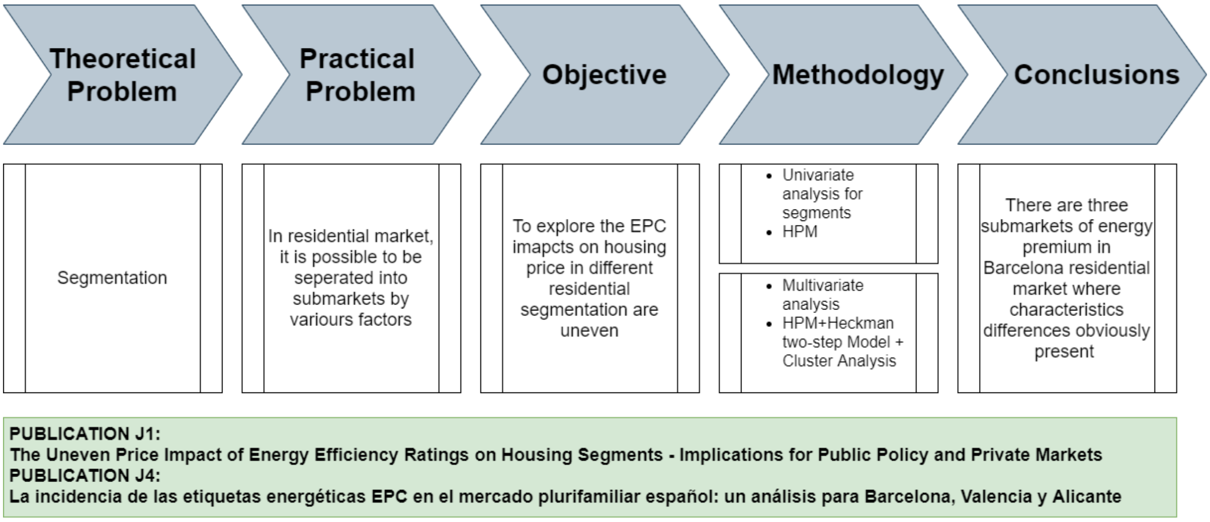


Figure 7. 1 Chapter 7's structure
Source: Own elaboration

This chapter aims to test whether the impact of EPC ratings on housing prices is the same in different market segments within a city. This analysis is relevant since the identification of divergent impacts may help to orientate specific energy and housing public policies, while simultaneously signalling opportunities for private developers. With this objective, this study uses data of listed apartments in Barcelona Metropolitan Area (BMA), Valencia Metropolitan Area (VMA) and Alicante Metropolitan Area (AMA) . This case is worth studying due to the late and overnight transposition of the 2010 EPBD in Spain: only 47 days separated the date of the publication of the RD 235/2013 (that transposed the Directive) and the 1st of June of 2013 when it was mandatory to include the EPC labels in real estate marketing. At the same time, due to the financial crisis, the public campaigns were almost nonexistent, making it impossible to make the households aware of the meaning and utility of the EPC scheme.

Broadly, the methodology consists of: (1) Acquire geoprocessing and depurate the data, (2) Calibrate a hedonic model for the entire depurated sample for three MAs and , (3) split the sample into housing segments using univariate and multivariate approaches, (4) calibrate specific models for each of the segments, and (5) identify whether the hedonic agenda for each of the segments is statistically different.

The main novelty of the multivariate approach, in relation to the previous studies that have analyzed market segments (Cerin et al., 2014; Fuerst et al., 2015; Hyland et al., 2013; Salvi et al., 2008), lies precisely in the segmentation of the market based on the multiple urban and architectural attributes that effectively affect the formation of real estate prices.

The remainder of this chapter is organized as follows: First, a brief decription of the Hedonic Price Model (HPM) is introduced which is the main model to analyze the different performance of energy efficiency in segmentations. Subsequently, HP estimations results are proposed for each segments which are derived by univariate and multivariate approaches. Finally, general discussions and conclusions about energy efficiency performance across segments are drawn.

7.2 Hedonic Price Model

The hedonic analysis assumes that the value of a dwelling can be broken down into the implicit value of each of the residential attributes (Fuerst et al., 2015). Therefore, it is based on the hypothesis that households make their residential choices by matching the marginal utility of housing attributes with their marginal price. Through a multivariate statistical procedure, the implicit price of each of these factors can be delineated (Rosen, 1974). In the literature, it is usual for this marginal value to be calculated through a regression model using, in the absence of a clear theoretical posture, a log-linear specification (Addae-Dapaah & Chieh, 2011). This procedure has several virtues, on one hand, it facilitates that the distribution of the dependent variable (the price) approaches normality, thus enabling calibration using OLS (Ordinary Least

Squares) while also reducing the statistical problem of heteroscedasticity (Malpezzi, 2008) and on the other, it allows for interpreting the coefficients as semi-elasticities: the per cent change in price produced by a unitary increment of the independent variable.

In this paper the functional expression being used is:

$$Ln(P) = k + \sum_{A=1}^{n} BA + \sum_{E=1}^{n} BE + \sum_{L=1}^{n} BL + e \qquad (7.1)$$

In equation (7.1), *Ln(P)* is the natural logarithm of the listing price of the depurated sample; *A* is a vector that includes the architectural characteristics of each of the studied dwellings (including energy rating); *E* is the same but referred to the building, while studied dwellings are multi-family type so that there are common services (e.g., lift or swimming pool) that can influence the price of these; *L* is a vector that internalizes the spatial factors of urban and socio-economic nature that impact on the formation of residential prices through land rent; finally, *B* are the coefficients representing semi-elasticities and *e* is the error term.

As will be explained in the next subsection, a large proportion of apartments does not contain an EPC rating. This fact reflects sellers not adhering to the obligation to exhibit the EPC label in the advertising as the Royal Decree 235/2013 mandates. This issue may introduce a sample selection bias if the sellers exhibiting the EPC label are not randomly distributed among the non-depurated sample. So, in order to fully assure the robustness of the analysis, as suggested in reference (Hyland et al., 2013), the 2-step Heckman model has been implemented. Such a model has been built as follows:

- First, a logistic model has been specified with the variables correlated with the presence of an EPC energy rating. The variables found to influence the probability of the presence of such information are: area, swimming pool, lift, air conditioner, heating, and socioeconomic indicators of the location of the apartments. In general, the poorer apartments exhibit a larger probability of including the EPC information in its advertisement.

- Second, using the above-stated variables as "selection variables" the 2-steps Heckman procedure has been implemented.

7.3 Segments by Residential Univariate Analysis

Before to explore the segments made by a multivariate approach, we firstly researched the existence of energy premium segments by a single variale, i.e. the energy premium in various Spanish Metropolitan Areas (MAs), including Alicante Metropolitan Area (AMA), Barcelona Metropolitan Area (BMA) and Valencia Metropolitan Area (VMA).

7.3.1 Data Description

This dataset consists of 14,058 green homes where 5,784 are in AMA, 4,857 are in BMA and 3,417 in VMA. Table 7.1 show the descriptive statistics for three MAs, indicating the important differences have emerged. Housing price in BMA is 57% more expensive than that in VMA concerning the total price. In addition, the average construction year of apartments in BMA is one year older than that in VMA and six years older than that in AMA. Compared with the architectural characteristics in AMA and VMA, apartments in BMA are within the smallest size (i.e. 87 m^2) and locate in the buildings that 35% of them are not equipped with a lift. On the contrary, as is to be expected, the proportion of homes in BMA is much higher than that in VMA in relation to the presence of heating[39]. Similarly, the proportion of homes with grand terraces is also largest, 12% in BMA [40] while there are less grand terraces in AMA and VMA, 7% and 6% respectively.

[39] It highlights the importance of the "small" climatic divergences

[40] Generally the attics and penthouses in the Ensanche (city centre) will have grand terraces.

As can be seen in Table 7.1, the differences in relation to EPC ratings are greater. The Barcelona houses, despite building's age is older, are better rated with 1.38 on an ordinal scale (where 1 = G and 7 = A), followed by the Valencian ones (0.87) and in last place are the Alicante ones (0.53). Indeed, it is possible to find, albeit with enormous difficulty, well-rated homes in BMA and VMA. However, the non-certificated homes in AMA and VMA have predominate proportions, i.e. 87% and 73% of apartments with rating "G" respectively while in Barcelona only 20%. This differentiation is important and it seems to influence the formation of the hedonic agenda of the EPC ratings.

Table 7. 1 Descriptive statistics of architectural variables and EPC ratings for three MAs

		AMA N=5,784	BMA N=4,857	VMA N=3,417
Architectural Variables	Total price (euros)	113,744	185,541	121,882
	Unitary price (euros/m^2)	1,153	2,095	1,149
	Floor area (m^2)	98.7	87.2	103.9
	Number of bathrooms	1.5	1.3	1.5
	Swimming pool (dummy)	27%	11%	8%
	Terraza area (m^2)	6.0	9.4	4.1
	Lift (dummy)	70%	65%	75%
	Kitchen quality*	3%	34%	6%
	Air conditioning (dummy)	37%	42%	40%
	Heating (dummy)	16%	67%	25%
	Chimeny (dummy)	1%	6%	1%
	Well preserved / reform (dummy)**	15%	17%	17%
	High quality of dwellings (dummy)***	3%	3%	2%
	Grand terraza(dummy)+	7%	12%	6%
	Construction year ++	1981	1974	1975
Energy Performace Certificates	Rating A	1%	3%	3%
	Rating B	0%	0%	0%
	Rating C	0%	3%	0%
	Rating D	1%	10%	2%
	Rating E	8%	51%	18%
	Rating F	3%	13%	4%
	Rating G	87%	20%	73%
	EPC Ordinal º	1.28	2.75	1.66
	Rating A+B+C+D	1.9%	16.3%	5.8%

Source: Own elaboration

7.3.2 Results and Discussion

As can be seen in Table 7.2, the MOD 1 EPC ORD indicates a positive impact of the EPC which is performed as a continuous variable (A=7, G=1). Housing prices become more expensive by 1.54% with the increase of each EPC rating. In other words, there will be a 9.26% growth of housing price if an apartment's energy efficiency (wherever it is in 3 MAs), heightens from “G” to “A”, ceteris paribus.

On the other hand, the climatic zones seem to mask aspects related to the consolidation of the urban fabric, rather than the climatic differences themselves. Importantly, the C2 zone (the coastal plain and the valleys in the BMA) and B3 (the Valencian coastal plain where the bulk of the central conurbation and the metropolitan sub-centers are concentrated) are introduced.

In order to study whether there is a homogeneous impact of the energy rating in the three MAs, MOD 2 EPC ORD x AM has been built with the same control variables as MOD 1. As can be seen in Table 7.2, the impact is not homogeneous: it is greater in Valencia (+ 3.35%) than in Barcelona (+ 1.79%) and, surprisingly, it is negative in Alicante (-1.23%). In relation to the work of Marmolejo (2016) carried out in the BAM, whose data analyzed is 18 months prior to ours, The impact of the EPC on housing prices has strengthened, going from a timid 0.852% (SE=0.41%) in Marmolejo (2016), to 1.79% (SE=0.31%) in this Section. As expected, energy efficiency gains will be higher with the promotion and development of energy policies.,

To study in detail what happens in the strange reversed sign of the energy class coefficient in Alicante and to analyze the HP for each EPC rating, the MODs 3-5 EPC NOM have been built by MAs. According to these models in Valencia and Barcelona, there is no linear progression of the impact of energy classes on prices, Instead, it tends to be logarithmic, that is, the marginal increase of housing price for an apartment with more efficient EPC ratings (e.g. rating “A”), is less than the less-efficient ones.

In Barcelona, an apartment certificated with rating “A” sells 10% more expensive than that classified with “G”. In Valencia, the surcharge for the same energy improvement scales up to 29%. This means an increase of 18,307 euros and 35,005 euros for the average value of the analyzed sample, respectively. However, class "E" has a premium of only 2% in Barcelona and 4% in Valencia in relation to class "G". Likewise, class "D" again has a higher impact in Valencia than in Barcelona. Therefore, there is a very different hedonic agenda between the two main metropolises studied, BMA and VMA. The diversity of energy classes play a significant role: 1) in Barcelona this diversity is greater and there are also more better-classified homes (for every 100 badly rated homes - "G" and "F" - there are 20 "good" rated "A", "C", "D" and "E"); 2) on the contrary, in Valencia the diversity of energy classes is lower, and there are also fewer well-rated homes (for every 100 poorly rated homes there are only 3 "good" rated homes). Thus, in Valencia the best-rated homes are relatively scarcer and it is possible that this is due to the fact that their premium is higher.

If the relative abundance of the best-rated homes supposes a loss of the power of differentiation of the market prices of the energy attribute, it means that as more better-rated homes appear, either due to the tightening of the regulations or because developers find advantages to investing in more efficient housing, we are likely to witness a loss of the price differentiating power of EPCs.

Table 7. 2 Estimation results for each segments

		R^2 aj	F	Sig.	R^2 aj	F	Sig.	R^2 aj	F	Sig.	R^2 aj	F	Sig.	R^2 aj	F	Sig.
Adjustment of Models		0.76	1,752	0.00	0.76	1,659	0.00	0.70	449	0.00	0.78	555	0.00	0.72	309	0.00
		MOD 1 EPC ORD N=14,058			**MOD 2 EPC ORD x MAs** N=14,058			**MOD 3 EPC NOM AMA** N=5,784			**MOD 4 EPC NOM BCN** N=4,857			**MOD 5 EPC NOM BCN** N=3,417		
		B	Beta	Sig.	B	Beta	Sig.	B	Beta	Sig.	B	Beta	Sig.	B	Beta	Sig.
Architectural Variables	(Constante)	7.34		0.00	14 Sig. al 95% conf.			14 Sig. al 95% conf.			14 Sig. al 95% conf.			14 Sig. al 95% conf.		
	Floor area	0.01	0.83	-												
	Number of bathrooms	0.13	0.14	0.00												
	Swimming pool (dummy)	0.17	0.12	0.00												
	Lift (dummy)	0.08	0.07	0.00												
	Air conditioning (dummy)	0.07	0.06	0.00												
	Grand terraza(dummy)	0.11	0.06	0.00												
	Heating (dummy)	0.06	0.05	0.00												
	Lift*Floor	0.01	0.05	0.00												
	Construction year	0.00	0.05	0.00												
	Kitchen quality	0.04	0.03	0.00												
	Well preserved / reform (dummy)	0.04	0.03	0.00												
	High quality of dwellings (dummy)	0.08	0.03	0.00												
	Chimeny (dummy)	0.06	0.02	0.00												
	Square Floor area	-0,00	-0.42	0.00												

Urbanistic and Territorial Variables	BMA	0.33	0.30	0.00												
	AMA	0.04	0.03	0.00												
	Percentage of residents with university education	0.01	0.23	-												
	Employ density	0.00	0.15	0.00												
	Distance to highway(km)	0.02	0.06	0.00												
	Access to sea (<200 m.)	0.13	0.05	0.00	8 Sig. al 95% conf.			11 Sig. al 95% conf.			10 Sig. al 95% conf.			8 Sig. al 95% conf.		
	Access to highway (dummy)	0.09	0.05	0.00												
	Locales (PB/100 hab)	0.00	0.03	0.00												
	Percentage of high value activities [a]	0.00	0.02	0.00												
	Percentage of opinion to noise	-0,00	-0.02	0.00												
Climatic Zone	Climatic zone C2	0.19	0.16	0.00	0.18	0.16	0.00				0.15	0.09	0.00			
	Climatic zone D1										-0.40	-0.02	0.00			
	Climatic zone B3	0.03	0.02	0.02	0.03	0.02	0.01							0.03	0.02	0.05
Energy Performace Certificates	EPC Ordinal	0.02	0.04	0.00												
	Rating A							0.08	0.01	0.05	0.10	0.03	0.00	0.29	0.10	0.00
	Rating C							-0.23	-0.03	0.00	0.06	0.02	0.00	0.18	0.01	0.25
	Rating D							0.02	0.00	0.59	0.07	0.04	0.00	0.16	0.05	0.00
	Rating E							-0.05	-0.03	0.00	0.02	0.02	0.10	0.04	0.03	0.00
	Rating F							-0.05	-0.02	0.01	0.01	0.00	0.62	-0.02	-0.01	0.38
Interaction Variables	EPC Ordinal * AMA				-0.01	-0.02	0.00									
	EPC Ordinal * BMA				0.02	0.05	0.00									
	EPC Ordinal * VMA				0.03	0.06	0.00									

Source: Own elaboration

However, the previous hypothesis seems to be rejected in Alicante where the diversity of energy classes is very scarce (1 better rated for every 100 apartments). As above mentioned, tthe energy premium in AMA is negative. Thus, only the very rare "A" homes have an 8% premium over the comparison "G", but all the rest of the classes have prices lower than the worst "G", ceteris paribus. Noted that in Alicante class "G" is abnormally abundant. More than 80% of green apartments are certificated with rating “G” regardless of the construction years. Gnerally, the homes recently built should have a stricter requirement and more likely to have a better EPC rating. Therefore, it is necessary to analyze in detail how different class “G” homes are in the three MAs and to understand why, against all prognosis, in Alicante they form surcharges instead of penalties.

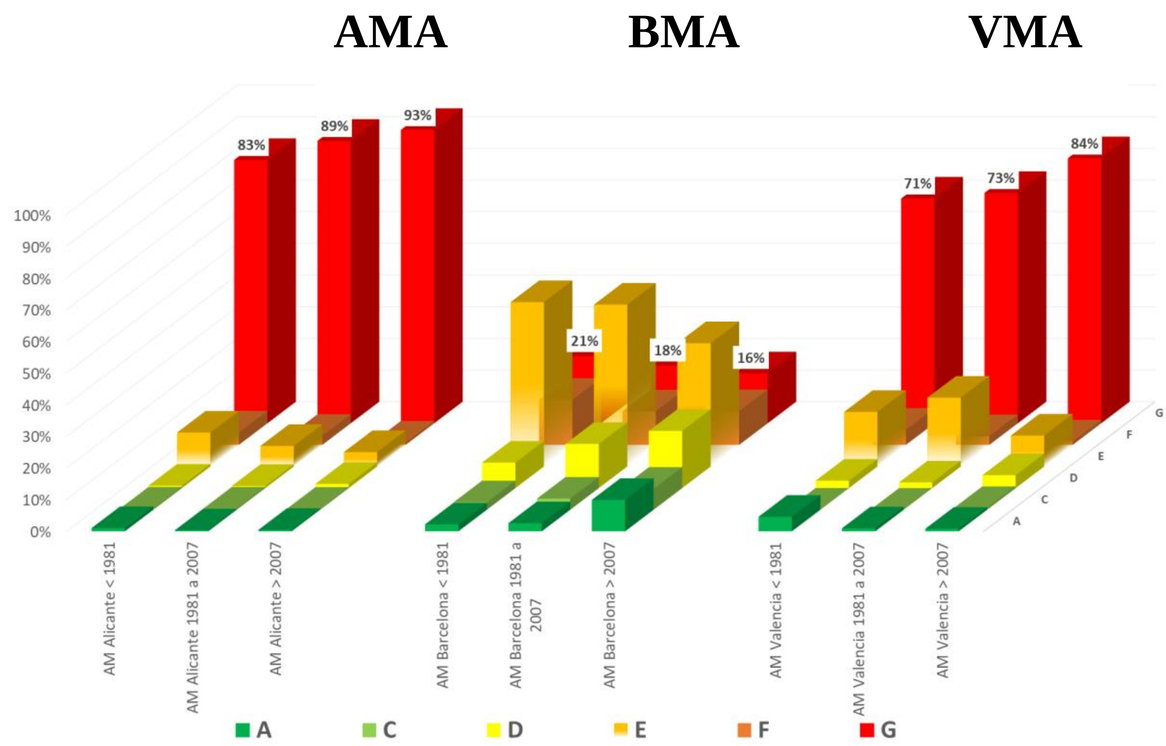


Figure 7. 2 Segmentations by energy class and announced year of construction
Source: Own elaboration

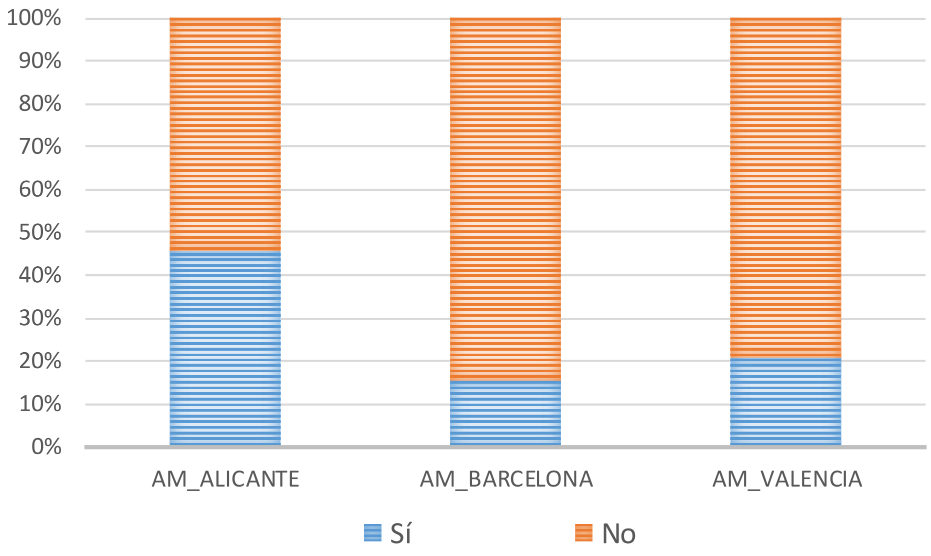
Figure 7.2 illustrates the relationship between the construction year and advertised energy class. As it can be seen, the Barcelona case follows the expected patterns: the most recent homes have greater energy efficiency, clearly a drop in "E" homes is observed in the post-CTE period in favor of classes "C" and " A". In VMA there is also a drop in “E” and “F” homes, but a strange rebound in class “G” in the period after 2007. Something similar happens in Alicante. These performances are in spectacular contrast to what happens in Barcelona.

It is likely that the very abundant presence of “G” homes in the VMA and AMA, is due to an intense rehabilitation process (without energy implications) in the post-CTE period, and therefore, the year construction declared is actually the year of home renovation. Indeed, the proportion of renovated homes is higher in Alicante, but above all:

(1) In Alicante the differentiation between “G” dwellings and the rest is very scarce, only 9 attributes are statistically different; Quite the contrary, in Barcelona there is a very clear divergence between the characteristics of park "G" in relation to the rest, since it differs at 95% confidence in 17 of its attributes with relevance in prices. It would seem as if the Alicante homes, regardless of their quality, were randomly distributed between the worst rated ("G") and the rest.

(2) In Alicante, energy inefficient “G” houses are generally better in all respects than the rest of the classes: they have a higher proportion of lift and air conditioning, they are newer, they are larger and they are more expensive; on the contrary, in Barcelona, as is to be expected, the worst rated homes have bad performances in the other attributes.

All of the above-mentioned highlights the important singularities of the advertised Alicante residential market: an inexplicable worse energy quality in post-CTE homes, an inexplicable inverse correlation between the energy rating and the rest of its quality attributes; and, above all, an inverse correlation between energy efficiency and property prices.



	Información de la clase energética		
	Sí	No	Total
AM_ALICANTE	8,461	10,186	18,647
AM_BARCELONA	7,511	41,913	49,424
AM_VALENCIA	5,015	19,276	24,291

Figure 7. 3 Proportion of advertisements with energy information
Source: Own elaboration

Could these inconsistencies be due to anomalies in the advertising of the energy class? Could it be that advertisers, in order not to incur an administrative fault derived from the omission of the energy class, are advertising the lowest of the classes? Figure 7.3 details the proportion of homes that includes the energy class in their advertisement, as seen in both Barcelona and Valencia, only between 15 and 20% of the offers respectively include the energy label (the rest are "pending"). On the other hand, in Alicante this proportion scales up to 45%. Do the bidders in AMA comply more vigorously with the legislation? Or, on the contrary, is there an informational distortion of enormous dimensions? As a further consequence, it has the complete trivialisation of the energy label in the Alicante real estate market to the extreme of producing inverted correlations with residential values.

Finally, Figure 7.4 compares the distribution of the energy classes that appear in the official regional registers and that advertised in the sample of the analyzed market. In the case of Alicante (and apparently also in Valencia), it is confirmed with great clarity that there is an oversize of class "G" in the advertised real estate offer in relation to the park actually certified. To test whether this divergence is significant, the Mann-Whitney U test has been carried out, which has confirmed that only in Barcelona there is a parallel between the energy information published in real estate offers and the energy reality of the certified park.

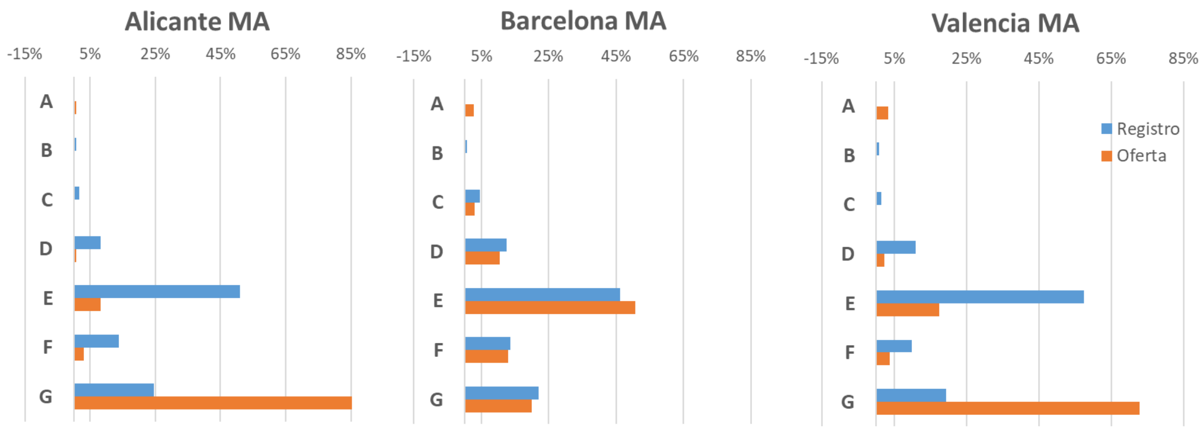


Figure 7. 4 Comparison between the EPC distribution of the official record and that published in the studied sample
Source: Own elaboration

The alleged above anomalies are not a novelty in Spain. Since the very dawn of RD 235/2013, news has appeared in the press about problems in: a) the qualification of some certifiers, b) the lack of rigor in carrying out certain certifications and c) the picaresque in the advertising of the energy class. Indeed, between the date of approval of the aforementioned Royal Decree and its entry into force, scarcely six weeks passed, which led to an avalanche of certifications.

“We [architects] come to us who want to pay 30 euros for certificates that companies charge at 50 euros” (Pilar Pereda, General Secretariat of COAM, in SÁNCHEZ, 2014).

"The risk that prices are being thrown is that their quality is being reduced ... energy certification is being trivialized" (Gonzalo CERVERA, Director of Tinsa Certify in SALIDO, 2013).

"The picaresque knows no limits [...] there are professionals who carry out distance certificates without visiting the home" (Ángel I. Cobos, Secretary of the Madrid Property Administrators Association in SÁNCHEZ, 2014).

"The level of deception ranges from technicians who make scams to sell more [certification services] to individuals or real estate companies who Photoshop the letter. (Pilar Pereda, General Secretary of COAM, in SÁNCHEZ, 2014).

Faced with these problems, both the competent administration and the courts have responded with administrative sanctions and sentences respectively. For example, in Murcia of the 26 inspections carried out, one year after the RD came into force, in buildings and tertiary premises, 90% were erroneous. Thus, in communities like Madrid, the first sanctioning files did not take long to appear, revealing discrepancies between the data used in the certification and the reality (Viúdez, 2013) and the first sanction to a certifier of 4,000 thousand euros arrived, in that same community , in December 2013 (Bueno, 2013). Navarra was one of the first Autonomous Communities to sanction real estate agencies that advertised their properties without including the energy class; while Catalonia made a campaign to remind them of this obligation (Bueno, 2014). Against this background, it is not difficult to assume that in certain markets there are misrepresentations that obscure the alleged energy transparency of the community real estate market.

7.4 Segments by Residential Multivariate Analysis

7.4.1 Methodology

The methodology was established in five stages (see details, data sources and flow procedure in Figure 7.5):

(1) Data acquisition, preliminary indexes computation, geoprocessing, depuration and representativeness analyses. This stage consists of:

Data gathering from different sources of information regarding listing apartment data and urban and territorial features. Each of the data sources has a specific geographic unit.

Computation of preliminary urban indicators. Using job positions data from census information, a principal component analysis (PCA) has been performed in order to eliminate concomitant information. Thus, the larger the value of “CP-high-socioeconomic-level” index, the larger the proportion of residents holding managerial, officers and intellectual job positions. Utilizing trip-chain information and following the example of reference (Marmolejo & Cerda Troncoso, 2017), two indicators for centrality have been computed: time-density stands for the number of hours per urbanized km^2 that people spend in a given transport zone; the centrality index accounts for the time-density, diversity of activities performed by people and modality in transport zones. The floor area ratio is calculated from the built area and the urbanized surface from the cadastral dataset. Finally, the land use diversity is computed using the Shannon index and data from the utilization of built premises at street level.

Transferring of territorial and urban data to an apartments database. By means of a geo-process, the original data and the preliminary urban indicators have been transferred to each of the apartments in the dataset. This specific process consists of using a buffer analysis where data is transferred according to the intersected area. In order to determine the radius of the buffer, a cross-validation procedure has been implemented. Such procedure consists of calibrating preliminary hedonic models and identifying the radius that leads to the largest covariance. After testing a 300, 600 and 900 m. radius, the first was selected.

Depuration of the dataset and representativeness analyses. Following reference (Marmolejo & González Tamez, 2009), the Mahalanobis distance has been used so as to eliminate outliers on a multi-attribute basis. Also, apartments with no EPC information have been discarded. In order to test whether the depurated sample is representative of the original non-depurated sample and representative of the EPC rating distribution contained in the EPC Catalan Official Register, two tests have been implemented. The first accounts for the statistical representativeness of the *number* of apartments, the second, using the ANOVA (Analysis of Variance) accounts for the representativeness of the *distribution* of EPC ratings.

(2). Specification and calibration of a hedonic model for all the depurated sample

Departing from the depurated sample, a hedonic model has been implemented as being further detailed.

In order to assure the robustness of the results regarding a possible selection bias, the 2-step Heckman procedure has been implemented, see below.

(3). Segmentation of the depurated sample.

First, a principal component analysis has been implemented so as to eliminate redundant information, such analysis has departed from the variables found to be correlated with prices in the model specified in (2) except for the EPC ratings in order to avoid endogeneity issues. Next, the apartments have been classified using a 2-step cluster analysis, considering the principal components previously calculated as segmentation variables.

(4). Specification and calibration of hedonic models for each of the segments.

The same procedure described in (2) has been repeated for each of the housing segments.

(5). *Finally, structural differences in the hedonic agenda for each of the segments have been identified using the Test of Chow*

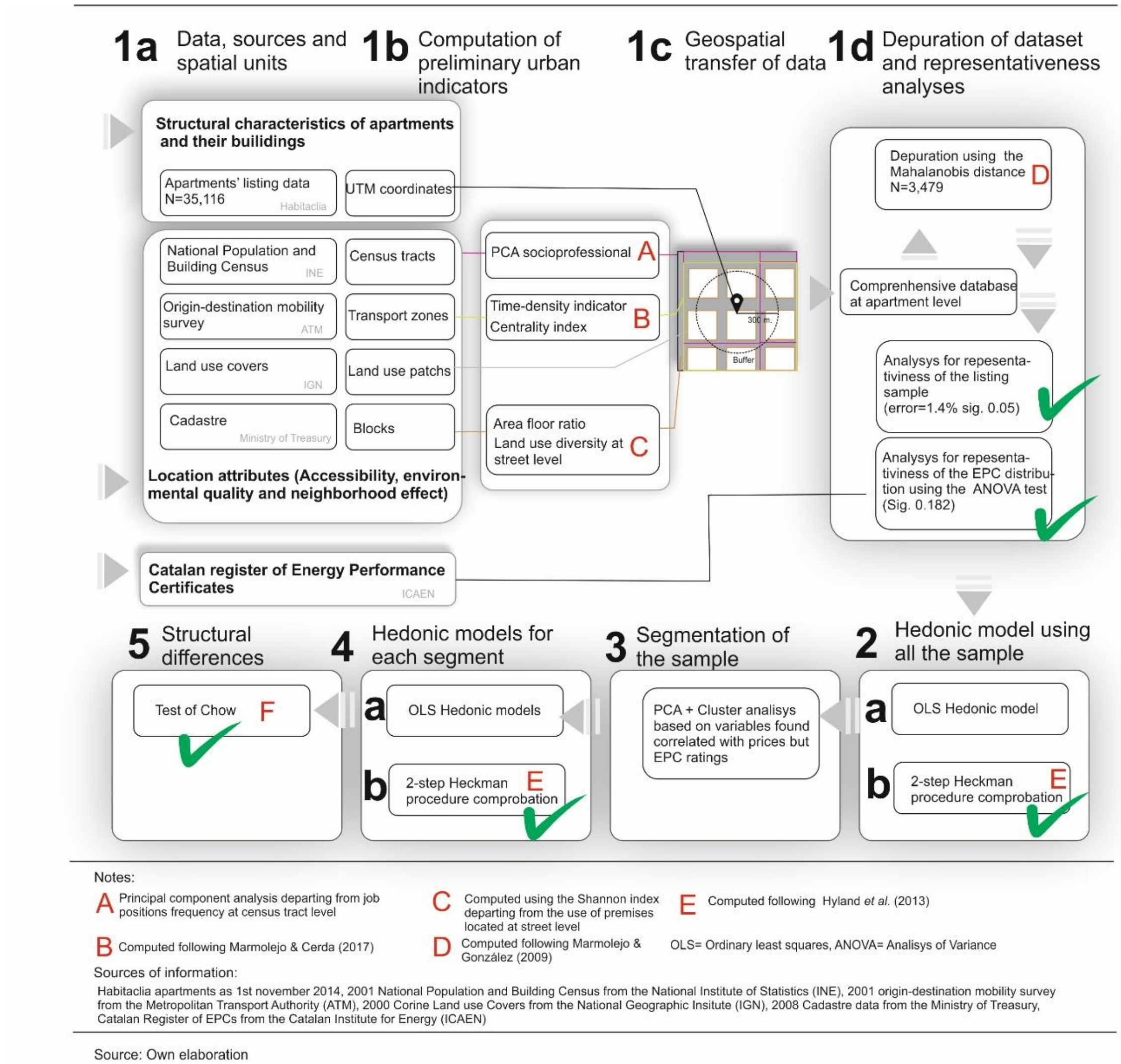


Figure 7. 5 Section 7.4's structure
Source: Own elaboration

7.4.2 Data Description

After discarding the cases with no EPC information and eliminating outliers on a multivariate basis, the depurated sample is made up of 3,479 apartments. Yet it is still representative of the universe of listed apartments (error = 1.4% sig. = 0.05). Also, according to the ANOVA test (sig. = 0.182), it is representative of the EPC rating distribution contained in the Official EPC Register. All in all, the depurated sample represents both the listed apartments and the energy efficiency performance of the certified housing stock.

Table 7.3 contains the descriptive statistics of the depurated sample. The average apartment is sold for 160 thousand Euro and has 84 sq. m, with 1.29 bathrooms and 2.9 bedrooms. In general, 29% of the sample have air conditioning, 42% have heating and 45% have elevators, while only 4% have a communal swimming pool. The people with a university degree living in the housing environment range from 2.34% to 66.10%. Finally, on an ordinal scale (A = 7, G = 1), the average EPC rating is 2.7. The dichotomous indicator "quality/retrofit" is constructed upon a semantic analysis of the description included in the advertisements, highlighting the high quality of the finishing, outstanding design or the fact that properties have been retrofitted. Only 10% of the depurated sample can be considered as "qualified/retrofitted". Finally, the important dispersion of variables stresses the large differences in housing and locative attributes across the city.

Table 7. 3 Descriptive statistics of architectural and spatial variables of the depurated sample

	Variable	N	Min	Max	Average	Std. Dev.
Structural characteristics of a dwelling	Price (Euro)	3479	34,000	715,000	159,707	88,017
	Unit price (Euro/sq. m)	3479	845	3542	1885	662
	Area (sq. m)	3479	25	234	84	28
	Number of bathrooms	3479	1	4	1.29	0.51
	Number of rooms	3479	–	15	2.91	0.90
	Ratio bathrooms/room	3479	–	2	0.48	0.23
	Energy Rating (ordinal) *	3479	1	7	2.70	1.25
	Level of the apartment in the building	3479	–	13	2.14	1.63
	Balcony or terrace area (sq. m)	3479	–	256	9.73	14.53
	Living room area (sq. m)	3479	–	90	12.04	9.83
	Air conditioner (dummy)	3479	–	1	29.00%	0.46
	Heating (dummy)	3479	–	1	42.00%	0.49
	Quality/retrofit (dummy) **	3479	–	1	10.00%	0.30
	Penthouse (dummy)	3479	–	1	3.50%	0.18
	Duplex/triplex (dummy)	3479	–	1	6.00%	0.23
	Year of construction	3479	1890	2015	1969	19.79
Structural characteristics of the building	Communal swimming pool (dummy)	3479	–	1	4.00%	0.05
	Communal garden (dummy)	3479	–	1	9.00%	0.28
	Lift (dummy)	3479	–	1	45.00%	0.50
Accessibility indicators	Built density (area floor ratio)	3479	0.19	5.90	1.93	1.24
	Time-density ***	3479	324	1,134,098	118,964	146,950
	Centrality Index ***	3479	2.52	20.41	11.29	2.29
	Land use diversity (of the context) +	3479	0.35	1.64	1.02	0.21
	Diversity of activities (of the context)	3479	–	2.92	2.03	0.38
	Average time to work (minutes)	3479	8.94	37.01	23.47	4.59
	Land use diversity at street level ++	3479	–	1.77	1.11	0.23
Environmental quality indicators	Average age of buildings (of the context)	3479	21	124	53.99	14.33
	% households that identify a greenery lack (of the context)	3479	12.45	97.89	64.37	13.58
	% Health facilities (of the context)	3479	–	42	2.01	2.89
	% Educational premises (of the context)	3479	–	93.00	2.13	2.97
	% Social services premises (of the context)	3479	–	66.66	1.85	4.32
	% Cultural premises (of the context)	3479	–	95	1.52	3.35
	% Premises for trade (of the context)	3479	–	89.93	41.45	13.47
	% Premises for offices (of the context)	3479	–	100.00	14.09	11.11
	% Industrial premises (of the context)	3479	–	97	9.51	11.57
Indicators of social hierarchy	% people holding university degree (of the context)	3479	2.34	66.10	19.07	11.25
	% buildings with doorman service (of the context)	3479	–	52.55	6.37	6.77
	CP low socioeconomic level +++	3479	–1.70	7.42	0.13	0.93
	CP high socioeconomic level +++	3479	–3.26	3.24	–0.32	0.77

* Energy rating A = 7, G = 1, according to the ratings of the EPC label contained in RD 235/2013;
** This variable adopts 1 when the description text of the advertisements signals a high level of quality, design or a recent retrofit;
*** These indicators depart from spatial-temporal patters of people calculated from the origin-destination survey as suggested by Marmolejo & Cerda (2017);
+ This indicator has been computed using the Shannon index departing from the land use covers contained in CORINE;
++ This indicator has been computed the Shannon index departing form the use of premises located at street level contained in Census;
+++ These indicators are the principal components coming from a Principal Component Analysis built on the job position of occupied residents living around the apartment according to census data.

Source: Own elaboration

Figure 7.6 depicts the distribution of EPC ratings, the vast majority of dwellings are rated “E” (48.30%), followed in this order by letters "G" (21.80%), “F” (13.50%), “D” (9.70%) and “C” (4.30%), while the best “A” is reserved only for a select club of properties that represent 2.30% of the sample. It is worth saying that the depurated sample does not contain “B” rated homes, as in general there are very few cases holding such a rating. The reason for this is that developers willing to invest in efficient homes do prefer to pay for the small marginal cost that enables upgrading the performance of the homes up to rating “A”.

Figure 7.6 also shows the spatial distribution of the analyzed sample according to its energy efficiency. Urban centres (labelled on the map) such as Barcelona and sub-centres exhibit medium and low-medium efficient dwellings. In contrast, the peripheral municipalities, especially those located in the suburbs of the previous sub-centres, have better-qualified stock. Rural municipalities (functionally integrated to Barcelona) depict the least efficient housing. In these ultra-peripheral municipalities, during the 1960s and 1970s, a large number of low-quality dwellings were built, often in suburbs of illegal origin. Thus, paradoxically, peripheral areas with low-density layouts (i.e., urban sprawled) which are energy-intensive in terms of transportation due to their car dependency have many energy-efficient dwellings.

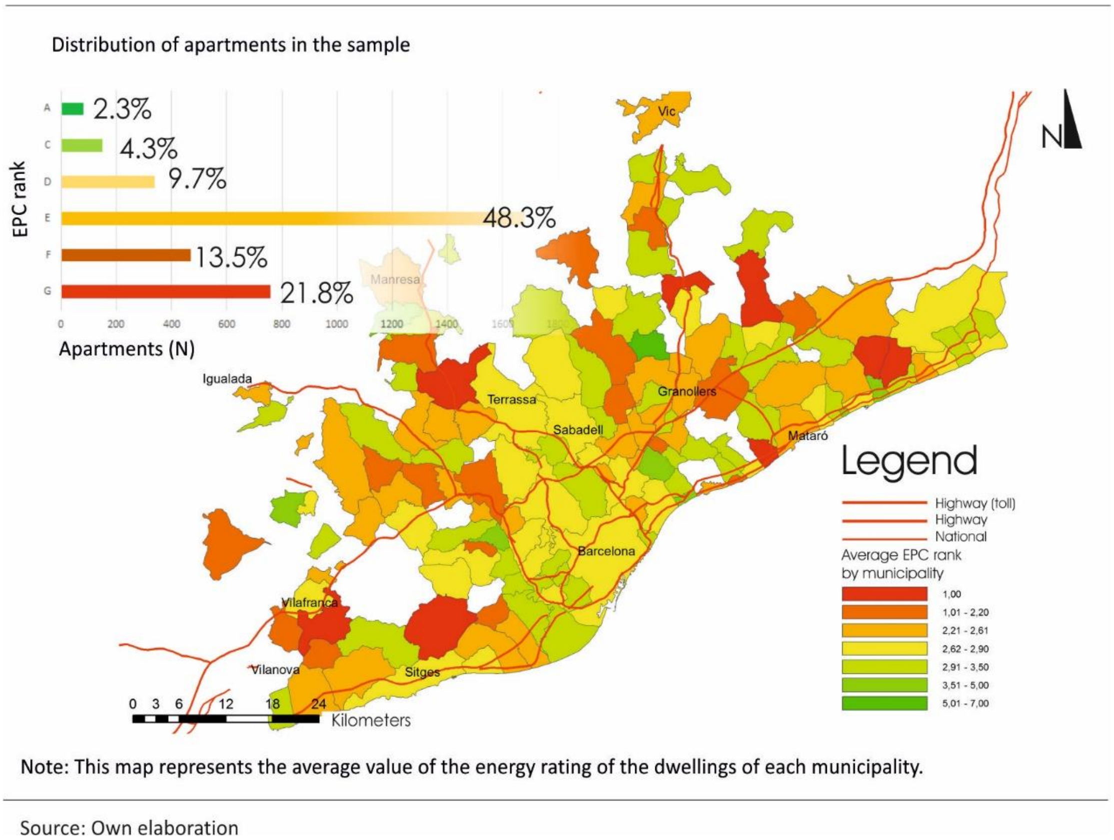
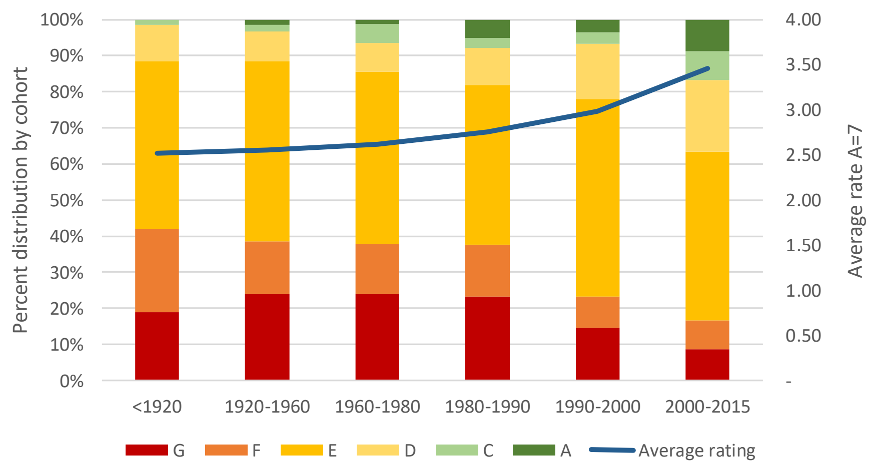


Figure 7. 6 Distribution of the EPC ratings across BMA
Source: Own elaboration

Behind the aforementioned spatial distribution, the construction year does play a role, since the first thermal isolation legislation in Spain dates back only to 1978 (becoming effective in 1981). Figure 7.7 shows the declining proportion of buildings ranked with “G” + “F” + “E”, especially after the “Oil Crisis” and the end of the post-war period where there is a proportional increase of the best-ranked dwellings. Thus, the average score (A = 7, G = 1) increases from 2.52 for dwellings built before 1920 to 3.46 for those built after the year 2000. In this last cohort, the minimum energy efficiency requirements DB-HE of the Spanish Technical Construction Code (RD 314/2006, RD 1371/2007, OM FOM 1635/2013) have had little impact due to a large reduction of new dwellings after the crisis of the construction industry started in 2007.



Source: Own elaboration

Figure 7. 7 EPC rating of the sample by construction year
Source: Own elaboration

In short, the residential stock listed in the Metropolitan Area of Barcelona is characterized by a very poor energy efficiency. Although this situation is not significantly worse than that reported by Fuerst et al. (2015) for the English residential market, their study based on sales data shows that 48% of the apartments are ranked “D”, while only one of the 85,007 apartments analyzed is rated as “A”. In this study, the average ordinal score is 2.7, better than the rating of the houses located in the cities of the south of Spain that were studied by De Ayala et al. (2016).

7.4.3 Results and Discussion

7.4.3.1 How energy premium perform across Barcelona?

Regarding the possible selection bias above-discussed in Chapter6, it seems to be minimal just as expected (due to the similar distribution of EPC ratings in the depurated dataset and the official register). Despite the fact that the inverse of the Mill’s ratio appears to be significant (B = 0.47; sig.= 0.02) in the second stage of the 2-step Heckman procedure, the coefficients of the remaining variables are practically the same than those obtained in the OLS model. For the sake of simplicity, the results are focused in the OLS models, nonetheless, at the bottom of each table, the coefficients for EPC classes coming from the Heckman procedure are detailed.

MODEL SUMMARY

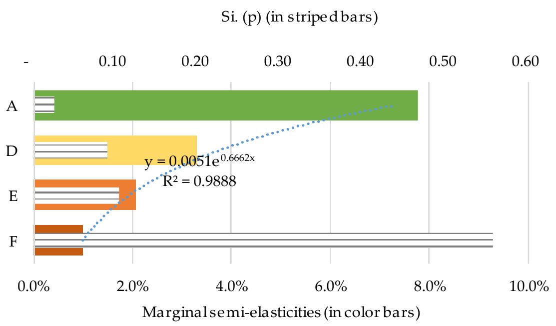
R	R squared	Adjusted R squared	Standard error of estimation
0.811	0.657	0.655	0.28444

ANOVA

	Sum of squares	df	Quadratic mean	F	Sig.
Regression	536.787	20	26.839	331.739	-
Residuals	279.770	3458	0.081		
Total	816.557	3478			

Coefficients

		Non-standardized coefficients		Standardized coefficients		
		B	Std. Error	Beta	t	Sig.
	(Constant)	10.222	0.050		205.146	0.000
Structural characteristics of dwellings	Area (sq.m)	0.018	0.001	1.02	23.46	0.00
	Air conditioner	0.095	0.013	0.09	7.03	0.00
	Number of bathrooms	0.056	0.012	0.06	4.68	0.00
	Heating	0.026	0.014	0.03	1.89	0.06
	Quality-retrofit indicator	0.035	0.017	0.02	2.05	0.04
	Area^2	-4.14E-05	0.000	-0.51	-12.01	0.00
	Construction year 1981-2006	0.078	0.016	0.05	4.78	0.00
	Construction year> 2006	0.118	0.024	0.05	4.82	0.00
Structural characteristics of the	Lift x floor level	0.011	0.002	0.06	5.11	0.00
	Communal swimming pool	0.128	0.026	0.05	4.92	0.00
Energy rating	A	0.078	0.035	0.02	2.25	0.02
	C	-0.029	0.026	-0.01	-1.11	0.27
	D	0.033	0.019	0.02	1.70	0.09
	E	0.021	0.013	0.02	1.63	0.10
	F	0.010	0.017	0.01	.59	0.56
Accessibilty	Floor area ratio	0.042	0.006	0.11	6.87	0.00
	Centrality indicator	0.011	0.003	0.05	3.66	0.00
Social hierarchy	% people holding a university degree	0.005	0.001	0.12	4.71	0.00
	CP high socioeconomic level	0.059	0.013	0.09	4.38	0.00
	% buildings with doorman service	0.005	0.001	0.07	4.27	0.00



Coefficients for EPC classes according to the second stage of the 2-steps Heckman procedures

		B	**Std. Error**	**Beta**	**t**	**Sig.**
Energy rating	A	0.077	0.035	0.024	2.219	0.03
	C	-0.029	0.026	-0.012	-1.135	0.26
	D	0.032	0.019	0.019	1.640	0.10
	E	0.020	0.013	0.021	1.566	0.12
	F	0.009	0.017	0.006	0.538	0.59

Notes: Dependent variable ln of the price, variables introduced by the stepwise method, except those related to the energy rating. In grey are the non-significant variables at 90% of confidence. Energy reference rating = G; Age reference cohort ≤ 1981; Source: Own elaboration.

Figure 7. 8 Model for the complete depurated sample
Source: Own elaboration

Figure 7.8 shows the best of the models able to explain upon 65.5% of the variance, the significant variables (sig. < 0.1) are organized by conceptual dimensions. In the dimension of structural features:

- The area is introduced with the expected positive sign, in fact, the introduction of its square (with the negative sign) is indicative of the existence of decreasing returns in the formation of prices.
- Three quality indicators are utilized, such as the presence of air conditioning, heating and the qualitative indicator of quality/retrofit.
- The number of bathrooms is not a factor. It seems reasonable that the number of rooms does not enter in the model, since the area, which is highly correlated with this indicator, has been taken into account.
- The age of the home also has an expected impact on prices. The age has been introduced as a dummy variable for construction periods. The limits of each of the period is related to the introduction and upgrading of the energy performance legal requirements, which in turns are also associated with improvements in other building aspects.

In the dimension of the common services present in the buildings where apartments are located:

- The interaction variable between the story in which the apartment is located and the presence/absence of elevators. The positive sign of the coefficient implies that price increases the apartment’s level in the building rises only applies when an elevator is present.

In the energy efficiency dimension:

- Of the 5 possible EPC ratings (the control rating is “G”), only “A” and “D” are significant. Thus, for the best ratings, there is a market premium of 7.8% (in relation to the worst “G” situation), while for the “D” rating the premium is 3.3% and 2.1% for “E” (although it is almost significant at 90% of confidence). Therefore, the appreciation of the best-rated dwellings is not linear; as the rank increases the marginal price increases progressively, following an exponential pattern. This finding has enormous potential for the promotion of efficient dwellings *since the larger premium for these dwellings might counterbalance the excess of construction costs.* The remaining of the ratings are not significant; however, with the exception of "C", these would have logical sing/value depending on the above-mentioned pattern. Energy-efficiency ratings do not always have the expected impact. Addae-Dapaah & Chieh (2011) report in their pioneering study on the impact of the Green Mark on sale residential prices in Singapore a higher positive impact for the lowest ratings compared to the most efficient ones. These authors argue a confusion of the Singapore market exists, perhaps because the scheme raises nominal ratings (“certificate”, “gold”, “superior gold” & “platinum”) and not ordinal (“A” –> “G “) as the EPC scheme does.

In the locational dimension:

- Two indicators are related to urban centres accessibility: the floor-area-ratio and the centrality indicator, both with the expected positive sign which is indicative of the trade-off between sale prices and transport costs.

- Three indicators related to the socio-economic stratification of the city appear, so the higher the apartment’s price: (1) the larger the proportion of people holding a university degree, (2) the larger the proportion of residents in qualified job positions, and (3) the larger the proportion of buildings with doorman service. It is worth noting that this latter service is commonly present in wealthy areas of the city. According to the coefficient of the typified variables, *social hierarchy indicators are the main explanatory variables of real estate prices*. This is both because the population has a higher purchasing power and because it seems they are willing to pay a *market premium* for locations dominated by similar socio-economic groups (i.e., neighbourhood effect).

In short, the EPC energy rating, despite its very late universalization in Spain, seems to matter at least to owners willing to be compensated for the sale of their equity. In Spain, given the predominance of housing ownership, the behaviour of sellers tends to be the same as buyers. Nevertheless, the asking market premium for the most efficient apartments (+7.8% or +12,409 Euros for the average dwelling in the sample) is surprisingly lower than the marginal value of comfort attributes such as air conditioning (9.5%), which in the light of the results obtained seems to play a more important role in price formation than the possible energy savings and environmental preservation that are implicit in energy-efficient buildings.

7.4.3.2 Are there real estate segmentations?

As has been explained in section 7.4.1, the depurated sample has been split into housing segments. The housing attributes found to be correlated with prices, in the model contained in Figure 7.8, but with energy ratings. Figure 7.9 shows the main features of each of the identified housing segments:

- *Cluster 1* (the smallest) is characterized by expensive dwellings (in absolute and unitary terms), with the largest area located in central zones, where the population with higher education levels employed in qualified positions live. However, the dwellings contained in this cluster do not exhibit the larger proportion of services such as heating, air conditioner or swimming pool due to their age and central location.

- *Cluster 2* consists of dwellings characterized by a medium price in absolute and unitary terms, as well as its area also being intermediate. Among the three groups, these are the most recent dwellings, and for that reason, these have a larger proportion of active-comfort systems: 92% are equipped with heating and 59% air conditioning systems, while in 24% of cases their advertisements highlight the exceptional quality and/or design. The location of this second cluster is med-central, and the proportion of people with a university degree is intermediate (in relation to the three groups). It is noted that 10% of them have a communal swimming pool, which suggests that they are oriented towards the middle-upper class and respond to the most recent residential trends.

- *Cluster 3* is the largest, and the apartments contained in this cluster were built in the post-war period characterized by a low-quality urban growth fed by rural immigration. Housing in this group is small in size, cheap in price, with no amenities and services (only 3% are air-conditioned and none of the apartment is heated). None have a swimming pool and an elevator is only present in 15%, although they are multi-family buildings located in multi floors zones (average floor area ratio is 1.67). Socioeconomic indicators suggest that this cluster is located in areas where the less educated population lives, occupying less qualified positions (e.g., salesmen/women, unskilled jobs, etc.).

		Cluster 1	Cluster 2	Cluster 3
Number of cases		338	1336	1805
Structural characteristics of dwellings	Price (Euro)	304,056	169,870	125,188
	Unit price (Euro/sq. m)	2783	1988	1641
	Area (sq. m)	109	86	77
	Air conditioner (%)	51%	59%	3%
	Number of bathrooms (average)	1.6	1.4	1.2
	Heating (%)	65%	92%	0%
	Quality/retrofit indicator (%)	10%	24%	0%
	Construction year (average)	1954	1978	1965
Structural characteristics of the building	Lift (%)	86%	75%	15%
	Communal swimming pool (%)	1%	10%	0%
Energy rating	A	2%	5%	0.2%
	C	3%	5%	4%
	D	13%	16%	4%
	E	56%	49%	46%
	F	11%	11%	16%
	G	15%	14%	29%
	EPC ordinal	2.84	3.09	2.39
Accessibility	Floor area ratio (average)	4.19	1.72	1.67
	Centrality indicator (average)	14.84	10.98	10.86
Social hierarchy	% people holding a university degree	41%	19%	15%
	CP high socioeconomic level	0.68	-0.24	-0.56
	% buildings with doorman service	20.3%	5.1%	4.7%

Figure 7. 9 Architectural and locative characteristics of the market segments
Source: Own elaboration

The energy rating of the three clusters is consistent with the age and architectural performance of housing, so on an ordinal scale (A = 7, G = 1) the average rating is 2.84; 3.09 and 2.39 respectively; that is, the newest dwellings, with better active-comfort conditioning, are the most efficient, while post-war dwellings are the most inefficient. The dwellings of the centres are located in an intermediate energy-efficiency situation.

Figure 7.10 shows the spatial distribution of the sample: the darker the colour, the greater the ascription of the sample to Cluster 1, standing out especially in the municipality of Barcelona.

The central urbanized zone highlights the predominance of dwellings typified as Cluster 3 in the low-income neighbourhoods, whereas in the 19th-century Enlargement zones the dwellings typified as Cluster 1 are predominant.

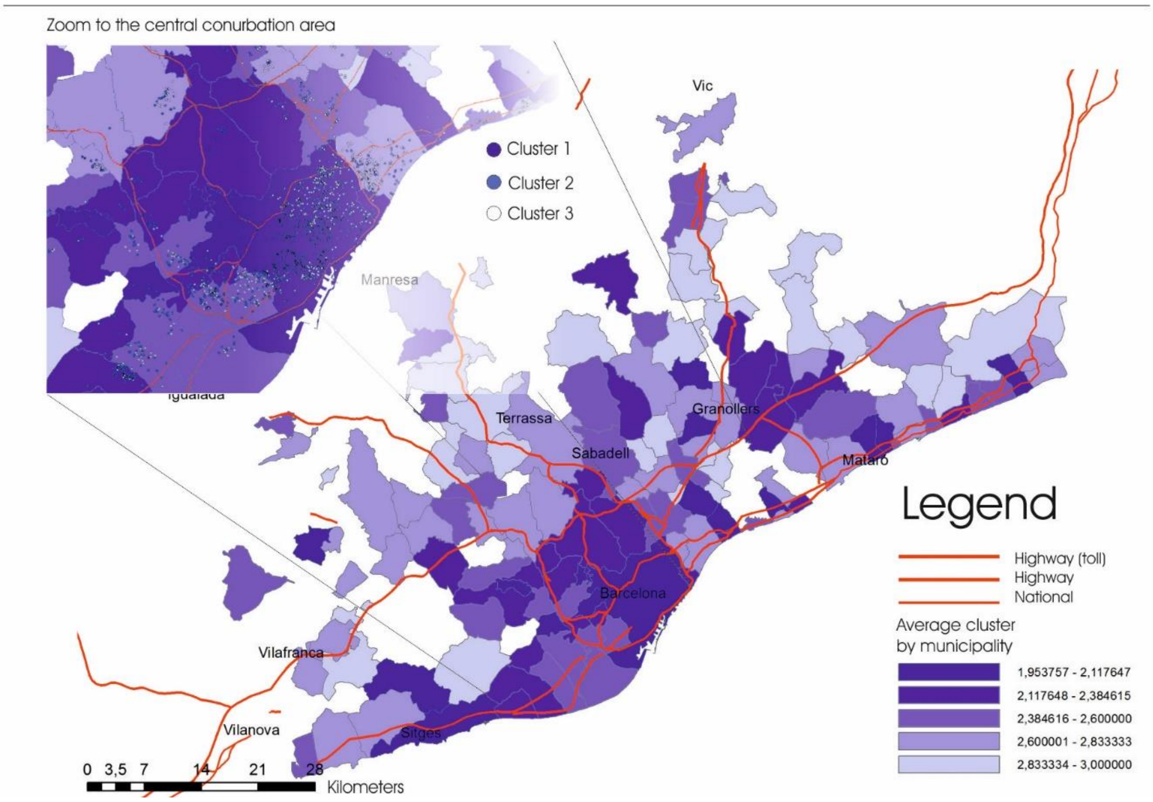


Figure 7. 10 Spatial distribution of the sample by the cluster membership
Source: Own elaboration

7.4.3.3 What differences of energy premium across real estate segmentations

Finally, regarding the main objective of this paper, Figure 7.11 contains the results of the calibrated models for each one housing segments. It is important to note that according to the Chow Test (F = 8.20 > F crit. 1.16 to 99% of confidence), structural differences do exist in the explanation of the prices of the different segments and therefore indicate divergent hedonic agendas. In this figure only the statistically significant (sig. < 0.05) variables are reported, except for those related to the different energy ratings, where again the letter “G” is the comparison situation. In all cases, the sign of the coefficients is as expected and match that of the complete sample explained in the last section, with the exception of Cluster 1 where, paradoxically, the sign of the high socioeconomic indicator is reversed, even after having verified the absence of multicollinearity issues. This issue likely occurs because the sample (the smallest of the three) is very homogeneous in locative terms due to the segmentation procedure used.

		Mod Cluster 1			Mod Cluster 2			Mod Cluster 3		
		r^2	r^2 aj	Sig.	r^2	r^2 aj	Sig.	r^2	r^2 aj	Sig.
		84.68%	84.16%	0.000	55.89%	55.36%	0.000	44.12%	43.78%	0.000
		B	**Beta**	**Sig.**	**B**	**Beta**	**Sig.**	**B**	**Beta**	**Sig.**
Structural characteristics of dwellings	Constant	10.749			10.312			10.243		
	Area (sq. m)	0.018	1.721	0.000	0.017	1.07	0.00	0.022	1.20	0.00
	Air conditioner	0.062	0.072	0.002	0.134	0.16	0.00			
	Number of baths				0.114	0.15	0.00			
	Heating				0.096	0.06	0.00			
	Quality/retrofit Indicator				0.055	0.06	0.00			
	Area^2	0.000	-0.885	0.000	- 0.000	- 0.61	0.00	- 0.000	- 0.59	0.00
	Construction year 1981-2006				0.087	0.09	0.00	0.086	0.04	0.03
	Construction year> 2006				0.104	0.08	0.00	0.262	0.06	0.00
Structural characteristics of the building	Lift x floor level	0.015	0.09	0.00	0.017	0.11	0.00			
	Communal swimming pool				0.134	0.10	0.00			
Energy rating	A	0.122	0.04	0.08	0.046	0.03	0.24	0.332	0.04	0.03
	C	0.042	0.02	0.50	0.053	0.03	0.17	- 0.086	- 0.04	0.02
	D	0.052	0.04	0.14	0.015	0.01	0.58	0.078	0.04	0.04
	E	0.015	0.02	0.58	0.017	0.02	0.46	0.018	0.02	0.28
	F	0.033	0.02	0.37	- 0.021	- 0.02	0.50	0.023	0.02	0.30
Accessibility	Floor area ratio				0.058	0.14	0.00	0.023	0.06	0.01
	Centrality indicator							0.007	0.04	0.10
Social hierarchy	% people holding a	0.009	0.23	0.00	0.006	0.12	0.00			
	CP high socioeconomic	- 0.156	- 0.14	0.00	0.079	0.14	0.00	0.101	0.17	0.00
	% buildings with doorman							0.010	0.10	0.00
Coefficients for EPC classes according to the second stage of the 2-steps Heckman procedure										
		B	**Beta**	**Sig.**	**B**	**Beta**	**Sig.**	**B**	**Beta**	**Sig.**
Energy rating	A	0.120	0.04	0.09	0.046	0.03	0.24	0.332	0.04	0.03
	C	0.037	0.01	0.55	0.053	0.03	0.17	- 0.086	- 0.04	0.02
	D	0.049	0.04	0.17	0.012	0.01	0.66	0.078	0.04	0.04
	E	0.014	0.02	0.59	0.015	0.02	0.51	0.018	0.02	0.28
	F	0.034	0.03	0.360	- 0.022	- 0.02	0.48	0.023	0.021	0.298

Notes: Dependent variable ln of the price, variables introduced by the stepwise method, except those related to the energy rating. In grey are the non-significant variables at 90% of confidence. Energy reference rating = G; Age reference cohort ≤ 1981.

Figure 7. 11 Models for the segmented sample
Source: Own elaboration

Focusing on the interest of this study, three interesting conclusions emerge:

1) The energy rating seems to affect the older dwellings, both those located in the centers/19th-Century Enlargement zones, and those located in poor neighbourhoods that emerged from the expansion of the metropolis during the post-war. Conversely, in the case of the state-of-the-art dwellings depicting amenities and active-comfort

systems, energy efficiency seems to play a null role from the perspective of price formation.

2) However, the impact of the rating is not equal in the two segments in which it appears as significant. Thus, the “A” rating has an impact of +12.2% (but with a level of significance on the edge of the limit demanded in our analysis) in the most expensive, central and well-endowed housing segment. On the other hand, the impact of the "A" rating is almost three times larger +33.2% (with a higher statistical significance) in the cheaper segment, located in working-class neighbourhoods and with worse active air conditioning services and in general with the poorest architectural quality. In this last cluster, the “D” rank also appears with an impact of +7.8% and in a reversed sense, the “C” rank with an impact located at –8.6%.
3) All in all, these findings suggest that real estate differentiation in the segment of the newest dwellings does not respond to the rationale behind the EPC scheme. On the contrary, in the case of the (very abundant) dwellings located in the lower tier, in the absence of attributes of architectural quality and amenities, the EPC produces a distinctive effect strongly influencing price differentiation.

These findings are consistent with the discussion of Encinas & Aguirre (2017) since sustainability attributes seem to play different roles across residential segments. In short, the impact of energy ratings, in the light of the aforementioned results, does not seem to equally affect the segments of the multi-family market. Real estate differentiation, from the perspective of the supply price formation mechanism, and in relation to the energy ranking seems to occur in the lower segment. Thus, in the dwellings with less architectural attributes related to residential quality, this ranking has a significant impact on prices. Such “brown discounts” may have enormous social repercussions on the conformation of energy submarkets, as discussed in the conclusions.

7.5 Conclusions

17 years ago, the Energy Performance of Buildings Directive (EPBD) joined the mainstream of green labels through its Energy Performance Certificates (EPC). Through this policy, the European Union opted to fade out informational asymmetries in energy efficiency in real estate transactions. This policy has aimed to foster the acquisition and lease of efficient buildings by means of energy-informed transactions.

Nonetheless, the universalization of EPC in Spain is quite recent (it is mandatory only as of the 1st of June 2013), the research reported here determined for the first time, conjointly with those works (De Ayala et al., 2016; C. Marmolejo-Duarte, 2016) if EPC ratings imply “market premiums” and “brown discounts”. The main contribution of this research is to explore whether such impact on prices, if any, is homogenous across multivariate housing segments. With this objective, in the absence of transaction prices, a sample of 3479 multi-family dwellings listed in metropolitan Barcelona is analyzed. This analysis, as is usual in international studies, has been based on the hedonic price method, which assumes that households equalize the marginal utility of the urban and architectural attributes of dwellings, to the marginal price they pay for benefit of them. Likewise, in order to identify market segments, a multivariate analysis is carried out departing from variables correlated with selling prices.

In general, the residential listed stock in Barcelona exhibits a poor energy performance, with an average EPC rating of 2.70 (“G” = 1, “A” = 7), with rating “E” being the most abundant (48.30%). Data showed a positive correlation between the year of construction of the dwellings and EPC ratings, with a sharp increase after the year of 1980 (when the first national energy efficiency legislation came into force). From a spatial perspective, the best-rated dwellings are located in the immediate suburbs of the metropolitan centralities, while the worst-rated are in the more distant suburban areas, some of a rural character, and others in urbanizations of illegal origin, with constructions of very poor architectural quality.

The results of the hedonic models suggest that there is a market premium for efficient rated dwellings. Thus, sellers of the best-rated dwellings are willing to be compensated for a higher amount, everything else equal, when selling their assets. As such, results suggest a market premium of +7.8%, +3.3% for "A", "D" ratings respectively in relation to the most inefficient rating "G". For the average apartment, these impacts can be translated into approximately 12 thousand and 5 thousand Euros, respectively. In addition, it is observed that such overpricing tends to increase exponentially as energy efficiency increases. This finding has a special interest in the private development of "green" dwellings since the prize for the most efficient apartments "A" increases exponentially regarding lower ratings. Nevertheless, it is still necessary to verify whether such a market premium can offset the over costs produced by new and most efficient building techniques, as has been studied by García-Navarro et al. (2014).

In any case, the impact of the energy ranking in Spain on residential prices is lower than the 15.00% ("A"/"G") reported by Brounen & Kok (2011)for the Netherlands case, as well as below the 19.90% ("A"/"G") detected by Hyland et al. (2013) for the Irish market and the 12.00% for "A" dwellings compared to "G" in the English case according to Fuerst et al. (2015). It is possible that behind these divergences are the differences in real estate prices, cost of energy, income level (in relation to the previous two), climatic differences and environmental concerns. These comparisons should be made with caution because although the European legal framework is the same, there are differences in the national transposition of the regulations and more specifically in the way of calculating energy EPC ratings (Garcia-Hooghuis & Neila, 2013).

Interestingly, the EPC asking market premium is not uniform across the residential segments:

Energy premium performance in univariate segments

In order to obtain unbiased coefficients, significant efforts have been invested in controlling the architectural, urban and territorial attributes that affect the formation of prices. The results suggest that as time passes, the impact of energy ratings on housing prices increases. Thus, the percentage increase in the price of green housing for each EPC rating has doubled in Barcelona, going from 0.852% (Marmolejo-Duarte, 2016) to 1.79% in just a year and a half. On the other hand, when employing the nominal EPC variables, the overprice of a class “A” home in relation to class “G” in Barcelona is 10% while in Valencia it scales up to 29%. That is to say, in relation to the respective average price, there are increases of 18 thousand and 35 thousand euros respectively which is sufficient to offset the marginal average overcharge calculated in Madrid by García-Navarro et al. (2014) for a multi-family dwelling. In contrast, the minimum “E” rating for new homes hardly receives an award.

Likewise, in Valencia where the supply is less diversified in energy terms and the best-rated homes are scarcer in relation to the worst-rated ones, the impact per EPC rating is 3.35%. That is greater than in Barcelona where the supply it is more diversified and efficient housing is more abundant in relative terms. This finding could have serious implications for energy policy as it has been designed, since it assumes that, in the face of greater homogeneity in the energy class derived from the increase in the upper classes, the price differentiation tends to disappear. Therefore, the advantages that developers of new or energy rehabilitated housing could have to offset the marginal costs of energy efficient construction. This conjecture is in line with the empirical evidence reported by Chegut et al. (2014) whose work in London has highlighted that for each new certificated building, there is a reduction in the price premium in relation to that of previously certified buildings in the same area. Exactly the same conclusion was pointed out by the pioneering work of Winward et al. (1998) who documented that the behavior of consumers at the dawn of the energy rating of household appliances depended on the proportion of certified goods in the store. It could also happen that energy savings in Valencia were relatively more interesting in relation to the lower price of housing (Bio Intelligence Service et al., 2013). This conjecture requires further study in future works, which necessarily involves the complex task of quantifying the real energy expenditure of households in the same spatial environments to which the real estate supply refers.

Finally, the analysis in the Alicante real estate market shows important singularities: 1) the proportion of homes with energy information in their advertisements is much higher than in Valencia and especially than in Barcelona; 2) contrary to all logic –and what happens in Barcelona and to a lesser extent in Valencia-, the most recent dwellings (post-CTE period) are rated worse than the oldest; 3) The worst rated homes have better benefits in the rest of their architectural attributes, unlike what happens in Barcelona where a worse energy rating corresponds to a worse quality of the home in general. This means that, despite the significant number of control variables used in the econometric models, the hedonic price of Alicante's energy rating is reversed. That is, a worse rating corresponds to a higher price, ceteris paribus. In addition, the Valencian MA, unlike Barcelona, the distribution of the energy class of the real estate advertisements does not coincide with that from official records. If this distortion were to respond to anomalies in the advertising of incorrect ratings, we would be witnessing a complete trivialization of energy policy as it has been designed within the European Commission. Thus, two clear implications for public policy as follows:

(1) The first, and most important, related to the eventual disappearance of the energy surcharge as the most efficient homes appear on the market and therefore the diversity of the supply increases. It would be a challenge for the EPC scheme that has relied on the free market as an efficient property provider.

(2) The second call for greater attention on the part of the competent administrations in verifying the correspondence between the publicized information and that contained in the certificate records.

Energy premium performance in multivariate segments

In the segment of more recent apartments, the EPC rating does not seem to play any role in the differentiation of real estate prices, which obscures the pursued objectives of the EPBD. In this market, with multiple architectural features and active technologies for environmental comfort, energy rating does not represent a differential element.

In the case of the deficient housing, the enormous price discrimination that appears, the energy rating, in the absence of other attributes of differentiation, does produce a significant “brown discount”. Specifically, in this segment, the worst rating “G” reduces the price of the dwellings by –33.20% in relation to “A” rated apartments.

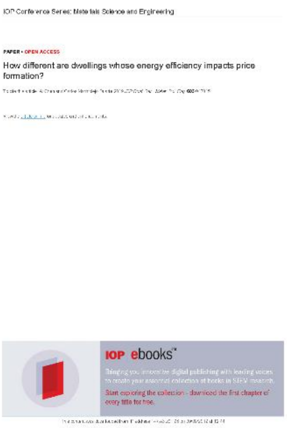
In the case of older dwellings, located in the middle/middle-high class areas, the results suggest that a moderated premium market is also formed that is equivalent to +12.2% (“A”/“G”) which opens room for energy retrofitting since most of such apartments are located in Enlargement zones which started to be built at the end of the 19th century.

In short, despite the recentness of the EPC policy in Spain, it seems to affect listing prices, although as has been seen, with uneven intensity throughout the residential segments. Thus, in the segment of recent homes with higher benefits, the rating plays a null role in the formation of prices. In this segment, private developers have to make an extra effort to communicate the economic and environmental benefits of efficient homes. Whereas, in the segment of lower price and quality dwellings, the energy rating institutionalized by the EPBD and its transposition is a true element of residential differentiation, in the absence of other architectural attributes. This finding is compatible with the conclusion of Olaussen et al. (2017) since EPC labels might be capturing omitted variables. In our case, it may be wrongly interpreted as quality in the case of the homes boasting the lowest attributes. In the Netherlands as the first country to transpose the EPBD, in the time when EPC was optional, the certification rate was higher in neighbourhoods with more deficient residential stock according to the study by Brounen & Kok (2011). That is, getting an EPC in low-quality areas was seen as a positive attribute in the marketing process of homes irrespective of the EPC ratings they obtain. The same seems to occur in Spain: as has been said, in section 7.2.2, the probability that a listed apartment includes EPC information is directly correlated with its low-quality.

Our findings from the multivariate approach are in line with not only the above-mentioned univariate approach for 3 Mas but also other studies analyzing the impact of EPC ratings on residential univariate-segments (Fuerst et al., 2015; Hyland et al., 2013; Salvi et al., 2008).

In most of those cases, their authors argue that the larger impact found in the low-tier segment is explained by the fact that these dwellings are targeted towards households with tighter budgets, for whom the possible energy savings are relevant. Nonetheless, such a rationale is not verified in Spain. Marmolejo et al. (2017) have been conducted, in Barcelona, a survey aimed to explore whether people do understand the EPC scheme. Their findings indicate that low income and poorly educated people, as residents of the deficient homes segment, have little knowledge on such a scheme, which in turns translates into an unwillingness to pay for efficient homes. As a matter of fact, such authors have found that, in general, people misunderstand the objective of the EPC rating, since they consider it an indicator of the global quality of homes. Such conclusions are not surprising due to the overnight implementation of the EPC scheme in Spain pointed out in the introductory section. Furthermore, their results are in line with preconditions Backhaus et al. (2011) indicated are required before expecting any impact of EPC scheme on home prices: homeowners should be aware of its existence; find the information about energy ratings useful and trust the information on EPCs. The practical absence, in Spain, of informative campaigns on the implementation of the scheme, on the one hand, and a generalized perception of EPCs as a bureaucratic formality and even a distrust of the technical procedure, on the other, make such preconditions difficult to meet.

In any case, from a social perspective, a larger "brown discount" for the less efficient dwellings implies a devaluation of the main equity of the poor population in countries, such as Spain, where ownership is the main tenure regime (over 71% according to INE). Such population living in inefficient homes are at risk of fuel poverty, and at the same time, for cognitive and financial reasons (aggravated by the energy efficiency "brow discount") have little opportunity to perform a retrofit in their dwellings. Therefore, a well-intentioned environmental policy might have unexpected pernicious effects from a social perspective, if relevant corrective measures are not introduced (e.g., retrofit subsidies). Fortunately, in Spain legislative initiatives crystallized in Law 8/2013 of Urban Rehabilitation, Regeneration and Renewal (now recast in the main corpus of land legislation), which, together with the autonomous legislation in matters of urban planning and housing, provide the necessary instruments to carry out actions in the most degraded areas. An example of this is the area of conservation and retrofitting of the "Carrer Pirineus" located in the working-class municipality of Santa Coloma de Gramenet (province of Barcelona), where, based on the aforementioned legislation, a rehabilitation of the private residential stock with energetic implications has been developed using municipal treasury as a "local bank" (Barón Rodríguez, 2017). These actions, however, require the political will, technical capacity, and a multidisciplinary approach.



IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

How different are dwellings whose energy efficiency impacts price formation?

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

CHAPTER 8

The evolution of energy efficiency impact on housing prices: an analysis for Metropolitan Barcelona

Marmolejo Duarte Carlos & Chen Ai

+

How different are dwellings whose energy efficiency impacts price formation?

Chen Ai & Marmolejo Duarte Carlos

CHAPTER 8 THE EVOLUTION AND SPATIAL AUTOCORRELATION OF ENERGY EFFICIENCY IMPACT ON HOUSING PRICE

8.1 Overview

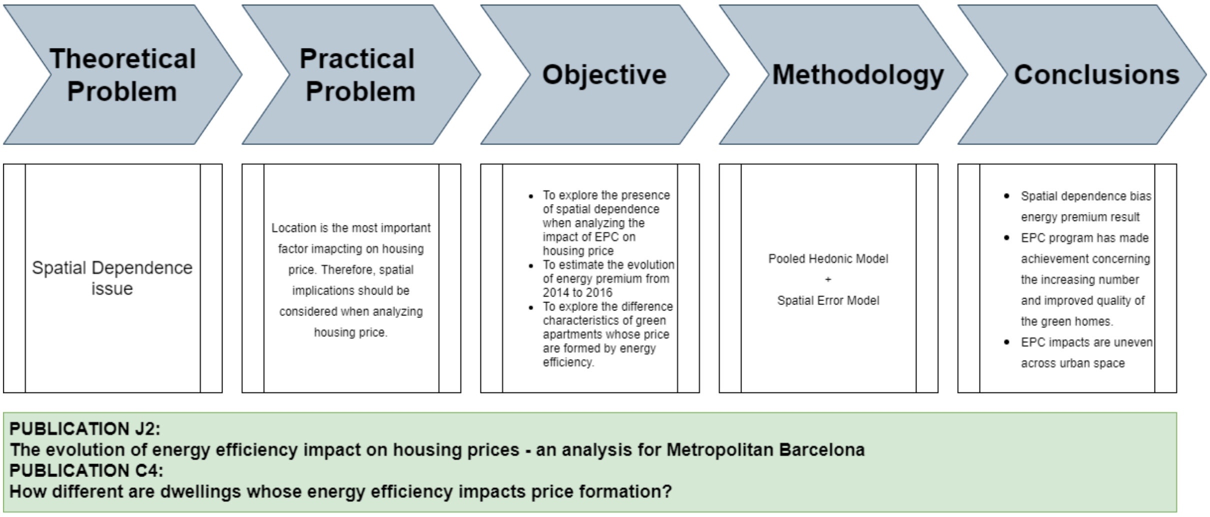


Figure 8. 1 Chapter 8's structure
Source: Own elaboration

According to RD 235/2013 text, as from 1st of June 2013, almost all properties to be let (to a new tenant) or sell must exhibit the EPC rank when advertised (Marmolejo & Bravi, 2017). The previously published research has found that EPC ranks are positively correlated with housing prices both in Spain and other EU member states. Nevertheless, the impact of EPC ranking in the Spanish residential market is sharply smaller than in other northern European countries. Behind such divergence, researchers have argued differences on climatic conditions, income, property prices as well as diverging concerns on environment conservation. Whether such impact remains low along the time is still a pending question. Thus, this paper tries to shed light on it, by means of three specific objectives:

1) To verify if the spatial dependence exists in Barcelona residential market
2) To study the evolution of EPC impacts on residential prices along the time after correcting spatial dependence issue

3) To explore the different performance of characteristics within and between EPC groups across urban space

In doing so, Section 8.2 introduces two models respectively: Spatial Error Model (SLM) and Pooled Hedonic Model (HPM) where the former is for objective 1 and the latter for objective 2. Subsequently, Section 8.3 discusses the estimation results concerning three specific objectives and finally, Section 8.4 draws the conclusions.

8.2 Methodology, Models and Data

8.2.1 Pooled Hedonic Model

The method used is the hedonic model (Rosen, 1974). This method assumes that the price paid for the asset from housing buyers is equal to the total utility they extract from it, being this a composite utility coming from the marginal attribute of the dwelling (e.g. area, quality, location, etc.). It is possible to calculate such marginal utility expressed in monetary terms by a regression model. In this paper, the used model used departs from the following function:

$$ln(P) = c + \sum_{i=1}^{n} X_i A_i + XE + \sum_{i=1}^{n} X_i B_i + \sum_{i=1}^{n} X_i L_i + \sum_{i=1}^{n} X_i S_i + \varepsilon \quad (8.1)$$

Where

P is the asking selling price

A is a set of apartment's *i* architectonic attributes

X_i are the coefficients for each of the variables expressed as price semi-elasticities (see below)

E is the apartment's energy rank derived from EPC

B is a set of *i* facilities and amenities of the buildings where the apartment is located

L is a set of locative *i* attributes regarding transport and environmental quality of the site where the apartment is located

S is a set of socioeconomic attributes of the population living around the apartment

ε is the error term

The functional form used is log-linear since it accomplishes with the basic statistics premises for ordinary least squares (OLS) calibrating process: normality of residuals, homoscedasticity, and multi-collinearity absence. Also, it allows to identify the marginal price of attributes expressed in semi-elasticities, it is to say the price increase in percentage terms associated with the unitary increase of the independent variables.

Due to the interest of this paper is to analyze whether the EPC rank marginal price has remained stable along the time, the procedure applied is that proposed by Sander (1992). It consists of analyzing the increase of prices using a pooled sample (*i.e.* 2014 and 2016 datasets together), controlling for the year to which each case belongs to and the eventual increase of EPC rank marginal price. As a result, equation (1) is transformed into:

$$\ln(P) = c + \sum_{i=1}^{n} X_i A_i + XE + \sum_{i=1}^{n} X_i B_i + \sum_{i=1}^{n} X_i L_i + \sum_{i=1}^{n} X_i S_i + B2016 + XE_{2016} + \varepsilon \quad (2)$$

Where

2016 is a year dummy variable equal to one if the dwelling comes from the 2016 dataset and zero otherwise

E2016 is an interaction term between the *E* energy rank and the dummy variable *2016.* In absence of an increase of the impact of energy rankings on housing prices the associated coefficient of this variable will appear as statistically insignificant.

8.2.2 Spatial Error Model

Finally, it has been found that apartments' prices do not only respond to their locative and architectonic attributes, but also the price of neighbouring apartments (*i.e.* spatial dependence). According to Moran's I (Table 8.1), the spatial autocorrelation of error from the pooled hedonic model of equation 2 is 0.22 (sig=0.00). The omission of this issue might lead to biased coefficients. For this reason, a spatial error model[41] has been implemented. As a result (2) is transformed into the actual model used in this paper:

$$\ln(P) = c + \sum_{i=1}^{n} X_i\, A_i + XE + \sum_{i=1}^{n} X_i B_i + \sum_{i=1}^{n} X_i L_i + \sum_{i=1}^{n} X_i\, S_i + B2016 + XE_{2016} + \varepsilon \quad (3)$$

Being $\varepsilon = \lambda W \varepsilon + u$

Where λ is the autoregressive coefficient, W is the spatial matrix (in this case calculated following rook contiguity criteria) and u is the uncorrected error term.

Table 8. 1 Diagnostics for spatial dependence

TEST	MI/DF	VALUE	PROB
Moran's I (error)	0.222	31.6392	0.0000
Lagrange Multiplier (lag)	1	910.067	0.0000
Robust LM (lag)	1	146.0912	0.0000
Lagrange Multiplier (error)	1	981.3782	0.0000
Robust LM (error)	1	217.4025	0.0000
Lagrange Multiplier (SARMA)	2	1127.4695	0.0000

Source: Own elaboration

8.2.3 Data Description

The two dates of datasets retrieved are: the 1st November 2014 and the 1st April 2016, both of them are posterior to the RD 235/2013 and this period comprises the end of one of the largest real estate crises in the history of Spain.

The complete dataset comprises 35,116 apartments for the year 2014 and 49,424 for the year 2016; the larger amount of cases in this latter year is a signal of the recovery of the real estate market after eight years of economic downturn. Nonetheless, despite the abovementioned obligation to include the energy ranking the advertisement, a large quantity of cases does not contain such information. For the year 2014-sample the compliance, rate is 12% and for the

[41] According to Ord (1975), the best way to correct the spatial dependence issue is looking at the largest and most significant value of the following Lagrange Multiplier Diagnostics: Lagrange Multiplier (lag); Robust Lagrange Multiplier (lag), Lagrange Multiplier (error), Robust Lagrange Multiplier (error) and Langrage Multiplier (SARMA).

year 2016 is 15%. As a result, the sample sizes are reduced. In order to eliminate outliers, the following procedure has been applied to each separated annual sample:

- Firstly, all flats with unitary prices beyond +/-1 standard deviation from the average unitary price were discarded.
- Next, a family of regression models was calculated, using the model with the best fit the Mahalanobis Distance was computed. According to Marmolejo & González (2009), this procedure allows for the elimination of outliers in the n-variables used in the regression analysis.
- Finally, it was detected the Mahalanobis Distance breaking point (i.e. the value where the slope increases abruptly) by using a sedimentation analysis.

The final depurated sample comprises 3,246 cases for the year 2014, and 5,139 cases for the year 2016. In order to guarantee a similar size for both of the year-samples, a random selection process has been implemented in the latter annual sample. As a result, the pooled sample is made of 6,492 cases. Table 8.2 exhibits the descriptive statistics of the main variables organized in conceptual dimensions.

From such data, it is clear that for the year 2014 the "average apartment" exhibits: a price of 162,851 Euros, an area of 84 m^2, 1.3 bathrooms, 2.9 bedrooms, and its average height-location is 2.1 stories with an average terrace area of 12 m^2. Regarding the condominium shared spaces, it is important to note that 4% of apartments have swimming pools, 9% gardens and 46% lift service. The conditioning systems are also presented: 31% of the apartments have air conditioner while 43% central heating system.

Table 8. 2 Descriptive statistics for the 2014 & 2016 depurated sample and selected variables

		2014 Sample				2016 Sample			
	N x 2	**Min**	**Max**	**Mean**	**Std. Deviation**	**Min**	**Max**	**Mean**	**Std. Deviation**
Structural architectonic characteristics of apartments									
Total price (Euros)	3,246	34,000	715,000	162,851	88,957	48,000	830,000	229,507	153,812
Unitary price (Euro/m^2)	3,246	845	3,542	1,914	661	602	10,172	2,592	1,295
Floor area	3,246	25	234	84	28	20	380	87	32
Number of bathrooms	3,246	-	4	1.3	1	-	4	1.4	1
Number of bedrooms	3,246	-	15	2.9	1	-	10	2.9	1
Ration bathroom/bedroom	3,246	-	2	0.5	0	-	2	0.5	0
Level of the apartment	3,246	-	13	2.1	2	-	19	2.2	2
Terrace area	3,246	-	256	9.5	14	-	240	9.5	21
Living room area	3,246	-	90	12	10	-	102	12	12
Large terrace (Dummy)	3,246	0	1	7%		0	1	13%	
Air conditioner (Dummy)	3,246	0	1	31%		0	1	48%	
Central heating (Dummy)	3,246	0	1	43%		0	1	68%	
Retrofited apartment (Dummy)	3,246	0	1	11%		0	1	19%	
Energy performance of apartments									
Energy class (ordinal)	3,246	1	7	2.7		1	7	2.84	
Energy class G (Dummy)	3,246	0	1	21%		0	1	19%	
Energy class F (Dummy)	3,246	0	1	14%		0	1	13%	
Energy class E (Dummy)	3,246	0	1	49%		0	1	50%	
Energy class D (Dummy)	3,246	0	1	10%		0	1	11%	
Energy class C (Dummy)	3,246	0	1	4%		0	1	3%	
Energy class B (Dummy)	3,246	-	-	-		0	1	1%	
Energy class A (Dummy)	3,246	0	1	2%		0	1	3%	
Architectonic characteristics of the buildings									

Swiming pool (Dummy)	3,246	0	1	4%		0	1	11%	
Garden (Dummy)	3,246	0	1	9%		0	1	16%	
Lift (Dummy)	3,246	0	1	46%		0	1	67%	
Building age	3,246	0	104	45	18	0	326	46	25
Locative attributes (transport, centrality and amenities)									
Commuting time (minutes)	3,246	12.9	41	24	4.5	12.9	41.4	24.6	3.9
Highway ramp (Dummy)	3,246	0	1	93%	26%	0	1	94%	23%
<800 m from railway station (Dummy)	3,246	0	1	50%	50%	0	1	56%	50%
Pop. density (residents/km^2)	3,246	11	144,421	21,935	22,700	16	152,596	24,262	23,273
Employment density (jobs/km^2)	3,246	5	56,454	9,511	9,738	7	73,563	10,548	10,078
Centrality index	3,246	3.5	20.5	11.4	2.4	4.7	20.5	12	2.7
Average gross area floor ratio (m^2/m^2)	3,246	0.2	6	2	1.3	0.2	6	2.3	1.6
<200m from sea shore (Dummy)	3,246	0	1	1.20%		0	1	3.90%	
Socio-economic attributes									
Doorman (%)	3,246	0%	72%	7%	10%	0%	94%	10%	14%
People with university degree (%)	3,246	1%	44%	11%	8%	1%	47%	14%	10%
Managers (%)	3,246	1%	34%	8%	4%	1%	32%	10%	5%
Professionals (%)	3,246	1%	45%	11%	8%	1%	44%	14%	10%
Technicians (%)	3,246	3%	25%	13%	4%	2%	25%	14%	4%
Clerks (%)	3,246	3%	21%	11%	3%	3%	21%	11%	3%
Service vendors (%)	3,246	3%	29%	15%	3%	5%	33%	15%	4%
Agriculture (%)	3,246	0%	8%	1%	1%	0%	10%	1%	1%
Craft & qualified manufacture (%)	3,246	2%	39%	17%	6%	1%	37%	15%	7%
Manufacturing (%)	3,246	1%	40%	13%	6%	1%	36%	11%	6%
Non qualified jobs (%)	3,246	2%	32%	10%	4%	1%	32%	9%	5%
PC1 High income (factor loadings)	3,246	-2.15	3.86	-0.11	0.81	-2.15	3.76	0.16	1.03
PC2 Med income (factor loadings)	3,246	-3.14	2.51	-0.24	0.96	-3.14	2.62	0.02	0.93

Source: Own elaboration

In terms of energy efficiency, the average ordinal EPC rank (G=1, A=7) is 2.7. While class A comprises only 2% of the sample, Class B is not present after depurating the data, being Class E the most abundant (49%) followed by class G 21%. Regarding the average location, 93% are located in municipalities with access to a metropolitan highway, and 50% near to a railway station (including subway, tram, and funicular). Both the population and employment densities proxies for centrality and service presence, as it can be seen the minimum value for such attributes is 11 residents/km^2 and 5 jobs/km^2 reaching 144,421 residents/km^2 and 56,454 jobs/km^2 respectively in the most central/serviced zones. 1.2% of the apartments are located within 200 meters from the seashore which proxies for environmental quality.

Regarding the socioeconomic level of the zones where the apartments are located, 7% of the neighbouring housing has doorman service as an average, 11% of neighbours hold a university degree and 8% work in managerial positions. Since these variables are closely correlated[42], a component factor analysis has been used including the job positions and education level. As a result, there are two principal components: PC1-High Income proxies for high-income job positions/high education level, the larger its value, the higher the proportion of neighbours in managerial, professional and specialized technical job positions as well as the higher the education level. PC2-Med Income proxies for medium-income level, incorporating clerks, service vendors or qualified manufacturing positions. Since such synthetic indicators are produced by means a factor analysis, they are completely uncorrelated.

As for the year 2016, the attributes of the apartments denote an improved quality and higher price. For example, in comparison to the 2014 dataset, the 2016 apartments are: more expensive, larger, best equipped (*i.e.* air conditioner, heating and lift, swimming pool and garden), more

[42] As a matter of fact, most of the variables in the dataset are correlated. Nonetheless, the models do not exhibit multicollinearity problems, since this issue has been controlled keeping the VIF well below 2.5 (except for the case of the area and the squared area since it allows to model a diminishing marginal function for this attribute).

efficient in energy performance terms, located in better zones (*i.e*. more central, closer to the seashore, transport stations and highway ramps) and wealthier zones. Why the apartments seem to be improved in all the aforementioned aspects? As it is known, 2014 year was still a moment of real estate crisis in Spain when most of the properties being offered at that time exhibited poor amenities and attributes. Furthermore, better quality properties are normally taken out of the market since their owners can get a better price quotation during the economic recovery period. Conversely, the worst apartments that usually belong to a low-income population do not follow such a pattern since this population niche exhibits a higher unemployment rate and mortgage evictions. This process is typical in countries such as Spain where the ownership is the dominant housing tenure.

8.3 Results and Discussion

8.3.1 The Existence of Spatial Dependence in Barcelona Residential Market

As stated in chapter 4, GeoDa could help to explore if the spatial dependence exists. Section 4.2 has introduced several methods to confirm the weighted matrix. In our case, Delaunay triangulation spatial relationship is selected to produce a contiguity weighted matrix since Thiessen polygon (i.e. Delaunay triangulation) is a good way to divide a case study into regular subparts which could be regarded as a notion of a market area.

After the contiguity weighted matrix is computed, the Moran's I index is calculated. In Figure 8.2, the Moran's scatterplot is shown. Noted that the dependent variable and lagged dependent variable are regarded as the x-axis and y-axis respectively. It indicates the Moran's Index is equal to 0.532, implying a high level of spatial autocorrelation.

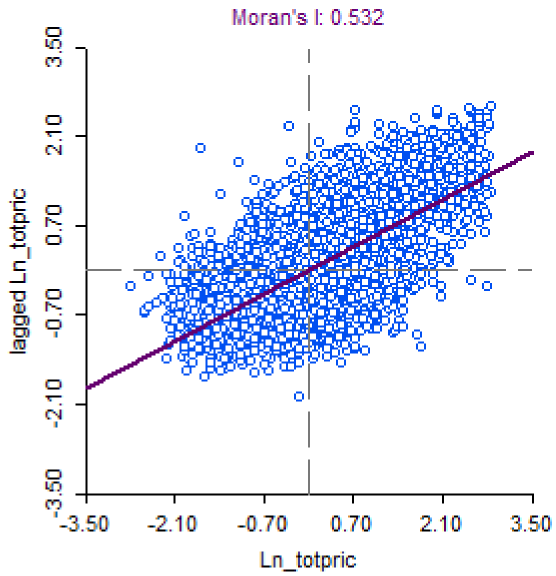


Figure 8. 2 Moran's I scatterplot of selling homes between 2014 and 2016
Source: Own elaboration

Subsequently, Figure 8.3 shows a distribution of the spatial autocorrelation in relation to selling an apartment between 2014 and 2016. The points coloured with red dark red and dark blue (High-High and Low-Low respectively) represent the positive relationship between the target point and its neighbours. That is to say, in the dark red area apartments with high selling price located together while blue dark is the area surrounded by an aggregation of cheap apartments.

In Barcelona residential market, high-high relationships are remarkably present in a high-income area (i.e. Sant Cugat), in Center of Barcelona, in a tourist area (i.e. Sitges) and the northeast coastline. These areas have their irreplaceable characteristics, resulting in the housing prices are higher than the average. However, Figure 8.4 also indicates that more than 60% of selling an apartment is out of a significant local statistic (grey colour.) under the control of a 99% confidence interval. This implies that numerous apartments in our case have not significant spatial autocorrelation which highlights us that more socio-economic variables should be taken into consideration when exploring the spatial relationship in the hedonic price analysis.

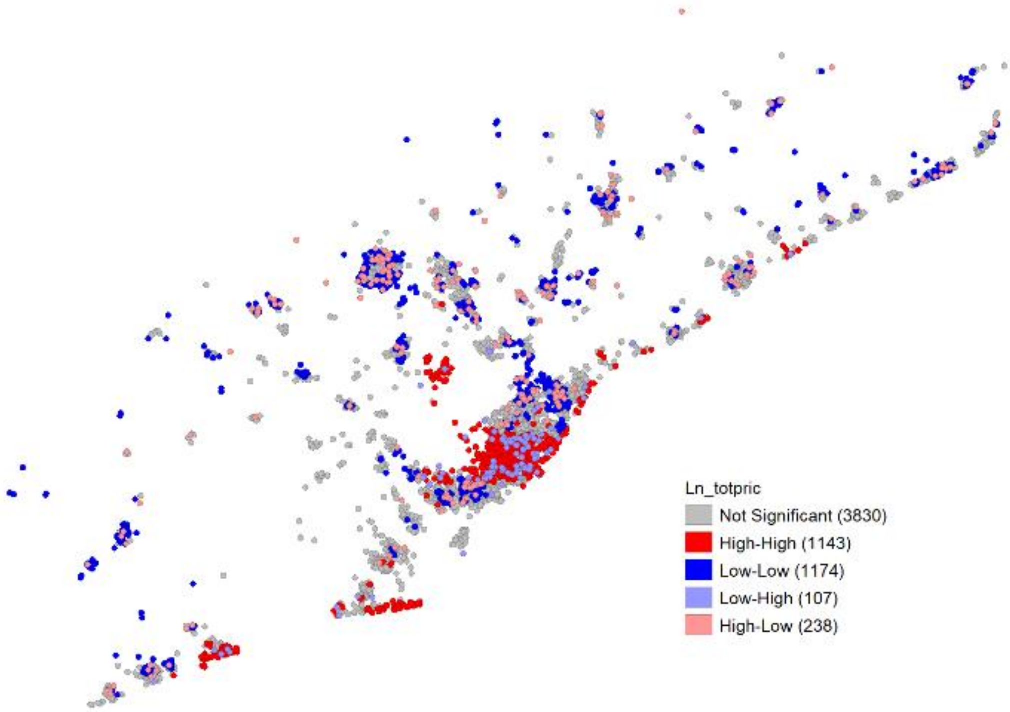


Figure 8. 3 LISA of selling apartments
Source: Own elaboration

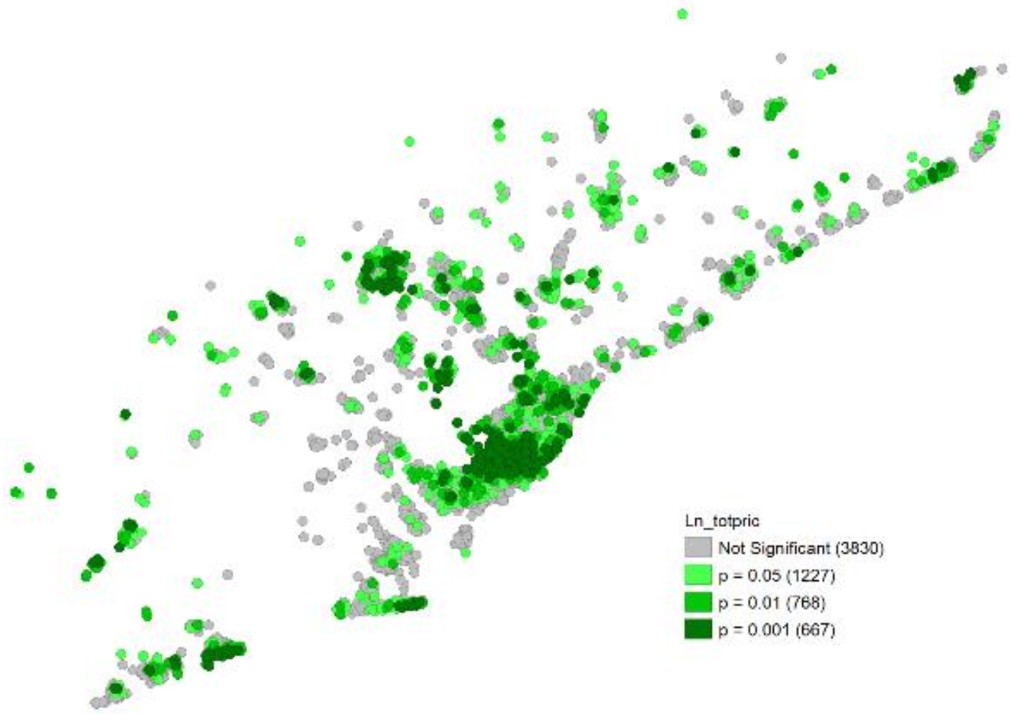


Figure 8. 4 Significance map of selling apartments
Source: Own elaboration

In sum, Moran's I (=0.532) confirms that spatial autocorrelation indeed exists in Barcelona residential market. Therefore, spatial error model (SEM) and spatial lag model (SAM) are employed to detect how these spatial autocorrelation impact on housing prices in relation to EPC premium.

8.3.2 The Performance of Energy Efficiency in The Residential Market from 2014 to 2016

Table 8.3 contains the results for the best model coming from the calibration of equation 3 in GeoDa. In such a table, it is possible to see that the average increase in terms of asking prices has been 4,1% for the period studied (1st Nov 2014-1st April 2016). The results organized by conceptual dimensions are as follow:

Structural architectonic characteristic of apartments and buildings: In the first place appears the area of the apartment, the negative sign of the square of this variable suggests the presence of diminishing returns. In this dimension the next variable to enter is the number of bathrooms: for each additional bathroom apartment's price increases 9.8%; the presence of lift is also an important factor its average impact is 8.9% of housing prices. Other structural attributes exhibit a modest influence on prices. For example, the presence of an air conditioner contributes to an average increase of 7.4% of asking prices, while the central heating system implies an increase of 4.1% of prices. It is important to note that the presence of a swimming pool in the buildings shows the highest contribution to housing prices (18,6%). Following Olaussen *et al*. (2017) the age has been introduced following an inverse function. Such an approach allows considering a larger impact of this attribute in the case of new and recently completed apartments, while in the case of old and very old ones the difference is smoother.

Energy efficiency attributes: There is also a positive increment of prices coming for efficient energy ranking as previous research has pointed out. In relation to rank G (the comparison base) energy class "A" increases prices in 8.6% for both years, the remainder of the classes for the base year fails to be statistically significant. This finding is plenty compatible with the results reported by Marmolejo (2016) since it confirms a scarce impact of energy efficiency on residential prices at the basis year. However, the interaction variables (*i.e.* 2016 x EPC ranks) suggest that the importance of energy ranks on price formation has clearly increased, as further discussed.

Locative attributes: The most relevant variables, regarding characteristics of transport, centrality as well as facilities and amenities, are the average gross area floor ratio (*i.e.* built-up density), followed by the centrality index and commuting time. The positive sign of the first two indicators confirms that prices peak in central zones; however, the positive sign of the third indicator requires a special interpretation. The metropolitan area of Barcelona is a polycentric system gathering together, beyond the central conurbation, mature subcentres that were formerly independent centres, small towns, and rural villages. In these latter settlements, housing price is cheaper than in centralities, at the same time commuting time is smaller than in the very centre (due they are largely self-contained in mobility terms). For this reason, commuting time is proxying for the location in the central conurbation, and consequently appears positively correlated with prices. The proximity to the seashore has a large impact on prices. It is important to note that housing price shows an average increase of 13.1% if the apartments are located within 200 meters from the waterfront.

Socioeconomic attributes: The synthetic indicators suggest that prices are enormously correlated with the place of residence of higher-educated people working in the best job positions (PC1-High Income). To a lesser extent, such positive correlation is also present for the case of medium-income classes (PC2- Med Income).

Table 8. 3 Results of the pooled 2014 - 2016 sample model

Spatial Error Model - Maximum Likelihood Estimation

R Square	0.764	Log-likelihood	-928	
Sigma Square	0.075	AIC	1917	
S.E of regression	0.274			
	B	Std. Error	Z-Value	Prob.
Lambda	0.462	0.016	28.317	-
(Constant)	10.125	0.056	182.398	-
Year 2016	0.041	0.015	2.684	0.007
Structural architectonic characteristics of apartments and buildings				
Area	0.015	0	37.546	-
Area^2	0	0	-19.709	-
Number of bathrooms	0.098	0.008	11.842	-
Air conditioner	0.074	0.008	8.905	-
Central heating	0.041	0.009	4.686	-
Retrofited apartment	0.034	0.01	3.437	0.001
Swiming pool	0.186	0.015	11.976	-
Lift	0.089	0.008	10.452	-
Inverse of building age	0.238	0.045	5.34	-
Energy performance of apartments				
Energy class A	0.086	0.034	2.492	0.013
Energy class C	-0.011	0.029	-0.375	0.708
Energy class D	0	0.019	0.02	0.984
Energy class E	0.007	0.013	0.572	0.567
Energy class F	0.019	0.016	1.132	0.258
Energy class A * Year 2016	0.067	0.044	1.515	0.13
Energy class B * Year 2016	0.107	0.041	2.619	0.009
Energy class C * Year 2016	0.106	0.041	2.597	0.009
Energy class D * Year 2016	0.105	0.026	4.071	-
Energy class E * Year 2016	0.008	0.018	0.462	0.644
Energy class F * Year 2016	-0.033	0.024	-1.386	0.166
Locative attributes (transport, centrality and amenities)				
Commuting time	0.004	0.001	2.597	0.009
<200m from sea shore	0.131	0.029	4.532	-
Highway ramp	0.081	0.022	3.712	-
<800 m from railway station	0.033	0.011	3.12	0.002
Centrality index	0.025	0.003	8.68	-
Average gross area floor ratio	0.048	0.005	9.029	-
Socio-economic attributes				
PC1 High income	0.104	0.006	17.356	-
PC2 Med income	0.072	0.007	10.979	-

Note: independent variables/covariates are introduced using the stepwise method.
Source: Own elaboration

Figure 8.5 portrays the evolution of the impact of energy efficiency classes on prices. According to the multiplicative-interaction terms built from the energy rank and the Year 2016, the impact of more efficient ranks has increased in a monotonic coherent fashion: 10.7%; 10,6% and 10,5% for ranks “B”, “C”, and “D” respectively. As a matter of fact, the increment of the impact of ranked “A” apartments is also positive but fails to meet the 90% confidence criteria. Overall, these results suggest that in a short period energy efficiency in Barcelona has gained importance in terms of residential prices. Green premiums and brown discounts have started to converge to what is observed in other European countries, opening new opportunities for the development of efficient housing and the retrofit of the existing stock as next discussed.

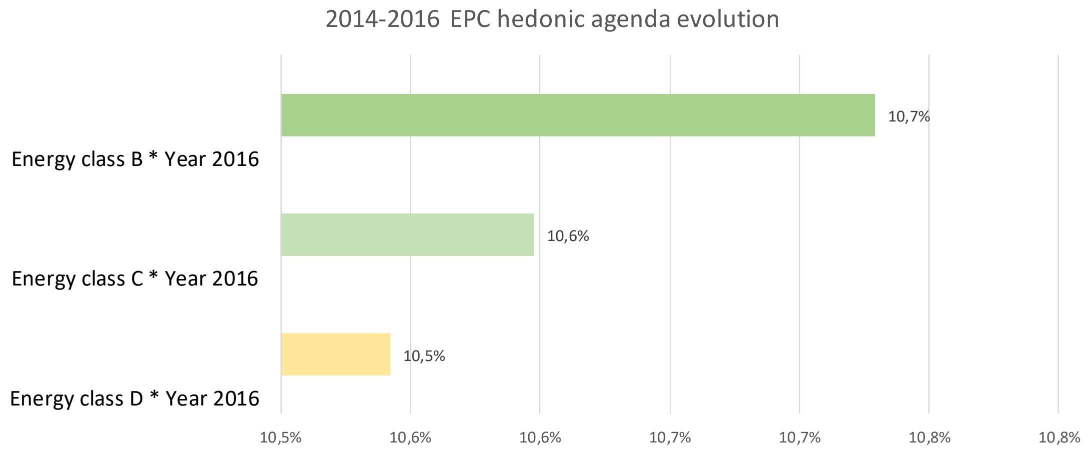


Figure 8. 5 Evolution of the energy rank impact on residential prices 2014-2016
Source: Own elaboration

8.3.3 How Different are The Apartments which Energy Efficiency Gains Relevance in Price Formation?

In order to explore significant differences in terms of architectonic and locative attributes, the 6,492 apartments are clustered in 4 groups. Group 1 (N = 73) is for the energy-labelled dwellings (ranking A) which impact significantly on housing prices in 2014 while the others are for Group 2 (N = 3,167) where no impact was found in the same year. Dwellings in the 2016 dataset are grouped in the same way, resulting in Group 3 (ranking B, C, D) where EPC ranking was found to have an impact on price formation and Group 4 where no impact was found- Each of such groups is formed by 485 and 2,718 apartments respectively. Next, an ANOVA test (at 90% confidence level) is implemented among these groups) for each of the architectonic and locative attributes.

8.3.2.1 Description of apartment's characteristics: insignificance vs significance:

According to the first column of Table 8.4, all the architectonic attributes in the 2014 dataset (excluded the number of bedrooms) are significantly different between homes clustered in Group 1 and 2. Conversely, in the remainder of accessibility and socioeconomic dimensions just the centrality index, population density and employment show significant differences. The average unit price for an "A"-ranked dwelling with a 90 square meters' size is 2,208 euros per square meter in 2014, 300 euros more per square meter than that in Group 2. Similarly, physical attributes (e.g. the number of bathrooms, area of outdoor spaces and living room) and amenities (e.g. air conditioning and heating) are more present in Group 1 where the probability to find a heated dwelling double in Group 2 in relation to Group 1. Regarding the accessibility and socioeconomic dimensions, the "A"- ranked dwellings in 2014 are located in metropolitan peripheries where the average centrality index is 10.73, less than the referenced Group 2. The same is true for population and employment densities. All in all, energy-efficient homes in 2014 are basically located at peripheral zones where buildings are constructed under newer construction codes requiring efficient thermal performances.

Table 8. 4 Statistical description for the groups in 2014 and 2016

Variables	2014				2016			
	Group 1 (N=73)	Group 2 (N=3,173)	ANOVA TEST F	ANOVA TEST Sig.	Group 3 (N=485)	Group 4 (N=2,761)	ANOVA TEST F	ANOVA TEST Sig.
Architectonic Attributes								
Total_price	197,784	162,047	11.55	0.001	275,192	221,404	51.58	0.000
Unit_price	2,209	1,908	14.87	0.000	3,029	2,514	67.04	0.000
Superficie	89.84	83.94	3.20	0.074	90.64	86.40	7.37	0.007
No_bedrooms	2.89	2.92	0.06	0.801	2.82	2.89	2.21	0.137
No_bathrooms	1.52	1.29	14.82	0.000	1.50	1.33	38.34	0.000
Dum_air_conditioning	0.67	0.30	47.38	0.000	0.60	0.45	37.82	0.000
Dum_heat	0.92	0.42	75.30	0.000	0.81	0.66	41.27	0.000
Dum_reform	0.30	0.10	30.71	0.000	0.28	0.18	30.19	0.000
Dum_lift	0.86	0.46	48.34	0.000	0.79	0.65	36.59	0.000
Ages of buildings	30.84	45.55	49.25	0.000	40.70	46.45	21.66	0.000
Construction_before 1981	0.51	0.84	57.91	0.000	0.62	0.77	48.44	0.000
Construction_between 1982-2006	0.25	0.12	11.16	0.001	0.21	0.17	4.35	0.037
Construction_after 2007	0.25	0.04	68.77	0.000	0.17	0.06	69.12	0.000
Storied	2.47	2.14	2.82	0.093	2.11	2.19	0.46	0.497
Areas_outdoor	12.60	9.40	3.63	0.057	9.71	9.45	0.06	0.800
Areas_living	15.18	12.11	6.75	0.009	13.19	11.69	6.18	0.013
Dum_grand_terrance	0.18	0.07	13.35	0.000	0.12	0.14	0.48	0.487
Dum_swim_pool	0.08	0.04	3.02	0.082	0.15	0.10	8.03	0.005

Dum_gard	0.27	0.09	30.77	0.000	0.20	0.15	7.17	0.007
Accessibility Attributes								
Time_commuting	24.61	24.00	1.32	0.250	24.57	24.65	0.19	0.666
Dum_sea (in 200 meters)	0.03	0.01	1.49	0.223	0.04	0.04	0.26	0.608
Dum_highway	0.96	0.93	1.18	0.278	0.94	0.94	0.10	0.758
Dum_trans_stations	0.53	0.50	0.36	0.547	0.57	0.56	0.33	0.568
Index_Central	10.73	11.39	5.52	0.019	12.47	11.94	16.39	0.000
Ratio_floor_areas	1.84	1.99	0.87	0.350	2.43	2.33	1.54	0.214
Socioeconomic Attributes								
Proportion of university degree	9.77	10.88	1.49	0.222	15.85	14.21	11.75	0.001
Density of population	16,884	22,051	3.70	0.054	21,623	24,730	7.42	0.006
Density of employment	7,021	9,569	4.89	0.027	9,456	10,742	6.77	0.009
PCA High income	-0.23	-0.11	1.64	0.201	0.32	0.13	13.32	0.000
PCA Med income	-0.22	-0.24	0.03	0.865	0.05	0.01	0.73	0.393
Pr_Manager	7.28	7.90	1.40	0.237	10.26	9.39	10.92	0.001
Pr_professiones	9.95	11.01	1.33	0.249	15.67	14.14	10.55	0.001
Pr_technics	13.31	13.29	0.00	0.974	14.97	14.35	9.60	0.002
Pr_admin	11.14	10.98	0.25	0.614	11.32	11.31	0.01	0.935
Pr_commer	15.20	15.05	0.15	0.702	14.21	14.77	8.48	0.004
Pr_agricultura_fisher	0.67	0.75	0.64	0.425	0.67	0.69	0.33	0.568
Pr_craftman	18.06	17.47	0.62	0.430	13.69	14.82	11.51	0.001
Pr_operation	13.73	13.28	0.38	0.535	10.22	10.88	4.69	0.030
Pr_unquality	10.61	10.17	0.68	0.408	8.89	9.55	8.54	0.004

Notes: Variables with grey colour are insignificant at 90% of confidence. Source: Own elaboration.
Source: Own elaboration

In the 2016 dataset for Groups 3 and 4, the same significant differences in the "architectonic attributes dimension" which are found in 2014, are identified but the number of storeys, area of outdoor spaces and the presence of large terraces (more than 20 m^2). In Group 3, the average unit price in 2016 is 3,029 euros per square meter for a "B", "C" or "D"-ranked dwelling with 91 square meters where the probability of amenities (e.g. air conditioning, heating and lift) is 15% larger than that in group 4. Unlike the result in 2014, almost all the socioeconomic attributes show significant differences between groups. The proportion of households holding a university degree as well as the proportion of high-level positions (e.g. managers, professionals) are higher in Group 3. All in all:

- There is a clear correlation between the impact of EPC rankings on housing prices and the quality of apartments. Namely, those energy-labelled dwellings that have a significant impact on housing prices are more expensive, larger and boast the best architectonic attributes. Homes, where EPC rankings have found to be significant on price formation, are newer than other, although half of them were constructed before 1981 when non-construction code with thermal implications existed in Spain.

- Also, the location of homes where EPC rankings have found to be impacting prices is different for the 2 analysed years. In 2014 A-ranked apartments (Group 1) were located in peripheries, conversely in 2016 “B”, “C” and “D”-ranked apartments (Group 2) were located in more centric locations. Such different location is reflected in the centrality index as well as urban densities. Differences in locations explain why gardened (i.e. outdoor spaces) and terraced apartments are identified in 2014 as those being impacted by energy efficiency and not in 2016 where more centric locations imply less outdoor areas.

- Finally, the different locational patterns are also reflected in the socioeconomic profile of areas: more central zones are characterised, in the case study, by an important presence of well-educated population holding privileged job positions, which in turns proxies for large income.

8.3.2.2 Comparison the differences of the apartment’s characteristics: 2014 vs 2016

As stated, the recast EPBD requires that the energy label information to be exhibited in the advertisement of real estate, in Spain such obligation was introduced by the transposition of the Directive in 2013. In order to explore the differences of characteristics in homes where EPC rankings have found to be relevant to the price formation, an ANOVA test has been used. The results are exhibited in Table 8.5.

In 2016, there are 485 homes (Group 3) where EPC rankings play a role in price formation, around seven times than the corresponding cluster (Group 1) in 2014. Such divergence in group size is explained because in 2014 only “A”-ranked homes form Group 1, while in 2016 Group 3 is formed by “B”, “C” and “D”-ranked apartments. According to table 4, three variables show significant differences in architectonic attributes between the two groups. The probability to find a heated home decreases from 92% in 2014 to 81% in 2016. Perhaps it is reflecting a correlation between energy class and quality. Also, by the fact that 62% of Group 3 homes were constructed before 1981while in Group 1 only 51% was built before any thermal building regulation came into force. Also, the centrality index which proxies for well-located apartments is larger, and the floor area ratio also increases up to 2.43. Finally, the proportion of households holding a university degree, the population and employment densities and the proportion of professional positions (e.g. managers, professions and technicians) shows considerably superior performance in 2016. It is noted that in 2016 the proportion of household holding university degrees increases by up to 15.85%, which is roughly double than that in 2014.

- There are more homes with energy rankings playing an important role in housing prices after the mandatory of EPC on advertising in 2013. In other words, a larger number of homes with various energy rankings is introduced in Barcelona Metropolitan market and does matter on housing prices.

- Also, there is a worse performance on architectonic attributes of energy labelled homes related to housing prices. Namely, the qualities of physical features of energy-efficient homes impacting on housing prices are lower along with the evolution of the EPC program. Generally, it is supposed that the correlation between the physical quality of dwellings and the energy ranking is positive. Therefore, it is explicable regarding this "Worse Performance" change, considering more homes with lower energy rankings introduced.

- Finally, energy-efficient homes related to housing prices are located in a central area where the proportion of household holding a university degree and the density of population is higher. It is noted that in 2014, the homes relevant to housing prices are located in a peripheral area although they are labelled as A rank.

Table 8. 5 Statistical description for the groups in 2014 and 2016

Variables	Group 1 in 2014 (N=73)	Group 3 in 2016 (N=485)	ANOVA	
			F	Sig.

Architectonic Attributes				
Dum_heat	0.92	0.81	5.45	0.020
Ages of buildings	30.84	40.70	8.01	0.005
Construction_before 1981	0.51	0.62	3.26	0.071
Accessibility Attributes				
Index_Central	10.73	12.47	27.86	0.000
Ratio_floor_areas	1.84	2.43	8.01	0.005
Socioeconomic Attributes				
Proportion of university degree	9.77	15.85	24.25	0.000
Density of population	16,884	21,623	2.98	0.085
Density of employment	7,021	9,456	4.21	0.041
PCA High income	-0.23	0.32	18.34	0.000
PCA Med income	-0.22	0.05	5.65	0.018
Pr_Manager	7.28	10.26	19.92	0.000
Pr_professiones	9.95	15.67	22.83	0.000
Pr_technics	13.31	14.97	11.19	0.001
Pr_commer	15.20	14.21	3.86	0.050
Pr_craftman	18.06	13.69	27.99	0.000
Pr_operation	13.73	10.22	19.16	0.000
Pr_unquality	10.61	8.89	8.80	0.003

Notes: Variables with grey colour are insignificant at 90% of confidence. Source: Own elaboration.
Source: Own elaboration

8.4 Conclusion

Housing energy-efficiency has become a relevant issue in the Spanish residential sector since in 2013 it was made mandatory to exhibit a label coming from an energy performance certificate (EPC) when transacting real estate. As stated, many studies have identified the impact of such EPC labels on housing prices. However, few studies focus on the differences in homes where the EPC rankings are found to be important in price formation in relation to those which energy performance plays a null role. This paper, using a spatial error hedonic approach, explores this issue using listing prices for apartments located at Metropolitan Barcelona.

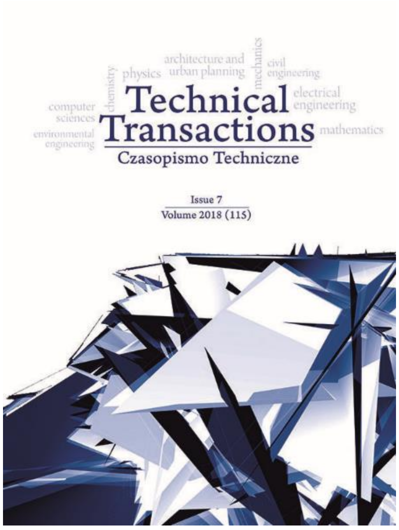
Departing from listing prices for 2014 and 2016 in this research, a set of spatial pooled regression models has been performed. Such analyses suggest that, as the time evolves, the market premium for energy efficiency (i.e. semi-elasticity or the per cent price increase for each EPC energy rank) has increased in the main real estate market of the second largest urban agglomeration of Spain. In absolute terms (i.e. Euros) such market premium is still more important since market prices have increased 4.1% in the studied period due to the change of economic cycle that has marked the end of the real estate crisis in Spain. According to Garcia

Navarro et al. (2014), the 2016 market premium for efficient homes found in this paper is able to overcome the increased construction costs associated with better energy-efficiency materials and building procedures. That is, matching the premia that developers can get from efficient buildings with the production cost is a critical issue in achieving the outcomes pursued by the Energy Performance of Building Directive. Our analyses suggest that in general, the more efficient ranks do exhibit an increased impact of housing prices. Such increment ranges 10.7% to 10.5% for the "B" to "D" ranks respectively. Rank "A", also shows a positive increase but fails to meet the significance criteria.

Results suggest that A-labelled homes do impact significantly on housing prices in 2014, while B/C/D-labelled ones in 2016. In average, an energy performance improvement from G class to A class brings in a growth 8.6% of housing prices in 2014, and an increase of 10.6% from class G to class B in 2016. After comparing with the specific characteristics for homes related to energy premium, we find that more homes with various energy rankings are introduced in the real estate market and they are located in more central areas in 2016, instead of the peripheral area in 2014. It is noted that the physical features show worse performances in 2016 since more ancient dwellings are present in the B/C/D Group.

Whether the rise of energy premiums for efficient homes in Spain is a product of the natural implementation of the EPC policy is an open question. Nonetheless, in this period, the significant increments in the price of energy have occurred in the country. This inflationist episode might have influenced households to penalize inefficient homes markedly. In any case, the increase of energy premiums in the Spanish residential market is a clear convergence to the European agenda of EPC hedonic prices.

These findings have implications for future analysis regarding energy premium and energy poverty, since specific characteristics in different submarkets may have a different impact on housing price.



CHAPTER 9

Is the energy price premium spatially aggregated? A listing price analysis of the residential market in Barcelona

Chen Ai & Marmolejo Duarte Carlos

CHAPTER 9 LOCAL SPATIAL IMPACTS OF ENERGY EFFICIENCY ON HOUSING PRICE

9.1 Overview

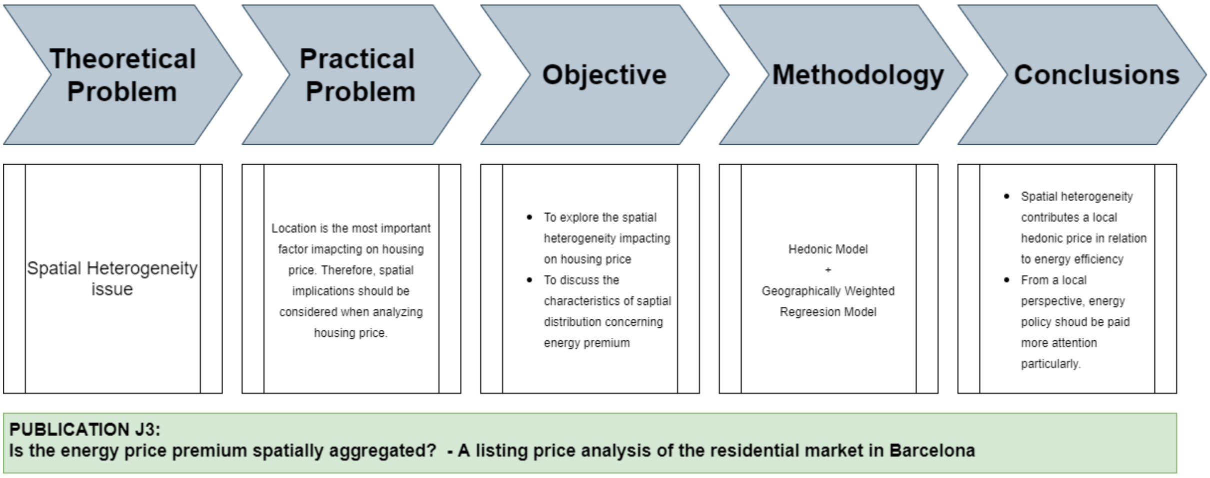


Figure 9. 1 Chapter 9's structure
Source: Own elaboration

This Chapter aims to 1) substantiate energy implicit housing prices in Metropolitan Barcelona and 2) examine the existence of spatial impacts of energy on housing prices. An Ordinary Least Squares Regression model (OLS) and Geographically Weighted Regression (GWR) is used to analyse implicit energy housing prices from the perspective of statistics and spatial distributions.

The rest of the chapter is organized as follows: 1) first the methods, study area, data, and applied models are described; 2) second, the results of the aforementioned models are presented 3) finally, in the concluding section, the findings and suggestions are discussed.

9.2 Methodology, Models and Data

According to the general objectives, statistical description of the sample (Table 9.1) should be done by providing a comprehensive understanding and necessary information regarding the dependent variable (the listing price of apartments) and independent variables (location and architectonic features of apartments). Subsequently, all attributes are employed and calculated by an OLS hedonic price model with the stepwise method, which can extract the significant attributes from this total sample. Thirdly, geographically weighted regression (GWR) will be executed with the same attributes to verify the spatial homogeneity of EPC class incidence over listing prices. Finally, a potential relationship between energy attributes and other socioeconomic attributes will be shown by graphic visualization, thus strengthening readers' comprehension.

9.2.1 Geographically Weighted Regression Linear Model

In order to examine whether and how energy attributes spatially impact housing prices, Geographically Weighted Regression (GWR), a prevalent spatial analysis model, has been employed. It could resolve autocorrelation issues and represent a "soft window" approach to submarket identification (non-stationary influence) (Marmolejo & González Tamez, 2009).

$$Ln(P)i = B_i(u_i, v_i) + \sum_{s=1}^{n} B_i\,(u_i, v_i)SQ_{is} + \sum_{a=1}^{n} B_{ia}(u_i, v_i)EL_{ia} + \sum_{n=1}^{n} B_{in}(u_i, v_i)A_{in} + \sum_{e=1}^{n} B_{ie}(u_i, v_i)NE_{ie} + \varepsilon_i \tag{9.1}$$

Where (u_i, v_i) denotes the coordinates of the ith point in space and $B_i\,(u_i, v_i)$ is a realization of the continuous function $B_i\,(u, v)$ at a point i. That is, a continuous surface of parameter values is allowed, and measurements of this surface are taken at certain points to denote the spatial variability of the surface. Regarding the primary OLS hedonic price model, it is easy to find the spatial information of every observation calculated in the GWR model that can reveal a spatial relationship among various attributes from diverse dimensions. Also, with a spatial distribution of energy attributes (Energy label) and their significances, it is easy to estimate the existence of non-stationary energy impacts on urban space.

9.2.2 Data Description

Listing prices for apartments and flats from Habitaclia (April 2016) are the main resource of information, including residential addresses, architectural and structural building features, unit listing prices, etc. After excluding the outliers using the Mahalanobis distance method, which accounts for 10.86% of the original database (40,844 flats), there are 4,436 flats with effective information (including energy label). Furthermore, it is worth mentioning that more than half of them are certificated with an E class energy label, followed by 18.37% G class, 12.58% F class, and 10.66% D class. Since the majority of the flats (about 85%) in BMA were constructed before the year 2000, at which time building techniques were limited and construction codes were permissive, high-energy label classes (A, B and C class) account in total for less than 18.5% of properties.

Table 9. 1 Descriptive statistics of the depurated sample

Dimensions	Variables	N	Minimum	Maximum	Mean	Std. Deviation
Structural and Qualitative Dimension (SQ)	Unit Price (euro/sq.m)	4,436	902	3,992	2,188	793
	Gross price (euro)	4,436	41,800	1,200,000	194,350	117,898
	Gross Area (m^2)	4,436	20	313	87.01	31.75
	Areas^2 (m4)	4,436	400	97,969	8,579	7,707
	Number of Bedrooms	4,436	1	8	3.07	4.00
	Number of Bathrooms	4,436	0	4	1.35	0.53
	Levels	4,436	0	14	2.09	1.98
	Construction Year	4,436	1817	2016	1968	28
	Terrace Areas (m^2)	4,436	0	180	8.32	16.79
	Dummy Storage	4,436	0	1	0.20	0.40
	Dummy Laundry	4,436	0	1	0.50	0.50
	Dummy Air Conditioner	4,436	0	1	0.44	0.50
	Dummy Heating	4,436	0	1	0.67	0.47
	Dummy High Quality Properties	4,436	0	1	0.03	0.18
	Dummy Elevator	4,436	0	1	0.68	0.47
	Dummy Swimming Pool	4,436	0	1	0.10	0.30
Accessible Dimension (A)	Dummy Access to Highway	4,436	0	1	0.88	0.32
	Dummy Access to Rail Station	4,436	0	1	0.51	0.50
	Distance to CBD (km)	4,436	0.12	62.01	17.28	14.39
	Working Commuting (minutes)	4,436	11.54	41.44	24.22	4.36

Dimensions	Variables	N	Minimum	Maximum	Mean	Std. Deviation
	Distance to Rail Station (km)	4,436	0	10.14	0.83	1.07
	Distance to Highway (km)	4,436	0.01	11.26	1.91	1.52
Neighbouring and Environmental Dimension (NE)	Percentage of People without Studies (%)	4,436	3.78	45.68	14.67	5.73
	Percentage of People with Primary Studies (%)	4,436	8.31	50.74	24.90	5.68
	Percentage of People with Secondary Studies (%)	4,436	20.77	67.1	46.84	5.26
	Percentage of People with University Studies (%)	4,436	0.63	50.55	13.59	8.96
	CP High Income	4,436	-2.39	2.61	0.14	0.92
	CP Medium Income	4,436	-1.26	2.09	0.44	0.51
	CP Medium-Low Income	4,436	-2.67	3.36	-0.09	0.85
	Proportion of Ruined Buildings (%)	4,436	0	59.38	1.27	2.76
	Proportion of Bad functional Buildings (%)	4,436	0	40.87	2.73	5.49
	Proportion of Deficient Buildings (%)	4,436	0	73.91	9.73	10.85
	Proportion of Good Buildings (%)	4,436	0	100	86.27	14.76
	Proportion of Noise Annoyance opinion (%)	4,436	5.15	77.43	38.12	11.40
	Proportion of Pollution opinion (%)	4,436	1.72	82.14	22.05	11.82
	Proportion of Dirty Streets opinion (%)	4,436	0.75	84.97	36.47	12.69
	Proportion of Bad Transportation opinion (%)	4,436	0.26	81.07	13.41	12.72
	Proportion of Deficient Green Zone opinion (%)	4,436	1.12	90	35.68	16.82
	Proportion of Delinquency opinion (%)	4,436	3.04	90.91	27.23	16.27
	Dummy Access to Sea (in 200 meter)	4,436	0	1	0.04	0.19
Energy Label Dimension (EL)	EPC_A	4,436	0	1	0.03	0.18
	EPC_B	4,436	0	1	0.01	0.10
	EPC_C	4,436	0	1	0.04	0.18
	EPC_D	4,436	0	1	0.11	0.31
	EPC_E	4,436	0	1	0.50	0.50
	EPC_F	4,436	0	1	0.13	0.33
	EPC_G	4,436	0	1	0.18	0.39
	Ord_EPC (from A=7 to G=1)	4,436	1	7	2.85	1.32

Source: Own elaboration

In the SQ dimension, there are several direct and indirect attributes, including price per square metre, the total price of flat, gross area, number of bedrooms/bathrooms as well as the level on which the apartment is located, building construction year, terrace area, and storage and laundry facilities (Yes = 1, No = 0). It is noted that two variables, square area and area/rooms, are specified, which reduces the extreme data bias of luxury flats. Also, this dimension includes the presence of air-conditioning, heating, and the overall quality of finishings. Other attributes refer to the presence of a lift or common swimming pool in the building where the apartment is located. It can be seen that the average size of flats is 87 square metres, the average listing price is 2,188 euros per square metre, and the average apartment consists of 3 bedrooms and 1.5 bathrooms. More than half have laundry rooms, heating appliances and lift.

In dimension A, the accessibility to transport infrastructure (highway, railway, subway) or the city centre, as well as commuting time to work, is included. Note that data concerning public transport can be easily acquired by Nearest Neighbour Analysis (NNA) in ArcGIS.

Hence, it is also useful to introduce these dummy variables about accessibility to public transport that results from buffer zones with a radius of 400 metres and 800 metres respectively in urban and suburban areas. In such cases, over 50 per cent of properties are located 17 km, 0.83 km and 1.91 km distance to CBD, train station and highway, respectively. In addition, the average commuting time from house to the workplace is 24 minutes according to the Census. Less commuting time possibly means more time spent on entertainment activities and lower transport costs, which promotes a willingness to purchase and thus higher housing prices.

The NE dimension consists of each neighbourhood's education and income level as well as building condition and perception of the built environment (all this data comes from the Census). In this sample, almost 50% of the people have some secondary education, followed by primary education (24.9%), no education (14.67%) and university education (13.59%). Similarly, this corresponds to the distribution of income levels, for which family groups with a medium-income is predominant. It is easy to see that neighbourhoods with better-educated households are commonly more affluent than those with less-educated residents. Education levels and income levels show a higher correlation coefficient, probably resulting in multi-collinearity. Furthermore, in the opinion of households, over 86% of buildings are considered functionally perfect, and around 33% of them suffered from noise annoyances, dirty streets, or deficient green zones. Waterfront views can also be represented as location and neighbourhood qualities that affect buying preferences and decision-making. Just a few properties are located within 200 metres of the sea; therefore, even in a coastal city such as Barcelona, properties with a perfect sea view are scarce.

The EL dimension shows 2 different energy ranking scales: I) Ordinal energy rankings from Class A to Class G are assigned from 7 to 1; II) Nominal energy rankings, in fact, are energy ranking dummy variables (e.g. if a property is certificated with Class E, just EPC_E dummy will be numbered "1", the other 6 Classes are "0")

9.3 Results and Discussion

In this section, we aim to explore how the energy category premium affects housing prices and then clarify its spatial distribution, which is supposed to be a discontinuous diversification. Table 9.2 presents estimation results from the OLS hedonic prices model and is classified by hierarchical regression into four dimensions. That is, attributes from the structural and qualitative dimension, accessible dimension, neighbouring and environmental dimension as well as energy label dimension are calculated in sequence. It shows a 1.9% increase in housing prices while promoting a one-level energy label or an increase 12.2% of property prices along with the nominal energy ranking improved from Class G to Class A. Subsequently, Table 3 shows estimation results from the GWR model and reveals a remarkable spatial variability for the core "Energy label" variable. Finally, spatial aggregations of energy labels are illustrated graphically, and their relationships with other socioeconomic attributes are elaborated below.

9.3.1 Energy Efficiency Premium in 2016

Hierarchical regression is the prevalent analysis method to explore whether additional attributes contribute to improving the model and core variables are generally applied in the final model. Columns 1–3 of Table 9.2 show OLS estimation results by structural, qualitative, accessible and environmental dimensions progressively. Columns 4 and 5 show relevant energy label variables in ordinal and nominal forms, in addition to the attributes introduced above.

Table 9. 2 Estimation of OLS model

	MOD1	**MOD2**	**MOD3**	**MOD4**	**MOD5**
R2	0.578	0.694	0.773	0.775	0.776
R2 adjusted	0.577	0.693	0.773	0.775	0.775
(Constant)	10.612	10.674	10.432	10.4	10.42
	(0.032***)	(0.032***)	(0.031***)	(0.031***)	(0.031***)
Gross Areas (m^2)	0.015	0.015	0.014	0.014	0.014
	(0.001***)	(0.001***)	(0.000***)	(0.000***)	(0.000***)
Areas^2 (m4)	-2.12E-05	-2.58E-05	-2.90E-05	-2.84E-05	-2.88E-05
	(0.000***)	(0.000***)	(0.000***)	(0.000***)	(0.000***)
Number of Bathrooms	0.082	0.112	0.099	0.094	0.093
	(0.012***)	(0.011***)	(0.009***)	(0.009***)	(0.009***)
Terrace Areas (m^2)	0.0001	0.001	0.002	0.002	0.002
	(0.000)	(0.000***)	(0.000***)	(0.000***)	(0.000***)
Dummy Quality Kitchen	0.057	0.04	0.054	0.052	0.052
	(0.011***)	(0.009***)	(0.008***)	(0.008***)	(0.008***)
Dummy Air Conditioner	0.092	0.046	0.065	0.061	0.059
	(0.011***)	(0.010***)	(0.008***)	(0.008***)	(0.008***)
Dummy Heating	0.065	0.108	0.083	0.08	0.08
	(0.012***)	(0.011***)	(0.009***)	(0.009***)	(0.009***)
Dummy High Quality Properties	0.1	0.058	0.06	0.057	0.056
	(0.029***)	(0.025*)	(0.022**)	(0.022**)	(0.022**)
Dummy Swimming Pool	0.074	0.178	0.12	0.119	0.119
	(0.017***)	(0.000***)	(0.013***)	(0.013***)	(0.013***)
Dummy Elevator	0.167	0.143	0.119	0.113	0.113
	(0.011***)	(0.000***)	(0.008***)	(0.008***)	(0.008***)
Dummy Access to Highway		0.059	0.034	0.038	0.038
		(0.014***)	(0.012**)	(0.012**)	(0.012**)
Dummy Access to Rail station		0.089	0.042	0.042	0.042

	(0.009***)	(0.008***)	(0.008***)	(0.008***)
Distance Access to CBD	-0.011	-0.008	-0.008	-0.008
	(0.000***)	(0.000***)	(0.000***)	(0.000***)
Dummy Access to Sea		0.125	0.13	0.129
		(0.020***)	(0.020***)	(0.020***)
Proportion of Noise Annoyance opinion (%)		0.003	0.003	0.003
		(0.000***)	(0.000***)	(0.000***)
Percentage of People with University Studies (%)		0.017	0.018	0.018
		(0.000***)	(0.000***)	(0.000***)
Ord_EPC			0.019	
			(0.003***)	
EPC_A				0.122
				(0.022***)
EPC_B				0.021
				(0.037)
EPC_C				0.08
				(0.022***)
EPC_D				0.081
				(0.015***)
EPC_E				0.022
				(0.010*)
EPC_F				0.024
				(0.014)

Notes: *Significant at 1%; **Significant at 0.5%; *** Significant at 0.1%; n/s not significant; Dependent variable: Ln total price.
Source: Own elaboration

In general, a significant growth of R square adjusted from 0.577 to 0.775 represents a better linear fitting goodness. That is to say, MOD4 and MOD5 (including four-dimensional attributes) in Table 9.2 can explain 77.5% of the variance of these apartments' listing selling prices based on a 95% confidence interval, compared with other models. The attributes from the structural and qualitative dimensions are still the dominant factors that affect housing prices, followed by the Neighbourhood and Environment dimensions, and the Accessibility dimension across Metropolitan Barcelona.

With crosswise comparison, all estimation coefficients changed slightly regarding MOD3, which is a completed variable set that excludes the energy efficiency label. Coefficients of variables in the SQ dimension decrease while those of the variables in the other 2 dimensions increase when the energy efficiency label is introduced. The most changed variables relate to the presence of an elevator and the number of bathrooms, decreasing 0.6% and 0.5% respectively; the variables relating to the presence of a high-quality kitchen, air conditioner, heating and high-quality properties decreased only a little, by an average of 0.3%. This means that the possible impact of an elevator on housing prices after taking into consideration energy label information decreases by 0.6%, controlled other variables. In the same way, the possibility of impacts on housing prices drops 0.5% and 0.3% regarding the previous variables stated. On the other hand, the possible impacts of "access to the highway" and "access to the sea" on housing prices increase 0.4% and 0.5% respectively, where otherwise almost remain the same. Energy label class does indeed have an impact on property price.

According to the standardized coefficient beta, the most critical attribute on housing prices in the SQ dimension is gross area while the square of the gross area has a negative sign, which represents the presence of the decreasing marginal utility principle. Subsequently, the presence of an elevator and public swimming pool leads to a significant increase of 11.3% and 11.9% in listing prices, respectively. Likewise, there are respective increases of 5.9% and 8% in residential value for apartments equipped with air conditioning and heating. The results demonstrate that the necessary facilities and appliances in flats and buildings are mostly responsible for gross property prices in this physical characteristics dimension. Note that the variable of a terrace area impacts housing prices with a 0.2% increase that remains the same whatever the energy label.

In the accessibility dimension, access to highway and transport stations bring about increases of 3.8% and 4.2% respectively for residential prices. In other words, if an apartment is located in a municipality with a highway ramp or within 400 m. or 800 m. of a train station (urban/suburban location), then there is an average 4% rise in property prices. In terms of distance to CBD, its coefficient demonstrates that the price of flats located far away from CBD decrease by 0.8% for each kilometre.

In the neighbourhood and Environment dimension, the within 200 metres of the sea variable, the proxy of the landscape environment, shows the most significant influences. Flats near the sea have a 12.9% higher price, which implies a strong willingness to pay for this feature. On the contrary, noise pollution seems to have no obvious effects on housing prices.

It can be deduced that benefits from the conglomeration of commercial and entertainment activities as well as the availability of transport can offset, to some extent, the influence of noise annoyance. In other words, buyers are willing to suffer noise annoyance to a certain degree in order to enjoy conveniences of daily life. The proportion of the population with a university degree represents potential consumers' social class and wealth level; this adds 1.8% to property prices for each per cent that each proportion increases.

In Column 4, the energy label is statistically significant in the model. According to the coefficients, when other variables are controlled for, the apartments' price increases by 1.9% with each better energy class. The coefficients for the control variables are generally consistent with expectations. More details on green premiums are listed in Column 5, where six energy label dummy variables (from A to F) replace the previous ordinal energy label, and the reference group is Class G. Class A, C, D, E are significantly positive while Class B and Class F are insignificant. In general, the green premium increases along with energy rating improvement: in comparison to "Class G", flats certificated as Class A show the highest increase of 12.2%, followed by 8% for Class C, 8.1% for Class D and 2.2% for Class E. In line with expectations, differences of energy label ranking (from efficiency to inefficiency) contribute to a continuous increase of property price.

9.3.2 Is The Impact of Energy Efficiency on Housing Price Stationary?

Simple OLS analysis may cause incorrect understanding and misjudgment if the distribution of attributes across the urban space shows an uneven spatial layout (Fuerst et al., 2015). In order to solve this problem, I will test the Monte Carlo Significance Test (Hope, 1968) after employing the Geographically Weighted Regression model. Finally, the spatial impacts (i.e. coefficients) for each observation will be studied furthermore.

9.3.2.1 Spatial variability test

As stated in Chapter 4, spatial autocorrelation is always developed with spatial heterogeneity. Table 9.3 shows the significance results by the Monte Carlo test which is a common method to detect if the spatial distribution for each parameter is stationary or non-stationary across urban space.

Table 9. 3 Test of spatial variability

Parameter	**P-value**	**Sig.**
(Constant)	0.0000	***
Gross Areas (m^2)	0.0000	***
Areas^2 (m^4)	0.0900	n/s
No. Bathrooms	0.0000	***
Dummy Swimming Pool	0.0000	***
Terrace Areas	0.5500	n/s
Dummy Elevator	0.0100	**
Dummy Quality Kitchen	0.4800	n/s
Dummy Air Conditioner	0.7100	n/s
Dummy Heating	0.0500	*
Dummy High-Quality Properties	0.8600	n/s
EPC_A	0.1200	n/s
EPC_B	0.5300	n/s
EPC_C	0.0000	***
EPC_D	0.0000	***
EPC_E	0.6200	n/s
EPC_F	0.3100	n/s
Dummy Access to Highway	0.0000	***

Dummy Access to Railway	0.2400	n/s
Distance to CBD	0.0000	***
Dummy to the seashore (in 200m)	0.0000	***
Proportion of annoyance	0.0000	***
Percentage of People with University Studies	0.0000	***

*** = significant at .1% level; ** = significant at 1% level; * = significant at 5% level
Source: Own elaboration

Concerning the structural and buildings characteristics, several variables, including the square of the floor area and terrace area as well as the presence of air conditioning for an apartment, are out of significant in spatial variability test. It implies that these impacts of quality variables on housing prices are even across Barcelona urban space. In contrast, the spatial impacts of the floor area, bedroom number as well as the presence of heating, swimming pool and elevator distribute in a non-stationary manner in Barcelona.

As expected, almost variables with respect to the accessibility and socio-economy aspect show uneven performance spatially but “access to the railway”. They are formed essentially by the current location and surrounding facilities which generally distribute unevenly across urban space.

Concerning the performance of EPC rating, C-rating and D-rating present a local spatial distribution in Barcelona while A and E ratings present a global performance.

9.3.2.2 GWR estimation results

Table 9.4 contains the results from the GWR model; as can be seen, there are 2,256 cross-validated cases (numbers locations to fit is 4,436 cases) used by the adaptive kernel and adjusted R2 increases from 0.775 to 0.808. This means the GWR model can explain 80.8% of cases, namely the local regression model can give a more accurate result than the OLS model. Regarding the Akaike information criteria, it shows a dramatic decrease from 256.06 to -371.59. Meanwhile, relative sigma decreases slightly, which suggests that GWR can give a more accurate result than the OLS model. In the table, upper and lower quartiles, as well as Huber's M-estimator, which is more robust than the mean, are detailed.

Table 9. 4 Estimation results of GWR model

GWR Model			*Akaike information criterion*	
R2	0.813		OLS	188.33
R2 adjusted	0.808		GWR	-403.14
Sigma (SE)	0.2279			

B Distribution Statistic	*Lower quartile*	*Huber's M-estimator*	*Upper quartile*
(Constant)	10.4263	10.5937	10.6387
Gross Areas (m^2)	0.0137	0.0150	0.0164
Areas^2 (m^4)	0.0000	0.0000	0.0000
Number of Bathrooms	0.5360	0.0899	0.1149
Dummy Swimming Pool	0.1178	0.1427	0.1762
Terrace Areas	0.0018	0.0020	0.0022
Dummy Elevator	0.1041	0.1291	0.1362
Dummy Quality Kitchen	0.0435	0.0548	0.1362
Dummy Air Conditioner	0.0492	0.0580	0.0631
Dummy Heating	0.0817	0.0918	0.0968
Dummy High Quality Properties	0.0509	0.0633	0.0906
EPC_A	0.0777	0.1543	0.1852
EPC_B	-0.0018	0.0395	0.0842
EPC_C	0.0485	0.0961	0.1383
EPC_D	0.0535	0.0717	0.0981
EPC_E	0.0219	0.0243	0.0266
EPC_F	0.0223	0.0410	0.0523
Dummy Access to Highway	-0.0608	0.0238	0.0863
Dummy Access to Railway	0.0101	0.0168	0.0863
Distance to CBD	-0.0333	-0.0171	-0.0073
Dummy Access to Sea	0.1201	0.1684	0.2569
Proportion of Noise Annoyance opinion	0.0009	0.0019	0.0027
Percentage of People with University Studies	0.0122	0.0138	0.0163

ANOVA	*Sum of squares*	*Df*	*Mean square*		
OLS residuals	268.1	23		N nearest neighbours	2256
GWR improvement	43.6	95.25	0.4582	Num. locations to fit	4436
GWR residuals	224.4	4317.75	0.052		

F	*Sig*
8.8164	0.0000

Notes: *Significant at 1%; **Significant at 0.5%; *** Significant at 0.1%; n/s not significant; Dependent variable: Ln gross price; GWR Adaptive kernel cross-validated.
Source: Own elaboration

Compared with the coefficient of OLS, coefficients of built areas and the proportion of high education, as well as the proportion of noise annoyance remain almost steady, while most variables present a slightly increasing impact, such as within 200 m. of the coast, the presence of a swimming pool and elevator.

There are two significant energy-efficient attributes (Class C and Class D) in the Monte Carlo test, in which these two attributes show the expected uneven spatial impacts on housing prices. Separately, the coefficient of Class C increases slightly to 9.6%, but D decreases to 7.71% in listed property prices compared to the reference group (Class G), which corresponds more to the expectations than the previous results from the OLS model (8% and 8.1% respectively).

This spatial variation in the remaining variables is not significant due to a reasonably high probability that the variation occurred by chance. This is useful information because now, in terms of mapping the local estimates, these variables exhibit significant spatial non-stationarity. These results suggest a non-stationary impact of the energy label.

9.3.3 Capitalization Effect of Energy Efficiency Rating

Before showing a series of visualizations of spatial energy data with socio-economic variables, a Pearson correlation is produced to detect the inner relationship between Class C and Class D and other variables. These two energy labels have a more significant impact on areas where low-income citizens live (more blue-collar workers with a lower price per square meters dwellings). In other words, they have a negative impact on areas inhabited by residents with higher income or elite professions. This means that energy penalties from a lower EPC rating in deprived areas are more prominent, which proves that EPCs do not affect the real estate market equally across urban areas, resulting in building energy-efficient segmentation. What is more, the more significant the differentiation of energy-efficient segmentation, the more likely it is that contradictions of social-class and energy dilemmas are produced.

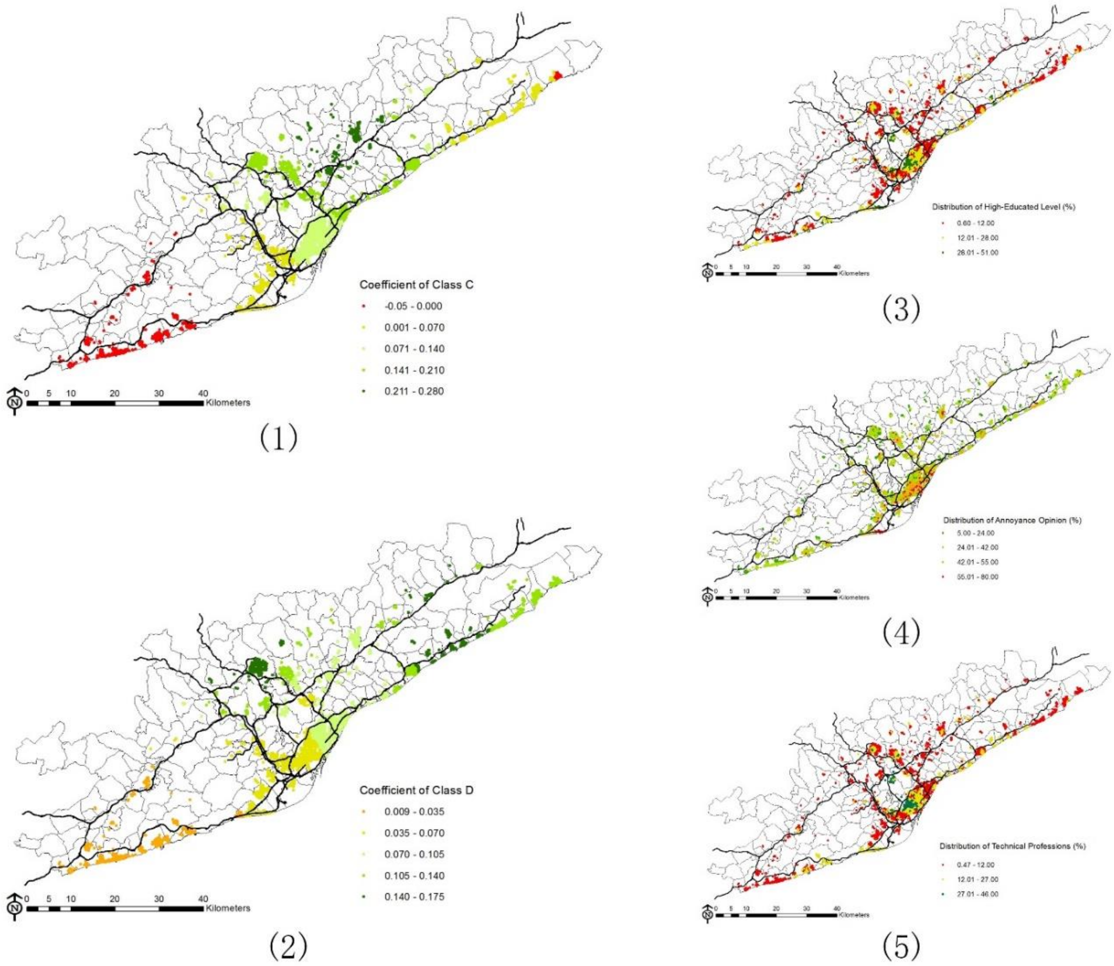


Figure 9. 2 Spatial distribution of energy label and other variables
(1): Class C; (2): Class D; (3): the proportion of university studies; (4): the proportion of noise annoyance; (5): the proportion of technical professions
Source: Own elaboration

As shown in Fig. 9.2–(1) and 9.1–(2), spatial energy distributions (Class C and Class D) influence housing prices for all observations. As stated above, Class C and Class D passed the Monte Carlo Test, demonstrating in this general sample that impacts from these two levels on housing prices are unsteady and cause a submarket of energy-efficient flats. From the left two figures, it is easy to see that energy labels Class C and D present a conglomeration in similar districts and zones: i) the middle part of BMA shows housing price sensitivity to energy label impacts, especially in Mollet del Valles and Granollers for Class C and Terrassa for Class D; ii) observations with inert or even negative impacts of energy label on housing prices located in the south-western part of BMA; iii) for north-eastern BMA, its sensitivity to energy labels is inversely related to Class C and Class D, where a negative impact for Class C and a significant influence for Class D are shown.

In order to explore the intrinsic relationship between the distribution of energy efficiency impacts and other corresponding social or architectural features, a visualization of the relevant spatial distribution of following attributes will be produced that will reveal some evidence about the inner association. As for the social-class attributes, the neighbourhoods with a higher proportion of university-educated households (similarity to the variable – PC households income) are mostly located around the centre of Barcelona city (San Cugat del Valles and Sabadell) where energy label impacts on residential value are also significant (Fig. 9.2–3). This is due to their extraordinary economic and employment circumstances, which attract more residents with high-level education. The more that highly educated, high-income families move in, the more chance there is that they can accept and afford premium property prices. This is also similar to the "Technical professions" attribute (Fig. 9.2–5). However, it is clear that the conglomeration of energy label effects on housing prices is more distinct and their borders transition more smoothly, compared with the distribution of university-educated groups and technical professionals in these districts and sectors. It is supposed that more factors contribute to the effects of energy label in addition to the socio-economic attributes above. It is worth noting that in the centre of Barcelona city, where citizens suffer from massive noise pollution (Fig. 9.2–4), the energy premium is higher than in the surrounding areas. Prompt installation of double-glazed windows probably increases the level of energy labels in which facilities materials are of importance to estimate its energy performance ranking (Florio & Teissier, 2015; Ramos, et al., 2016), in order to enjoy life conveniences (e.g. commercial activities, transport, etc.). In other words, there is a higher demand for energy efficiency measurements in noise-contaminated areas, further illustrating the greater sensitivity to high-level energy labels. In general, the energy-label attribute does, to some extent, have a non-stationary impact of energy premium across urban areas; furthermore, there are certain inner and implicit relationships between energy label and socio-economic attributes. Therefore, which attributes play a decisive role in the spatial aggregation of energy implicit housing prices and how to judge and quantify them is a task for future research.

9.4 conclusion

Plenty of studies based on the Hedonic Pricing method and model have confirmed that energy labels have an impact on housing prices. However, the effectiveness of this mandatory certificates program is still unknown due to the different variables chosen and real estate market conditions (Bio Intelligence Service et al., 2013; Bottero & Bravi, 2014). As the second-largest metropolitan area in Spain, Metropolitan Barcelona has achieved a great deal in terms of building energy efficiency, and its dynamic real estate market offers enough information to survey how the EPC program is progressing. Little research has discussed the socio-economic impact of energy efficiency on property prices in Spanish urban areas, despite a 9.9% increase of housing prices for dwellings certificated with high energy ranking in 5 Spanish cities (De Ayala et al., 2016) and a 9.62% increase of listing prices of properties improved from Class G to Class A in Barcelona (Marmolejo, 2016).

In general, the Results from this OLS hedonic price model suggest that mainly structural and quality features play a significant role in housing prices, followed by accessibility, neighbourhood and environment. After all, the majority of the aforementioned attributes relate to the physical features of houses, their location, and their energy efficiency. In Metropolitan Barcelona the certificated energy label A of renovated flats can charge, related to flats with label G, for a 12.2% increase premium or an increasing effect, 1.19% of listing prices, of a one-letter improvement in energy efficiency. This is a higher premium price than that stated in previous studies in Spain (9.62%/0.85%) and we inferred that the number of green properties and the capitalization of energy efficiency, along with the mandatory EPC program progressed and perception of energy label information enhanced, are gradually increasing and strengthening. The results of the Geographically Weighted Regression (GWR) model and Monte Carlo Significance Test indicate that, as expected, energy label Class C and D, in addition to other socioeconomic attributes, show an uneven distribution across urban space. The centre of BMA shows the highest effect of energy label on housing prices, followed by the north-eastern and south-western parts. This corresponds to the distribution of high-level professions (managers, technicians, etc.) and neighbourhoods with highly educated citizens, demonstrating that such socio-economic attributes do matter in the uneven effect of energy label class on property prices. Furthermore, research on the inner social meanings and relations behind energy labels should be conducted in the future to promote the EPC program and relevant energy policies.

PART III

GENERAL CONCLUSION

AND

DISCUSSION

CHAPTER 10

GENERAL CONCLUSION,

NOVELTY

AND

FUTURE RESEARCH

CHAPTER 10 CONCLUSIONS

10.1 Concluding Summary

Under the crisis of energy depletion, how to reduce energy consumption and improve the corresponding energy efficiency has become an increasingly popular topic. According to OECD reported, the energy consumption of the building sector has accounted for 25% of the total consumption around the world. In fact, only a relatively small part of energy consumption occurs during housing construction while the considerable energy is consumed mainly for residents' daily life (e.g. the utilization of water, electricity and gas). Therefore, how to reduce such energy consumption in domestic activities and improve the energy efficiency are the most imminent matter.

With the establishment of EPBD and the formulation of related laws and regulations, considerable energy-saving projects and plans have appeared into the public views and aroused heating discussions regarding the procedures and achievement of energy efficiency. Thereinto, energy performance certificate (EPC), a comprehensive concept of energy performance in a house, has become a mandatory exhibition in the advertisement when houses are sold or rented. This indicator of energy efficiency has impacted not only on the housing market but also brought new thinkings regarding the formulation of energy policies as well as the sustainable development of cities.

In practice, the researches in relation to the impacts of EPC on housing price have been going on for many years. A large number of studies have shown that EPC indeed has a positive impact on housing prices. However, most of them mainly focused on such energy efficiency performance in UK, Ireland or Nordic countries. From another aspect, it could be said that the spread of the residential energy efficiency in these countries has made the great achievement to some extent because only numerous practical cases in relation to energy label registration or energy efficiency improvement can provide sufficient and massive research data to analyze.

In contrast, few studies pay more attention to such energy efficiency performance in southern European countries. Several reasons leading to such situation are supposed: 1) the beginning time of EPC promotion in southern Europe is later than in the North and West; 2) in the preparation stage, there is lack and insufficient explanation for the meaning of EPC to the public (Marmolejo-Duarte et al., 2019, 2020) ; 3) supplementary regulations and policies in relation to energy efficiency improvement maybe fails due to an unclear understanding of the local condition from policy-makers. According to the definition of EPC, its delimitation for each rating are based on the climatic zone. That is to say, the predominant conclusion[43] in relation to the energy efficiency impacts on housing price may fail due to the differences of EPC standard when analyzing such impact in the area with a Mediterranean climate.

Therefore, this work aims to detect the green premium of housing price in the Barcelona Metropolitan Area (i.e. Mediterranean climate). Theoretically, housing price is affected by a huge number of factors including the properties of the house itself, the accessibility and other socio-economic indicators. The spatial implication is an all-pervading presence. In the process of research, four empirical studies as the main body of this dissertation are proposed to fulfil four specific objectives.

(1) To explore the possibility of selection biases when detecting the “green premium” in Barcelona residential market
(2) To explore the EPC impacts on housing price in different residential segmentation are uneven

[43] mainly concluded by the studies in Northern and Western Europe

(3) To explore the presence of spatial dependence when analyzing the impact of EPC on housing price

(4) To explore the presence of spatial heterogeneity when analyzing the impact of EPC on housing price

In order to fulfil these objectives, a series of mathematical model and spatial models are employed to solve the specific problems. In 1974, Rosen proposed firstly the Hedonic Price Theory which demonstrated that the sum of implicit prices for each attribute is equal to consumer's WTP under an equilibrium market. He implied that a commodity's price could be regressed on its bundle of attributes. With several decades years' efforts by numerous reseachers, HPM has become the most fundamental model when analyzing the composition of housing price. In our case, it is necessary to check the selection biases so that we employ Heckman two-step model which was made by Heckman (1976). He initially integrated the probit model and HPM together to avoid the sample selection bias by creating a tool variable-IMR that could help to identify how the value of unobserved cases impact on the dependent variable. After a series of HPMs employed to identify submarket, three spatial models are analyzed to figure out the spatial dependence and heterogeneity problems, in which SLM and SEM are mainly to solve the former problem while the GWR model for the latter one. Generally, the issue of spatial dependence always happens with its heterogeneity so that a comprehensive model flow, at least consists of these previous three spatial models. In fact, spatial models could be regarded as the spatial performance of HPM after introducing the spatial matrix and spatial relationship. In the sense, this thesis proposes a comprehensive model flow from statistical to spatial perspectives.

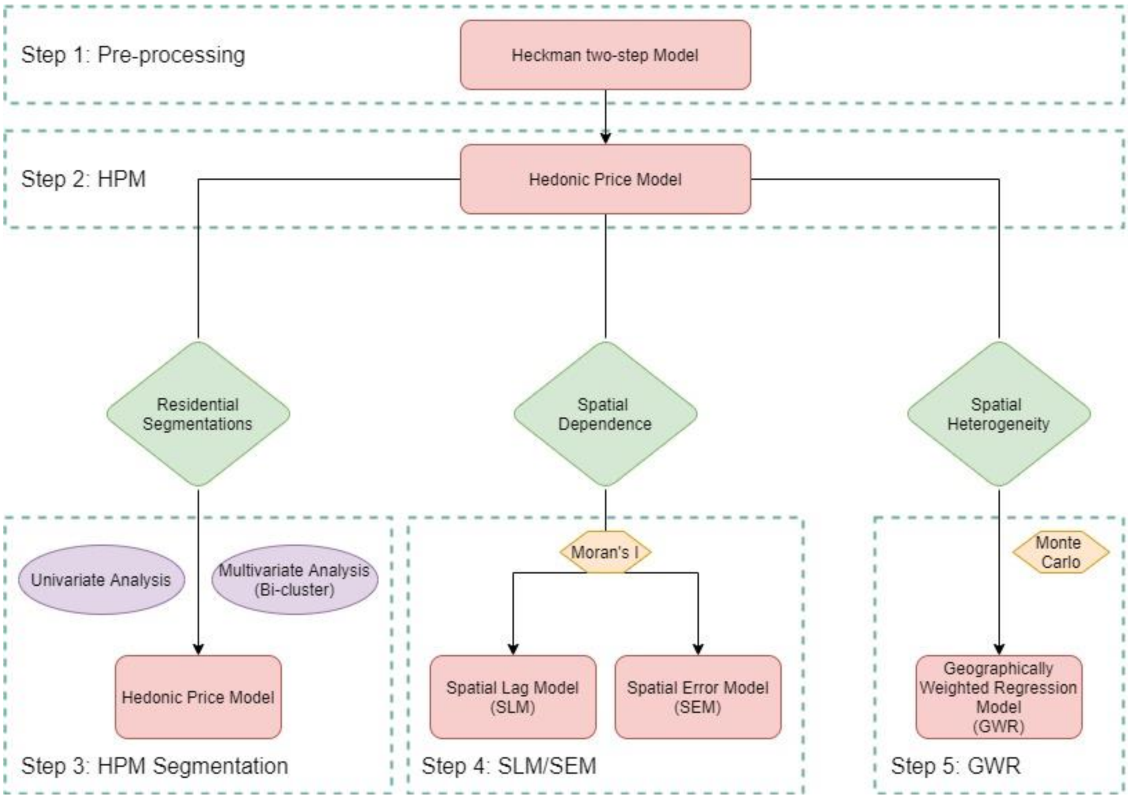


Figure 10. 1 The integrated model flow
Source: Own elaboration

After an introduction to the thesis's research context, Chapter 2 described the current situation of energy efficiency around the world, EU and Spain. Chapter 3 and 4 have combed the basis theoretical basis in relation to our target object: housing price and its possible spatial implications, which support the following empirical studies for these four specific objectives. In consideration of the consistent topic, Chapter 5 depicted the case study – Barcelona Metropolitan Area and a general introduction of the data used. Furthermore, Chapter 5 also presented the literature review consistent with specific objectives.

In the following sections, main concluding and findings are summarized and then a general discussion about the novelty of this work as well as the future studies based on the conclusion of this work.

10.1.1 To explore the possibility of selection biases when detecting the “green premium” in Barcelona residential market

Before exploring whether the EPC impacts on housing price in BMA, a test of the selection bias should be made. In addition to the green homes, non-certificated ones also have an impact on housing price. It may bias the final estimation result if exclusively studying with the dataset that consisted of certificated dwellings. Numerous studies in Section 5.3.2 have verified the necessary to explore the presence of selection biases.

Therefore, the first objective of this dissertation is to explore the possibility of selection biases when detecting the “green premium” in Barcelona residential market.

In order to address this problem, Chapter 6 has employed Heckman two-step model to detect the presence of selection biases and the results finally support our supposition that it is indeed necessary to check the possibility of selection biases. At the meanwhile, a statistical variable “IMR” as the production of the Heckman two-step model could correct such bias.

There are two main conclusions for this study. Firstly, the selection bias indeed happens in the study of energy efficiency on housing price across BMA and furthermore, this bias low the energy efficiency performance on housing price. After correcting this selection bias, the green premium reached a rational price level (i.e. 12% increase from G-rating to A-rating or 2% growth per rating improved) although it is still in a price gap comparing with such premium in other Western and Northern European countries. Secondly, apartments in the Barcelona city, Sant Cugat del Valles and the zone surrounding Sitges are more sensitive to selection bias regarding the energy efficiency price study. In comparison with other variables’ distribution across urban space, we found those areas affected largely by selection bias often charge a high housing price and more university-educated people are willing to live there. That is to say, the housing price in a “rich/wealthy” zone are affected largely by those characteristics belonging to non-certificated apartments. Furthermore, also implied that it is possible that the presence of residential submarkets which are formed by housing price performance.

The introduction, theories and literature review have stated in Chapter 2, 3 and 5 while the empirical results and discussions are presented in Chapter 6.

10.1.2 To explore the EPC impacts on housing price in different residential segmentation are uneven

As concluded in Chapter 6, it is doubtful that residential market of Barcelona maybe have been separated into various segmentations in which energy premium may show the different monetary performance.

Therefore, Chapter 7 aims to 1) detect the presence of segmentations in Barcelona residential market by the definition of univariate variable and multivariate variables and further 2) estimate the energy premium in various segmentations based on their particular characteristics. To fulfil these objectives, a simple univariate analysis and a two-step cluster analysis are employed where the former is separated by three Metropolitan areas (i.e. three segmentations) and the latter is based on variables found correlated with prices but EPC rating. Then, three segmentations in terms of the univariate and multivariate analysis are respectively produced with specific characteristics. Finally, six specific HPMs are made for segmentations.

There are several highlights for the conclusions:

Univariate analysis

1) the proportion of homes with energy information in their advertisements is much higher than in Valencia and especially than in Barcelona; 2) contrary to all logic –and what happens in Barcelona and to a lesser extent in Valencia-, the most recent dwellings (post-CTE period) are rated worse than the oldest; 3) The worst-rated homes have better benefits in the rest of their architectural attributes, unlike what happens in Barcelona where a worse energy rating

corresponds to a worse quality of the home in general. This means that, despite the significant number of control variables used in the econometric models, the hedonic price of Alicante's energy rating is reversed. That is, a worse rating corresponds to a higher price, ceteris paribus. In addition, the Valencia MA, unlike Barcelona, the distribution of the energy class of the real estate advertisements does not coincide with that from official records. If this distortion were to respond to anomalies in the advertising of incorrect ratings, we would be witnessing a complete trivialization of energy policy as it has been designed within the European Commission.

Multivariate Analysis

1) when making buying-decision, people prefer those direct characteristics for a better living condition (e.g. equipped with air conditioning) instead of a general and comprehensive indicator (e.g. EPC rating). According to the estimation results in Section 7.3.1, we found that the housing premium increases 7.7% with an energy efficiency improvement from G-rating to A-rating while the same apartment equipped with air conditioning can charge for a 9.5% increase price. 2) there are three real estate segmentations across Barcelona urban space and they have very impressive and distinguished characteristics performances. Regarding the "newest" cluster, the average rating EPC is highest among the three segmentations but energy efficiency did not play a significant role in the formation of housing price. It is supposed that ***the strict control of structural quality may cause the inefficiency of green premium***[44]. However, maximum energy premium from G-rating to A-rating appears in the cheapest and worst quality housing segment, reaching to 33.2% growth while in the most expensive and best-location cluster, there is only 12% housing premium for an energy efficiency reform. It is concluded that ***high rating of EPC has been regarded as a proxy of the apartment's quality***

[44] More details about this issue are discussed in Section 10.3

in a "poor" area. 3) In consideration of the misunderstanding regarding EPC rating in the "poor" area, more relative policies should be reconsidered. Although most of the energy-efficiency policies were formulated with good original intentions (e.g. help the poor enjoy the benefits from residential energy efficiency), they still fail to fulfil their destinations since the actual local situation was not fully considered or the preparatory work (e.g. EPC transparency to the public) was not perfectly assimilated in the implementation process. This implies that not only a strict control of the residential quality attributes but also a poor control of that may be inflating the relevance of the EPC rating effect.

The introduction, theories and literature review have stated in Chapter 2, 3 and 5 while the empirical results and discussions are presented in Chapter 7. The detalled policy implications will be discussed in the Section 10.3

10.1.3 To explore the presence of spatial dependence when analyzing the impact of EPC on housing price

As stated in Chapter 3, "location" is the most important impact on housing price while the spatial implications derived from such locations should be paid more attention to. In statistical analysis, spatial implication consists of two main part: spatial dependence issue and spatial heterogeneity issue that we have discussed in Chapter 4. To identify spatial implications in details, we firstly try to explore the impact of spatial dependence. Considering a new dataset was collected in 2016, this study aims to see the evolution of EPC's impact on housing price during 2014 and 2016 applied by a comprehensive model integrated with pooled hedonic model and spatial error model. Dissimilar to the method for segmentation in Chapter 7, four groups in two year-period (2014 vs 2016) are established according to the significance of energy efficiency impact on housing price and moreover, their specific characteristic performance in each group are described.

There are three main conclusions in the part. 1) It firstly confirmed that spatial dependence indeed exists and has biased energy efficiency price across urban space. After correcting such bias, we found the energy efficiency, in particular medium-high[45] energy efficiency, have a more significant impact on housing price from 2014 to 2016. 2) More apartments' prices are affected by their energy efficiency label from 2014 to 2016. Concerning the difference of apartments' characteristic, those labelled apartments with better structural quality are affected largely by EPC rating, compared with those green homes without impacts on housing price. Moreover, "sensitive" apartments more likely located in the zone with lower population density and employment but in 2014 far away from the centre while 2016 closer to the CBD. 3) Along with the popularity of energy efficiency project, we found the disparity in different professions which is also regarded as the proxy of social stratification and income gap, has begun to play a role in the energy premium. That is to say, at the beginning of the EPC implementation, the formation of energy premium occurred more randomly. However, the trend of energy premium, after three years of EPC implementation, concentrated increasingly in the "rich/wealthy" area. It is consistent with the conclusion in Chapter 7. Thus, how to figure out this unexpected result is a quite important issue for researchers and policy-makers.

The introduction, theories and literature review have stated in Chapter 2, 4 and 5 while the empirical results and discussions are presented in Chapter 8. The detalled policy implications will be discussed in the Section 10.3.

10.1.4 To explore the presence of spatial heterogeneity when analyzing the impact of EPC on housing price

In order to fulfil this objective, the geographically weighted regression model is applied to detect the presence of spatial heterogeneity, i.e. the spatial non-stationary. As stated in Chapter

[45] Including rating A, B, C, D

4, GWR is the most commonly used method to identify spatial heterogeneity, thereinto, the production of GWR – Monte Carlo test for spatial variability could reveal the differences between a global aspect vs local aspect in relation to “green premium” performance across urban space.

This work has highlighted that spatial heterogeneity is a common spatial bias when analyzing housing price across urban space. As expected, the energy premium in Barcelona shows a non-stationary impact. Instead of the stationary performance of rating-A and E in the OLS estimation result, rating-C and D show spatial variability exhibiting that if improving from rating-G to C, the apartment’s housing price will have an increase from 6% in the southeastern of Barcelona city (i.e. Hospitalet de Llobregat) to 27% surrounding Granollers and Mollet de Valles. Similarly, the impact of rating-D has the same trend as rating C shown. Energy premium of rating-D also has the lowest increase (about 4.6%) in the southeastern of Barcelona city while reaching up to more than 16% surrounding Terrassa and Arenys de Mar.

There are two main conclusions. 1) From a global perspective, different rating of energy efficiency has significant external effects on housing prices. In addition, the traditional hedonic price and GWR models exhibit the specific capitalization effect of energy efficiency ratings. All the ratings except rating-B and rating F show significant impacts on housing price. It indicates that the EPC scheme has made great achievement and its effectiveness has been transformed into capitalization. However, the few apartments certificated with rating-B and the fake shown information of rating-F cause the significance of their energy premium is out of effectiveness; 2) From a local perspective, the capitalization effects of energy efficiency reveal obvious spatial heterogeneity. The GWR results confirm that the spatial distribution of energy premium is non-stationary and shows certain regularity. That is to say the premium of rating-C and D increase from southeastern Barcelona city to the northwestern BMA. Although it shows different feedbacks in different areas, it also demonstrates the existence of spatial heterogeneity in relation to energy premium in the AM; 3) The detailed segmentation for each rating's performance of energy premium provide references to owners and buyers. For example, the best improvement from rating G to rating C is the apartment located in Granollers while from G to D is in Terrassa since they have the highest benefit in the specific area.

The introduction, theories and literature review have stated in Chapter 2, 4 and 5 while the empirical results and discussions are presented in Chapter 9. The detalled policy implications will be discussed in the Section 10.3.

10.2 Innovation

This dissertation is framed by the project "EnerVALUE" which aims to solve the energy efficiency performance in the residential market. Although this thesis is just a part of the comprehensive project, several novelties or innovations has been figured out as Figure 10.1 shown.

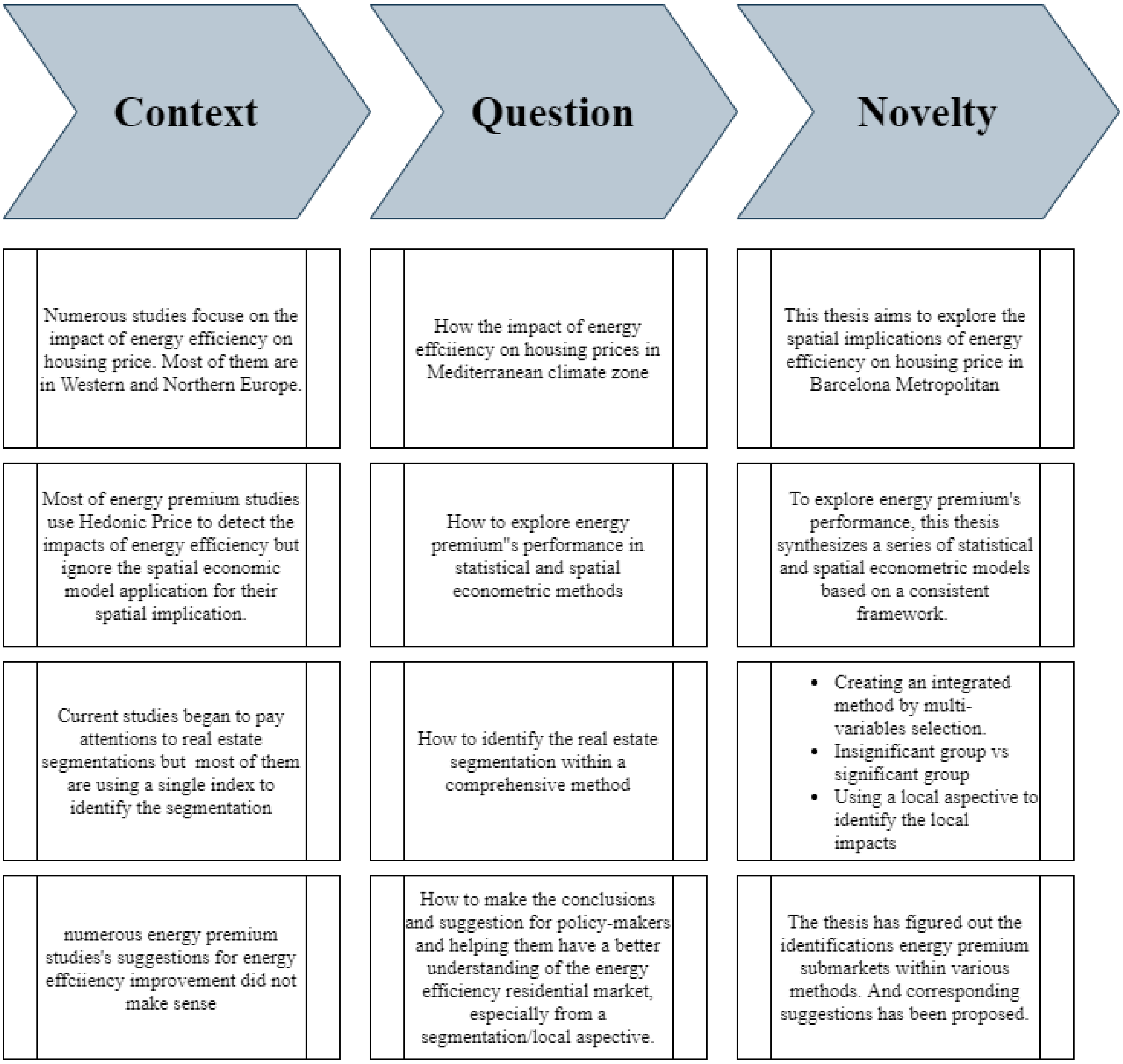


Figure 10. 2 Thesis's novelty
Source: Own elaboration

Novelty 1: It is a study of energy premium in a Mediterranean climate zone.

According to the research background in Chapter 2 and the literature review in Chapter 5, energy efficiency premium has become a hot topic in the past 15 years. However, most of these studies usually focus on Western and Northern Europe. In consideration to the difference of EPC standard in various climate zones and specific EPC transformed frameworks in each country, it is necessary to pay more attention to countries or zones with the Mediterranean climate in relation to the energy premium studies. Thus, this thesis tries to apply such study in the Barcelona Metropolitan Area which is a considerable famous and typical Mediterranean climatic zone.

This is a relatively new research in this field, which can help people better understand the performance of EPC around the world, especially in areas with relatively mild climates.

Novelty 2: It synthesizes a comprehensive method to identify the energy premium

According to the theoretical basis of housing value and spatial econometric stated in Chapter 3-5, considerable models are employed to analyze the energy premium in the residential market but most of them merely studied this topic in a single perspective. For example, hedonic price model, the commonly used in energy premium studies, are always integrated with Spatial Error Model (SEM) or Spatial Lag Model (SLM) to figure out the spatial dependence bias. Nevertheless, the spatial dependence issue always goes with spatial heterogeneity. That is to say, merely analyzing spatial dependence or spatial heterogeneity bias is not compatible.

Therefore, this dissertation proposed a relatively comprehensive method, which includes Heckman two-step model for sample selection bias, the hedonic price model for energy premium performance, the SEM/SLM for spatial dependence correction, the bi-cluster analysis for clusters' identification as well as GWR for spatial heterogeneity amendment.

Novelty 3: It introduces several methods to identify the segmentation of energy premium

As can be seen in the literature review of Chapter 5, most of the current studies identify segmentation/submarket within a single-variable. For example, a residential market could be divided into several submarkets (i.e. apartment, duplexed house, etc.) by architecture typology, However, it is well known that real estate market is a quite complex system which is affected by numerous indicators. Thus, merely identifying groups with a single variable cannot represent the real residential segmentations.

Therefore, this dissertation has proposed three methods to identify the segmentation according to specific objectives. The first and most applied method for other residential markets is to use a series of variables which are sensitive to housing price, e.g. the architectural quality, accessibility and socio-economic indicators. And then, a bi-cluster analysis is applied for the real segmentations. The second and third method derived from the estimation results of the spatial econometric model where observations are grouped by their specific significance in spatial performance.

In sum, this dissertation tried to solve the problem of segmentation's identifications but it is impossible to develop a perfectly common method/variable's selection system since the current situation for each real estate market varies. The multi-variable segmentation method proposed by this dissertation is still worthy of consideration.

Novelty 4: This work tried to discuss and evaluate the effectiveness of energy efficiency policies

According to the results of segmentation in Chapter 7-9, we have found the obvious difference characteristics among Barcelona's residential segmentations. At the same time, we have discussed the effectiveness of the EPC program based on energy efficiency performance with monetary form. Details about the suggestions for energy efficiency has been discussed in Chapter 6-9 and also concluded in the Section 10.3.

10.3 Policy Implications

In the previous four empirical studies, we have discussed the HPM results and drawn conclusions in accordance with various specific objectives. Considering that the four studies in this thesis are organized logically in line with energy efficiency performance, this section mainly discuss, based on the previous stated achievement, the general implications concerning the political and social aspect.

10.3.1 Residential energy efficiency information promotion and dissemination

According to the presence of the number of EPCs and the performance of EPC on housing price, the development of the EPC program in various metropolitan areas is out of equilibrium. Compared with that in Valencia and Alicante metropolitan areas, Chapter 7 has concluded that Barcelona is the most "green" area belonging to the number of EPC certificates.

This conclusion implies that the progress of energy efficiency performance in the residential sector in different districts or areas is with significant differences based on the same and general energy efficiency framework in Spain. In particular, this great difference, to some extent, also happens in various zones even in the same district. The possible reasons that lead to this disproportionate situation are the following:

- Different situation in the real estate market. Barcelona MA is the most prosperous building energy-efficiency (BEE) market in Spain since it is one of the most developed economies MA where its normal transaction status in the real estate market is the most active. Therefore, a large number of homes began to register actively for EPCs when EPCs exhibition is the obligation for the home transactions.
- Different acceptance by the public and the market. As an international MA, Barcelona always opens its mind about the new things (e.g. BEE). Facing to the publicity of BEE launched by the government or ministries, the first reaction of Barcelona's citizens is to understand and accept it, rather than directly reject it。

This process of differentiation in the EPC program shows that the promotion and development of the BEE are imperfect and there is still much room for improvement. For the local policy-makers, it is important to frame suitable BEE policies and promotion plans after investigating the local real estate market and consumers' preferences. In the initial phase of the EPCs project, consumers were passively attracted to pay attention to residential energy efficiency by the rigid regulations (i.e. mandatory registration and exhibition) or the public announcement. After seven years of execution, policy-makers should encourage consumers to participate in the BEE project actively. To date, the financial policies (e.g. green mortgage and retrofit subsidies) seem effective measures and the total financial expenditure is also large. In fact, the little allowance for each house energy efficiency renovation is still a drop in the bucket due to numerous existing homes.

This thesis confirms the existence of green premium in Spanish real estate market wherein that premium in Barcelona MA is quite significant. In addition to protecting the environment and energy saving, we should highlight that the behaviour of energy-efficient renovation could bring in the "capital gains" when promoting BEE at least in Barcelona. Theoretically speaking, the drive of capital gains can maximize consumers' subjective initiative in the process of BEE renovation.

10.3.2 Asymetric and false EPC informatoion

Concerning the huge difference between the registration and advertising information of EPC, it could regard as, to some extent, a failure for energy efficiency performance program. Theoretically, EPC's registration happens before advertising so that there is no necessary to offer or adverse fake information. The alleged above anomalies are not a novelty in Spain. Since the very dawn of RD 235/2013, news has appeared in the press about problems in: a) the qualification of some certifiers, b) the lack of rigor in carrying out certain certifications and c) the picaresque in the advertising of the energy class. Indeed, between the date of approval of the aforementioned Royal Decree and its entry into force, scarcely six weeks passed, which led to an avalanche of certifications.

Faced with these problems, both the competent administration and the courts have responded with administrative sanctions and sentences respectively. For example, in Murcia of the 26 inspections carried out, one year after the RD came into force, in buildings and tertiary premises, 90% were erroneous. Thus, in communities like Madrid, the first sanctioning files did not take long to appear, revealing discrepancies between the data used in the certification and the reality (Viúdez, 2013) and the first sanction to a certifier of 4,000 thousand euros arrived, in that same community , in December 2013 (Bueno, 2013). Navarra was one of the first Autonomous Communities to sanction real estate agencies that advertised their properties without including the energy class; while Catalonia made a campaign to remind them of this obligation (Bueno, 2014). Against this background, it is not difficult to assume that in certain markets there are misrepresentations that obscure the alleged energy transparency of the community real estate market.

Generally, policy-makers should enact stricter regulations and laws in the full process of the EPC program where a clear statement about the punishment and reward mechanism should be clarified. For those fake advertising information, it is essential to regulate stakeholders' rights and obligations fundamentally. It involves homeowner, real estate agencies and relevant governmental ministries: owners should be responsible to register and submit the energy efficiency certificate; real estate agencies verify and confirm the accuracy of the certificate information by checking with the EPC registration office and regularly submit all selling and sold homes summary to the office; the relevant ministries should collect regularly and return to visit real estate agencies.

10.3.3 "Green Premium" vs "Brown Discount"

As previous stated, it has discussed the green premium of housing price in Barcelona which could inspire homeowners to improve their buildings' energy efficiency. Unfortunately, inefficient homes that has not been renovated for a better energy efficiency performance, from a social perspective, have to bear a larger "brown discount". That is to say, such population living in inefficient homes are at risk of fuel poverty, and at the same time, for cognitive and financial reasons (aggravated by the energy efficiency “brow discount”) have little opportunity to perform a retrofit in their dwellings. Therefore, a well-intentioned environmental policy might have unexpected pernicious effects from a social perspective, if relevant corrective measures are not introduced (e.g., retrofit subsidies).

In practice, just living with the adequate warmth, cooling, lighting and the energy to power appliances to guarantee a decent standard of living and citizens’ health is still a dilemma. In European Union, it is estimated that more than 50 million households are exposed to this “energy poverty” which results from a combination of high energy expenditure, low household income inefficient buildings and appliances, and specific household energy needs.

Fortunately, in Spain legislative initiatives crystallized in Law 8/2013 of Urban Rehabilitation, Regeneration and Renewal (now recast in the main corpus of land legislation), which, together with the autonomous legislation in matters of urban planning and housing, provide the necessary instruments to carry out actions in the most degraded areas. An example of this is the area of conservation and retrofitting of the “Carrer Pirineus” located in the working-class municipality of Santa Coloma de Gramenet (province of Barcelona), where, based on the aforementioned legislation, a rehabilitation of the private residential stock with energetic implications has been developed using municipal treasury as a “local bank” (Barón Rodríguez, 2017). These actions, however, require the political will, technical capacity, and a multidisciplinary approach.

In fact, the green premium will not always exist. Hen the number of efficient homes in the market reach a certain capacity, the benefits resulted from energy-efficient improvement will become smaller until it disappears. With the extreme tearing of green premium and brown discount, many social and unexpected problems emerge. The most serious is social segmentation: the tenants are kicked out by a higher rent due to the “green premium” in an area and then they find a “brown discount” place that they are affordable to pay. Finally, the high-income households will live in the area with high-efficient homes while the poor group in an inefficient place. From a social perspective, it is an antagonism between the rich and the poor (i.e. social differentiation) and furtherly social conflicts and turbulence may happen. In such case, the policies related to social welfare, education and employment also should be comprehensively considered, in addition to building energy efficiency policies.

In general, it is, for policy-makers, still urgent to 1) comprehensively popularize the concept of energy efficiency; 2) enhance citizens’ cognition and awareness by investigating their preferences and thinkings, and gain the public understanding and support; 3) encourage the general public to subjectively improve residential energy efficiency; 4) cooperating with relevant compulsory measures and incentive policies to make a productive achievement.

10.4 Limitations and Future Perspectives

Although this dissertation has tried to solve the general objective – the spatial implication of energy premium in the Barcelona Metropolitan Area, there are several limitations to this current work. In this section, four main limitations are discussed and corresponding highlights for the future research are also mentioned

(1) Limitation to the variables for the housing price model

As is well-known, the real estate market is a synthetical and diverse research object. It is affected by considerable indicators, for example, building’s quality, neighbourhood’s comfortability, etc. Therefore, how to introduce the suitable variables into the housing price model is particularly practical real estate markets within the various state of the market, is still pending.

Dissimilar to referenced studies’ variables choices (e.g. less than 10 variables), considerable variables concerning architectural quality, accessibility and socio-economy is controlled in this dissertation. It helps to have a better understanding of the real estate market in details but the necessity of a strict control of those variables arouse our thinking. Actually, we have proposed in Chapter 7 that an over control of architectural quality may bias the energy premium until total fail. Thus, the first future research has appeared: ***whether an in-depth control of architectural quality maintains the energy premium's performance equal.***

Along with the difussion of the EPC scheme, more and more data could be collected, including time-series information. Since the observations in the real estate market are various in every collected period, the methods and models concerning panel data are not suitable for our case. As discussed in Chapter 8, a pooled hedonic price model could be used for two years dataset. In addition, ***the exploration of other methods aimed at avoiding the biases introduced from time-series*** may also be our next research direction.

(2) Limitation to the selection of spatial econometric model

As stated in Figure 4.9, we have discussed the procedure to select the spatial econometric model but a condition that if spatial lag and spatial error have significantly and equivalent impacts on energy premium, how to select the suitable spatial model to calculate and analyze. In such case, we should discuss furtherly the other spatial model (e.g. Dubin model). This is the third future research: ***how to develop the spatial model when considering within a more comprehensive and complex situation.***

(3) Limitations to the application of the comprehensive model in a Mediterranean climatic zone.

In this dissertation, we just merely introduced a comprehensive model to analyze the spatial implications of energy premium in the Barcelona Metropolitan Area. In order to test the model's fitness for other countries or zones within the Mediterranean climate, a future research should be paid attention to this application.

Actually, we have published a paper collaborated with a research group in Turin, Italy to discuss the spatial implication of energy premium between Barcelona and Turin (Dell'Anna, et al., 2019). Next, ***how to apply the two databases framed with the same climatic zone into the comprehensive model synthesized by this dissertation*** is our future research.

(4) Limitation to the discussion of energy efficiency policies

This work simply employs a cluster analysis and ANOVA to identify submarkets. However, the behind drivers to this segregation/segmentation are not discussed, instead of a superficial comparison by the characteristic performance of corresponding variables.

Therefore, the future research direction is to closely ***explore the inner nature of segregations and what happened when implementing target energy efficiency policies to the rich and the poor groups.***

PUBLICATIONS LIST

I. Chen, A., & Marmolejo Duarte, C. R. (2018). The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases. In *Libro de proceedings, CTV 2018: XII Congreso Internacional Ciudad y Territorio Virtual:"Ciudades y Territorios Inteligentes": UNCuyo, Mendoza, 5-7 septiembre 2018* (pp. 247-262). Centre de Politica de Sol i Valoracions, CPSV/Universitat Politècnica de Catalunya, UPC.

II. Marmolejo-Duarte, C., & Chen, A. (2019). The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments. Implications for Public Policy and Private Markets. *Sustainability*, *11*(2), 372.

III. Marmolejo-Duarte, C., & Chen, A. (2019). The evolution of energy efficiency impact on housing prices: an analysis for Metropolitan Barcelona. *Revista de la Construcción*, *18*(1), 156-166.

IV. Chen, A., & Marmolejo-Duarte, C. (2019, September). How different are dwellings whose energy efficiency impacts price formation?. In *IOP Conference Series: Materials Science and Engineering* (Vol. 603, No. 4, p. 042015). IOP Publishing.

V. Chen, A., & Marmolejo-Duarte, C. (2018). Is the energy price premium spatially aggregated? A listing price analysis of the residential market in Barcelona. *Technical Transactions*, *11*(7), 5-19.

VI. Marmolejo-Duate, C., & Chen, A. (2019). The impact of EPC rankings on the Spanish residential market: an analysis for Barcelona, Valence and Alicante. *Ciudad y Territorio, Estudios Territoriales*, *199*.

VII. Dell'Anna, F., Bravi, M., Marmolejo-Duarte, C., Bottero, M. C., & Chen, A. (2019). EPC green premium in two different european climate zones: a comparative study between Barcelona and Turin. *Sustainability*, *11*(20), 5605.

VIII. Marmolejo-Duarte, C., Spairani, S., del Moral, C., Delgado, L., Egusquiza, A., & Ai, C. (2019, September). How Relevant is Energy Efficiency in The Marketing of Homes? Evidence from Real Estate Agents in Spain. In *IOP Conference Series: Materials Science and Engineering* (Vol. 603, No. 3, p. 032053). IOP Publishing.

IX. Marmolejo-Duarte, C., Moral, C. D., Delgado, L., Spairani Berrio, S., Botton, J. D., Pérez, C., Chen, A. & Gyurkovich, M. (2019). Energy efficiency in the residential market and implications for architecture education in Spain.

X. Marmolejo-Duarte, C., Chen, A., & Bravi, M. (2020). Spatial implications of EPC rankings over residential prices. In *Values and Functions for Future Cities* (pp. 51-71). Springer, Cham.

REFERENCES

Addae-Dapaah, K., & Chieh, S. J. (2011). Green Mark Certification: Does the Market Understand? *Journal of Sustainable Real Estate*, *3*(1), 162–191. doi: 10.5555/jsre.3.1.u6k03v6l60003072

Administration, U. S. F. H., & Hoyt, H. (1939). *The Structure and Growth of Residential Neighborhoods in American Cities*. U.S. Government Printing Office.

Akerlof, G. A. (1970). The Market for "Lemons": Quality Uncertainty and the Market Mechanism. *The Quarterly Journal of Economics*, *84*(3), 488–500. doi: 10.1016/B978-0-12-214850-7.50022-X

Alonso, W. (1964). *Location and land use. Toward a general theory of land rent.* Retrieved from https://www.cabdirect.org/cabdirect/abstract/19641802976

Andrew, M., & Meen, G. (2006). Population structure and location choice: A study of London and South East England*. *Papers in Regional Science*, *85*(3), 401–419. doi: 10.1111/j.1435-5957.2006.00092.x

Anselin, L. (1988). Lagrange Multiplier Test Diagnostics for Spatial Dependence and Spatial Heterogeneity. *Geographical Analysis*, *20*(1), 1–17. doi: 10.1111/j.1538-4632.1988.tb00159.x

Anselin, L. (1995). Local Indicators of Spatial Association—LISA. *Geographical Analysis*, *27*(2), 93–115. doi: 10.1111/j.1538-4632.1995.tb00338.x

Anselin, L. (1999). The future of spatial analysis in the social sciences. *Geographic Information Sciences*, *5*(2), 67–76.

Anselin, L., & Bera, A. (1998). Spatial dependence in linear regression models with an application to spatial econometrics. *Handbook of Applied Economics Statistics, Springer-Verlag, Berlin*, *21*, 74.

Atkinson, S., & Crocker, T. (1992). The Exchangeability of Hedonic Property Price Studies. *Journal of Regional Science*, *32*(2), 169–183. doi: 10.1111/j.1467-9787.1992.tb00177.x

Backhaus, J., Tigchelaar, C., & de Best-Waldhober, M. (2011). Key findings & policy recommendations to improve effectiveness of Energy Performance Certificates & the Energy Performance of Buildings Directive. *The Netherlands: IDEAL EPBD (Improved Dwellings by Enhancing Actions on Labeling for the Energy Performance of Buildings Directive)*.

Bailey, T. C. (1994). A review of statistical spatial analysis in geographical information systems. In *Spatial analysis and GIS* (pp. 13–44). London: Taylor and Francis.

Bailey, T. C., & Gatrell, A. C. (1995). *Interactive spatial data analysis* (Vol. 413). Harlow-New York: Longman: Longman Scientific & Technical Essex.

Ball, M. J. (1973). Recent Empirical Work on the Determinants of Relative House Prices. *Urban Studies*, *10*(2), 213–233. doi: 10.1080/00420987320080311

Balta-Ozkan, N., Watson, T., & Mocca, E. (2015). Spatially uneven development and low carbon transitions: Insights from urban and regional planning. *Energy Policy*, *85*, 500–510. doi: 10.1016/j.enpol.2015.05.013

Banfi, S., Farsi, M., Filippini, M., & Jakob, M. (2008). Willingness to pay for energy-saving measures in residential buildings. *Energy Economics*, *30*(2), 503–516. doi: 10.1016/j.eneco.2006.06.001

Barón Rodríguez, A. (2017). *The Role of Thermal Comfort in The Energy Efficiency Policy: Improving Quality of Life in the Pyrenees Street in Santa Coloma de Gramanet* (Master's Thesis, Universitat Politècnica de Catalunya). Universitat Politècnica de Catalunya, Barcelona, Spain. Retrieved from https://upcommons.upc.edu/handle/2117/111728

Bayer, P., Ferreira, F., & McMillan, R. (2007). A Unified Framework for Measuring Preferences for Schools and Neighborhoods. *Journal of Political Economy*, *115*(4), 588–638. doi: 10.1086/522381

Bell, K. P., & Bockstael, N. E. (2000). Applying the Generalized-Moments Estimation Approach to Spatial Problems Involving Micro-Level Data. *The Review of Economics and Statistics*, *82*(1), 72–82. doi: 10.1162/003465300558641

Ben-Akiva, M., & Lerman, S. R. (1977). Disaggregate travel demand and mobility choice models and measures of accessibility. *Third International Conference on Behavioral Demand Modeling, Australia*.

Benjamin, J., Chinloy, P., & Hardin, W. (2007). Institutional - Grade Properties: Performance and Ownership. *Journal of Real Estate Research*, *29*(3), 219–240. doi: 10.5555/rees.29.3.30018x8567405445

Benjamin, J. D., Chinloy, P., & Hardin, W. G. (2006). Local Presence, Scale and Vertical Integration: Brands as Signals. *The Journal of Real Estate Finance and Economics*, *33*(4), 389–403. doi: 10.1007/s11146-006-0339-y

Bergström, L., & van Ham, M. (2010). *Understanding Neighbourhood Effects: Selection Bias and Residential Mobility* (SSRN Scholarly Paper No. ID 1682714). Rochester, NY: Social Science Research Network. Retrieved from Social Science Research Network website: https://papers.ssrn.com/abstract=1682714

Betz, T., Cook, S. J., & Hollenbach, F. M. (2017). *Spatial Interdependence and Instrumental Variable Models*. doi: 10.31235/osf.io/pgrcu

Bhatti, M., & Church, A. (2004). Home, the culture of nature and meanings of gardens in late modernity. *Housing Studies*, *19*(1), 37–51. doi: 10.1080/0267303042000152168

Bian, X., & Fabra, N. (2020). Incentives for information provision: Energy efficiency in the Spanish rental market. *Energy Economics*, *90*, 104813. doi: 10.1016/j.eneco.2020.104813

Bio Intelligence Service, Lyons, R., & IEEP. (2013). *Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries* (p. 158) [Final Report]. Paris, France: European Commission (DG Energy). Retrieved from European Commission (DG Energy) website: https://ec.europa.eu/energy/sites/ener/files/documents/20130619-energy_performance_certificates_in_buildings.pdf

Bisello, A., Antoniucci, V., & Marella, G. (2020). Measuring the price premium of energy efficiency: A two-step analysis in the Italian housing market. *Energy and Buildings*, *208*, 109670. doi: 10.1016/j.enbuild.2019.109670

Black, J., & Conroy, M. (1977). Accessibility Measures and the Social Evaluation of Urban Structure. *Environment and Planning A: Economy and Space*, *9*(9), 1013–1031. doi: 10.1068/a091013

Bottero, M., & Bravi, M. (2014). Valutaziones dei benefici conessi al riasparmio energetico degli edifice: Un approccio econométrico. *GEAM. GEOINGEGNERIA AMBIENTALE E MINERARIA*, *3*, 15–24.

Bottero, M., Bravi, M., Dell'Anna, F., & Mondini, G. (2018). Valutazione dell'efficienza energetica degli edifici con il metodo dei prezzi edonici: Gli effetti spaziali sono rilevanti. *Valori e Valutazioni*, *21*, 27–39.

Bowes, D. R., & Ihlanfeldt, K. R. (2001). Identifying the Impacts of Rail Transit Stations on Residential Property Values. *Journal of Urban Economics*, *50*(1), 1–25. doi: 10.1006/juec.2001.2214

Brasington, D. M., & Hite, D. (2005). Demand for environmental quality: A spatial hedonic analysis. *Regional Science and Urban Economics*, *35*(1), 57–82. doi: 10.1016/j.regsciurbeco.2003.09.001

Brounen, D., & Kok, N. (2011). On the economics of energy labels in the housing market. *Journal of Environmental Economics and Management*, *62*(2), 166–179. doi: https://doi.org/10.1016/j.jeem.2010.11.006

Brown, L. A., & Moore, E. G. (1970). The Intra-Urban Migration Process: A Perspective. *Geografiska Annaler: Series B, Human Geography*, *52*(1), 1–13. doi: 10.1080/04353684.1970.11879340

Brunsdon, C., Fotheringham, A. S., & Charlton, M. E. (1996). Geographically weighted regression: A method for exploring spatial nonstationarity. *Geographical Analysis*, *28*(4), 281–298.

Bueno, J. (2013, December 18). Primera sanción por falsear los datos de un certificado energético. *ELMUNDO*. Retrieved from https://www.elmundo.es/economia/2013/12/18/52b18334268e3e65428b4577.html

Bueno, J. (2014). El certificado de eficiencia energética sigue “en tierra de nadie.” *EL MUNDO*. Retrieved from https://www.elmundo.es/economia/2014/12/19/5492bbc4268e3ecf3c8b4573.html

Burgess, E. W. (1925). *The urban community: Selected papers from the proceedings of the American Sociological Society*. University of Chicago Press.

Bürgle, M. (2006, March 15). *Residential location choice model for the Greater Zurich area:* 20 p. Monte Verita/Ascona. doi: 10.3929/ETHZ-A-005228652

Burns, L. D., & Golob, T. F. (1976). The role of accessibility in basic transportation choice behavior. *Transportation*, *5*(2), 175–198. doi: 10.1007/BF00167272

Cajias, M., & Piazolo, D. (2013). Green performs better: Energy efficiency and financial return on buildings. *Journal of Corporate Real Estate*, *15*(1), 53–72. doi: 10.1108/JCRE-12-2012-0031

Can, A. (1992). Specification and estimation of hedonic housing price models. *Regional Science and Urban Economics*, *22*(3), 453–474. doi: 10.1016/0166-0462(92)90039-4

Cerin, P., Hassel, L. G., & Semenova, N. (2014). Energy Performance and Housing Prices: Does higher dwelling energy performance contribute to price premiums? *Sustainable Development*, *22*(6), 404–419. doi: 10.1002/sd.1566

Cervero, R., & Duncan, M. (2004). Neighbourhood Composition and Residential Land Prices: Does Exclusion Raise or Lower Values? *Urban Studies*, *41*(2), 299–315. doi: 10.1080/0042098032000165262

Charlton, M., & Fotheringham, A. S. (2009). *Geographically Weighted Regression*. National Centre for Geocomputation. National University of Ireland, Maynooth, County Kildare, Ireland. Retrieved from https://www.geos.ed.ac.uk/~gisteac/fcl/gwr/gwr_arcgis/GWR_Tutorial.pdf

Chasco, C., & Gallo, J. L. (2013). The Impact of Objective and Subjective Measures of Air Quality and Noise on House Prices: A Multilevel Approach for Downtown Madrid: Spatial Multilevel Modeling in Madrid. *Economic Geography*, *89*(2), 127–148. doi: 10.1111/j.1944-8287.2012.01172.x

Chau, K. W., Ho, D. C. W., Leung, H. F., Wong, S. K., & Cheung, A. K. C. (2004). Improving the living environment in Hong Kong through the use of a building classification system: A win-win-win solution for the Community, the Government and Tertiary Institutions in Hong Kong. *Hong Kong Construction Manager: The Chartered Institute of Building (Hong Kong) Newsletter*.

Chau, K. W., & Zou, G. (2018). Energy Prices, Real Estate Sales and Industrial Output in China. *Energies*, *11*(7), 1847. doi: 10.3390/en11071847

Chegut, A., Eichholtz, P., & Kok, N. (2014). Supply, Demand and the Value of Green Buildings. *Urban Studies*, *51*(1), 22–43. doi: 10.1177/0042098013484526

Cheshire, P., & Sheppard, S. (1995). On the Price of Land and the Value of Amenities. *Economica*, *62*(246), 247–267. doi: 10.2307/2554906

Chin, H. C., & Foong, K. W. (2006). Influence of School Accessibility on Housing Values. *Journal of Urban Planning and Development*, *132*(3), 120–129. doi: 10.1061/(ASCE)0733-9488(2006)132:3(120)

Christaller, W. (1933). *Die zentralen Orte in Süddeutschland (the central places in southern Germany).* Jena: Gustav Fischer.

Clark, D. E., & Herrin, W. E. (2000). The impact of public school attributes on home sale prices in California. *Growth and Change*, *31*(3), 385–407. doi: 10.1111/0017-4815.00134

Court, A. T. (1939). Hedonic price indexes with automotive examples. In *The Dynamics of Automobile Demand* (pp. 98–119). New York: General Motors.

Dalvi, M. Q., & Martin, K. M. (1976). The measurement of accessibility: Some preliminary results. *Transportation*, *5*(1), 17–42. doi: 10.1007/BF00165245

Darmofal, D. (Ed.). (2015a). Spatial Heterogeneity. In *Spatial Analysis for the Social Sciences* (pp. 119–138). Cambridge: Cambridge University Press. doi: 10.1017/CBO9781139051293.008

Darmofal, D. (Ed.). (2015b). Spatial Lag and Spatial Error Models. In *Spatial Analysis for the Social Sciences* (pp. 96–118). Cambridge: Cambridge University Press. doi: 10.1017/CBO9781139051293.007

Das, P., & Wiley, J. A. (2014). Determinants of premia for energy-efficient design in the office market. *Journal of Property Research*, *31*(1), 64–86. doi: 10.1080/09599916.2013.788543

Daughety, A. F., & Reinganum, J. F. (2008). Communicating quality: A unified model of disclosure and signalling. *The RAND Journal of Economics*, *39*(4), 973–989. doi: 10.1111/j.1756-2171.2008.00046.x

De Ayala, A., Galarraga, I., & Spadaro, J. V. (2016). The price of energy efficiency in the Spanish housing market. *Energy Policy*, *94*, 16–24. doi: 10.1016/j.enpol.2016.03.032

de Palma, A., Motamedi, K., Picard, N., & Waddell, P. (2005). A model of residential location choice with endogenous housing prices and traffic for the Paris region. *European Transport \ Trasporti Europei*, (31), 67–82.

de Palma, A., Picard, N., & Waddell, P. (2007). Discrete choice models with capacity constraints: An empirical analysis of the housing market of the greater Paris region. *Journal of Urban Economics*, *62*(2), 204–230. doi: 10.1016/j.jue.2007.02.007

Deardorff, A. V. (n.d.). “Excess profit,” Deardorff’s International Economics Glossary. Retrieved September 9, 2020, from “Excess profit,” Deardorff’s International Economics Glossary website: http://www-personal.umich.edu/~alandear/glossary/e.html#ExcessProfit

Dell’Anna, F. (2020). *Energy and Economic Evaluations to Design Urban Transformation and Requalification Programs* (PhD Thesis, Politecnico di Torino). Politecnico di Torino, Turin, Italy. Retrieved from https://www.researchgate.net/publication/340502030_Energy_and_Economic_Evaluations_to_Design_Urban_Transformation_and_Requalification_Programs

Dell’Anna, F., Bravi, M., Marmolejo Duarte, C., Bottero, M. C., & Chen, A. (2019). EPC Green Premium in Two Different European Climate Zones: A Comparative Study between Barcelona and Turin. *Sustainability*, *11*(20), 5605. doi: https://doi.org/10.3390/su11205605

Dennis, K. (2006). The Compatibility of Economic Theory and Proactive Energy Efficiency Policy. *The Electricity Journal*, *19*(7), 58–73. doi: 10.1016/j.tej.2006.07.006

Des Rosiers, F., Bolduc, A., & Thériault, M. (1999). Environment and value Does drinking water quality affect house prices? *Journal of Property Investment & Finance*, *17*(5), 444–463. doi: 10.1108/14635789910294877

Des Rosiers, F., Thériault, M., & Villeneuve, P. (2000). Sorting out access and neighbourhood factors in hedonic price modelling. *Journal of Property Investment & Finance*, *18*(3), 291–315. doi: 10.1108/14635780010338245

Diewert, W. E. (2003, May 27). *Hedonic regressions: A review of some unresolved issues*. Presented at the Seventh Meeting hosted by the National Institute for Statistics and Economic Studies, France in Paris.

Dubin, R. A. (1992). Spatial autocorrelation and neighborhood quality. *Regional Science and Urban Economics*, *22*(3), 433–452. doi: 10.1016/0166-0462(92)90038-3

Dujardin, C., Selod, H., & Thomas, I. (2008). Residential Segregation and Unemployment: The Case of Brussels. *Urban Studies*, *45*(1), 89–113. doi: 10.1177/0042098007085103

Echavarria Ochoa, J. C., & Roca Cladera, J. (2014, September). *Valor y diversidad: El caso de la Región Metropolitana de Barcelona*. 560–572. Università degli Studi Roma Tre. doi: 10.5821/ctv.7930

Eichholtz, P., Kok, N., & Quigley, J. M. (2010). Doing Well by Doing Good? Green Office Buildings. *American Economic Review*, *100*(5), 2492–2509. doi: 10.1257/aer.100.5.2492

Encinas, F., & Aguirre, C. (2017). Sustainability and The Market: Real Estate Marketing Approaches. *Architecture, City and Environment*, *12*(35), 137–164. doi: http://dx.doi.org/10.5821/ace.12.35.5141

Encinas, F., Marmolejo-Duarte, C., Sanchez de la Flor, F., & Aguirre, C. (2018). Does energy efficiency matter to real estate-consumers? Survey evidence on willingness to pay from a cost-optimal analysis in the context of a developing country. *Energy for Sustainable Development*, *45*, 110–123. doi: 10.1016/j.esd.2018.05.008

Epple, D., Quintero, L., & Sieg, H. (2014). *A New Approach to Estimating Hedonic Pricing Functions for Metropolitan Housing Markets* (No. 1516; p. 51). FRB of Cleveland Working Paper. Retrieved from https://economics.sas.upenn.edu/sites/default/files/filevault/event_papers/eqs_9_19_15.pdf

Espina, P. Z. (2009). Estimación de la pobreza en las comunidades autónomas españolas, mediante la distancia DP2 de Pena. *Estudios de economía aplicada*, *27*(2), 397–416.

European, C. (2008). *Proposal for a Directive of the European Parliament and of the Council on the Energy Performance of Buildings (recast)*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52008PC0780

European Commission. (2016). *Commission Staff Working Document: Evaluation of Directive 2010/31/EU on the Energy Performance of Buildings. Accompanying the Document Proposal for a Directive of the European Parliament and of the Council Amending Directive 2010/31/EU on the Energy Performance of Buildings* (p. 109) [Commission Staff Working Document:]. Brussels, Belgium: European Union, European Commission.

Evans, A. W. (1973). *The economics of residential location*. Springer.

Ferreira, M., Almeida, M., & Rodrigues, A. (2017). Impact of co-benefits on the assessment of energy related building renovation with a nearly-zero energy target. *Energy and Buildings*, *152*, 587–601. doi: 10.1016/j.enbuild.2017.07.066

Florio, P., & Teissier, O. (2015). Estimation of the Energy Performance Certificate of a housing stock characterised via qualitative variables through a typology-based approach model: A fuel poverty evaluation tool. *Energy and Buildings*, *89*, 39–48. doi: 10.1016/j.enbuild.2014.12.024

Follain, J. R., & Jimenez, E. (1985). Estimating the demand for housing characteristics: A survey and critique. *Regional Science and Urban Economics*, *15*(1), 77–107. doi: 10.1016/0166-0462(85)90033-X

Fortin, M.-J., Drapeau, P., & Legendre, P. (1990). Spatial autocorrelation and sampling design in plant ecology. In G. Grabherr, L. Mucina, M. B. Dale, & C. J. F. Ter Braak (Eds.), *Progress in theoretical vegetation science* (pp. 209–222). Dordrecht: Springer Netherlands. doi: 10.1007/978-94-009-1934-1_18

Fotheringham, A. S., Brunsdon, C., & Charlton, M. (2003). *Geographically Weighted Regression: The Analysis of Spatially Varying Relationships*. John Wiley & Sons.

Freeman III, A. M. (1979). *Benefits of environmental improvement: Theory and practice*. United States: N. Retrieved from https://www.osti.gov/biblio/5626540

Freeman III, A. M. (1993). Nonuse values in natural resource damage assessment. In *Valuing Natural Assets: The Economics of Natural Resource Damage Assessment* (pp. 264–303). Routledge.

Fuerst, F., & McAllister, P. (2011). The impact of Energy Performance Certificates on the rental and capital values of commercial property assets. *Energy Policy*, *39*(10), 6608–6614. doi: 10.1016/j.enpol.2011.08.005

Fuerst, F., McAllister, P., Nanda, A., & Wyatt, P. (2015). Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England. *Energy Economics*, *48*, 145–156. doi: 10.1016/j.eneco.2014.12.012

Gabriel, S. A., & Rosenthal, S. S. (1989). Household Location and Race: Estimates of a Multinomial Logit Model. *The Review of Economics and Statistics*, *71*(2), 240–249. JSTOR. doi: 10.2307/1926969

García, J. A. B., & Hernández, J. E. R. (2008). Housing demand in Spain according to dwelling type: Microeconometric evidence. *Regional Science and Urban Economics*, *38*(4), 363–377. doi: 10.1016/j.regsciurbeco.2008.02.002

Garcia Pozo, A. (2009). A Nested Housing Market Structure: Additional Evidence. *Housing Studies*, *24*(3), 373–395. doi: 10.1080/02673030902875029

Garcia-Hooghuis, A., & Neila, F. J. (2013). Transposition of The 2002/91/EC and 2010/31/EU “Energy Performance Building Directive” in The EU Members States. Consequences and Implications. *Informes de La Construcción, 65*(531), 289–300.

García-Navarro, J., Gonzalez-Diaz, M. J., & Valdivieso, M. (2014). Assessment of construction costs and energy consumption resulting from house energy ratings in a residential building placed in Madrid:" Precost&e Study". *Informes de La Construcción*, *66*(535). doi: https://doi.org/10.3989/ic.13.052

García-Navarro, J., González-Díaz, M. J., & Valdivieso, M. (2014). «Estudio Precost&e»: Evaluación de los costes constructivos y consumos energéticos derivados de la calificación energética en un edificio de viviendas situado en Madrid. *Informes de La Construcción, 66*(535), 1–10. doi: 10.3989/ic.13.052

Gatzlaff, D. H., & Haurin, D. R. (1998). Sample Selection and Biases in Local House Value Indices. *Journal of Urban Economics*, *43*(2), 199–222. doi: 10.1006/juec.1997.2045

Geary, R. C. (1954). The Contiguity Ratio and Statistical Mapping. *The Incorporated Statistician*, *5*(3), 115–146. JSTOR. doi: 10.2307/2986645

Getis, A., & Ord, J. (1992). The analysis of spatial association by use of distance statistics, geographycal analysis. *Perspectives on Spatial Data Analysis; Springer: Berlin/Heidelberg, Germany*.

Gibbons, S., & Machin, S. (2008). Valuing school quality, better transport, and lower crime: Evidence from house prices. *Oxford Review of Economic Policy*, *24*(1), 99–119. doi: 10.1093/oxrep/grn008

Gillingham, K., & Palmer, K. (2014). Bridging the Energy Efficiency Gap: Policy Insights from Economic Theory and Empirical Evidence. *Review of Environmental Economics and Policy*, *8*(1), 18–38. doi: 10.1093/reep/ret021

Giraudet, L.-G. (2018). *Energy efficiency as a credence good: A review of informational barriers to building energy savings* [FAERE Policy Paper]. Paris, French: FAERE:

Gonzalez Caceres, A. (2018). Shortcomings and Suggestions to the EPC Recommendation List of Measures: In-Depth Interviews in Six Countries. *Energies*, *11*(10), 2516. doi: 10.3390/en11102516

Gonzalez Caceres, A., & Diaz, M. (2018). Usability of the EPC Tools for the Profitability Calculation of a Retrofitting in a Residential Building. *Sustainability*, *10*(9), 3159. doi: 10.3390/su10093159

Gordon, B. L., & Winkler, D. T. (2017). The Effect of Listing Price Changes on the Selling Price of Single-Family Residential Homes. *The Journal of Real Estate Finance and Economics*, *55*(2), 185–215. doi: 10.1007/s11146-016-9558-z

Guo, J. Y., & Bhat, C. R. (2007). Operationalizing the concept of neighborhood: Application to residential location choice analysis. *Journal of Transport Geography*, *15*(1), 31–45. doi: 10.1016/j.jtrangeo.2005.11.001

Habib, M. A., & Miller, E. J. (2009). Reference-Dependent Residential Location Choice Model within a Relocation Context. *Transportation Research Record*, *2133*(1), 92–99. doi: 10.3141/2133-10

Haider, M., & Miller, E. J. (2000). Effects of transportation infrastructure and location on residential real estate values—Application of spatial autoregressive techniques. In *Transportation Land Use and Smart Growth: Planning and Administration* (pp. 1–8). Washington: Transportation Research Board Natl Research Council.

Halden, D., Mcguigan, D., Nisbet, A., & Mckinnon, A. (2000). *Accessibility: Review of measuring techniques and their application*. Great Britain, Scottish Executive, Central Research Unit.

Hansen, W. G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*, *25*(2), 73–76. doi: 10.1080/01944365908978307

Harris, C. D., & Ullman, E. L. (1945). The Nature of Cities: *The ANNALS of the American Academy of Political and Social Science*, *242*(1), 7–17. (Sage CA: Thousand Oaks, CA). doi: 10.1177/000271624524200103

Harris, D. R. (1999). “Property Values Drop When Blacks Move in, Because...”: Racial and Socioeconomic Determinants of Neighborhood Desirability. *American Sociological Review*, *64*(3), 461. doi: 10.2307/2657496

Haurin, D. R., & Brasington, D. (1996). School Quality and Real House Prices: Inter- and Intrametropolitan Effects. *Journal of Housing Economics*, *5*(4), 351–368. doi: 10.1006/jhec.1996.0018

Heckman, J. J. (1976). The Common Structure of Statistical Models of Truncation, Sample Selection and Limited Dependent Variables and a Simple Estimator for Such Models. In *Annals of Economic and Social Measurement* (Vol. 5, pp. 475–492). NBER. Retrieved from http://www.nber.org/chapters/c10491

Heckman, J. J. (1977). *Sample Selection Bias As a Specification Error (with an Application to the Estimation of Labor Supply Functions)*. Retrieved from https://www.nber.org/papers/w172

Heckman, J. J. (1990a). Selection Bias and Self-selection. In J. Eatwell, M. Milgate, & P. Newman (Eds.), *Econometrics* (pp. 201–224). London: Palgrave Macmillan UK. doi: 10.1007/978-1-349-20570-7_29

Heckman, J. J. (1990b). Selectivity bias: New developments. *American Economic Review*, *80*(2), 313–318.

Heckman, J. J., & Robb, R. (1986). Alternative Methods for Solving the Problem of Selection Bias in Evaluating the Impact of Treatments on Outcomes. In H. Wainer (Ed.), *Drawing Inferences from Self-Selected Samples* (pp. 63–107). New York, NY: Springer. doi: 10.1007/978-1-4612-4976-4_7

Hicks, J. R., & Allen, R. G. D. (1934). A Reconsideration of the Theory of Value. Part I. *Economica*, *1*(1), 52–76. JSTOR. doi: 10.2307/2548574

Hill, R. (2011). *Hedonic Price Indexes for Housing* (OECD Statistics Working Papers No. 2011/01). Paris, France: OECD Publishing,. Retrieved from OECD Publishing, website: https://doi.org/10.1787/5kghzxpt6g6f-en

Himmelberg, C., Mayer, C., & Sinai, T. (2005). Assessing High House Prices: Bubbles, Fundamentals and Misperceptions. *Journal of Economic Perspectives*, *19*(4), 67–92. doi: 10.1257/089533005775196769

Ho, D. C. W., Leung, H. F., Wong, S. K., Cheung, A. K. C., Lau, S. S. Y., Wong, W. S., … Chau, K. W. (2004). Assessing the health and hygiene performance of apartment buildings. *Facilities*, *22*(3/4), 58–69. doi: 10.1108/02632770410527789

Ho, D. C. W., & Yau, Y. (2004). Building safety & condition index: Benchmarking tool for maintenance managers. *Proceedings of the CIB W70 Facilities Management and Maintenance Symposium*, 149–155. Hong Kong.

Hoch, I., & Waddell, P. (2010). Apartment Rents: Another Challenge to the Monocentric Model. *Geographical Analysis*, *25*(1), 20–34. doi: 10.1111/j.1538-4632.1993.tb00277.x

Hope, A. C. A. (1968). A Simplified Monte Carlo Significance Test Procedure. *Journal of the Royal Statistical Society: Series B (Methodological)*, *30*(3), 582–598. doi: 10.1111/j.2517-6161.1968.tb00759.x

Hyland, M., Lyons, R., & Lyons, S. (2013). The value of domestic building energy efficiency—Evidence from Ireland. *Energy Economics*, *40*, 943–952. doi: https://doi.org/10.1016/j.eneco.2013.07.020

Ingram, D. R. (1971). The concept of accessibility: A search for an operational form. *Regional Studies*, *5*(2), 101–107. doi: 10.1080/09595237100185131

Isard, W. (1956). Regional Science, the Concept of Region, and Regional Structure. *Papers in Regional Science*, *2*(1), 13–26. doi: 10.1111/j.1435-5597.1956.tb01542.x

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2002). Environmental Policy and Technological Change. *Environmental and Resource Economics*, *22*(1), 41–70. doi: 10.1023/A:1015519401088

Jensen, O. M., Hansen, A. R., & Kragh, J. (2016). Market response to the public display of energy performance rating at property sales. *Energy Policy*, *93*, 229–235. doi: 10.1016/j.enpol.2016.02.029

Jiang, B. (2018). Geospatial Analysis Requires a Different Way of Thinking: The Problem of Spatial Heterogeneity. In M. Behnisch & G. Meinel (Eds.), *Trends in Spatial Analysis* *and Modelling: Decision-Support and Planning Strategies* (pp. 23–40). Cham: Springer International Publishing. doi: 10.1007/978-3-319-52522-8_2

Jim, C. Y., & Chen, W. Y. (2006). Impacts of urban environmental elements on residential housing prices in Guangzhou (China). *Landscape and Urban Planning*, *78*(4), 422–434. doi: 10.1016/j.landurbplan.2005.12.003

Jochem, E., & Madlener, R. (2003). *The Forgotten Benefits of Climate Change Mitigation: Innovation, Technological Leapfrogging, Employment, and Sustainable Development* (p. 26). Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers. Retrieved from Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers. website: https://www.researchgate.net/profile/Reinhard_Madlener/publication/237436626_WORKING_PARTY_ON_GLOBAL_AND_STRUCTURAL_POLICIES_OECD_Workshop_on_the_Benefits_of_Climate_Policy_Improving_Information_for_Policy_Makers_The_Forgotten_Benefits_of_Climate_Change_Mitigation_Innovation_T/links/58569c4b08ae81995eb6ac7d/WORKING-PARTY-ON-GLOBAL-AND-STRUCTURAL-POLICIES-OECD-Workshop-on-the-Benefits-of-Climate-Policy-Improving-Information-for-Policy-Makers-The-Forgotten-Benefits-of-Climate-Change-Mitigation-Innovation.pdf

Jones, K., & Simmons, J. W. (1990). *Location, location, location*. Nelson Canada.

Jones, S. R. (1981). ACCESSIBILITY MEASURES: A LITERATURE REVIEW. *Transport and Road Research Laboratory*. Retrieved from https://trid.trb.org/view/168069

Jud, D., & Seaks, T. (1994). Sample selection bias in estimating housing sales prices. *Journal of Real Estate Research*, *9*(3), 289–298.

Kain, J. F., & Quigley, J. M. (1970). Measuring the Value of Housing Quality. *Journal of the American Statistical Association*, *65*(330), 532–548. doi: 10.1080/01621459.1970.10481102

Karlqvist, A. (1972). Accessibility and urban structure. *Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, Mass (Mimeographed)*.

Kiel, K. A., & Zabel, J. E. (2008). Location, location, location: The 3L Approach to house price determination. *Journal of Housing Economics*, *17*(2), 175–190. doi: 10.1016/j.jhe.2007.12.002

Kim, C. W., Phipps, T. T., & Anselin, L. (2003). Measuring the benefits of air quality improvement: A spatial hedonic approach. *Journal of Environmental Economics and Management*, *45*(1), 24–39.

Kim, J. H., Pagliara, F., & Preston, J. (2005). The Intention to Move and Residential Location Choice Behaviour. *Urban Studies*, *42*(9), 1621–1636. doi: 10.1080/00420980500185611

Koenig, J. G. (1978). Accessibility and individual behavior: Accessibility indicators as a determinant of trip rate and urban development. *PTRC Summer Meeting (Mimeographed)*.

Kohlhase, J. E. (1991). The impact of toxic waste sites on housing values. *Journal of Urban Economics*, *30*(1), 1–26. doi: 10.1016/0094-1190(91)90042-6

Kong, F., Yin, H., & Nakagoshi, N. (2007). Using GIS and landscape metrics in the hedonic price modeling of the amenity value of urban green space: A case study in Jinan City, China. *Landscape and Urban Planning*, *79*(3–4), 240–252. doi: 10.1016/j.landurbplan.2006.02.013

Lancaster, K. J. (1966). A New Approach to Consumer Theory. *Journal of Political Economy*, *74*(2), 132–157. doi: 10.1086/259131

Larsson, N. (2004, March). *An Overview of Green Building Rating and Labelling Systems*. 15–21. Retrieved from https://www.academia.edu/31650420/An_Overview_of_Green_Building_Rating_and_Labelling_Systems

Lee, H., & Ghosh, S. K. (2009). Performance of information criteria for spatial models. *Journal of Statistical Computation and Simulation*, *79*(1), 93–106. doi: 10.1080/00949650701611143

Lee, L.-F. (2004). Asymptotic Distributions of Quasi-Maximum Likelihood Estimators for Spatial Autoregressive Models. *Econometrica*, *72*(6), 1899–1925. doi: 10.1111/j.1468-0262.2004.00558.x

Levin, J. (2001). Information and the Market for Lemons. *The RAND Journal of Economics*, *32*(4), 657–666. JSTOR. doi: 10.2307/2696386

Li, F., Norrbin, S., Rasmussen, D., & Ueland, J. (2005). Hedonic regression models when unmeasured quality differences are present. *Florida State University, Tallahassee, FL*.

Li, H., Wei, Y. D., Wu, Y., & Tian, G. (2019). Analyzing housing prices in Shanghai with open data: Amenity, accessibility and urban structure. *Cities*, *91*, 165–179. doi: 10.1016/j.cities.2018.11.016

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2005). *Geographic Information Systems and Science*. John Wiley & Sons.

Lu, B., Charlton, M., Harris, P., & Fotheringham, A. S. (2014). Geographically weighted regression with a non- Euclidean distance metric: A case study using hedonic house price data. *International Journal of Geographical Information Science, 28*(4), 660–681. doi: 10.1080/13658816.2013.865739

Luttik, J. (2000). The value of trees, water and open space as reflected by house prices in the Netherlands. *Landscape and Urban Planning*, *48*(3–4), 161–167. doi: 10.1016/S0169-2046(00)00039-6

Lützkendorf †, T., & Speer ‡, T. M. (2005). Alleviating asymmetric information in property markets: Building performance and product quality as signals for consumers. *Building Research & Information*, *33*(2), 182–195. doi: 10.1080/0961321042000323815

Lynch, A. K., & Rasmussen, D. W. (2001). Measuring the impact of crime on house prices. *Applied Economics*, *33*(15), 1981–1989. doi: 10.1080/00036840110021735

Magnus, J. R. (1978). Maximum likelihood estimation of the GLS model with unknown parameters in the disturbance covariance matrix. *Journal of Econometrics*, *7*(3), 281–312. doi: 10.1016/0304-4076(78)90056-8

Mahan, B. L., Polasky, S., & Adams, R. M. (2000). Valuing urban wetlands: A property price approach. *Land Economics*, *76*(1), 100–113. doi: 10.2307/3147260

Malpezzi, S. (2008). Hedonic Pricing Models: A Selective and Applied Review. In *Housing Economics and Public Policy* (pp. 67–89). John Wiley & Sons, Ltd. doi: 10.1002/9780470690680.ch5

Marmolejo Duarte, C., & González Tamez, C. (2009). Does noise have a stationary impact on residential values? *Journal of European Real Estate Research*, *2*(3), 259–279. doi: 10.1108/17539260910999992

Marmolejo-Duarte, C. (2016). The impact of the energy rating on residential values: An analysis for the multifamily market in Barcelona. *Inf. Constr*, *68*, 1–12.

Marmolejo-Duarte, C., García-Hooghuis, A., & García-Masiá, A. (2017). How Much Does The Energy Class of Our Dwellings Matter to Us? An Analysis of The Level of Understanding of EPCs, Willing To Pay And Reasons for Payment in BarcelonaI. *Hábitat Sustentable*, 54–65.

Marmolejo-Duarte, C., Spairani, S., & García-Hooghuis, A. (2020). Overview of the Energy Performance Certificates in Spain. The perspective of the main actors of the real estate housing industry (In Press). *Ciudad y Territorio Estudios Territoriales*.

Marmolejo-Duarte, C., Spairani, S., Moral, C. del, Delgado, L., Egusquiza, A., & Chen, A. (2019). How Relevant is Energy Efficiency in The Marketing of Homes? Evidence from Real Estate Agents in Spain. *IOP Conference Series: Materials Science and Engineering*, *603*, 032053. doi: 10.1088/1757-899X/603/3/032053

Marmolejo-Duarte, Carlos. (2016). La incidencia de la calificación energética sobre los valores residenciales: Un análisis para el mercado plurifamiliar en Barcelona. *Informes de la Construcción*, *68*(543), 156. doi: 10.3989/ic.16.053

Marmolejo-Duarte, Carlos, & Cerda Troncoso, J. (2017). Spatiotemporal behavior of the population as an approach to analyze urban structure: The case of Metropolitan Barcelona. *Cuadernos Geográficos*, *56*(2), 111–133.

Marshall, A. (1890). Principles of economics Macmillan. *London (8th Ed. Published in 1920)*.

McCord, M., Lo, D., Davis, P. T., Hemphill, L., McCord, J., & Haran, M. (2020). A spatial analysis of EPCs in The Belfast Metropolitan Area housing market. *Journal of Property Research*, *37*(1), 25–61. doi: 10.1080/09599916.2019.1697345

Moghimi, V., & Jusan, M. B. M. (2015). Priority of structural housing attribute preferences: Identifying customer perception. *International Journal of Housing Markets and Analysis*, *8*(1), 36–52. doi: 10.1108/IJHMA-11-2013-0057

Mok, H., Chan, P., & Cho, Y. (1995). A Hedonic Price Model for Private Properties in Hong-Kong. *Journal of Real Estate Finance and Economics*, *10*(1), 37–48. doi: 10.1007/BF01099610

Moran, P. A. (1950). Notes on continuous stochastic phenomena. *Biometrika*, *37*(1/2), 17–23.

Morton, C., Wilson, C., & Anable, J. (2018). The diffusion of domestic energy efficiency policies: A spatial perspective. *Energy Policy*, *114*, 77–88. doi: 10.1016/j.enpol.2017.11.057

Muñoz, P. L. S. (2014, February 6). Picaresca en la certificación. *El País*. Retrieved from https://elpais.com/economia/2014/02/06/vivienda/1391692114_309183.html

Murayama, Y., & Thapa, R. B. (2011). Spatial Analysis: Evolution, Methods, and Applications. In Y. Murayama & R. B. Thapa (Eds.), *Spatial Analysis and Modeling in Geographical Transformation Process: GIS-based Applications* (pp. 1–26). Dordrecht: Springer Netherlands. doi: 10.1007/978-94-007-0671-2_1

Murphy, L. (2014). The influence of the Energy Performance Certificate: The Dutch case. *Energy Policy*, *67*, 664–672. doi: 10.1016/j.enpol.2013.11.054

Olaussen, J. O., Oust, A., & Solstad, J. T. (2017). Energy performance certificates – Informing the informed or the indifferent? *Energy Policy*, *111*, 246–254. doi: 10.1016/j.enpol.2017.09.029

Ord, J. K., & Cliff, A. (1973). Spatial autocorrelation. *London: Pion*.

Ord, J. K., & Getis, A. (1995). Local Spatial Autocorrelation Statistics: Distributional Issues and an Application. *Geographical Analysis*, *27*(4), 286–306. doi: 10.1111/j.1538-4632.1995.tb00912.x

Ord, K. (1975). Estimation Methods for Models of Spatial Interaction. *Journal of the American Statistical Association*, *70*(349), 120–126. doi: 10.1080/01621459.1975.10480272

Palm, P. (2015). The office market: A lemon market? A study of the Malmö CBD office market. *Journal of Property Investment & Finance*, *33*(2), 140–155. doi: 10.1108/JPIF-12-2014-0073

Parkinson, A., De Jong, R., Cooke, A., & Guthrie, P. (2013). Energy performance certification as a signal of workplace quality. *Energy Policy*, *62*, 1493–1505. doi: 10.1016/j.enpol.2013.07.043

Pascual, R. P., Paoletti, G., & Lollini, R. (2017). Impact and reliability of EPCs in the real estate market. *Energy Procedia*, *140*, 102–114. doi: 10.1016/j.egypro.2017.11.127

Pinjari, A. R., Bhat, C. R., & Hensher, D. A. (2009). Residential self-selection effects in an activity time-use behavior model. *Transportation Research Part B: Methodological*, *43*(7), 729–748. doi: 10.1016/j.trb.2009.02.002

Pinjari, A. R., Pendyala, R. M., Bhat, C. R., & Waddell, P. A. (2011). Modeling the choice continuum: An integrated model of residential location, auto ownership, bicycle ownership, and commute tour mode choice decisions. *Transportation*, *38*(6), 933. doi: 10.1007/s11116-011-9360-y

Pope, J. C. (2008). Fear of crime and housing prices: Household reactions to sex offender registries. *Journal of Urban Economics*, *64*(3), 601–614. doi: 10.1016/j.jue.2008.07.001

Puhani, P. (2000). The Heckman Correction for Sample Selection and Its Critique. *Journal of Economic Surveys*, *14*(1), 53–68. doi: 10.1111/1467-6419.00104

Qian, Q. K., & Chan, E. H. W. (2007). Key issues for research on government policies for Building Energy Efficiency (BEE) promotion in Mainland China. *SB07HK–Sustainable Building Conference Hong Kong*, 4–5.

Qian, Q. K., & Chan, E. H. W. (2008, April 22). *Features of incentive schemes as part of public policy for promoting building energy efficiency*. Presented at the Ecocity World Summit 2008 International Conference, San Francisco, USA. Retrieved from http://hdl.handle.net/10397/46645

Qian, Queena K., Chan, E. H. W., & Choy, L. H. T. (2013). How transaction costs affect real estate developers entering into the building energy efficiency (BEE) market? *Habitat International*, *37*, 138–147. doi: 10.1016/j.habitatint.2011.12.005

Quigley, J. M. (1973). *RESIDENTIAL LOCATION WITH MULTIPLE WORKPLACES AND A HETEROGENEOUS HOUSING STOCK.*. (UC Berkeley Transportation Library). Retrieved from https://trid.trb.org/view/562081

Ramos, A., Labandeira, X., & Löschel, A. (2016). Pro-environmental Households and Energy Efficiency in Spain. *Environmental and Resource Economics*, *63*(2), 367–393. doi: 10.1007/s10640-015-9899-8

Rehdanz, K., & Maddison, D. (2008). Local environmental quality and life-satisfaction in Germany. *Ecological Economics*, *64*(4), 787–797. doi: 10.1016/j.ecolecon.2007.04.016

Reiersøl, O. (1945). *Confluence analysis by means of instrumental sets of variables* (PhD Thesis). Almqvist & Wiksell.

Ripley, B. (1984). *Spatial Statistics*. Wiley, New York.

Roca Cladera, J. (1988). *La estructura de valores urbanos: Un análisis teórico-empírico* (Instituto de Estudios de Administración Local). Instituto de Estudios de Administración Local, Madrid, Spain. Retrieved from https://www.iberlibro.com/ESTRUCTURA-VALORES-URBANOS-ANALISIS-TEORICO-EMPIRICO/12529133261/bd

Roca Cladera, J. (1990). *El mercado inmobiliario del a.m.b. (Mayo 89-feb.90)* (Centre de Política de Sòl i Valoracions (CPSV)). Barcelona, Spain: Centre de Política de Sòl i Valoracions (CPSV). Retrieved from https://futur.upc.edu/1669248

Roca Cladera, J., Arellano, B., & Moix, M. (2011). Estructura urbana, policentrismo y sprawl: Los ejemplos de Madrid y Barcelona. *Ciudad y territorio, estudios territoriales*, *43*(168), 299–321.

Roca Cladera, J., Burns, M. C., & Moix, M. (2001a). *Caracterización de las áreas metropolitanas españolas* (Centre de Política de Sòl i Valoracions (CPSV)). Barcelona, Spain: Centre de Política de Sòl i Valoracions (CPSV). Retrieved from https://futur.upc.edu/1665543

Roca Cladera, J., Burns, M. C., & Moix, M. (2001b). *El sistema metropolitano español en el contexto europeo e internacional* (Centre de Política de Sòl i Valoracions (CPSV)). Barcelona, Spain: Centre de Política de Sòl i Valoracions (CPSV). Retrieved from https://futur.upc.edu/1665553

Roca Cladera, J., Marmolejo Duarte, C., & Moix, M. (2009). Urban Structure and Polycentrism: Towards a Redefinition of the Sub-centre Concept: *Urban Studies*. (Sage UK: London, England). doi: 10.1177/0042098009346329

Roca Cladera, J., Moix Bergadà, M., & Biere Arenas, R. M. (2017a). *Metodología para la obtención del valor de repercusión de inmuebles comerciales*. Retrieved from https://upcommons.upc.edu/handle/2117/115204

Roca Cladera, J., Moix Bergadà, M., & Biere Arenas, R. M. (2017b). *Metodología para la obtención del valor de repercusión de inmuebles de oficinas*. Retrieved from https://upcommons.upc.edu/handle/2117/115203

Rosen, S. (1974). Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy*, *82*(1), 34–55. doi: 10.1086/260169

Rousseau, D. M., & Fried, Y. (2001). Location, location, location: Contextualizing organizational research. *Journal of Organizational Behavior*, 1–13.

Salido Cobo, J. (2013). El certificado energético para viviendas también se despacha en cupones de descuento. *EL MUNDO*. Retrieved from https://www.elmundo.es/elmundo/2013/07/02/suvivienda/1372752464.html

Salvi, M., Horehájová, A., & Müri, R. (2008). Der Nachhaltigkeit von Immobilien einen finanziellen Wert geben–Minergie macht sich bezahlt. *Center for Corporate Responsibility and Sustainability, Universität Zürich, Zürich. Abrufbar Unter Www. Ccrs. Uzh. Ch*. Retrieved from https://www.minergie.ch/media/zkb_minergie_studie_2008.pdf

Sander, W. (1992). The effect of women's schooling on fertility. *Economics Letters*, *40*(2), 229–233. doi: 10.1016/0165-1765(92)90229-R

Schovelin, R., & Roca, J. (2016). Un modelo para seleccionar atributos de un edificio residencial que maximiza el precio de venta. *Obras y Proyectos*, (19), 61–72. doi: 10.4067/S0718-28132016000100005

Sedlacek, S., & Maier, G. (2012). Can green building councils serve as third party governance institutions? An economic and institutional analysis. *Energy Policy*, *49*, 479–487. doi: 10.1016/j.enpol.2012.06.049

Seko, M., & Sumita, K. (2007). Japanese Housing Tenure Choice and Welfare Implications after the Revision of the Tenant Protection Law. *The Journal of Real Estate Finance and Economics*, *35*(3), 357–383. doi: 10.1007/s11146-007-9040-z

Sermons, M. W. (2000). Influence of Race on Household Residential Utility. *Geographical Analysis*, *32*(3), 225–246. doi: 10.1111/j.1538-4632.2000.tb00426.x

Shen, Y., & Karimi, K. (2017). The economic value of streets: Mix-scale spatio-functional interaction and housing price patterns. *Applied Geography*, *79*, 187–202. doi: 10.1016/j.apgeog.2016.12.012

Sheppard, S. (1999). Hedonic analysis of housing markets. In *Applied Urban Economics*: *Vol. 3*. *Handbook of Regional and Urban Economics* (pp. 1595–1635). Elsevier. doi: 10.1016/S1574-0080(99)80010-8

Simmons, P. J. (1974). *Choice and demand [by] Peter J. Simmons*.

Sirmans, G. S., MacDonald, L., Macpherson, D. A., & Zietz, E. N. (2006). The Value of Housing Characteristics: A Meta Analysis. *The Journal of Real Estate Finance and Economics*, *33*(3), 215–240. doi: 10.1007/s11146-006-9983-5

Sirmans, S., Macpherson, D., & Zietz, E. (2005). The Composition of Hedonic Pricing Models. *Journal of Real Estate Literature*, *13*(1), 1–44. doi: 10.5555/reli.13.1.j03673877172w0w2

Smirnov, O., & Anselin, L. (2001). Fast maximum likelihood estimation of very large spatial autoregressive models: A characteristic polynomial approach. *Computational Statistics & Data Analysis*, *35*(3), 301–319. doi: 10.1016/S0167-9473(00)00018-9

Smith, A. (1937). *The wealth of nations [1776]*. na.

Smith, N. (1979). Toward a Theory of Gentrification A Back to the City Movement by Capital, not People. *Journal of the American Planning Association*, *45*(4), 538–548. doi: 10.1080/01944367908977002

Song, Y., & Sohn, J. (2007). Valuing spatial accessibility to retailing: A case study of the single family housing market in Hillsboro, Oregon. *Journal of Retailing and Consumer Services*, *14*(4), 279–288. doi: 10.1016/j.jretconser.2006.07.002

Stewart, J. Q. (1947). Empirical Mathematical Rules concerning the Distribution and Equilibrium of Population. *Geographical Review*, *37*(3), 461–485. JSTOR. doi: 10.2307/211132

Taltavull de La Paz, P., Perez-Sanchez, V., Mora-Garcia, R. T., & Perez-Sanchez, J. C. (2019). Green Premium Evidence from Climatic Areas: A Case in Southern Europe, Alicante (Spain). *Sustainability*, *11*(3), 686. doi: 10.3390/su11030686

Taltavull, P., Anghel, I., & Ciora, C. (2017). Impact of energy performance on transaction prices: Evidence from the apartment market in Bucharest. *Journal of European Real Estate Research*, *10*(1), 57–72. doi: 10.1108/JERER-12-2016-0046

Tobler, W. R. (1970). A Computer Movie Simulating Urban Growth in the Detroit Region. *Economic Geography*, *46*(sup1), 234–240. doi: 10.2307/143141

Trapero, X. B. P. (1977). *Problemas de la medición del bienestar y conceptos afines:(una aplicación al caso español)* (Instituto Nacional de Estadística.). Madrid: España: Presidencia del Gobierno, Instituto Nacional de Estadística.

Ürge-Vorsatz, D., Herrero, S. T., Dubash, N. K., & Lecocq, F. (2014). Measuring the Co-Benefits of Climate Change Mitigation. *Annual Review of Environment and Resources*, *39*(1), 549–582. doi: 10.1146/annurev-environ-031312-125456

Ürge-Vorsatz, D., Novikova, A., & Sharmina, M. (2009, June). *Counting good: Quantifying the co-benefits of improved efficiency in buildings*. *108*, 185–195.

Viúdez, J. (2013, September 14). El caos del certificado energético. *El País*. Retrieved from https://elpais.com/sociedad/2013/09/13/actualidad/1379090592_775839.html

Von Thünen, J. H. (1826). *Der isolierte Staat in Beziehung auf Nationalökonomie und Landwirtschaft (The Isolated State)*. Gustav Fischer, Stuttgart.

Wabe, J. S. (1971). A Study of House Prices as a means of Establishing the Value of Journey Time, the Rate of Time Preference and the Valuation of some Aspects of Environment in the London Metropolitan Region. *Applied Economics*, *3*(4), 247–255. doi: 10.1080/00036847100000012

Waddell, P. (2006). *Reconciling Household Residential Location Choices and Neighborhood Dynamics* (p. 24).

Wang, D., & Li, S. (2006). Socio-economic differentials and stated housing preferences in Guangzhou, China. *Habitat International*, *30*(2), 305–326. doi: 10.1016/j.habitatint.2004.02.009

Wang, Y., Zhang, S. X., & Leung, M. Y. (2005). *Appraisal on integrated characteristics influencing condominiums price in van by structural equation model* (Y. Wang, Ed.). Beijing: China Architecture & Building Press.

Weber, A. (1909). *Theory of the Location of Industries*. Chicago: The University of Chicago Press.

Weibull, J. W. (1980). On the Numerical Measurement of Accessibility. *Environment and Planning A: Economy and Space*, *12*(1), 53–67. doi: 10.1068/a120053

Wen, H., Zhang, Y., & Zhang, L. (2014). Do educational facilities affect housing price? An empirical study in Hangzhou, China. *Habitat International*, *42*, 155–163. doi: 10.1016/j.habitatint.2013.12.004

Wiley, J. A., Benefield, J. D., & Johnson, K. H. (2010). Green Design and the Market for Commercial Office Space. *The Journal of Real Estate Finance and Economics*, *41*(2), 228–243. doi: 10.1007/s11146-008-9142-2

Winward, J., Schiellerup, P., & Boardman, B. (1998). *Cool labels The first three years of the European Energy Label* (No. OU-ECU-RR--20 ; p. 131). Oxford, United Kingdom. Retrieved from http://hdl.handle.net/10068/378212

Wu, H., Jiao, H., Yu, Y., Li, Z., Peng, Z., Liu, L., & Zeng, Z. (2018). Influence Factors and Regression Model of Urban Housing Prices Based on Internet Open Access Data. *Sustainability*, *10*(5), 1676. doi: 10.3390/su10051676

Wu, W., Zhang, W., & Dong, G. (2013). Determinant of residential location choice in a transitional housing market: Evidence based on micro survey from Beijing. *Habitat International*, *39*, 16–24. doi: 10.1016/j.habitatint.2012.10.008

Wyon, D. P. (1994). The economic benefits of a healthy indoor environment. *La Riforma Medica*, *109*(N2, Suppl. 1), 405–416.

Xiao, Y. (2017). Hedonic Housing Price Theory Review. In Y. Xiao (Ed.), *Urban Morphology and Housing Market* (pp. 11–40). Singapore: Springer. doi: 10.1007/978-981-10-2762-8_2

Xiao, Y., Orford, S., & Webster, C. J. (2016). Urban configuration, accessibility, and property prices: A case study of Cardiff, Wales. *Environment and Planning B-Planning & Design*, *43*(1), 108–129. doi: 10.1177/0265813515600120

Yu, T.-H., Cho, S.-H., & Kim, S. G. (2012). Assessing the Residential Property Tax Revenue Impact of a Shopping Center. *Journal of Real Estate Finance and Economics*, *45*(3), 604–621. doi: 10.1007/s11146-010-9292-x

Zhou, J., Yang, L., & Li, L. (2018). The implications of high-speed rail for Chinese cities: Connectivity and accessibility. *Transportation Research Part A: Policy and Practice*, *116*, 308–326.

Zolfaghari, A., Sivakumar, A., & Polak, J. W. (2012). Choice set pruning in residential location choice modelling: A comparison of sampling and choice set generation approaches in greater London. *Transportation Planning and Technology*, *35*(1), 87–106. doi: 10.1080/03081060.2012.635420

APPENDECES

Appendix I: The Identification Of Climatic Zone In Spain

Table Appendix 1 Climatic Zone in mainland

Capital	**Z.C.**	**Altitude**	**A4**	**A3**	**A2**	**A1**	**B4**	**B3**	**B2**	**B1**	**C4**	**C3**	**C2**	**C1**	**D3**	**D2**	**D1**	**E1**
Albacete	D3	677										h<450			h<950			h≥950
Alicante/Alicant	B4	7					h<250					h<700			h≥700			
Almería	A4	0	h<100				h<250	h<400				h<800			h≥800			
Ávila	E1	1054														h<550	h<850	h≥850
Badajoz	C4	168									h<400	h<450			h≥450			
Barcelona	C2	1											h<250			h<450	h<750	h≥750
Bilbao/Bilbo	C1	214												h<250			h≥250	
Burgos	E1	861															h<600	h≥600
Cáceres	C4	385									h<600				h<1050			h≥1050
Cádiz	A3	0		h<150				h<450				h<600	h<850			h≥850		
Castellón/Castelló	B3	18						h<50				h<500			h<600	h<1000		h≥1000
Ceuta	B3	0						h<50										
Ciudad Real	D3	630									h<450	h<500			h≥500			
Córdoba	B4	113					h<150				h<550				h≥550			
Coruña, La/A Coruña	C1	0												h<200			h≥200	
Cuenca	D2	975													h<800	h<1050	h≥1050	
Gerona/Girona	D2	143											h<100			h<600		h≥600
Granada	C3	754	h<50				h<350				h<600	h<800			h<1300			h≥1300
Guadalajara	D3	708													h<950	h<1000		h≥1000
Huelva	A4	50	h<50				h<150	h<350				h<800			h≥800			
Huesca	D2	432										h<200			h<400	h<700		h≥700

Capital	Z.C.	Altitude	A4	A3	A2	A1	B4	B3	B2	B1	C4	C3	C2	C1	D3	D2	D1	E1
Jaén	C4	436					h<350				h<750				h<1250			h≥1250
León	E1	346																h<1250
Lérida/Lleida	D3	131										h<100			h<600			h≥600
Logroño	D2	379											h<200			h<700		h≥700
Lugo	D1	412															h<500	h≥500
Madrid	D3	589										h<500			h<950	h<1000		h≥1000
Málaga	A3	0						h<300				h<700			h≥700			
Melilla	A3	130																
Murcia	B3	25						h<100				h<550			h≥550			
Orense/Ourense	D2	327										h<150	h<300			h<800		h≥800
Oviedo	D1	214												h<50			h<550	h≥550
Palencia	D1	722															h<800	h≥800
Palma de Mallorca	B3	1						h<250				h≥250						
Pamplona/Iruña	D1	456											h<100			h<300	h<600	h≥600
Pontevedra	C1	77												h<350			h≥350	
Salamanca	D2	770														h<800		h≥800
San Sebastián/Donostia	D1	5															h<400	h≥400
Santander	C1	1												h<150			h<650	h≥650
Segovia	D2	1013														h<1000		h≥1000
Sevilla	B4	9					h<200				h≥200							
Soria	E1	984														h<750	h<800	h≥800
Tarragona	B3	1						h<50				h<500			h≥500			
Teruel	D2	995										h<450	h<500			h<1000		h≥1000
Toledo	C4	445									h<500				h≥500			
Valencia/València	B3	8						h<50				h<500				h<950		h≥950
Valladolid	D2	704														h<800		h≥800
Vitoria/Gasteiz	D1	512															h<500	h≥500

Capital	Z.C.	Altitude	A4	A3	A2	A1	B4	B3	B2	B1	C4	C3	C2	C1	D3	D2	D1	E1
Zamora	D2	617														h<800		h≥800
Zaragoza	D3	207										h<200			h<650			h≥650

Table Appendix 2 Climatic Zone of Canaria island

Capital	Z.C.	Altitud	α3	A2	B2	C2
Palmas de Gran Canaria, Las	α3	114	h<350	h<750	h<1000	h≥1000
Santa Cruz de Tenerife	α3	0	h<350	h<750	h<1000	h≥1000

Source: Documento Básico HE-Ahorro de energía (DBHE)

Appendix II: Final Report of Enery Performance Certifications

CERTIFICADO DE EFICIENCIA ENERGÉTICA DE EDIFICIOS

IDENTIFICACIÓN DEL EDIFICIO O DE LA PARTE QUE SE CERTIFICA:

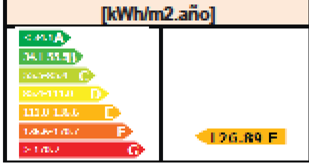
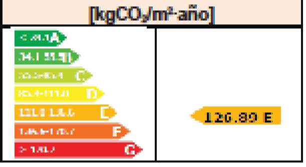
Nombre del edificio			
Dirección			
Municipio		**Código Postal**	
Provincia		**Comunidad Autónoma**	
Zona climática		**Año construcción**	
Normativa vigente (construcción / rehabilitación)			
Referencia/s catastral/es			

Tipo de edificio o parte del edificio que se certifica:	
☐ Edificio de nueva construcción	☐ Edificio Existente
☐Vivienda ☐Unifamiliar ☐Bloque ☐Bloque completo ☐Vivienda individual	☐Terciario ☐Edificio completo ☐Local

DATOS DEL TÉCNICO CERTIFICADOR:

Nombre y Apellidos		**NIF/NIE**	
Razón social		**NIF**	
Domicilio			
Municipio		**Código Postal**	
Provincia		**Comunidad Autónoma**	
e-mail:		**Teléfono**	
Titulación habilitante según normativa vigente			
Procedimiento reconocido de calificación energética utilizado y versión:			

CALIFICACIÓN ENERGÉTICA OBTENIDA:

CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE [kWh/m2.año]	EMISIONES DE DIÓXIDO DE CARBONO [kgCO$_2$/m^2·año]
	

El técnico abajo firmante declara responsablemente que ha realizado la certificación energética del edificio o de la parte que se certifica de acuerdo con el procedimiento establecido por la normativa vigente y que son ciertos los datos que figuran en el presente documento, y sus anexos:

Fecha: ___/___/____

Firma del técnico certificador:

Anexo I. *Descripción de las características energéticas del edificio.*
Anexo II. *Calificación energética del edificio.*
Anexo III. *Recomendaciones para la mejora de la eficiencia energética.*
Anexo IV. *Pruebas, comprobaciones e inspecciones realizadas por el técnico certificador.*

Registro del Órgano Territorial Competente:_

Fecha (de generación del documento) -
Ref. Catastral - Página X de X

ANEXO I
DESCRIPCIÓN DE LAS CARACTERÍSTICAS ENERGÉTICAS DEL EDIFICIO

En este apartado se describen las características energéticas del edificio, envolvente térmica, instalaciones, condiciones de funcionamiento y ocupación y demás datos utilizados para obtener la calificación energética del edificio.

1. SUPERFICIE, IMAGEN Y SITUACIÓN

Superficie habitable [m²]	

Imagen del edificio	Plano de situación
	

2. ENVOLVENTE TÉRMICA

Cerramientos opacos

Nombre	Tipo	Superficie [m²]	Transmitancia [W/m²·K]	Modo de obtención

Huecos y lucernarios

Nombre	Tipo	Superficie [m2]	Transmitancia [W/m2·K]	Factor solar	Modo de obtención. Transmitancia	Modo de obtención. Factor solar

3. INSTALACIONES TÉRMICAS

Generadores de calefacción

Nombre	Tipo	Potencia nominal [kW]	Rendimiento Estacional [%]	Tipo de Energía	Modo de obtención
TOTALES		-			

Generadores de refrigeración

Nombre	Tipo	Potencia nominal [kW]	Rendimiento Estacional [%]	Tipo de Energía	Modo de obtención
TOTALES		-			

Instalaciones de Agua Caliente Sanitaria

Fecha (de generación del documento) -
Ref. Catastral -
Página X de X

Demanda diaria de ACS a 60ºC (litros/día)	-

Nombre	Tipo	Potencia nominal [kW]	Rendimiento Estacional [%]	Tipo de Energía	Modo de obtención
-	-	-	-	-	-

Sistemas secundarios de calefacción y/o refrigeración (sólo edificios terciarios)

Nombre	-		
Tipo	-		
Zona asociada	-		
Potencia calor [kW]	Potencia frío [kW]	Rendimiento estacional calor [%]	Rendimiento estacional frío [%]
-	-	-	-
Enfriamiento gratuito	Enfriamiento evaporativo	Recuperación de energía	Control
-	-	-	-

Torres de refrigeración (sólo edificios terciarios)

Nombre	Tipo	Servicio asociado	Consumo de energía [kWh/año]
-	-	-	-
TOTALES			

Ventilación y bombeo (sólo edificios terciarios)

Nombre	Tipo	Servicio asociado	Consumo de energía [kWh/año]
-	-	-	-
TOTALES			

4. INSTALACIÓN DE ILUMINACIÓN (sólo edificios terciarios)

Espacio	Potencia instalada [W/m²]	VEEI [W/m²·100lux]	Iluminancia media [lux]	Modo de obtención
-	-	-	-	-
TOTALES	-			

5. CONDICIONES DE FUNCIONAMIENTO Y OCUPACIÓN (sólo edificios terciarios)

Espacio	Superficie [m²]	Perfil de uso
-	-	-

6. ENERGÍAS

Térmica

Nombre	Consumo de Energía Final,cubierto en función del servicio asociado [%]			Demanda de ACS cubierta [%]
	Calefacción	Refrigeración	ACS	
Paneles solares	-	-	-	30
Caldera de biomasa	-	-	-	
TOTAL	-	-	-	-

Eléctrica

Nombre	Energía eléctrica generada y autoconsumida [kWh/año]
-	-
TOTAL	-

Fecha (de generación del documento) -
Ref. Catastral -

Página X de X

ANEXO II
CALIFICACIÓN ENERGÉTICA DEL EDIFICIO

Zona climática		Uso	

1. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN EMISIONES

INDICADOR GLOBAL		INDICADORES PARCIALES			
	125.89 E	CALEFACCIÓN		ACS	
		Emisiones calefacción [kgCO₂/m²·año]	*B*	*Emisiones ACS [kgCO₂/m²·año]*	
		50,2			
		REFRIGERACIÓN		ILUMINACIÓN	
Emisiones globales [kgCO₂/m²·año][1]		*Emisiones refrigeración [kgCO₂/m²·año]*		*Emisiones iluminación [kgCO₂/m²·año]*	

La calificación global del edificio se expresa en términos de dióxido de carbono liberado a la atmósfera como consecuencia del consumo energético del mismo.

	kgCO2/m2.año	kgCO2/año
Emisiones CO2 por consumo eléctrico	-	-
Emisiones CO2 por otros combustibles	-	-

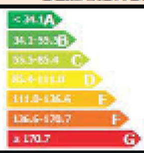
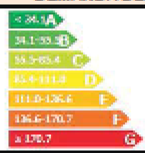
2. CALIFICACIÓN ENERGÉTICA DEL EDIFICIO EN CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE

Por energía primara no renovable se entiende la energía consumida por el edificio procedente de fuentes no renovables que no ha sufrido ningún proceso de conversión o transformación.

INDICADOR GLOBAL		INDICADORES PARCIALES			
	126.89 E	CALEFACCIÓN		ACS	
		Energía primaria calefacción [kWh/m²·año]	*A*	*Energía primaria ACS [kWh/m²·año]*	
		32			
		REFRIGERACIÓN		ILUMINACIÓN	
Consumo global de energía primaria no renovable [kWh/m²·año][1]		*Energía primaria refrigeración [kWh/m²·año]*		*Energía primaria iluminación [kWh/m²·año]*	

3. CALIFICACIÓN PARCIAL DE LA DEMANDA ENERGÉTICA DE CALEFACCIÓN Y REFRIGERACIÓN

La demanda energética de calefacción y refrigeración es la energía necesaria para mantener las condiciones internas de confort del edificio.

DEMANDA DE CALEFACCIÓN		DEMANDA DE REFRIGERACIÓN	
	126.89 E		125.89 E
Demanda de calefacción [kWh/m²·año]		*Demanda de refrigeración [kWh/m²·año]*	

1 El indicador global es resultado de la suma de los indicadores parciales más el valor del indicador para consumos auxiliares, si los hubiera (sólo edificios terciarios, ventilación, bombeo, etc…). La energía eléctrica autoconsumida se descuenta únicamente del indicador global, no así de los valores parciales.

Fecha (de generación del documento) -

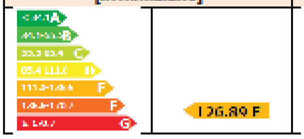
Ref. Catastral -

Página X de X

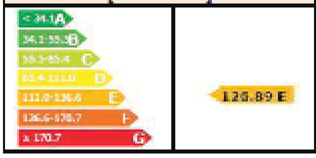
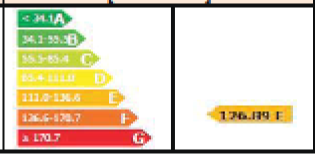
ANEXO III
RECOMENDACIONES PARA LA MEJORA DE LA EFICIENCIA ENERGÉTICA

Denominación

CALIFICACIÓN ENERGÉTICA GLOBAL

CONSUMO DE ENERGÍA PRIMARIA NO RENOVABLE [kWh/m2.año]	EMISIONES DE DIÓXIDO DE CARBONO [$kgCO_2/m^2$·año]
	

CALIFICACIONES ENERGÉTICAS PARCIALES

DEMANDA DE CALEFACCIÓN [kWh/m^2·año]	DEMANDA DE REFRIGERACIÓN [kWh/m^2·año]
	

ANÁLISIS TÉCNICO

Indicador	Calefacción			Refrigeración			ACS			Iluminación			Total		
	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original	Valor		ahorro respecto a la situación original
Consumo Energía final [kWh/m^2·año]	150,3		12,8%												
Consumo Energía primaria no renovable [kWh/m^2·año]	180,4	D	10,2%												
Emisiones de CO_2 [$kgCO_2/m^2$·año]															
Demanda [kWh/m^2·año]															

Nota: Los indicadores energéticos anteriores están calculados en base a coeficientes estándar de operación y funcionamiento del edificio, por lo que solo son válidos a efectos de su calificación energética. Para el análisis económico de las medidas de ahorro y eficiencia energética, el técnico certificador deberá utilizar las condiciones reales y datos históricos de consumo del edificio.

DESCRIPCIÓN DE MEDIDA DE MEJORA
Características técnicas de la medida (modelo de equipos, materiales, parámetros característicos) *(Según anexo ...)*
Coste estimado de la medida
Otros datos de interés

Fecha (de generación del documento) -
Ref. Catastral -
Página X de X

ANEXO IV
PRUEBAS, COMPROBACIONES E INSPECCIONES REALIZADAS POR EL TÉCNICO CERTIFICADOR

Se describen a continuación las pruebas, comprobaciones e inspecciones llevadas a cabo por el técnico certificador durante el proceso de toma de datos y de calificación de la eficiencia energética del edificio, con la finalidad de establecer la conformidad de la información de partida contenida en el certificado de eficiencia energética.

Fecha de realización de la visita del técnico certificador	

Appendix III: List of Municipalities in Barcelona Metropolitan Area

Table Appendix 3 List of municipalities in BMA

NO.	Municipal Code	Municipal Name	Habitants (2019)	Area (km^2)	Density(Hab/km^2)
1	8001	Abrera	10,840	20	542
2	8003	Alella	8,998	10	900
3	8005	Ametlla del Vallès (L')	7,632	14	545
4	8006	Arenys de Mar	14,164	6	2,361
5	8007	Arenys de Munt	7,807	21	372
6	8009	Argentona	11,402	25	456
7	8013	Avinyonet del Penedès	1,588	29	55
8	8015	Badalona	219,547	21	10,356
9	8019	Barcelona	1,621,537	101	15,991
10	8020	Begues	6,271	50	125
11	8023	Bigues i Riells	7,807	28	279
12	8025	Bruc (El)	1,743	47	37
13	8027	Cabanyes (Les)	842	1	842
14	8028	Cabrera d'Igualada	36,923	8	4,615
15	8029	Cabrera de Mar	4,269	9	474
16	8030	Cabrils	6,698	7	957
17	8032	Caldes d'Estrac	2,672	1	2,672
18	8033	Caldes de Montbui	16,159	38	425
19	8035	Calella	18,034	8	2,254
20	8039	Campins	515	7	71
21	8040	Canet de Mar	13,181	5	2,929
22	8041	Canovelles	15,704	7	2,243
23	8042	Cànoves i Samalús	2,995	28	105
24	8043	Canyelles	3,783	14	270
25	8046	Cardedeu	15,775	12	1,315
26	8051	Castellar del Vallès	22,007	45	489
27	8054	Castellbisbal	11,977	31	386
28	8056	Castelldefels	62,080	13	4,775
29	8058	Castellet i la Gornal	2,044	47	43
30	8065	Castellví de la Marca	1,603	29	55
31	8066	Castellví de Rosanes	1,576	16	99
32	8068	Cervelló	8,393	22	382
33	8069	Collbató	3,780	18	210
34	8072	Corbera de Llobregat	13,843	18	769
35	8073	Cornellà de Llobregat	86,519	7	12,360
36	8074	Cubelles	12,773	14	912
37	8075	Dosrius	4,658	41	114
38	8076	Esparreguera	21,260	27	787
39	8077	Esplugues de Llobregat	46,862	5	9,372

NO.	Municipal Code	Municipal Name	Habitants (2019)	Area (km^2)	Density(Hab/km^2)
40	8081	Fogars de Montclús	446	39	11
41	8082	Fogars de la Selva	1,437	32	45
42	8085	Font-rubí	1,430	37	39
43	8086	Franqueses del Vallès (Les)	15,775	30	526
44	8087	Gallifa	172	16	11
45	8088	Garriga (La)	14,183	19	746
46	8089	Gavà	45,994	31	1,484
47	8091	Gelida	6,151	27	228
48	8094	Granada (La)	1,866	6	311
49	8096	Granollers	60,658	15	4,044
50	8097	Gualba	1,065	23	46
51	8101	Hospitalet de Llobregat (L')	1,621,537	101	15,991
52	8105	Llagosta (La)	13,517	3	4,506
53	8106	Llinars del Vallès	8,581	28	306
54	8107	Lliçà d'Amunt	13,491	22	613
55	8108	Lliçà de Vall	6,088	11	553
56	8110	Malgrat de Mar	17,822	9	1,980
57	8114	Martorell	25,844	13	1,988
58	8115	Martorelles	4,893	4	1,223
59	8118	Masnou (El)	21,935	3	7,312
60	8119	Masquefa	7,747	17	456
61	8120	Matadepera	8,266	25	331
62	8121	Mataró	121,722	22	5,533
63	8123	Molins de Rei	24,067	16	1,504
64	8124	Mollet del Vallès	51,365	11	4,670
65	8125	Montcada i Reixac	33,453	23	1,454
66	8126	Montgat	10,270	3	3,423
67	8135	Montmeló	8,873	4	2,218
68	8136	Montornès del Vallès	14,723	10	1,472
69	8137	Montseny	342	27	13
70	8145	Olèrdola	3,280	30	109
71	8146	Olesa de Bonesvalls	1,556	31	50
72	8147	Olesa de Montserrat	22,257	17	1,309
73	8148	Olivella	2,842	39	73
74	8153	Òrrius	487	6	81
75	8154	Pacs del Penedès	831	6	139
76	8155	Palafolls	8,061	16	504
77	8156	Palau-solità i Plegamans	13,594	15	906
78	8157	Pallejà	11,134	8	1,392
79	8158	Papiol (El)	3,900	9	433
80	8159	Parets del Vallès	16,720	9	1,858
81	8161	Piera	13,652	57	240
82	8162	Hostalets de Pierola (Els)	2,219	34	65

NO.	Municipal Code	Municipal Name	Habitants (2019)	Area (km^2)	Density(Hab/km^2)
83	8163	Pineda de Mar	25,568	10	2,557
84	8164	Pla del Penedès (El)	891	9	99
85	8167	Polinyà	7,105	9	789
86	8168	Pontons	458	26	18
87	8169	Prat de Llobregat (El)	63,418	31	2,046
88	8172	Premià de Mar	27,590	2	13,795
89	8174	Puigdàlber	449	1	449
90	8179	Rellinars	658	18	37
91	8180	Ripollet	37,088	4	9,272
92	8181	Roca del Vallès (La)	9,656	37	261
93	8184	Rubí	70,006	32	2,188
94	8187	Sabadell	206,493	38	5,434
95	8193	Sant Iscle de Vallalta	1,193	18	66
96	8194	Sant Adrià de Besòs	33,761	4	8,440
97	8196	Sant Andreu de la Barca	26,401	6	4,400
98	8197	Sant Andreu de Llavaneres	9,745	12	812
99	8198	Sant Antoni de Vilamajor	5,091	14	364
100	8200	Sant Boi de Llobregat	82,428	22	3,747
101	8202	Sant Celoni	15,992	65	246
102	8203	Sant Cebrià de Vallalta	3,075	16	192
103	8204	Sant Climent de Llobregat	3,779	11	344
104	8205	Sant Cugat del Vallès	87,118	48	1,815
105	8206	Sant Cugat Sesgarrigues	927	6	155
106	8207	Sant Esteve de Palautordera	2,245	11	204
107	8208	Sant Esteve Sesrovires	6,704	19	353
108	8209	Sant Fost de Campsentelles	7,656	13	589
109	8210	Sant Feliu de Codines	5,495	15	366
110	8211	Sant Feliu de Llobregat	42,919	12	3,577
111	8214	Vilassar de Dalt	8,476	9	942
112	8217	Sant Joan Despí	32,030	6	5,338
113	8219	Vilassar de Mar	19,052	4	4,763
114	8221	Sant Just Desvern	15,811	8	1,976
115	8222	Sant Llorenç d'Hortons	2,219	20	111
116	8223	Sant Llorenç Savall	2,371	41	58
117	8227	Sant Martí Sarroca	2,997	35	86
118	8230	Premià de Dalt	9,788	7	1,398
119	8231	Sant Pere de Ribes	275,090	41	6,710
120	8232	Sant Pere de Riudebitlles	2,319	5	464
121	8234	Sant Pere de Vilamajor	3,728	35	107
122	8235	Sant Pol de Mar	4,904	8	613
123	8238	Sant Quirze del Vallès	17,819	14	1,273
124	8240	Sant Sadurní d'Anoia	11,790	19	621
125	8244	Santa Coloma de Cervelló	7,744	7	1,106

NO.	Municipal Code	Municipal Name	Habitants (2019)	Area (km^2)	Density(Hab/km^2)
126	8245	Santa Coloma de Gramenet	119,717	7	17,102
127	8248	Santa Eulàlia de Ronçana	6,458	14	461
128	8249	Santa Fe del Penedès	366	3	122
129	8251	Santa Margarida i els Monjos	6,459	17	380
130	8252	Barberà del Vallès	31,144	6	5,191
131	8256	Santa Maria de Martorelles	806	4	202
132	8259	Santa Maria de Palautordera	8,235	17	484
133	8260	Santa Perpètua de Mogoda	23,443	16	1,465
134	8261	Santa Susanna	3,019	13	232
135	8263	Sant Vicenç dels Horts	27,701	9	3,078
136	8264	Sant Vicenç de Montalt	5,267	8	658
137	8266	Cerdanyola del Vallès	58,747	32	1,836
138	8267	Sentmenat	7,376	28	263
139	8270	Sitges	27,668	44	629
140	8273	Subirats	3,008	56	54
141	8279	Terrassa	210,941	70	3,013
142	8281	Teià	5,969	7	853
143	8282	Tiana	7,590	8	949
144	8284	Tordera	14,017	84	167
145	8287	Torrelavit	1,275	24	53
146	8288	Torrelles de Foix	2,348	37	63
147	8289	Torrelles de Llobregat	5,430	14	388
148	8290	Ullastrell	1,687	7	241
149	8291	Vacarisses	5,431	41	132
150	8294	Vallgorguina	2,193	22	100
151	8295	Vallirana	13,326	24	555
152	8296	Vallromanes	2,204	11	200
153	8300	Viladecavalls	7,079	20	354
154	8301	Viladecans	63,489	20	3,174
155	8304	Vilobí del Penedès	1,071	9	119
156	8305	Vilafranca del Penedès	36,656	20	1,833
157	8306	Vilalba Sasserra	588	6	98
158	8307	Vilanova i la Geltrú	63,196	34	1,859
159	8902	Vilanova del Vallès	4,121	15	275
160	8904	Badia del Vallès	13,679	1	13,679
161	8905	Palma de Cervelló (La)	3,057	5	611
162	17023	Blanes	38,368	18	2,132
163	17027	Breda	3,707	5	741
164	17083	Hostalric	3,773	3	1,258
165	17095	Lloret de Mar	34,997	49	714
166	17101	Massanes	730	26	28
167	17146	Riells i Viabrea	3,465	26	133
168	17159	Sant Feliu de Buixalleu	804	61	13

NO.	Municipal Code	Municipal Name	Habitants (2019)	Area (km^2)	Density(Hab/km^2)
169	17202	Tossa de Mar	5,662	38	149
170	43002	Albinyana	2,200	19	116
171	43016	Arboç (L')	5,063	14	362
172	43020	Banyeres del Penedès	2,696	12	225
173	43024	Bellvei	1,840	8	230
174	43028	Bisbal del Penedès (La)	3,528	33	108
175	43030	Bonastre	584	25	23
176	43037	Calafell	21,871	20	1,094
177	43051	Cunit	11,102	10	1,110
178	43074	Llorenç del Penedès	2,393	5	516
179	43120	Querol	507	72	7
180	43131	Roda de Barà	5,586	16	349
181	43135	Salomó	445	12	37
182	43137	Sant Jaume dels Domenys	2,622	24	107
183	43140	Santa Oliva	2,988	9	332
184	43163	Vendrell (El)	33,340	37	901

Appendix IV: Original Publications

THE MARGINAL PRICE OF HOUSING ENERGY-EFFICIENCY IN METROPOLITAN BARCELONA: ISSUES OF SAMPLE SELECTION BIASES

EL PRECIO MARGINAL DE LA EFICIENCIA ENERGÉTICA DE LA VIVIENDA EN LA BARCELONA METROPOLITANA: PROBLEMAS DE SESGO DE SELECCIÓN DE MUESTRAS

CHEN, Ai
Department of Architectural Technology (TA), Centre of Land Policy and Valuations (CPSV)
Technical University of Catalonia (UPC)
PhD student
Av. Diagonal, 649, 4th floor, Barcelona, C.P. 08028, Spain
E-mail: ai.chen@upc.edu
Telephone: +34 934054385

MARMOLEJO-DUARTE, Carlos
Department of Technology of Architecture (TA), Center for Land Policy and Valuations (CPSV)
Polytechnic University of Catalonia (UPC)
Associated Professor
Av. Diagonal, 649, 4th floor, Barcelona, C.P. 08028, Spain
E-mail: carlos.marmolejo@upc.edu
Telephone: +34 934054385

Key words: sample selection biases; energy-efficiency price; EPCs; Metropolitan Barcelona

Palabras clave: sesgos de selección de muestra; precio de la eficiencia energética; EPCs; Barcelona Metropolitana

Abstract

Purpose

Housing energy-efficiency has become a hot issue in the residential sector along with the mandatory requirement by EPBD to exhibit an energy performance certificates (EPC) when transacting real estate. Numerous studies have focused on energy-efficient marginal price using hedonic price models. Nevertheless, in some markets such as the Spanish one a vital proportion of properties to be let or sold do not exhibit the EPCs in the real estate advertisement. By not considering this issue the impact of EPCs on housing prices may result biased. In other words, those cases without EPC labels that are not considered, when analyzing impacts of energy label on housing prices, do actually matter to them. This ignorance of sample selection bias may reduce the accuracy of results, or even give an adverse estimation. In this case, we aim to explore the presence of sample selection bias and correcting these biases for better the following studies.

Methodology

A collected selling listing prices from Habitaclia, one of the leading web-based real estate listings in Catalonia is the main source of information and Heckman model is used to identify the likelihood of selection bias in metropolitan Barcelona by the two-step method, including a Selection model and a Hedonic Price model. After tested robustness and quantized the bias

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

from those non-EPC-labeled properties, an energy-efficient premium will be revised and compared with the traditional OLS estimate results.

Conclusion

The estimation results suggest that the sample selection indeed exist and does matter to energy-efficient premium in Barcelona Metropolitan. This premium increases from 9.6% to 12.6% when houses improve energy ranking from G to A, or from 0.9% to 2% with every ranking increasing after correcting those sample selection bias. At the same time, we found that the effect of sample selection bias is stronger where properties are higher with medium-high floor area size.

Resumen

Propósito

La eficiencia energética de la vivienda se ha convertido en un problema desde la obligatoriedad impuesta por la EPBD de exhibir un certificado de eficiencia energético (EPC) al realizar transacciones de bienes raíces. Numerosos estudios se han centrado en precios marginales de la eficiencia energética utilizando modelos de precios hedónicos. Sin embargo, en algunos mercados como el español, una importante proporción de propiedades en alquiler o venta no exhiben los EPC en el anuncio inmobiliario. Al no considerar este tema, el impacto de las EPC en los precios de la vivienda puede resultar sesgado. En otras palabras, estos casos sin etiquetas EPC no pueden ser considerados. Este desconocimiento del sesgo de la selección de la muestra puede reducir la precisión de los resultados, o incluso dar una estimación adversa. En este caso, el objetivo de este trabajo es explorar la presencia del sesgo en la selección de la muestra y corregirlo, para mejorar los siguientes estudios.

Metodología

Se utilizan, como principal fuente de información, los listados de propiedades inmobiliarias de *Habitaclia*, empresa líder en Internet en Cataluña y se aplica el modelo de Heckman para identificar la probabilidad de sesgo de la selección en la Barcelona Metropolitana, mediante el método de dos pasos, que incluye el modelo de Selección y el modelo de Precios Hedónicos. Después de probar la robustez y cuantificar el sesgo de las propiedades no etiquetadas con EPC, se revisará eficiencia energética Premium y se comparará con los resultados de la estimación tradicional de OLS.

Conclusión

En la Barcelona Metropolitana, los resultados de la estimación sugieren que la selección de la muestra es efectiva y que si importa la eficiencia energética Premium. Esta prima aumenta del 9.6% al 12.6% en el caso de viviendas que mejoran su ranquing energético desde G a A, o desde 0,9% a 2%, con cada aumento de clasificación, después de corregir el sesgo de selección de muestra. Al mismo tiempo, encontramos el efecto que el efecto del sesgo de selección de la muestra es más fuerte en las propiedades son más grandes con una superficie media-alta.

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

1. Introduction

Energy efficiency in the housing sector has become a hot issue along with Energy Performance Certificates (EPCs) introduced by Energy Performance of Buildings Directives (EPBD) in 2002. Numerous studies have concluded the EPC impacts on housing prices by hedonic models. Brounen and Kok (2011) indicated that there is an energy-efficiency premium 3.6% with energy ranking increase in Netherland. Fuest et al. (2015) found in England and Wales, an 11.8% housing premium increases when dwellings improved from ranking G to ranking A. Likewise, Hyland et al. (2013) found the same trend of the increase premium is higher when selling in Ireland. Bottero and Bravi (2014) indicated the detailed 26.44 euros per square meter increase with energy ranking in Turin. De Ayala et al. (2016) suggested in Spanish 5 cities, there is housing prices premium after making a survey to ask for the opinion value from households. Marmolejo (2016) concluded there is a 0.85% increase on housing prices in Metropolitan Barcelona Area while in 2019, the premium increase to 1.4% with energy ranking (Marmolejo and Chen, 2019). However, there are still studies out of conspicuous premium or total inverse penalty on housing prices (Bio intelligence et al. 2013; Fregonara et al. 2017).

Regarding sample selection biases, a number of studies has indicated that selection bias do matter to housing prices and residential analysis (Jud and Seaks, 1994; Gatzlaff and Haurin, 1998; Hill, 2011; Hedman and Van-Ham, 2012). They proposed that a necessary selection biased correction should implement before any hedonic price models and calculations. They indicated the missing test for sample selection biases might have an inverse impact on estimation results or the conclusion. For this reason, Heckman two-step method was put forward by Heckman (1976) and developed by following relative studies (Heckman, 1977, 1986, 1990; Puhani, 2000). They suggested that the biases can be estimated by a procedure where a proxy variable could be produced and the Heckman two-step model is the best choice to solve the selection biases. Gordon and Winkler (2016) applied a corrected-biased model to explore the impacts of the price percentage discount in housing prices in North Alabama. They found a discount impact 2.98% was made after correcting sample selection biases. The same conclusions were suggested using the Heckman two-step model by Seko and Sumita (2007) and Gracias and Enriques (2008). They indicated that the impact of the tenure choice is negative when properties were transacted. However, just a few studies show attention to the sample selection biases when analyzing the relationship between EPC and housing prices. Brounen and Kok (2011) found that homes with a “green” label sell at a premium of 3.6% relative to otherwise comparable dwellings with non-green labels using Heckman two-step method. In such case, this paper is to explore the presence of selection biases and to correct these biases by the Heckman two-step model, as an initial analysis of hedonic housing prices.

The remainder of this paper is organized as follows: first, a general introduction to the methodology and models in detail; next, a description of the scope of the study and data statistics; followed by the results and discussion; and finally as a conclusion and acknowledge.

2. Methodology

After having delimited the case study, the method has consisted in 4 steps:

1) First, a sample depuration procedure will be made by eliminating cases which prices was +/- standard deviation above or below average price and using Mahalanobis distance.

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. “Ciudades y Territorios Inteligentes”. UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

2) Second, a Probit model will be elaborated which can be regarded as the selection equation model of Heckman two-step model. In this model, dependent variable is a binary one where the energy-labeled dwellings is equal to 1 and otherwise is 0. Subsequently, a new variable - "Inverse Mills Ratio" (IMR) will be produced which represents the existence of sample selection biases if the P-value of IMR is less than 0.05 (confidence level =95%).

3) Third, a four-equation OLS hedonic price model will be built into 2 groups where the difference is the expressive forms of energy label in dwellings. Noted the IMR variable will be applied in these two groups to correct impacts of sample selection biases.

4) Finally, estimation results from the former four equations will be analyzed to identify the corrected impacts of sample selection biases, and a coefficient-estimated distribution of energy label and related variables also will be made as maps by ArcGIS.

2.1 Heckman two-step Model

Often, dwellings without energy-labels, according to previous literature, fail to estimate in the study to explore impacts of energy label on housing prices. However, such dwellings have influence on the local housing prices and housing prices of energy-label equipped dwellings, in turn, will be affected by the condition of local real estate markets. That is to say, those cases we used are non-random ones and this ignorance may lead to bias in our estimation.

In order to identify and eliminate this bias, an econometric model called Heckman two-step model was made by Heckman (1976). He pointed that the maximum likelihood estimation of a nonlinear model (e.g. Probit model) produced consistence, asymptotically normal estimator and the usual standard error and test statistics are valid if the selection is entirely a function of the exogenous variables. Heckman two-step model is made of 2 equations:

2.1.1 Selection equation - Probit model

Using all n cases, estimate a probit model of a series related buildings and economic characteristics and factors on the presence of energy label for a dwelling. Then IMR is produced to identify the existence of sample selection biases.

$$Dum\_EPC_i = \beta_i + \sum_{s=1}^{n} \beta_{is} SD_{is} + \sum_{k=1}^{n} \beta_{ik} SB_{ik} + \sum_{m=1}^{n} \beta_{im} A_{im} + \sum_{f=1}^{n} \beta_{if} E_{if} + \sum_{a=1}^{n} \beta_a S_{ia} + \varepsilon_i$$

In equation (I), the existence of EPC of an apartment i depends on a set of variables related to SD structural attributes of dwellings; SB structural attributes of buildings; A accessibility indicators; E environmental quality indicator; S socioeconomic hierarchy indicator while ϵ is a vector representing the random error.

In the SD and SB dimension, there are covariates and factors related to physical structural features (such as dwelling's and building's quality) and facilities (such as lift, heating as well as air conditioner). It is worth saying, heating and air conditioner as well as the presence of reform of dwellings is correlated to energy efficiency, since in Spanish regulation and law of energy efficiency in buildings EPC is made of some items related to such facilities. This dimension also includes the EPC ranks that are mandatory to be noted in the advertisement of properties as it has been sold.

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

The A dimension includes accessibility indicators, such as centrality index, average time to work. It is worth saying that centrality index is an integrated variable which includes information of time-density, density of activities, distance travelled by people making activities in a given zone by using DP2 methodology (Pena, 1977; Zarzosa, 2009).

The E dimension includes perception of the presence of green areas and percentage of different functional facilities (e.g. health facility, social services, cultural premises). It is supposed that higher proportion of such facilities proportion in a city or in local districts will contribute to a higher housing price premium due providing to a satisfactory living environment.
In the S dimension, education and income level and are key factors. It includes the percentage of residents holding a university degree living around each of the analyzed apartments. In order to depict a wider picture of the socioeconomic structure of the city a Principal Component Analysis (PCA) has been computed departing from the professional categories (e.g. managers, clerks, blue-collar workers, etc.) of employed people living around each of the apartments. The resulting PC represents proxies for high and low-income population. Socioeconomic indicators are relevant for price formation and EPC rank market premium since income and education are correlated with purchasing power, social prestige and environmental concerns (Banfi et al., 2008; Himmelberg et al., 2005).

Noted that in this model, a new variable, IMR, is produced by the model calculation. It is the ratio of the probability density of fucntion over the cumuative distribution function of a distribution. This is usually applied to explore the presence of sample selection bias. The coefficient of inverse mills ration in probit model can explain the presence of selection bias if the P value is less than 0.05 (based on confidence level 95%)

2.1.2 OLS hedonic price equation

Hedonic price model is made by Rosen (1974). This method assumes that the price paid for the asset from housing buyers is equal to the total utility they extract from it, being this a composite utility coming from the marginal attribute of the dwelling (e.g. area, quality, location, etc.) It is possible to calculate such marginal utility expressed in monetary terms by a regression model.
In the literature little advice can be found on the functional form that hedonic modes shall adopt (Can, 1992; Sheppard, 1999; Malpezzi, 2003; Epple et al. 2014).

Nonetheless, the semi-log function has been intensively used in the context of real estate price analysis. Marmolejo and Gonzalez (2009) summarized advantages of semi-log function:

i) It helps to normalize the price and residual distributions which is fundamental for OLS regression analysis;

ii) Coefficients can be read as semi-elasticity (i.e. coefficients express marginal price variation in percent terms for each unit of change), making it possible to directly compare the importance of the attributes with the results of other studies.

Four models are established by using the samples equipped with EPC label information as following:

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. “Ciudades y Territorios Inteligentes”. UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

$$MOD1: ln(\mathrm{P})_1 = \beta_{i1} + \sum_{s=1}^{n} \beta_{is} SD_{is} + \sum_{k=1}^{n} \beta_{ik} SB_{ik} + \sum_{m=1}^{n} \beta_{im} A_{im} + \sum_{f=1}^{n} \beta_{if} E_{if} + \sum_{a=1}^{n} \beta_{a} S_{ia} + \beta_{n1} EPC_{in} + \varepsilon_i$$

$$MOD2: ln(\mathrm{P})_2 = \beta_{i2} + \sum_{s=1}^{n} \beta_{is} SD_{is} + \sum_{k=1}^{n} \beta_{ik} SB_{ik} + \sum_{m=1}^{n} \beta_{im} A_{im} + \sum_{f=1}^{n} \beta_{if} E_{if} + \sum_{a=1}^{n} \beta_{a} S_{ia} + \beta_{n2} EPC_{in} + IMR + \varepsilon_i$$

$$MOD3: ln(\mathrm{P})_3 = \beta_{i3} + \sum_{s=1}^{n} \beta_{is} SD_{is} + \sum_{k=1}^{n} \beta_{ik} SB_{ik} + \sum_{m=1}^{n} \beta_{im} A_{im} + \sum_{f=1}^{n} \beta_{if} E_{if} + \sum_{a=1}^{n} \beta_{a} S_{ia} + \beta_{n3} EPC_{io} + \varepsilon_i$$

$$MOD4: ln(\mathrm{P})_4 = \beta_{i4} + \sum_{s=1}^{n} \beta_{is} SD_{is} + \sum_{k=1}^{n} \beta_{ik} SB_{ik} + \sum_{m=1}^{n} \beta_{im} A_{im} + \sum_{f=1}^{n} \beta_{if} E_{if} + \sum_{a=1}^{n} \beta_{a} S_{ia} + \beta_{n4} EPC_{io} + IMR + \varepsilon_i$$

Where:

EPC_{in} indicates the nominal EPC level in an apartment i (seven variables assigned 1 if it is in existence)

EPC_{io} indicates the ordinal EPC level in an apartment i (variable assigned as A=7, B=6, C=5, D=4, E=3, F=2, G=1)

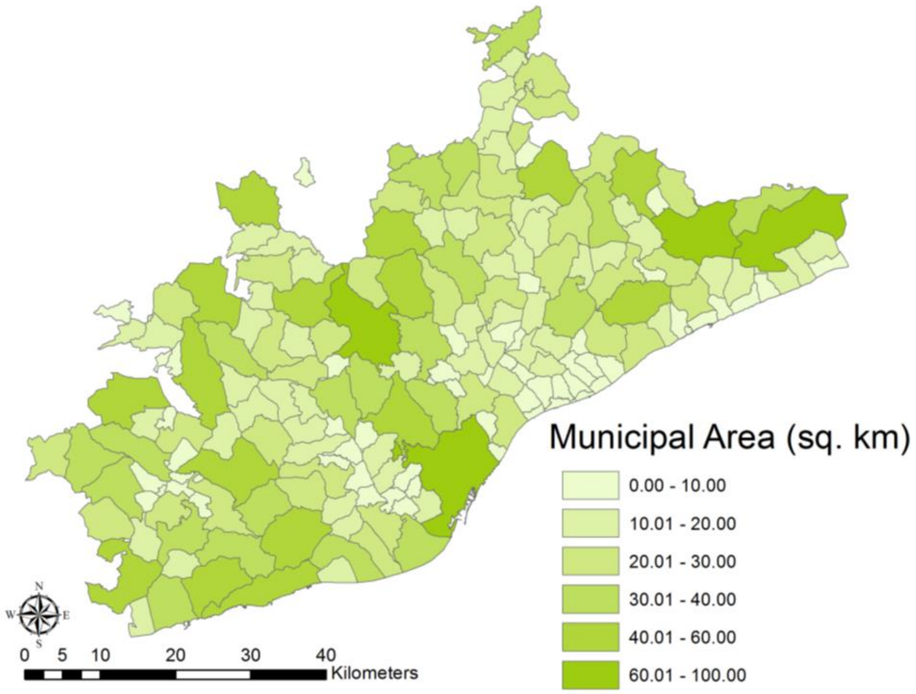
IMR means the Inverse Mills Ratio, the corrected variable of selection biases where it is come from the previous probit model.

2.2 Case study and data

2.2.1 Case study

Metropolitan Barcelona Area (MBA) is selected as case study. In order to identify the limits of this agglomeration the travel-to-work method based on interaction value of Roca et al. (2009) has been used, such approach allows also to detect centralities, which in turns is relevant for this study since accessibility to centers and sub-centres might influence residential prices. As a result, a selected-functional AMB is formed by 189 municipalities in 3,810 sq. km. comprising a population of 5.22 million people.

Figure 1. **Delimitation of Barcelona Metropolitan Area**



Source: own elaboration

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

2.2.2 Data sources

Selling listing prices for apartments coming from Habitaclia is the main source of information. Habitaclia is one of the leading web-based real estate listings in Catalonia. The original dataset comprises 35,116 flats and includes architectonic structural attributes as well as geo-locations. Data refers to November 2014, it is to say, almost 1 years after the RD 235/2013 has made it mandatory to include EPC label information in real estate advertising. Nonetheless such obligation in the sample only 15% of the offers do include energy information. It is worth saying, that autonomous community Catalonia is one of the regions in Spain with the higher proportion of certified houses.

In order to control all the location attributes that might influence apartments' listing price (i.e. environmental quality, accessibility and socioeconomic structure of neighborhoods) a comprehensive GIS has been built departing from the following complementary sources of information:

- *Dwelling and population census INE (2001):* It includes socioeconomic information of resident population as well as perception of noise annoyance at census track level and employment information and journey to work flows at municipal level. Data from the last 2011 census has been discarded since it is based in a survey that is not representative in statistical terms at census track level.
- *Metropolitan Transport of Barcelona (2005):* Street cartography has been used to identify the main transport axis as well as train and metro stations that have been conveniently digitalized. Departing from such information, the precise distance among census tracts has been calculated using TransCAD.
- *Cadastral database (2013):* The information of built-up density and area allocated from a selection of land use has been retrieved at census tract level.

2.2.3 Data description

All the contextual information has been incorporated into each of the analyzed flats using a spatial query departing from a buffer of 300 meters of radius around each dwelling. In order to eliminate extreme cases a twofold approach has been used: 1) first all the cases with price values located beyond +/- Std. Dev from the average valued have been removed, 2) second, the remaining cases have been depurated using the Mahalanobis Distance.

This latter procedure allows to remove the cases whose price is not explained by the covariates but rather by other unmeasured aspects, such as landscaping or specific insulation against noise pollution (Li, 2005). After filtering invalid cases, an effective sample with 4,248 labeled dwellings has been made.

Table 1 shows the statistical description of attributes for the 4,248 cases database. According to such data the average selling price for apartments is 211,396 Euro (implying a unitary price of 2,197 Euro/sq. m.), the area of an average aparment is 89 sq. m, and has 1.36 bathrooms. Regarding the facilities of condominium, 6% of apartments are equipped with swimming pool and 48% have lift; 33% of the listed apartments have air conditioners and 46% heating systems. The area of terraces and balconies in very dense and hot Mediterranean cities is pretty well appreciated by housing demand.

Regarding EPC rank the average class is 2.72, where the most efficient class in Spain is A=7 and the worst is G=1, only 15.77% of the sample is ranked as class A, B or C. All in all, it depicts a housing stock where thermal energy efficiency has a large room for improvement.

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

Table 1. **Descriptive statistics for depurated sample**

Dimensions	Variables	N	Minimum	Maximum	Mean	Std. Deviation
Structual Characteristics of Dwelling	Price (Euro)	4,248	22,800	8,000,000	211,396	251,925
	Unit price (Euro/sq.m)	4,248	304	15,385	2,197	1,352
	Area (sq.m)	4,248	25	600	89	39
	Number of bathrooms	4,248	0	6	1.36	0.60
	Number of rooms	4,248	0	15	2.95	0.96
	Ratio bathrooms/rooms	4,248	0	3	0.49	0.23
	Energy Rating (ordinal)	4,248	1	7	2.72	1.29
	Level of the apartment in the building	4,248	0	18	2.26	1.83
	Balcony or terrace areas (sq.m)	4,248	0	256	10.77	16.67
	Living room area (sq.m)	4,248	0	100	12.61	11.13
	Air conditioner (dummy)	4,248	0	1	0.33	0.47
	Heating (dummy)	4,248	0	1	0.46	0.50
	Quality/retrofit (dummy)	4,248	0	1	0.11	0.31
	Penthouse (dummy)	4,248	0	1	0.04	0.20
	Duplex/triplex (dummy)	4,248	0	1	0.05	0.22
Structual Characteristics of Building	Communal swimming pool (dummy)	4,248	0	1	0.06	0.24
	Communal garden (dummy)	4,248	0	1	0.10	0.30
	Elevator (dummy)	4,248	0	1	0.48	0.50
Accessibility Indicators	Built density (area floor ratio)	4,248	0.19	5.90	2.08	1.37
	Time-density	4,248	324	1,154,882	136,251	171,947
	Centrality index	4,248	2.52	20.53	11.59	2.54
	Land use diversity (of the context)	4,248	0.35	1.64	1.04	0.22
	Diversity of activities (of the context)	4,248	0.00	1.92	1.32	0.27
	Average time to work (minutes)	4,248	7.95	37.01	23.31	4.48
	Land use diversity at street level	4,248	0.00	90.10	12.93	14.16
Environmental Quality indicators	Average age of buildings (of the context)	4,248	21.17	124.35	55.65	16.29
	Perception of the presence of green areas	4,248	12.45	97.89	64.00	14.00
	% Health facilities (of the context)	4,248	0.00	41.88	2.08	2.96
	% Educational premises (of the context)	4,248	0.00	93.00	2.17	3.08
	% Social services premises (of the context)	4,248	0.00	68.47	1.84	4.30
	% Cultural premises (of the context)	4,248	0.00	95.15	1.64	3.87
	% Premises for trade (of the context)	4,248	0.00	89.93	40.75	13.55
	% Premises for offices (of the context)	4,248	0.00	100.00	16.52	14.12
	% Industrial premises (of the context)	4,248	0.00	97.01	8.88	11.26
Indicators of Social Hierarchy	% People holding university degree (of the context)	4,248	2.34	68.73	21.78	14.38
	% buildings with porter services (of the context)	4,248	0.00	84.67	8.34	10.59
	CP low socioeconomic level	4,248	-1.97	7.42	0.03	0.96
	CP high socioeconomic level	4,248	-3.26	7.16	-0.21	0.85

Source: own elaboration

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

3. Results and discussion

3.1 The presence of sample selection biases

Table 2 shows the estimation results of the selection model where the dependent variable is the presence of EPC information when transacting in the market. It is a dummy variable where dwellings equipped EPC label is equal to 1, otherwise 0.

In Table 2, the appliances (e.g. air conditioning and heating) and facilities in buildings (e.g. lift and public swimming pool) do matter to the presence of EPC but their impacts are negative. We deduce that the insulation function in energy-efficient dwellings is better than those unequipped ones, especially considering Mediterranean climate in Barcelona Metropolitan. For a better energy–efficient dwelling, that is to say, it is likely to resist the presence of the air conditionings and heatings.

Noted Here the p-value of IMR is close to 0.000, indicating selection biases in this sample indeed exist. Subsequently, this corrected variable, IMR, will be introduced into the following hedonic models to detect and revise those selection biases.

Table 2. **Estimation Results of Selection Model (Probit Model)**

	Coef.	Std. Err.	z	P>z	[95% Conf.Interval]	
Dependent Variable:Dum_EPC						
Constant	-1.12	0.094	-11.850	0.000	-1.304	-0.934
Unit price (Euro/sq.m)	0.00	0.000	2.520	0.012	0.000	0.000
Area (sq.m)	0.00	0.000	0.780	0.433	0.000	0.001
Level of the apartment in the building	0.03	0.005	5.390	0.000	0.016	0.034
Balcony or terrace areas (sq.m)	0.00	0.000	-0.950	0.341	-0.001	0.000
Living room area (sq.m)	0.00	0.001	-3.530	0.000	-0.004	-0.001
Air conditioner (dummy)	-0.03	0.022	-1.590	0.112	-0.078	0.008
Heating (dummy)	-0.28	0.023	-12.380	0.000	-0.326	-0.237
Quality/retrofit (dummy)	-0.04	0.028	-1.320	0.186	-0.091	0.018
gran terrace	0.00	0.000	0.200	0.843	-0.001	0.001
Communal swimming pool (dummy)	-0.11	0.043	-2.500	0.012	-0.192	-0.023
Communal garden (dummy)	0.02	0.034	0.570	0.567	-0.048	0.087
Elevator (dummy)	-0.18	0.021	-8.540	0.000	-0.224	-0.140
Built density (area floor ratio)	-0.02	0.011	-1.850	0.064	-0.041	0.001
Centrality index	0.00	0.005	0.520	0.602	-0.008	0.013
Perception of the presence of green areas	0.00	0.001	0.860	0.392	-0.001	0.002
% People holding university degree (of the context)	0.01	0.002	3.830	0.000	0.003	0.010
% buildings with porter services (of the context)	-0.01	0.001	-4.400	0.000	-0.009	-0.003
CP low socioeconomic level	0.01	0.019	0.580	0.559	-0.026	0.048
CP high socioeconomic level	-0.16	0.035	-4.540	0.000	-0.226	-0.090
	Coef.	**Std. Err.**	**z**	**P>z**	**[95% Conf.Interval]**	
IMR	-1.19	0.151	-7.900	0.000	-1.489	-0.897
rho	-1.00					
sigma	1.19					

Note: Dependent variables is the dummy of EPC in dwellings. Coefficients (Coef.), Standard Error (Std.Err.), Confidence (Conf.). The grey variables mean they could not represent the effect of variables on the presence of EPC.
Source: own elaboration

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. “Ciudades y Territorios Inteligentes”. UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

3.2 Corrected samples selection biases on housing prices

Table 3 shows the estimation results of various hedonic models where column 1 (MOD1) and column 3 (MOD3) are the ordinary least squares (OLS) models separated by the nominal and ordinal EPC variables. The other two columns are the results of the Heckman two-step model by IMR variables corrected the samples selection biases. Noted that variables show significance at confidence of 95% and ranking G is the control group.

Table 3. **Estimation Results of Hedonic Models**

		MOD1 **(OLS Model)**	MOD2 **(Heckman two-step Model)**	MOD3 **(OLS Model)**	MOD4 **(Heckman two-step Model)**
	R square	0.654	0.721	0.653	0.721
	R square adjusted	0.652	0.720	0.651	0.720
	Sigma	0.2859	0.3661	0.2862	0.3660
	(Constant)	10.236*** (0.05)	10.861*** (0.151)	10.229*** (0.05)	10.840*** (0.152)
	IMR		-0.408*** (0.094)		-0.410*** (0.094)
Structural characteristics of dwellings	**Area (sq.m)**	0.018*** (0.001)	0.011*** (0.000)	0.018*** (0.001)	0.011*** (0.000)
	Air conditioner	0.101*** (0.013)	0.146*** (0.017)	0.101*** (0.013)	0.146*** (0.017)
	Number of bathrooms	0.064*** (0.012)	0.128*** (0.013)	0.062*** (0.012)	0.129*** (0.013)
	Heating	0.044*** (0.013)	0.182*** (0.031)	0.046*** (0.013)	0.184*** (0.031)
	Quality/retrofit indicator	0.042** (0.017)	0.066*** (0.021)	0.043** (0.017)	0.066** (0.021)
	Area^2	0.000*** (0.000)	0.000*** (0.000)	0.002*** (0.000)	0.003*** (0.000)
Structural characteristics of buildings	**Lift*floor level**	0.012*** (0.002)	0.022*** (0.003)	0.013*** (0.002)	0.022*** (0.003)
	Communal swimming pool	0.134*** (0.026)	0.293*** (0.029)	0.136*** (0.026)	0.294*** (0.029)
Accessibility	**Floor/area ratio**	0.038*** (0.006)	0.052*** (0.007)	0.038*** (0.006)	0.052*** (0.007)
	Centrality indicator	0.01*** (0.003)	0.025*** (0.004)	0.01*** (0.003)	0.025*** (0.004)
Socio hierarchy	**% people holding university**	0.005*** (0.001)	-0.007*** (0.001)	0.005*** (0.001)	0.007*** (0.001)
	CP high socioeconomic level	0.061*** (0.014)	0.101*** (0.019)	0.061*** (0.014)	0.101*** (0.019)
	% buildings with porter services	0.004*** (0.001)	0.003*** (0.001)	0.005*** (0.001)	0.003*** (0.001)
Energy rating	**A**	0.096*** (0.034)	0.126*** (0.037)		
	C	-0.027 (0.026)	0.071** (0.029)		
	D	0.039* (0.019)	0.058*** (0.022)		
	E	0.022 (0.013)	0.036** (0.015)		
	F	0.011 (0.017)	0.007 (0.020)		
	Ord_EPCs			0.009* (0.004)	0.020*** (0.005)

Notes: Dependent variable is ln (total price); *** significance at 99%, ** significance at 95%, *significance at 90%; The grey variables mean they could not represent the effect of variables on the presence of EPC.

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

ISBN: 978-84-8157-661-0

After correcting sample selection biases by IMR, the R square increase from 0.65 to 0.72. That is to say, the model with the same variables can explain more than 7% cases, which can strengthen the persuasion and results' accuracy. Noted that IMR shows a negative impact on housing prices. The less selection biases, that is to say, the higher housing prices premium.

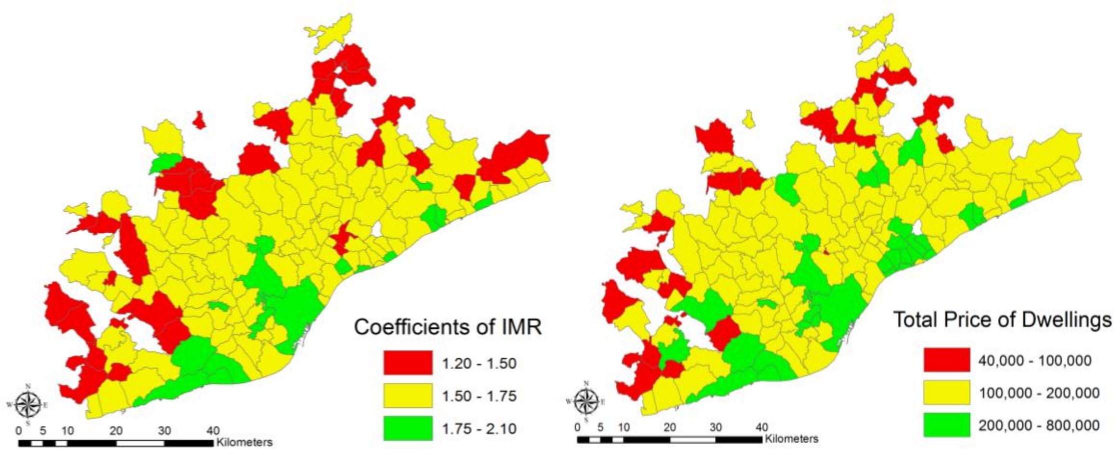
Majority variables show an increase premium on housing prices after biases corrected, especially the impact of the presence of heating and public swimming pool on housing prices, around 15% premium growth. The same conclusion we have concluded from the previous selection model where appliances and facilities in buildings contributed to the presence of EPC.

Regarding energy efficiency information, an energy-efficient premium on housing prices increases from 9.6% to 12.6% when dwellings are improved from ranking G to ranking A or from 0.9% to 2% with energy ranking increase after corrected sample selection biases. Noted that more nominal EPC variables show the significant impacts on housing prices (e.g. ranking C and ranking E). It is to say that sample selection biases may not only influence on estimation results but also on model specification.

3.3 Selection biases impacts across urban

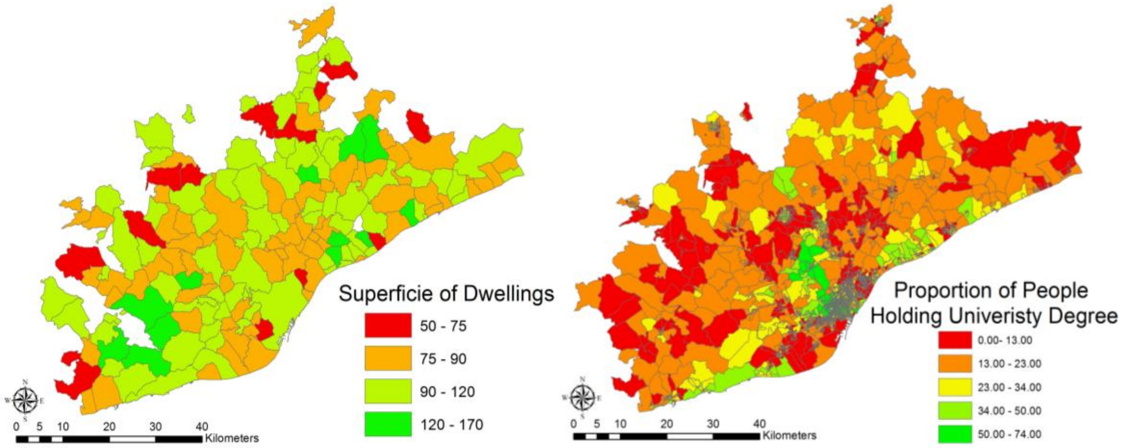
As previous stated, IMR shows the impact of selected biases in the whole sample: the larger number the higher impacts. Figure 2 (a) shows that distribution of IMR and housing prices on unity price and total prices. The sample selected biases are higher along the coastline, such as Sitges, Barcelona and Maresme zones. In figure 2 (b), we can find these zones affected by selection biases are the place where housing prices are higher. That is to say, it is likely that selection biases happened in the place with high housing prices. The same distribution is to other factors, such as floor area of dwellings and the zone of the proportion of people holding university degree (see figure 2 (c) and figure 2 (d)). Generally, selection biases are more likely happened to dwellings with high prices and medium size floor area, surrounding by a higher proportion university education neighborhood.

Figure 2: **(a) Coeffcients of IMR; (b) Totoal Price of Dwellings; (c) Superficie of Dwellings; (d) Porportion of People Holding University Degree**



(a) (b)

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.



(c) (d)

Source: own elaboration

4. Conclusions

The process of Energy Performance Certificates has made a great achievement after it is introduced by EPBD in 2002. In order to enhance the public awareness on energy efficiency and promote EPCs process in the residential market, it is mandatory to offer EPCs information when transacting in real estate market from 2010.

Therefore, numerous studies on housing prices impacted by EPCs are investigated but a few studies concerning the selection biases when taking into consideration. In such case, we applied Heckman two-step method to detect the presence of selection biases and corrected these biases in the Hedonic model using IMR.

Our results suggest that selection biases indeed exist and have impact on housing prices regarding energy efficient label. This premium increases from 9.6% to 12.6% when houses improve energy ranking from G to A, or from 0.9% to 2% with every ranking increasing. That is to say, correcting the impact of selection biases brings a 3% increase on housing prices from G to A or 1.1% with energy ranking.

Simultaneously, we find that selection biases are more likely happened to dwellings with high prices and medium size floor area, surrounding by a higher proportion university education neighborhood.

References

BANFI, S.; FARSI, M.; FILIPPINI, M. & JAKOB, M. *Willingness to pay for energy-saving measures in residential buildings*. In: Energy economics, 2008, 30 (2): 503-516. [On line] Available at: https://www.sciencedirect.com/science/article/pii/S0140988306000764 DOI: https://doi.org/10.1016/j.eneco.2006.06.001

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

BERGSTRÖM, L. & VAN HAM, M. *Understanding neighbourhood effects: Selection bias and residential mobility.* In: IZA Discussion Paper, No. 5193: 77-99. 2012. [On line] Available at SRRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1682714 & https://ssrn.com/abstract=1682714

BIO INTELLINGE SERVICE; MUDGAL, S.; LYONS, L. & COCHEN, F. *Energy Performance Certificates in Buildings and Their Impact on Transaction Prices and Rents in Selected EU Countries*, Bio Intelligence ServiceWorking Paper, April 2013. [On line] Available at: https://ec.europa.eu/energy/sites/ener/files/documents/20130619-energy_performance_certificates_in_buildings.pdf

BOTTERO, M & BRAVI, M. *Valutaziones dei benefici conessi al riasparmio energetico degli edifice: un approccio económetrico*. En: GEAM. GEOINGEGNERIA AMBIENTALE E MINERARIA, 2014, 15-24. [On line] Available at: https://iris.polito.it/retrieve/handle/11583/2595754/80875/articolo%20GEAM.pdf

BROUNEN, D. & KOK, N. *On the economics of energy labels in the housing market*. In: Journal of Environmental Economics and Management, 2011, 62 (2): 166-179. [On line] Available at: https://www.sciencedirect.com/science/article/abs/pii/S0095069611000337?via%3Dihub DOI: https://doi.org/10.1016/j.jeem.2010.11.006

CAN, A. *Specification and estimation of hedonic housing price models*. In: Regional science and urban economics, 1992, 22 (3): 453-474. [On line] Available at: https://www.sciencedirect.com/science/article/pii/0166046292900394?via%3Dihub DOI: https://doi.org/10.1016/0166-0462(92)90039-4

DE AYALA, A.; GALARRAGA, I. & SPARDO, J. *The Price of Energy Efficiency in the Spanish Housing Market*, Energy Policy, 2016, 94, 16-24. [On line] Available at: https://www.sciencedirect.com/science/article/pii/S0301421516301355 DOI: https://doi.org/10.1016/j.enpol.2016.03.032

EPPLE, D.; QUINTERO, L. & SIEG, H. *A new approach to estimating hedonic pricing functions for metropolitan housing markets*. In: FRB of Cleveland, No. 1516. 2014.

FREGONARA, E; ROLANDO, D. & SEMERARO, P. *Energy Performance Certificates in the Turin real estate market.* In: Journal of European Real Estate Research, 2017, 10 (2): 149-169. [On line] Available at: https://www.emeraldinsight.com/doi/pdfplus/10.1108/JERER-05-2016-0022 DOI: https://doi.org/10.1108/JERER-05-2016-0022

FUERST, F.; MCALLISTER, P.; NANDA, A. & WYATT, P. *Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England*. In: Energy Economy, March 2015, 48, 145-156. [On line] Available at: https://www.sciencedirect.com/science/article/pii/S0140988314003296 DOI: https://doi.org/10.1016/j.eneco.2014.12.012

GARCÍA, J. A. B. & HERNÁNDEZ, J. E. R. *Housing demand in Spain according to dwelling type: Microeconometric evidence*. In: Regional science and urban economics, 2008, 38 (4): 363-377. [On line] DOI: https://doi.org/10.1016/j.regsciurbeco.2008.02.002 Available at: https://www.sciencedirect.com/science/article/pii/S0166046208000471

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

GATZLAFF, D. H. & HAURIN, D. R. *Sample selection and biases in local house value indices*. In: Journal of Urban Economics, March 1998, 43 (2): 199-222. [On line] Available at: https://www.sciencedirect.com/science/article/pii/S0094119097920453 DOI: https://doi.org/10.1006/juec.1997.2045

GORDON, B. L. & WINKLER, D. T. *The effect of listing price changes on the selling price of single-family residential homes*. In: Journal of Real Estate Finance and Economics, 2017, 55 (2): 185-215. [On line] Available at: https://link.springer.com/article/10.1007/s11146-016-9558-z DOI: https://doi.org/10.1007/s11146-016-9558-z

HECKMAN, J. J. *The common structure of statistical models of truncation, sample selection and limited dependent variables and a simple estimator for such models*. In: BERG, V. (Editor), NBER, Annals of Economic and Social Measurement, 1976, 5 (4): 475-492. [On line] Available at: https://www.nber.org/chapters/c10491

HECKMAN, J. J. *Sample selection bias as a specification error (with an application to the estimation of labor supply functions*). In: NBER, National Bureau of Economic Research, March 1977, Working Paper, 172. Cambridge, Mass., USA. [On line] Available at: https://www.nber.org/papers/w0172.pdf DOI: https://doi.org/10.3386/w0172

HECKMAN, J. J. & ROBB, R. Alternative methods for solving the problem of selection bias in evaluating the impact of treatments on outcomes. In: WAINER, H. (eds) Drawing Inferences from Self-Selected Samples. Springer, New York, NY, pp. 63-107. Springer, 1986. [On line] Available at: https://link.springer.com/chapter/10.1007/978-1-4612-4976-4_7#citeas DOI: https://doi.org/10.1007/978-1-4612-4976-4_7

HECKMAN, J. J. *Selectivity bias: new developments.* In: American Economic Review, 1990, 80 (2): 313-318.

HECKMAN, J. J. *Selection bias and self-selection*. In: Durlauf S.N., Blume L.E. (eds) Microeconometrics. The New Palgrave Economics Collection. Palgrave Macmillan, London. Springer. pp. 201-224, 1990. [On line] DOI: https://doi.org/10.1057/9780230280816_29 Available at: https://link.springer.com/chapter/10.1057/9780230280816_29

HILL, R. *Hedonic price indexes for housing*. In: OECD Statistics Working Papers, 2011/01, OECD Publishing, Paris, 2011. [On line] DOI: http://dx.doi.org/10.1787/5kghzxpt6g6f-en

HIMMELBERG C., M. C. & SINAI, T. *Assessing high houses prices: Bubbles, fundamentals and misperceptions*. In: Journal of Economic Perspectives, American Economic Association, 2005, 19 (4): 67-92. [On line] DOI: http://dx.doi.org/10.1257/089533005775196769 Available at: https://www.aeaweb.org/articles?id=10.1257/089533005775196769

HYLAND, M.; LYONS, R. & LYONS, S. *The Value of Domestic Building Energy Efficiency: Evidence from Ireland.* In: Energy Economics, November 2013, 40, 943-952. [On line] Available at: https://www.esri.ie/system/files/media/file-uploads/2015-07/JACB201377.pdf DOI: https://doi.org/10.1016/j.eneco.2013.07.020

JUD, G. D. & SEAKS, T G. *Sample selection bias in estimating housing sales prices*. In: Journal of Real Estate Research, Summer 1994, 9 (3): 289-298. [On line] Available at: https://www.jstor.org/stable/44095499

LI, F.; NORRBIN, S.; RASMUSSEN, D. & UELAND, J. *Hedonic regression models when unmeasured quality differences are present.* Working paper, Florida State University, Tallahassee, FL. 2005.

MALPEZZI, S. *Hedonic pricing models: a selective and applied review*. In: O'SULLIVAN, T. & GIBB, K. (Editors) Housing economics and public policy, February 2008, 67-89. [On line] Available at: https://onlinelibrary.wiley.com/doi/pdf/10.1002/9780470690680.ch5 DOI: https://doi.org/10.1002/9780470690680.ch5

MARMOLEJO-DUARTE, C. *The incidence of the energy rating on residential values: an analysis for the multifamily market in Barcelona*. In: Informes de la Construccion, 2016, 68 (543): e-156. [On line] DOI: http://dx.doi.org/10.3989/ic.16.053 Available at: http://informesdelaconstruccion.revistas.csic.es/index.php/informesdelaconstruccion/article/view/5659/6533

MARMOLEJO-DUARTE, C. & CHEN, A. *The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments. Implications for Public Policy and Private Markets*. In: Sustainability, 2019, 11 (2): 372. [On line] Available at: https://www.mdpi.com/2071-1050/11/2/372 DOI: https://doi.org/10.3390/su11020372

MARMOLEJO-DUARTE, C. & GONZÁLEZ-TAMEZ, C. *Does noise have a stationary impact on residential values?* In: Journal of European Real Estate Research, 2009, 2, 259-279. [On line] Available at: https://www.emeraldinsight.com/doi/abs/10.1108/17539260910999992 DOI: https://doi.org/10.1108/17539260910999992

PENA-TRAPERO, J. B. & PENA-TRAPERO, X. *Problemas de la medición del bienestar y conceptos afines: una aplicación al caso español.* Madrid: España: Instituto Nacional de Estadística. 1977. 218 p.

PUHANI, P. *The Heckman correction for sample selection and its critique*. In: Journal of economic surveys, 2000, 14 (1): 53-68. [On line] DOI: https://doi.org/10.1111/1467-6419.00104 Available at: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1467-6419.00104

ROCA-CLADERA, J.; MARMOLEJO-DUARTE, C. & MOIX, M. *Urban structure and polycentrism: Towards a redefinition of the sub-centre concept*. In: Urban Studies, 2009, 46: 2841-2868. [On line] DOI: https://doi.org/10.1177/0042098009346329 Available at: https://journals.sagepub.com/doi/abs/10.1177/0042098009346329

ROSEN, S. *Hedonic prices and implicit markets: product differentiation in pure competition*. In: Journal of Political Economy, February 1974, 82 (1): 34-55. [On line] Available at: https://www.jstor.org/stable/1830899

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. "Ciudades y Territorios Inteligentes". UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

SEKO, M. & SUMITA, K. *Japanese housing tenure choice and welfare implications after the revision of the tenant protection law*. In: Journal of Real Estate Finance and Economics, 2007, 35 (3): 357-383. [On line] Available at: http://hdl.handle.net/10.1007/s11146-007-9040-z DOI: https://doi.org/10.1007/s11146-007-9040-z

SHEPPARD, S. *Hedonic analysis of housing markets*. In: Handbook of regional and urban economics, 1999, 3: 1595-1635. [On line] DOI: https://doi.org/10.1016/S1574-0080(99)80010-8 Available at: https://www.sciencedirect.com/science/article/pii/S1574008099800108

ZARZOSA-ESPINA, P. *Estimación de la pobreza en las comunidades autónomas españolas, mediante la distancia DP2 de Pena*. In: Estudios de economía aplicada, (2009, 27 (2): 397-416. [On line] Available at: https://dialnet.unirioja.es/descarga/articulo/3056904.pdf

Citación: CHEN, A. & MARMOLEJO-DUARTE, C. *The marginal price of housing energy-efficiency in Metropolitan Barcelona: issues of sample selection biases.* En: Libro de proceedings, CTV 2018. XII Congreso Internacional Ciudad y Territorio Virtual. “Ciudades y Territorios Inteligentes”. UNCuyo, Mendoza, 5-7 septiembre 2018. Barcelona: CPSV, 2018, p. 247-262.

CIUDAD Y TERRITORIO
ESTUDIOS TERRITORIALES
Vol. LI, Nº 199, primavera 2019
ISSN(P): 1133-4762
ISSN(E): 2659-3254
Págs. 105-104

La incidencia de las etiquetas energéticas EPC en el mercado plurifamiliar español: un análisis para Barcelona, Valencia y Alicante.

Carlos MARMOLEJO-DUARTE (1) & Ai CHEN (2)

(1) Profesor Titular Dpto. Tecnología de la Arquitectura, ETS de Arquitectura de Barcelona e Investigador del Centro de Política de Suelo y Valoraciones - Universidad Politécnica de Cataluña (UPC)
(2) Doctoranda del Programa de Gestión y Valoración Urbana y Arquitectónica de la UPC

RESUMEN: Este artículo estudia hasta qué punto la incidencia de los EPC sobre los precios de oferta plurifamiliares es homogénea en tres metrópolis españolas con tamaños diferentes. Para ello, se aplica el método de los precios hedónicos a la totalidad de la oferta con información energética de uno de los principales portales inmobiliarios. Los resultados sugieren varias cosas: en primer lugar, en Barcelona, el impacto por cada clase energética es superior al reportado previamente, lo que indica un progreso temporal positivo en el sentido vaticinado por la Directiva de Eficiencia Energética en la Edificación; en Valencia, donde la diversidad energética de la oferta es menor y los apartamentos bien cualificados son muy escasos, el impacto es mayor; en cambio, en Alicante aparece un efecto revertido puesto que las viviendas peor calificadas se venden más caras que el resto, lo cual podría derivar de anomalías en la publicitación de la clase energética. Todo junto plantea serios retos para la política energética residencial en nuestro país.

DESCRIPTORES: *Energy performance certificates.* Calificación energética. Precios residenciales. Barcelona. Valencia. Alicante.

The impact of EPC rankings on the Spanish residential market: an analysis for Barcelona, Valence and Alicante.

ABSTRACT: This paper studies whether the impact of EPC is the same in three Spanish metropolises different in size. In doing so, a hedonic analysis is carried out departing from all the listing information

Recibido: 18.10.2017; Revisado: 26.10.2018 Correo electrónico: carlos.marmolejo@upc.edu Nº ORCID: https://orcid.org/0000-0001-7051-7337; https://orcid.org/0000-0002-8912-0660
Los autores agradecen los comentarios y sugerencias realizados por los evaluadores anónimos, que han contribuido a mejorar y enriquecer el manuscrito original, así como a Habitaclía por haber facilitado la información usada en los análisis.

containing EPC data coming from one of the largest real estate listing webs. The results suggest: firstly, in Barcelona the impact of EPC rankings is larger than evidence coming from previous research, this finding indicates a progress on the effectiveness of the energy policy behind the EPC scheme as foreseen by the Energy Performance of Buildings Directive; secondly, in Valence, where the energy ranking diversity is small and efficient apartments are scarce the impact is larger; conversely, in Alicante there is a reverted effect, since the less efficient apartments are sold at a larger price, this unexpected finding may be originated by anomalies in the advertising of energy rankings. All in all, imply important challenges for the energy policy in Spain.

KEYWORDS: Energy Performance Certificates. Energy Certification. Housing Prices. Barcelona. Valence. Alicante

1. Introducción

Con el objetivo de romper la asimetría informativa que caracteriza la apreciación de la eficiencia energética por parte de compradores e inquilinos la Comisión Europea diseñó hace tres lustros los Energy Performance Certificates (EPC) a través de la Directiva de Eficiencia Energética en la Edificación (DEEE 2002/91/EC; refundida en la DEEE 2010/31/UE y recientemente modificada por la DEEE 2018/844/UE). La meta es reducir a un indicador simple las repercusiones de la eficiencia de las edificaciones en materia de consumo energético y emisiones de dióxido de carbono. Por tanto, los EPC al igual que el resto de etiquetas verdes tiene un rol de "intermediación" (Chegut & al., 2014) y además de certificación independiente. La principal hipótesis de dicha política sostiene que una mayor transparencia energética da origen a decisiones mejor informadas que como ulterior consecuencia animan la construcción y rehabilitación de viviendas eficientes. De esta forma, en un escenario de decisiones racionales, es previsible que se forme una predilección por las viviendas más cualificadas reflejada en los precios y en las condiciones de comercialización. Estas ventajas animarían a la oferta a producir viviendas más eficientes, incluso cuando esto supusiese un sobrecoste marginal. En definitiva, esta política se afilia directamente con la estrategia contra el cambio climático (García-Hooghuis & Neila, 2013) y la dependencia de las importaciones energéticas.

Diferentes estudios realizados en la Unión Europea han constatado que efectivamente las viviendas mejor cualificadas bajo el esquema EPC forman sobreprecios; sin embargo, el impacto de cada escalón energético sobre los precios es muy variopinto entre los países e incluso dentro de un mismo estado tiende a variar. Por ende, no hay razones para pensar que en el nuestro es homogéneo a lo largo de los diferentes mercados residenciales. En España, a pesar de la muy tardía transposición de la refundición de la DEEE (2010/31/UE) a través del RD 235/2013, también se ha estudiado el impacto de la clase energética y se ha puesto de relieve que también existe una mayor apreciación de las viviendas más eficientes. Sin embargo, dichos estudios se han basado o bien en la opinión no cualificada del valor que tienen las viviendas (De Ayala & al., 2016) o bien en ofertas publicitadas (Marmolejo, 2016) justo después de que fuese obligatorio exhibir la clase energética en la publicidad conducente a la comercialización inmobiliaria. Por tanto, es necesario revisitar sus resultados con el objetivo de estudiar:

1. La evolución de la incidencia de las clases energéticas sobre la formación de los precios a casi 3 años de que su inclusión en la publicidad sea obligatoria. Especialmente en un escenario de cambio del ciclo económico y de escalada de los precios de la energía; y
2. Si dicha incidencia es homogénea en mercados inmobiliarios de tres metrópolis de dimensión diferente, y con ciertas divergencias en su clima mediterráneo.

Para ello, al igual que los trabajos del estado del arte, se acude al método de los precios hedónicos que presupone que al elegir una vivienda los hogares igualan la utilidad marginal que les proporciona cada uno de sus atributos al precio que pagan. Así, mediante un análisis econométrico es posible discernir el precio implícito de cada atributo (incluida la clase energética). En concreto, se parte de información de más de 110.000 ofertas plurifamiliares de uno de los portales inmobiliarios con mayor presencia en las metrópolis funcionales de Alicante, Barcelona y Valencia, y de un conjunto de fuentes de información que permiten controlar la gran diversidad de variables urbanísticas, socioeconómicas y climáticas con incidencia en la formación de los valores inmobiliarios.

Los resultados sugieren que, en la Barcelona metropolitana, el impacto de los EPC sobre los precios se ha acentuado a medida que ha pasado el tiempo. Esto constituye una excelente noticia para los promotores interesados en impulsar proyectos de nueva planta y rehabilitación con mejores prestaciones energéticas. Sin embargo, la comparación del precio implícito de Barcelona con el del área metropolitana valenciana sugiere que, a medida que las viviendas mejor calificadas se hacen más abundantes, el sobreprecio de la eficiencia energética tiende a desparecer puesto que la diferenciación inmobiliaria devenida de dicho atributo se difumina. Por su parte, en Alicante los modelos econométricos revelan un impacto revertido de la etiqueta energética: las viviendas peor calificadas "G" reciben un precio superior que el resto. Asimismo, dichas viviendas "G" son mejores en el resto de prestaciones arquitectónicas, lo que aunando a la mayor proporción de viviendas con información energética podría indicar serias anomalías en la publicitación de la clase energética que como ulterior consecuencia comportaría a la plena banalización del cometido de esta política comunitaria.

El resto del artículo se organiza así: primero se ofrece una breve revisión de los trabajos que en la Unión Europea en general y en España en particular han estudiado el impacto de los EPC sobre los precios inmobiliarios; a continuación, se explicita la metodología y los datos utilizados; luego se exponen y discuten los resultados y en las conclusiones se presenta una síntesis del trabajo realizado.

2. La incidencia de los Energy Performance Certificates sobre los precios inmobiliarios

La reforma de la DEEE (2010/31/UE) y la Directiva 2012/27/31 es el marco vigente sobre el que se ha transpuesto la certificación energética "universal" en los estados miembros. Diferentes estudios han puesto de manifiesto que las personas están dispuestas a pagar (DAP) más por las viviendas eficientes. En España Marmolejo & al. (2017) han encontrado, a partir de una valoración contingente, que la DAP adicional por una vivienda bien calificada se equipara al ahorro en la factura energética. Si bien, dicho ahorro no es la única, ni principal razón por las que los hogares están dispuestos a pagar más, los hábitos sostenibles y la percepción del uso de bienes sostenibles como una acción socialmente responsable aparecen, según dicho estudio, correlacionados con la DAP. A conclusiones similares han llegado Marmolejo & Bravi (2017) quienes, utilizando experimentos de elección, han encontrado, además que el nivel formativo (después de controlar el nivel de ingresos) está positivamente correlacionado con la DAP más por una vivienda eficiente.

Otra familia de estudios ha probado si, más allá de las intenciones declaradas por las personas, una mayor DAP por inmuebles eficientes se convierte en un mayor precio de mercado. Dentro de esta familia, el estudio pionero de Brounen & Kok (2011) analizó por vez primera la incidencia de estas nuevas etiquetas "verdes" sobre los precios residenciales en los Países Bajos, a pesar de que los datos utilizados corresponden al periodo en el cual la parte compradora podía eximir a la vendedora de aportar el EPC. Dicho estadio encontró una correlación positiva entre las viviendas mejor calificadas y los precios de venta verificados en las transacciones inmobiliarias. Dichos autores, como casi todos los demás cuyos trabajos se resumen en la Fig. 1, parten del supuesto que las calificaciones energéticas son una medida categórica de la eficiencia de las viviendas. De forma que, considerando la calificación intermedia "D" como base de comparación, encontraron que el precio marginal va del 10% para la clase "A", al -5% para la clase "G", es decir, por encima de la situación de referencia se forman *market premiums* mientras que por debajo *market penalties* que en este caso son conocidos como *brown discounts*. En ese mismo país, Kok & Jennen (2012) estudiaron también de forma pionera en Europa la incidencia de los EPC en el mercado oficinesco, encontrando que únicamente las oficinas calificadas con la letra "C" (en relación a la calificación "D") formaban un sobrevalor del 4,7% en sus precios de transacción rentística. El estudio de Hyland & al. (2013) realizado en diferentes ciudades irlandesas fue el primero en comparar simultáneamente la incidencia de los EPC sobre el mercado de alquiler y venta. Para ello, dichos autores partieron de precios de oferta de ambos mercados encontrando que la incidencia del ranking energético es mayor en el mercado de compraventa en relación al de alquiler. Así, por ejemplo, una vivienda en venta calificada como "A" (en relación a "D") tiene un sobreprecio del 9,3%, y únicamente de 1,8% si se comercializa en el mercado de alquileres. Igualmente, la "penalización" de una vivienda calificada como "F" o "G" (en relación a "D)" es muy superior (-10,60%) a la que recibe otra del mercado de alquiler (-3,20%). La mayor incidencia de las etiquetas verdes sobre los precios de venta en relación a los de alquiler es una regularidad que ya había sido reportada por otros trabajos anteriores basados en otros esquemas certificatorios. Ejemplos de dichas investigaciones son el trabajo de Fuerst & Mcallister (2011) para las oficinas LEED en los EE.UU. (+31,4% en venta y sólo +9,2% en alquiler) o Eichholtz & al. (2010) para las oficinas LEED (+11,1% en venta y solo +5,8% en alquiler) y Energy Star (+13% en venta y sólo +2,1% en alquiler). La menor diferenciación de precios de alquiler en relación a los de compraventa tiene serias repercusiones para la política de vivienda en países como España que apuestan por el alquiler como alternativa a la propiedad.

De la tabla de la Fig. 1 destaca el trabajo de Mudgal & al. (2013) encargado directamente por la Comisión Europea como parte de los estudios encaminados a evaluar la eficacia de la DEEE. Según se puede observar, se trata de un estudio realizado en varios países, con la novedad que el ranking energético se ha tomado como continuo y no categórico. Nuevamente, la incidencia de los EPC es más acusada en los precios de venta en relación a los de alquiler. De dicho estudio, cabe resaltar que los EPC parecen incidir más en los *hinterlands* (p.e. Bélgica e Irlanda, siendo Austria una excepción) que en las ciudades capitales. Según sus autores, este impacto diferencial se explica porque los ahorros en la factura energética son más importantes en relación al precio base de la vivienda en las zonas de menor jerarquía urbana (donde las viviendas son más baratas). Asimismo, no siempre una mayor calificación energética implica un sobreprecio, puesto que en el mercado de alquiler de Oxford existe aparentemente una penalización a las viviendas mejor calificadas (-4% por escalón EPC). Aunque los autores de este trabajo reconocen las enormes deficiencias de sus análisis puesto que, en dicha ciudad, las viviendas señoriales más antiguas y mejor localizadas, con precios elevados, tienen a su vez, una baja calificación energética. En general el muy pobre control de las características urbanísticas (p.e. accesibilidad, calidad de la urbanización y jerarquía social) con incidencia sobre los valores residenciales según lo ha estudiado Roca (1988) es una deficiencia de dicho trabajo y puede sesgar los coeficientes de sus modelos. Por esta razón en este artículo se han realizado importantes esfuerzos para construir variables de control.

El trabajo de Chegut & al. (2014) reviste de particular interés para esta investigación puesto que ha identificado que el impacto de las certificaciones energéticas en la formación de los precios depende de la cantidad de edificios previamente certificados en la *zona.* De esta manera, a partir del análisis de los precios de alquiler y de venta de oficinas en Londres en el periodo 2000-2009 certificadas con el esquema BREEAM dichos autores han encontrado que por cada edificio "verde" que aparece en el mercado el precio marginal del alquiler se reduce en un 2% y el de venta en un 5%. Por ende, los sobreprecios son mayores para los edificios pioneros en la certificación y menor para los que se certifican tardíamente. Si bien, el balance general sigue siendo positivo puesto que los edificios certificados incrementan su precio de venta en un 14,7% y de alquiler en 19,7% en relación con los no certificados. Y de hecho existe un proceso de "gentrificación" *(sic)* ya que los edificios certificados ejercen un efecto de externalidad mediante el cual el valor de los edificios del entorno se incrementa.

En España dos son los trabajos pioneros en el estudio de la agenda hedónica de los EPC. De Ayala & al. (2016) parten de valores de venta declarados por una muestra de encuestados de 5 ciudades (Madrid, Bilbao, Sevilla, Vitoria y Málaga) y de un cálculo propio de la clase energética y determinan que las viviendas clasificables como "A", "B" o "C" tienen un valor, en opinión de sus propietarios, superior en un 9,8% que aquéllas clasificadas como "D", "E", "F" o "G". Por su lado Marmolejo (2016) utiliza valores de oferta para una muestra de viviendas en venta en la Barcelona metropolitana y encuentra un sobreprecio de 5,11% por pasar de la clase "G" a la "A", o del 9,62% si se acepta que las personas perciben la escala de calificaciones de forma nominal. Como se ve, en nuestro país la incidencia de la clase energética sobre los precios es inferior a la reportada para otros países, lo cual guarda coherencia con los inviernos suaves, especialmente en el área mediterránea, en relación a los países más septentrionales.

Sin embargo, ambos trabajos requieren una mayor profundización, el primero no sólo porque analiza valores de opinión (no cualificada), sino también porque tiene un escaso control de los factores locativos microterritoriales y de la calidad arquitectónica de la vivienda que, como señala Roca (1988), tienen una enorme influencia en los valores, y su no consideración puede conllevar un sesgo de los resultados. El segundo, porque precisamente los factores microterritoriales hacen que la variable "clase energética" resulte estadísticamente significativa en los modelos, y por ende sugiere un impacto heterogéneo de este factor a lo largo del mercado inmobiliario. El presente trabajo pretende, por ende, explorar con mayor detalle este aspecto, al comparar tres metrópolis distintas y además estudiar si en Barcelona la repercusión de los EPC sobre los precios se ha mantenido en los niveles previamente reportados.

3. Ámbito de estudio, metodología y datos

El ámbito de estudio está conformado por los 341 municipios inscritos dentro del ámbito funcional de las áreas metropolitanas (AM) de Barcelona

Casos de estudio	Mercado	Tipo de escala como se han interpretado los escalones EPC	Impacto marginal de las EPC en los precios de		Para la calificación_ en relación a la _	Tipo de precios	Autoría
			Venta	Alquiler			
Países Bajos	Residencial	Categórica	10,00%		A/D	Cierre	Brounen & Kok (2011)
			5,50%		B/D		
			2,00%		C/D		
			-0,50%		E/D		
			-2,50%		F/D		
			-5,00%		G/D		
Países Bajos	Oficinas	Categórica		4,70%	C/D	Cierre	Kok & Jennen (2012)
Irlanda	Residencial	Categórica	9,30%	1,80%	A/D	Oferta	Hyland *et al*. (2013)
			5,50%	3,90%	B/D		
				-1,90%	E/D		
			-10,60%	-3,20%	F,G/D		
Viena	Residencial	Coninua	Entre el 10% y 11%	Entre el 5% y el 6%	escalón	Oferta	Mudgal *et al.* (2013)
Baja Austria			Entre el 5% y el 6%	4,40%	escalón		
Bruselas (Flandes)			4,30%	3,20%	escalón		
Bruselas (Capital)			2,90%	2,60%	escalón		
Bruselas (Wallonia)			5,40%	1,50%	escalón		
Lille			3,20%	nd	escalón		
Marsella			4.3%	nd	escalón		
Ciudades de Irlanda			1,70%	1,40%	escalón		
Irlanda no ciudades			3,80%	1,40%	escalón		
Oxford (Reino Unido)			0,40%	-4%	escalón		
Reino Unido	Residencial	Categórica	5,0%		A,B/D		Fuerst *et al.* (2015)
			1,80%		C/D		
			-1%		F,E/D		
			-7%		G/D		
España (Madrid, Bilbao, Sevilla, Vitoria y Málaga)	Residencial	Categórica	9,80%		A,B,C/D,E,F,G	Opinión	De Ayala *et al.* (2016)
AM de Barcelona	Residencial	Continua	0,85%		escalón	Oferta	Marmolejo (2016)
			9,62%		A/G		
			3,87%		D/G		

FIG. 1 / **Selección de estudios que han analizado el impacto de los EPC sobre los precios inmobiliarios**

Fuente: Elaboración propia con base en los estudios citados

(184 municipios, 3.760 km^2 y 5,22 millones de habitantes en 2016), Valencia (121 mun., 3.669 km^2 y 2,12 millones de habitantes) y Alicante (36 mun., 1.824 km^2 y 1,09 millones de habitantes). La delimitación funcional es fruto de la aplicación del método de Roca & al. (2009) basado en el análisis de la movilidad obligada del Censo del 2001[1]. Dicho procedimiento permite, además, identificar centralidades (centro principal y subcentros) cuya accesibilidad puede incidir en los precios de la vivienda.

[1] Como es sabido, el censo del año 2011 al haberse basado en una encuesta presenta enormes limitaciones tanto en el análisis de los flujos de movilidad intermunicipales, como en la explotación del resto de variables a escala de sección censal. Por ello, tanto a efectos de delimitación, como de control de las variables socioeconómicas se han usado datos del censo del 2001.

A partir de aquí, la metodología ha consistido en tres pasos:

1. Construcción de un sistema de información geográfica con datos relacionados con las ofertas inmobiliarias y la caracterización urbana/territorial.

2. Traslación de los datos urbano/territoriales a las viviendas mediante el uso de un área de influencia de 300 m. de radio[2].

3. Calibración de una familia de modelos hedónicos a escala de vivienda para las AM en conjunto y de forma individual.

La valoración del impacto de la calificación energética se realiza mediante el método de los precios hedónicos. Dicha técnica asume que el valor de una vivienda puede desgranarse en el valor implícito de cada uno de los atributos residenciales (véase en FUERST & al., 2015 una exposición de la teoría económica subyacente). Así, se parte de la hipótesis que los hogares realizan sus elecciones residenciales igualando la utilidad marginal de los atributos de la vivienda con su precio marginal. De forma que, mediante un procedimiento estadístico multivariante, puede deslindarse el precio implícito de cada uno de ellos (ROSEN, 1974). En la literatura especializada es usual que dicho valor marginal se calcule a través de un modelo de regresión, y en defecto de una postura teórica clara sobre la especificación funcional, de tipo log-lineal (ADDAE-DAPAAH & CHIEH, 2011). Este procedimiento tiene varias virtudes, por una parte, facilita que la distribución de la variable dependiente (el precio) se aproxime a la normalidad admitiendo el uso de los MCO y, por otra, permite interpretar los coeficientes como semi-elasticidades, es decir como variaciones porcentuales en el precio de las viviendas por cada unidad que incrementen las variables independientes, y por tanto los resultados son fácilmente comparables con aquéllos de otras investigaciones. En concreto, en este artículo la expresión funcional usada es:

$$LnP = \sum_{A=1}^{n} B * A + \sum_{TU=1}^{n} B * TU + \sum_{CE=1}^{n} B * CE \quad (1)$$

En la ecuación (1) P es el logaritmo natural del precio de oferta de una muestra estadísticamente significativa de las viviendas en venta en cada ámbito de estudio, A es un vector que controla las características arquitectónicas de los apartamentos y de las zonas y servicios comunes de sus edificios; *TU* es un vector que controla las características territoriales (incluida la zona climática) y urbanísticas del emplazamiento de las viviendas y *CE* son los indicadores de clase energética objeto de esta investigación. En este sentido, se prueban dos hipótesis de percepción de la clase energética, tanto como variable continua y como nominal.

Los datos de oferta provienen de Habitaclia uno de los principales portales en la comercialización residencial en las Comunidades Autónomas estudiadas, en total se cuenta con 113.340 ofertas de viviendas plurifamiliares en las tres AM a fecha al 1 de abril del 2016. De esta misma base se extraen las características arquitectónicas de cada vivienda a partir de los parámetros y del texto libre publicitado por el anunciante[3].

El universo anterior se ha depurado así:

1. Se han eliminado los casos cuyo precio de venta sobrepasaba la media +/- una desviación estándar.

2. Se han eliminado los casos sin información sobre la clase energética.

3. Con los restantes se ha calculado de la Distancia de Mahalanobis que permite identificar aquellos casos cuyas características con repercusión en el precio se alejan de la generalidad. Por ende, se eliminan los casos anómalos en las n dimensiones explicativas de los precios.

De esta forma se ha obtenido una muestra depurada de 14.058 apartamentos estadísticamente representativa del universo de partida (error del 0,95% sobre el valor medio con un nivel de confianza del 95%).

Los datos de caracterización urbana y territorial provienen de las siguientes fuentes de información: Censo 2001 de Población y Vivienda escala de sección censal[4]; cubiertas del suelo del CORINE Land Cover 2001; una construcción propia de

[2] Asimismo, se han probado modelos con radios de influencia a partir de cada vivienda de 600 y 900 m., los cuales se han descartado por presentar un menor ajuste a los reportados en este artículo.

[3] A través de un análisis semántico se han construido variables cualitativas que identifican las viviendas en las cuales se hace alusión a una alta calidad inmobiliaria, un buen estado de conservación o reforma reciente y una buena calidad de la cocina.

[4] Se usan datos del 2001, ya que los del 2011 no son representativos de unidades espaciales pequeñas. Por ejemplo, para el municipio de Barcelona, en la variable ocupación de la población con empleo, a un dígito de desagregación de la Clasificación Nacional de la Ocupación, únicamente se puede recuperar información del Censo del 2011 para una decena de secciones censales de las más de 1.500 que existen en la ciudad.

las zonas climáticas calculadas con los criterios del apéndice B.1 del DB HE del CTE según su articulado de septiembre de 2013, con la ayuda del Modelo Digital del Terreno (MDT 200 m.) del Centro Nacional de Información Geográfica; línea de costa municipal y zonas naturales protegidas (incluidas las submarinas para capturar las externalidades que producen) de la misma fuente anterior; red viaria de TeleÁtlas 2011, así como una digitalización propia de las estaciones ferroviarias (metro, cercanías, tranvía, funiculares, etc.) y de las rampas de acceso y salida de autopistas y autovías. Todas las distancias utilizadas se realizaron con TransCAD, y por ende responden al recorrido sobre la red viaria. Además, se probó, sin éxito, la introducción de indicadores derivados de la radiación, la temperatura y su oscilación del Mapa Climático Digital de la Península Ibérica de la UAB. La FIG. 2 contiene los estadísticos descriptivos únicamente de las variables que resultaron significativas en los modelos que se explicitan en el siguiente apartado.

		N	Mínimo	Máximo	Media	Desv. Est.
Precio de oferta en venta	Precio total (euros)	14.058	23.000	1.000.000	140.528	87.046
	Precio unitario (euros/m2)	14.058	487	3.747	1.477	704
Variables de control arquitectónicas	Superficie (m2)	14.058	20,0	319,0	96,0	33,1
	Número de baños	14.058	-	4,0	1,5	0,6
	Piscina (dummy)	14.058	-	1,0	17%	37%
	Sup. terraza (m2)	14.058	-	250,0	6,7	17,4
	Ascensor (dummy)	14.058	-	1,0	70%	46%
	Calidad de cocina*	14.058	-	1,0	14%	35%
	Aire acondicionado (dummy)	14.058	-	1,0	40%	49%
	Calefacción (dummy)	14.058	-	1,0	36%	48%
	Chimenea (dummy)	14.058	-	1,0	3%	16%
	Bien conservado/reforma (dummy)**	14.058	-	1,0	16%	37%
	Alta calidad (dummy) ***	14.058	-	1,0	3%	16%
	Terraza grande (dummy)+	14.058	-	1,0	8%	28%
	Año construcción ++	14.058	1.881	2.017	1.977	21
Variables de control urbanísticas	% residentes con estudios universitarios	14.058	1%	59%	13%	9%
	Densidad de empleo municipal (LTL/km2)	14.058	2,7	7.893	1.544	2.223
	Mar a 200 m o menos	14.058	-	1,0	5,0%	21%
	Acceso a autopista/autovia (dummy) +++	14.058	-	1,0	91%	29%
	Distancia a autopista/autovia (km)	14.058	0,0	15,3	2,3	1,9
	% municipal servicios alto valor añadido ª	14.058	1%	20%	12%	4%
	Locales en PB/100 hab	14.058	-	74,3	5,2	6,3
	% hogares que opinan viven en un entorno ruidoso	14.058	1%	89%	39%	0%
Calificación energética	Clase A	14.058	-	1,0	2,1%	14%
	Clase B	14.058	-	-	0,0%	0%
	Clase C	14.058	-	1,0	1,2%	11%
	Clase D	14.058	-	1,0	4,5%	21%
	Clase E	14.058	-	1,0	25,2%	43%
	Clase F	14.058	-	1,0	6,7%	25%
	Clase G	14.058	-	1,0	60,3%	49%
	EPC Ordinalº	14.058	1,0	7,0	1,9	1,3
Zonas climáticas	B3 (**AM Valencia**, AM Barcelona)	14.058	-	1,0	22%	0,4
	B4 (**AM Alicante**)	14.058	-	1,0	41%	0,5
	C2 (**AM Barcelona**)	14.058	-	1,0	31%	0,5
	C3 (AM Alicante, **AM Valencia**, AM Barcelona)	14.058	-	1,0	4%	0,2
	D1 (AM Barcelona)	14.058	-	1,0	0%	0,0
	D2 (AM Valencia, AM Barcelona)	14.058	-	1,0	2%	0,1
	D3 (AM Alicante, AM Barcelona)	14.058	-	-	0%	-
	E1 (AM Valencia, AM Barcelona)	14.058	-	-	0%	-

Notas

Únicamente se muestran las variables que han resultado significativas en los modelos, excepto las energéticas

* Es 1 cuando en el texto descriptivo de la oferta se hace alusión a elementos de calidad en los materiales y equipamiento de la cocina

** Es 1 cuando en el texto descriptivo de la oferta se indica un estado de conservación bueno, excelente o una reforma reciente

*** Es 1 cuando en el texto descriptivo de la oferta se alude a elementos del diseño, las vistas y las calidades excepcionales

.+ Es 1 cuando la terraza o balcon es superior a 20 m2

.++ Si este valor no está presente en el anuncio, se toma el año de construcción medio de la sección censal donde está el edificio

.+++ Es 1 si el municipio en el que se encuentra el inmueble tiene acceso directo a una autopista o autovía

ª Es la proporción de lugares de trabajo localizados (LTL) de los sectores de las finanzas, los servicios a las empresas, serv inmobiliarios, seguros, educación/investigación

º G= clase energética menos eficiente=1, A=clase energética más eficiente =/, según RD 235/2013

En negrita aparecen las zonas climáticas con mayor extensión territorial dentro de cada Área Metropolitana Funcional

Fuente: Elaboración propia partir de las fuentes indicadas

FIG. 2 / **Estadísticos descriptivos de la muestra de las 3 AM**

Fuente: Elaboración propia partir de las fuentes indicadas

Como se ve, la vivienda tipo se vende, de media, por 140 mil euros, tiene 96 m2, 1,5 baños. Las ofertas cuentan en un 17% con piscina y en un 70% con ascensor, el aire acondicionado está más presente (40%) que la calefacción –por radiadores- (36%). Sólo un 3% de la oferta destaca por su alta calidad inmobiliaria (arquitectónica y/o vistas) o la presencia de chimenea y únicamente un 8% tiene una terraza grande (mayor a 20 m2). El año medio de construcción es 1977, si bien existe una importante dispersión de antigüedades.

La inmensa mayor parte de las viviendas es clase "G" (60,3%) o "E" (25,2%) siendo las clases superiores "A"+"B"+"C" una verdadera rareza (sólo un 3,3% entre las dos extremas). En cuanto a las zonas climáticas dominantes (por extensión territorial) destacan en el AM barcelonesa la C2 (los valles y la planicie costera); la C3 (meseta central) y B3 (planicie costera) en el AM valenciana; y la B4 (extendida a la práctica totalidad) en el AM alicantina.

Si los datos se analizan por AM emergen importantes diferencias. Las viviendas barcelonesas son 57% más caras que las valencianas si se considera el precio total y un 82% por m^2, a pesar de que: 1) son un año más antiguas que las valencianas y seis que las alicantinas; 2) son más pequeñas y 3) tienen ascensor en una menor proporción. Por

		AM Alicante	AM Barcelona	AM Valencia
		N=5.784	N=4.857	N=3.417
		Media	Media	Media
Precio de oferta en venta	Precio total (euros)	113.744	185.541	121.882
	Precio unitario (euros/m2)	1.153	2.095	1.149
Variables de control arquitectónicas	Superficie (m2)	98,7	87,2	103,9
	Número de baños	1,5	1,3	1,5
	Piscina (dummy)	27%	11%	8%
	Sup. terraza (m2)	6,0	9,4	4,1
	Ascensor (dummy)	70%	65%	75%
	Calidad de cocina*	3%	34%	6%
	Aire acondicionado (dummy)	37%	42%	40%
	Calefacción (dummy)	16%	67%	25%
	Chimenea (dummy)	1%	6%	1%
	Bien conservado/reforma (dummy)**	15%	17%	17%
	Alta calidad (dummy) ***	3%	3%	2%
	Terraza grande (dummy)+	7%	12%	6%
	Año construcción ++	1.981	1.974	1.975
Calificación energética	Clase A	1%	3%	3%
	Clase B	0%	0%	0%
	Clase C	0%	3%	0%
	Clase D	1%	10%	2%
	Clase E	8%	51%	18%
	Clase F	3%	13%	4%
	Clase G	87%	20%	73%
	EPC Ordinalº	1,2790	2,7511	1,6634
	Diversidad energética de la oferta H	0,53	1,38	0,87
	Clase A+B+C+D	1,9%	16,3%	5,8%

Notas
La diversidad energética se ha calculado con el coeficiente de entropia Shannon (H) cuanto más alto más diversidad

Fuente: Elaboración propia partir de las fuentes indicadas

FIG. 3 / **Estadísticos descriptivos de las variables arquitectónicas y de clase energética por AM**

Fuente: Elaboración propia partir de las fuentes indicadas el contrario, como es de esperar, en Barcelona la proporción de viviendas con calefacción es muy superior a Valencia (lo que pone de relieve la importancia de las "pequeñas" divergencias climáticas), así como también es mayor la proporción de viviendas con terrazas grandes (con una clara influencia de los áticos y sobreáticos del Ensanche de la ciudad central). En esta muestra en particular el precio medio unitario es ligeramente más bajo en Valencia en relación a Alicante.

Según se observa en la FIG. 3 las diferencias en la clase energética son mayores si cabe. Las

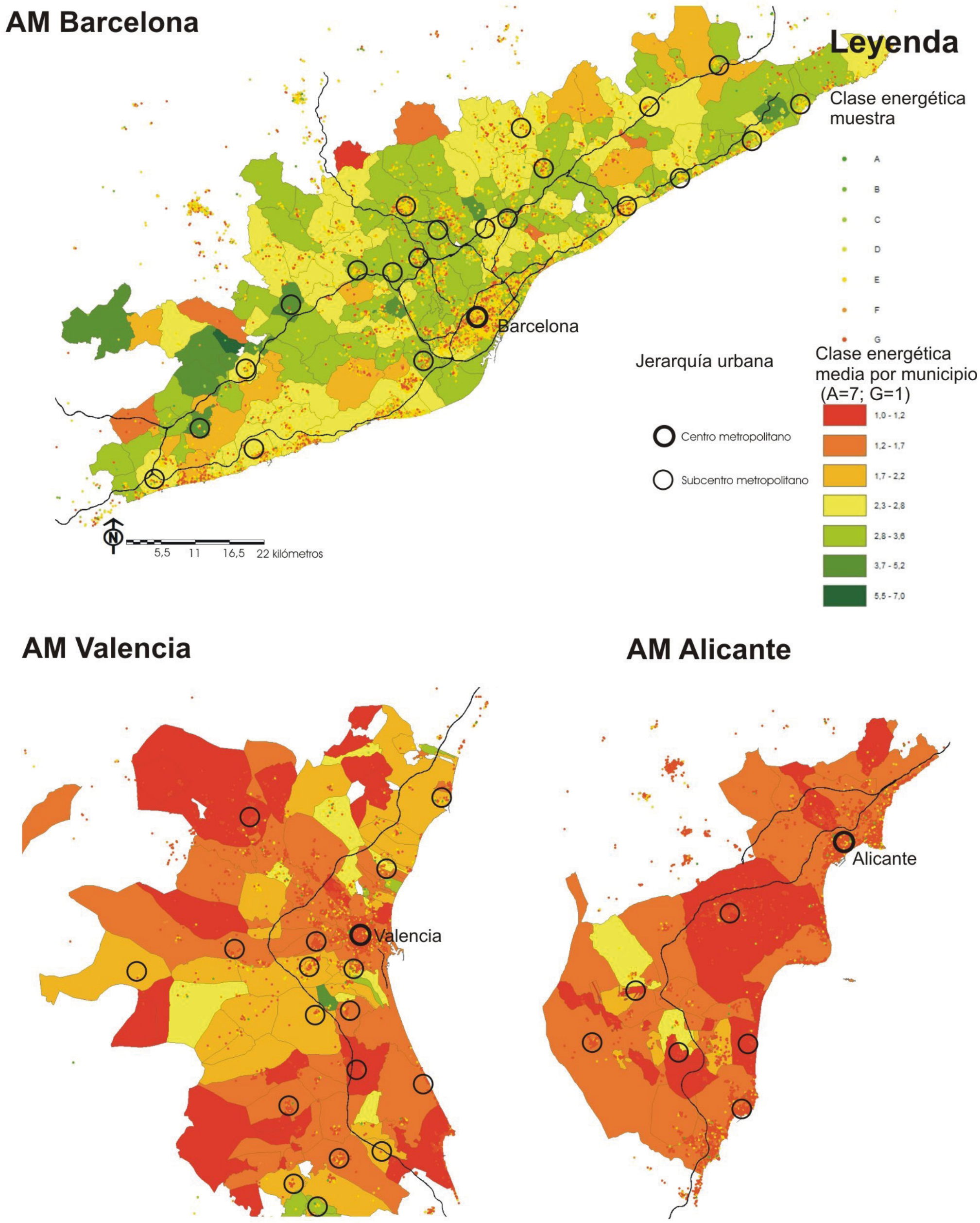


FIG. 4 / **Delimitación metropolitana, distribución de la muestra y EPC medio por municipio**

Fuente: Elaboración propia

viviendas barcelonesas, a pesar de ser más antiguas, están mejor calificadas con un 1,38 en una escala ordinal (donde 1=G y 7=A), seguidas por las valencianas (0,87) y en último lugar están las alicantinas (0,53). La diversidad de calificaciones[5] también es mayor en Barcelona (H=1,38) en relación a Valencia (H=0,87) y sobre todo a Alicante (H=0,53). En efecto, en Barcelona y Valencia es posible encontrar, si bien con enorme dificultad, viviendas bien calificadas, mientras que en Alicante dominan de forma preponderante (87%) las viviendas *publicitadas* con clase "G"; mientras que en Valencia esta clase representa el 73% y en Barcelona únicamente el 20%. Esta diferenciación es importante y, como se verá más adelante, parece tener influencia en la formación de la agenda hedónica de las clases energéticas.

La Fig. 4 detalla la delimitación metropolitana, la distribución y calificación de la muestra y la media de las clases por municipio. Así, se observa que los centros y subcentros metropolitanos tienden a tener una mejor calificación energética media que las zonas periféricas e intersticios metropolitanos.

4. Resultados

La FIG. 5 detalla los coeficientes de la familia de modelos construidos con la muestra completa de las tres AM. El primero (MOD 1-ARQ), capaz de explicar el 52% de la varianza del precio, está construido exclusivamente con los atributos arquitectónicos, cuyos coeficientes aparecen con el signo esperado, siendo, además de la superficie, la calefacción, la buena calidad de la cocina, el número de baños y el ascensor los más explicativos el precio ofertado según los coeficientes estandarizados. El signo negativo del cuadrado de la superficie revela la existencia de rendimientos decrecientes en el precio marginal de este atributo. El MOD 2 ARQ+URB introduce los atributos territoriales y urbanísticos cuya omisión podría conllevar sesgos en los coeficientes de la eficiencia energética como se ha discutido en el estado del arte. Con meridiana claridad la variable instrumental AM Barcelona aparece como la más influyente en los precios (el coeficiente negativo de Valencia denota, como ya se ha dicho, que en esta muestra particular los precios son, de media, ligeramente más baratos en Valencia en relación con Alicante que es la base de comparación en este MOD 2 hasta el 4). Sigue, en importancia, el nivel de formación de la población que vive en un radio de 300 m. de las viviendas. La densidad de empleo municipal es, según la teoría estándar de la economía urbana, un indicador de centralidad (tanto por las oportunidades laborales como por los servicios prestados por los empleados) y como se ve resulta muy relevante en la explicación de los precios residenciales. Menor importancia tiene la accesibilidad por autopista o autovía, cuya influencia es bipolar: positiva si el municipio donde está la vivienda tiene, al menos, una entrada y/o salida; y negativa a medida que la vivienda se aproxima a estos ejes viarios[6]. Por ende, se captura la accesibilidad (positiva) y las externalidades (negativas) de dichas infraestructuras. En ese mismo sentido aparece, con signo negativo, el ruido percibido por los hogares en el entorno de su vivienda. La densidad de locales per cápita mide el nivel de dotación de toda clase de servicios en el entorno de la vivienda.

Por su parte, el MOD 3 ARQ+URB+EPC-y-ZC indica un impacto positivo de la clase energética considerada como una variable continua: por cada escalón que incrementa la clase energética los precios de salida se encarecen un 1,54%. Por tanto, según este modelo, pasar de una clase "G" a otra "A", todo lo demás igual, representa un sobreprecio de 9,26% de media para las tres AM. Por su parte, las zonas climáticas parecen enmascarar aspectos relacionados con la consolidación del tejido urbano más que las diferencias climáticas en sí mismas, significativo de ello es la introducción de la zona C2 (la planicie costera y los valles en el AM barcelonesa) y de la B3 (la planicie costera valenciana donde se concentra el grueso de la conurbación central y los subcentros metropolitanos).

A efectos de estudiar si existe un impacto homogéneo de la calificación energética en los tres mercados metropolitanos se ha construido el MOD 4 EPCxAM con las mismas variables de control que el MOD 3. Como se ve en la Fig. 6 el impacto no es homogéneo: es más grande en Valencia (+3,35%) que en Barcelona (+1,79%) y, sorprendentemente, es negativo en Alicante (-1,23%). La divergencia en el impacto de las clases energéticas encontrada, va en línea de los recientes hallazgos de Marmolejo & Chen (2019). Dichos autores han encontrado,

[5] El cálculo de este indicador sigue el procedimiento de cálculo de la entropía de Shannon:

$$H_n = -1 * \sum_i^n PJ_i \bullet \ln(PJ_i)$$

H es la diversidad de calificaciones energéticas incluidas en los anuncios inmobiliarios en un área metropolitana (AM) n; P es la probabilidad de encontrar una clase J energética i en dicha AM.

[6] Este indicador también captura la perificidad en la que se ubican estas infraestructuras en relación a los centros/subcentros urbanos.

Ajuste de los modelos		R^2 aj	F	Sig.	R^2 aj	F	Sig.	R^2 aj	F	Sig.
		0,52	1.097	0,00	0,76	1.815	0,00	0,76	1.752	0,00
		MOD 1 ARQ			MOD 2 ARQ+URB			MOD 3 ARQ+URB+EPC y ZC		
		B	Beta	Sig.	B	Beta	Sig.	B	Beta	Sig.
Varibles de control arquitectónicas	(Constante)	15,85		0,00	7,64		0,00	7,34		0,00
	Superficie (m2)	0,01	0,49	0,00	0,01	0,83	0,00	0,01	0,83	-
	Número de baños	0,14	0,14	0,00	0,14	0,15	0,00	0,13	0,14	0,00
	Piscina	0,13	0,09	0,00	0,17	0,12	0,00	0,17	0,12	0,00
	Ascensor	0,14	0,12	0,00	0,08	0,07	0,00	0,08	0,07	0,00
	Aire acondicionado	0,03	0,02	0,00	0,07	0,06	0,00	0,07	0,06	0,00
	Terraza grande	0,13	0,07	0,00	0,10	0,05	0,00	0,11	0,06	0,00
	Calefacción	0,33	0,30	0,00	0,06	0,05	0,00	0,06	0,05	0,00
	Ascensor * Planta	0,01	0,04	0,00	0,01	0,05	0,00	0,01	0,05	0,00
	Año construcción	-0,00	-0,11	0,00	0,00	0,04	0,00	0,00	0,05	0,00
	Calidad de cocina	0,24	0,16	0,00	0,05	0,03	0,00	0,04	0,03	0,00
	Bien conservado/reforma	0,01	0,00	0,04	0,04	0,03	0,00	0,04	0,03	0,00
	Alta calidad	0,11	0,03	0,00	0,08	0,03	0,00	0,08	0,03	0,00
	Chimenea	0,17	0,05	0,00	0,06	0,02	0,00	0,06	0,02	0,00
	Superficie^2	-0,00	-0,11	0,00	-0,00	-0,42	0,00	-0,00	-0,42	0,00
Variables de control territoriales y urbanísticas	AM Barcelona				0,48	0,43	0,00	0,33	0,30	0,00
	AM Alicante				0,02	0,02	0,00	0,04	0,03	0,00
	% residentes con estudios universitarios				0,01	0,23	0,00	0,01	0,23	-
	Densidad de empleo municipal				0,00	0,17	0,00	0,00	0,15	0,00
	Distancia a autopista/autovia				0,02	0,06	0,00	0,02	0,06	0,00
	Mar a 200 m o menos				0,13	0,05	0,00	0,13	0,05	0,00
	Acceso a autopista/autovia				0,08	0,04	0,00	0,09	0,05	0,00
	Locales en PB/100 hab				0,00	0,03	0,00	0,00	0,03	0,00
	% municipal servicios alto valor añadido				0,00	0,02	0,01	0,00	0,02	0,00
	% hogares que opinan viven en un entorno ruidoso				-0,00	-0,02	0,00	-0,00	-0,02	0,00
Clase energética	EPC continua							0,0154	0,04	0,00
Zona climática	Zona climática C2							0,19	0,16	0,00
	Zona climática B3							0,03	0,02	0,02

Notas: Variable dependiente Ln Precio (Euros), tanto las variables como los factores se han introducido siguiendo el método de pasos sucesivos en el MOD2 y el MOD 3 la variable de control territorial es el AM de Valencia. Las variables están ordenadas por bloques en orden descendiente según el coeficiente Beta del MOD 3

Fuente: Elaboración propia

FIG. 4 / **Modelos con la muestra conjunta de las 3 AM**

Fuente: Elaboración propia

en Barcelona, que el impacto de las clases energéticas no es homogéneo a lo largo de los diferentes submercados residenciales. Siendo nulo en el caso de los apartamentos de recinte construcción con las mejores prestaciones arquitectónicas, y muy significativo en el caso de los apartamentos antiguos de peor calidad en dónde, según dichos autores, en ausencia de atributos de calidad, la clase energética juega un rol erróneo en la diferenciación de los precios inmobiliarios.

En relación con el trabajo de Marmolejo (2016) realizado en el AM de Barcelona, cuyos datos analizados son 18 meses anteriores a los nuestros,

> "el impacto de los EPC sobre los precios se ha fortalecido, pasando de un tímido 0,852% (con un error estándar del 0,41%) en dicho trabajo, a un 1,79% -con un error estándar del 0,31%-) en el nuestro. Lo que es plenamente coherente con el proceso de

Ajuste de los modelos		R^2 aj	F	Sig.	R^2 aj	F	Sig.	R^2 aj	F	Sig.	R^2 aj	F	Sig.
		0,76	1.659	-	0,70	449	-	0,78	555	-	0,72	309	-
		MOD 4 EPCxAM N=14.058			**MOD 5 EPC NOM ALC** N=5.784			**MOD 5 EPC NOM BCN** N=4.857			**MOD 5 EPC NOM VLC** N=3.417		
		B	Beta	Sig.	B	Beta	Sig.	B	Beta	Sig.	B	Beta	Sig.
	EPC continua * AM Alicante	- 0,012	- 0,02	0,00									
	EPC continua * Am Barcelona	,0179	,051	,000									
	EPC continua * Am Valencia	0,033	0,06	0,00									
Clase energética	Clase A				0,08	0,01	0,05	0,10	0,03	0,00	0,29	0,10	0,00
	Clase C				- 0,24	- 0,03	0,00	0,06	0,02	0,00	0,18	0,01	0,25
	Clase D				0,02	0,00	0,59	0,07	0,04	0,00	0,16	0,05	0,00
	Clase E				- 0,05	- 0,03	0,00	0,02	0,02	0,10	0,04	0,03	0,00
	Clase F				- 0,05	- 0,02	0,01	0,01	0,00	0,62	- 0,02	- 0,01	0,38
	Clase G (clase energética base)												
Control de variables arquitectó-nicas		14 sig. al 95% conf.			14 sig. al 95% conf.			14 sig. al 95% conf.			14 sig. al 95% conf.		
Control de variables urbanís-ticas y territoriales		8 sig. al 95%			11 sig. al 95%			10 sig. al 95%			8 sig. al 95% conf.		
Zona climática	Zona climática C2	0,18	0,16	0,00				0,15	0,09	0,00			
	Zona climatica D1							- 0,40	- 0,02	0,00			
	Zona climática B3	0,03	0,02	0,01							0,03	0,02	0,05

Notas: Variable dependiente Ln Precio (Euros), tanto las variables como los factores se han introducido siguiendo el método de pasos sucesivos, excepto en los MOD 5 donde como es habitual se ha forzado su introducción. En dichos modelos la variable de referencia es la G. En gris claro aparecen las variables que no son significativas al 90% de cofianza. Todas las variables de control han resultado con el signo esperado que coincide con el reporte del MOD 3

Fuente: Elaboración propia

FIG. 6 / **Modelos por cada AM y cada clase energética**

Fuente: Elaboración propia

> maduración necesario para que el mercado inmobiliario responda a la política energética de la DEEE, aunque también podría responder al encarecimiento de la factura energética de los hogares en España."

Para estudiar con detalle lo que ocurre en el extraño signo revertido del coeficiente de clase energética en Alicante y, además, analizar el precio hedónico de cada clase energética se han construido los MOD 5-EPC-NOM por AM. Según dichos modelos en Valencia y Barcelona no existe una progresión lineal del impacto de las clases energéticas sobre los precios,

> "sino que tiende ser logarítmica, es decir las clases superiores (más eficientes) producen un incremento marginal de los precios menor a las inferiores."

En Barcelona, una vivienda clasificada como "A" se vende un 10% más cara que una clasificada como "G". En Valencia, el sobreprecio por la misma mejora energética escala hasta un 29%. Esto significa un incremento de 18.307 euros y 35.005 euros para el valor medio de la muestra analizada respectivamente. Por su parte la clase "E"[7] tiene un premio de sólo un 2% en Barcelona y un 4% en Valencia en relación a la clase "G". Asimismo, la clase "D" nuevamente tiene un impacto superior en Valencia que no en Barcelona. Por tanto, se constata una agenda hedónica muy diferente entre las dos principales metrópolis estudiadas, en donde la diversidad de las clases energéticas puede tener un rol: en Barcelona la diversidad es mayor y además hay más viviendas mejor clasificadas (por cada 100 viviendas mal calificadas –"G" y "F" - hay 20 "bien" calificadas "A","C", "D" y "E"); por el contrario, en Valencia la diversidad de las clases energéticas es menor,

[7] La mínima habitual, para la nueva planta, dadas las condiciones legales vigentes en 2016

y además hay menos viviendas bien calificadas (por cada 100 viviendas mal calificadas hay sólo 3 "bien" calificadas). De forma que en Valencia las viviendas mejor calificadas son relativamente más escasas y es posible que a ello atienda el hecho que su sobreprecio sea superior. En cualquier caso,

> "si la abundancia relativa de las viviendas mejor calificadas supone una pérdida del poder de diferenciación de los precios de mercado del atributo energético, eso quiere decir que a medida que aparezcan más viviendas mejor calificadas, o bien por el endurecimiento de las normativas o bien porque los promotores encuentren ventajas por invertir en viviendas más eficientes, entonces es probable que asistamos a una pérdida del poder de diferenciación de precios de los EPC."

Sin embargo, la hipótesis anterior parece refutarse en Alicante donde la diversidad de clases energéticas es escasísima como lo es aún más la presencia de viviendas "bien" calificadas en relación a las mal calificadas (1 de las primeras por cada 100 de las segundas). Como se ha dicho antes, en dicha AM la correlación entre la clase energética, medida como una variable continua y los precios es negativa. Así, únicamente las, muy escasas, viviendas "A" tienen un sobreprecio del 8% en relación a las de comparación "G", pero todo el resto de clases tienen precios inferiores a las peores "G", todo lo demás igual. Cabe recordar que en Alicante la clase "G" es anormalmente abundante, especialmente si atendemos al hecho que las viviendas son las más recientes del conjunto de metrópolis estudiadas, y por ende con mayor probabilidad de estar construidas después de la entrada en vigor de la NBE CT-78 (vigente de 1981 a 2007) y el DB HE1 del CTE (aplicable a partir del 2008). Por tanto, cabe analizar con mayor detalle, cuan diferentes son las viviendas clase "G" en las tres AM para entender porque, en contra de todo pronóstico, en Alicante forman sobreprecios en vez de penalizaciones.

La Fig. 7 ilustra la relación que existe entre la antigüedad y la clase energética publicitada. Como se ve, el caso barcelonés sigue los patrones esperados: las viviendas más recientes tienen una mayor eficiencia energética, con claridad se observa una caída de las viviendas "E" en el periodo post-CTE a favor de las clases "C" y "A". En el AM valenciana también existe una caída de las viviendas "F" y "G", pero un extraño repunte de la clase "G" en el periodo posterior al 2007. En Alicante pasa algo semejante, si bien con mayor intensidad, puesto que las viviendas cuyo año de construcción declarado es posterior al 2007 están calificadas, en un 93%, con clase

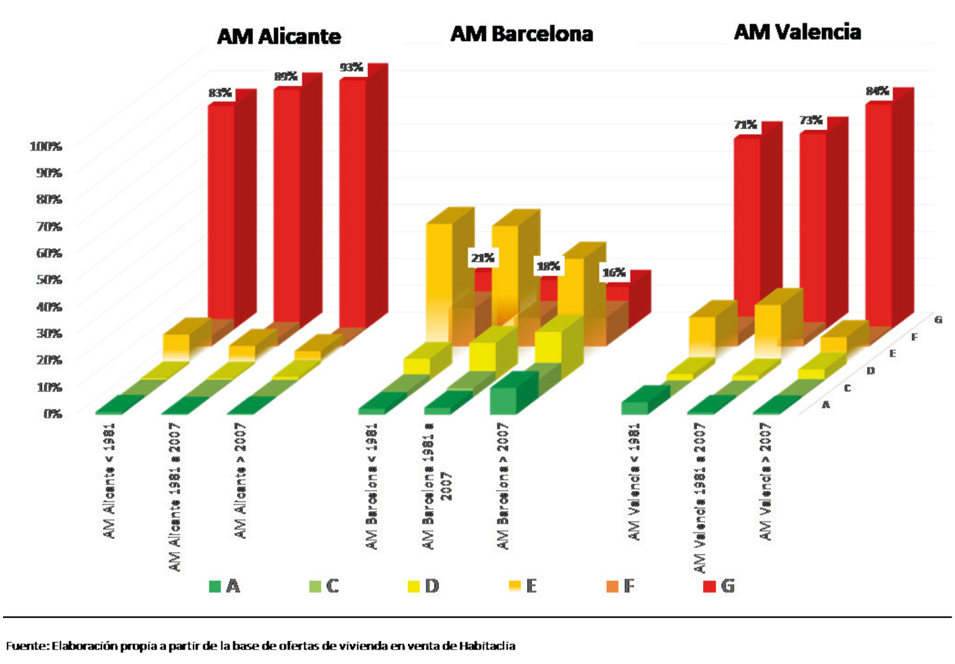


FIG. 7 / **Segmentación de la muestra por clase energética y año anunciado de construcción**

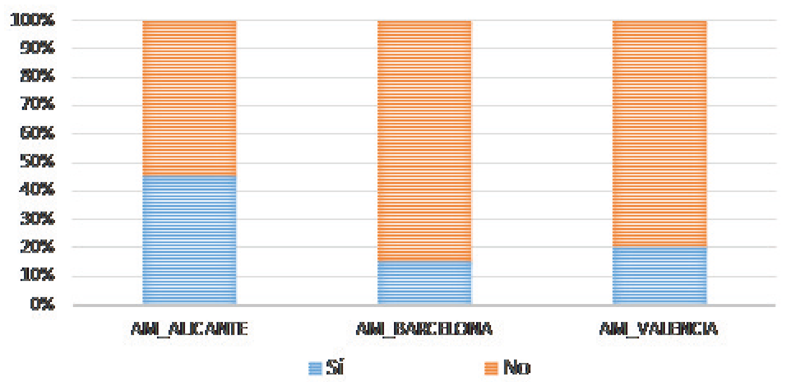
Fuente: Elaboración propia a partir de la base de ofertas vivienda en venta de Habitaclia

"G"; cifra que contrasta espectacularmente con lo que ocurre en Barcelona donde esa proporción es sólo del 16%.

Es probable que la muy abundante presencia de viviendas "G" en la Comunidad Valenciana, y muy particularmente en Alicante, se deba a un intenso proceso de rehabilitación (sin implicaciones energéticas) en el periodo post-CTE, y por ende, que el año de construcción declarado en realidad sea el año de remozamiento de la vivienda[8]. Para contrastar esta conjetura se han comparado, por AM, las características de las viviendas que han resultado explicativas de los precios, y que son estadísticamente diferentes entre las viviendas clase "G" y el resto. Y en efecto, la proporción de viviendas reformadas es mayor en Alicante, pero, sobre todo:

1. En Alicante la diferenciación entre las viviendas "G" y el resto es muy escasa, únicamente 9 atributos son estadísticamente diferentes; muy por el contrario, en Barcelona existe una clarísima divergencia entre las características del parque "G" en relación al resto, puesto que difiere al 95% de confianza en 17 de sus atributos con relevancia en los precios. Parecería como si las viviendas alicantinas, con independencia de su calidad, estuviesen aleatoriamente distribuidas entre las peor calificadas ("G") y el resto.

2. En Alicante, las viviendas energéticamente ineficientes "G" son en general mejores en todos los aspectos que el resto de clases: tienen ascensor y aire acondicionado en mayor proporción, son más nuevas, son más grandes y son más caras; por el contrario, en Barcelona, como es esperable, las viviendas peor calificadas tienen menores prestaciones en el resto de atributos.



	Información de la clase energética		
	Sí	**No**	**Total**
AM_ALICANTE	8.461	10.186	18.647
AM_BARCELONA	7.511	41.913	49.424
AM_VALENCIA	5.015	19.276	24.291

Fuente: Elaboración propia

FIG. 8 / **Proporción de anuncios publicitarios con información energética**

Fuente: Elaboración propia

[8] Desafortunadamente no es posible contrastar esta información debido a que las ofertas no incluyen la referencia catastral, ni tampoco la dirección exacta, y por ende no es posible comprobar si el año de construcción declarado por los anunciantes coincide con la información catastral. La ausencia de dicha información también impide hacer un análisis pormenorizado vivienda a vivienda sobre la coincidencia entre la clase energética anunciada y la que consta en el registro público de certificados.

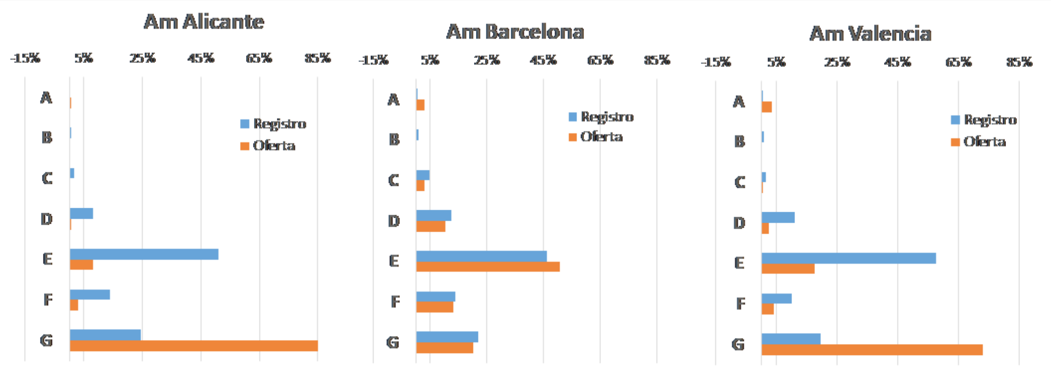
Todo lo anterior destaca las importantes singularidades del mercado residencial alicantino publicitado: una inexplicable peor calidad energética en las viviendas post-CTE, una inexplicable correlación inversa entre la calificación energética y el resto de sus atributos de calidad; y, sobre todo, una correlación inversa entre la eficiencia energética y los precios inmobiliarios.

¿Podrían obedecer dichas incoherencias a anomalías en la publicitación de la clase energética? ¿Podría ocurrir que los anunciantes con tal de no incurrir en una falta administrativa derivada de la omisión la clase energética estén publicitando la menor de las clases? La Fig. 8 detalla la proporción de las viviendas que incluyen la clase energética en su anuncio publicitario, como se ve tanto en Barcelona como en Valencia únicamente entre un 15 y un 20% de las ofertas respectivamente incluyen la etiqueta energética (el resto está "en trámite"). En cambio, en Alicante esta proporción escala hasta el 45% ¿A caso los oferentes en dicha AM cumplen con mayor ahínco la legislación? O, por el contrario, ¿se está produciendo una distorsión informativa de descomunales dimensiones? que como ulterior consecuencia tiene la completa banalización de la etiqueta energética en el mercado inmobiliario alicantino al extremo de producirse correlaciones invertidas con los valores residenciales.

La conjetura anterior tiene cierto sustento en el trabajo de Taltavull & al. (2017), quienes utilizando el mismo método en el área de Alicante, pero usando la calificación consignada en el registro de certificaciones energéticas, han encontrado una correlación positiva entre los precios y la eficiencia energética.

Finalmente, la Fig. 9 compara la distribución de las clases energéticas que constan en los registros oficiales autonómicos y la publicitada en la muestra de mercado analizado. Con meridiana claridad se confirma para el caso de Alicante (y al parecer también en Valencia) que existe una sobredimensión de la clase "G" en la oferta inmobiliaria publicitada en relación al parque efectivamente certificado. Para probar si dicha divergencia es significativa se ha realizado la prueba de U de Mann-Whitney la cual ha confirmado que únicamente en Barcelona existe un paralelismo entre la información energética publicitada en las ofertas inmobiliarias y la realidad energética del parque certificado.

Las presuntas anomalías anteriores no son una novedad en España. Desde los propios albores del RD 235/2013 han aparecido en la prensa noticias sobre problemas en: a) la cualificación de algunos certificadores, b) el poco rigor en la realización de ciertas certificaciones y c) la picaresca en la publicitación de la clase energética. En efecto, entre la fecha de aprobación del citado Real Decreto y su entrada en vigor pasaron escasas seis semanas lo que derivó en un alud de certificaciones que, en un escenario de recesión económica, desembocó en una guerra de precios a la baja que lastró el precio de la certificación a honorarios equivalentes a una quinta parte de los originalmente previstos.



Fuente: Elaboración propia con base en datos de Habitaclia (oferta) y de los Registros Oficiales de la CCAA de Cataluña y Valencia

FIG. 9 / **Comparación entre la distribución EPC del registro oficial y el publicitado en la muestra estudiada**

Fuente: Elaboración propia con base en datos de Habitaclia (oferta) y de los Registros Oficiales de la CCAA de Cataluña y Valencia

> “Nos llegan [arquitectos] colegiados a los que les quieren pagar 30 euros por certificados que las empresas cobran a 50 euros” (Pilar Pereda, Secretaría General del COAM, en SÁNCHEZ, 2014).
>
> “El riesgo que se estén tirando los precios es que se está reduciendo su calidad… se está banalizando la certificación energética” (Gonzalo CERVERA, Director de Tinsa Certify en SALIDO, 2013).
>
> “La picaresca no conoce límites […] hay profesionales que realizan certificados a distancia sin visitar la vivienda” (Ángel I. Cobos, Secretario del Colegio de Administradores de Fincas de Madrid en SÁNCHEZ, 2014).
>
> “El nivel de engaño va desde técnicos que hacen chanchullos para vender más [servicios de certificación] hasta particulares o inmobiliarias que cambian con Photoshop la letra. (Pilar Pereda, Secretaria General del COAM, en SÁNCHEZ, 2014).

Frente a dicha problemática tanto las administraciones competentes como los tribunales han respondido con sanciones administrativas y sentencias respectivamente. Por ejemplo, en Murcia de las 26 inspecciones realizadas, a un año de entrada en vigor del RD, en edificios y locales terciarios el 90% eran erróneas. Así, en comunidades como Madrid, los primeros expedientes sancionadores no tardaron en aparecer, revelando discrepancias entre los datos utilizados en la certificación y la realidad (VIÚDEZ, 2013) y la primera sanción a un certificador de 4.000 mil euros llegó, en esa misma comunidad, en diciembre de 2013 (BUENO, 2013). Durante el 2014 la misma comunidad madrileña incoó 21 expedientes sancionadores: 9 por falsear los datos, 9 más por arrendar inmuebles sin contar con un EPC y 3 por actuar como certificador sin tener la titulación habilitante. De todos ellos 16 acabaron en sanción (BUENO, 2014). Navarra fue de las primeras CCAA en sancionar a las agencias inmobiliarias que anunciaban sus inmuebles sin incluir la clase energética; mientras que Cataluña hizo una campaña para recordarles esta obligación (BUENO, 2014). Ante este panorama no es difícil suponer que en ciertos mercados existen sendas tergiversaciones que oscurecen la pretendida transparencia energética del mercado inmobiliario comunitario.

[9]Para el entorno de las viviendas analizadas en este artículo

5. Conclusiones

A 2,9 años de que sea obligatorio, según el RD 235/2013, incluir la clase energética en la publicidad conducente a la venta y el alquiler inmobiliario este trabajo indaga si: 1) a medida que ha pasado el tiempo la incidencia de la clase energética se ha mantenido estable en relación a los resultados previamente publicados por MARMOLEJO (2016) para Barcelona; y 2) es homogénea a lo largo de diferentes mercados metropolitanos plurifamiliares con climas y, sobre todo, tamaños distintos. De esta forma se analiza, con el concurso del método de precios hedónicos, información relativa a los precios de oferta plurifamiliar del portal *Habitaclia* que tiene una importante presencia en las tres áreas metropolitanas funcionales (AM) elegidas: Barcelona, Valencia y Alicante; que tanto por su tamaño (5,22; 2,12; y 1,09 millones de habitantes) como por su diversidad climática (temperaturas medias[9] de 8,65 oC en enero /23,61 oC en julio; 10,41 /24,71 y 11,02 /25,51 respectivamente) resultan un excelente caso de estudio, en donde observar divergencias en el impacto de las clases energéticas sobre los precios inmobiliarios.

Con el objeto de obtener coeficientes insesgados importantes esfuerzos se han invertido en controlar los atributos arquitectónicos, urbanísticos y territoriales con incidencia en la formación de los precios. Los resultados sugieren que a medida que pasa el tiempo la incidencia de las calificaciones energéticas sobre los precios de oferta se acentúa. Así, el incremento porcentual del precio de la vivienda por cada escalón energético se ha duplicado en Barcelona pasando del 0,852% (MARMOLEJO, 2016) al 1,79% en sólo un año y medio. Por otra parte, si se parte del supuesto que la calificación energética es apreciada como una variable nominal (y no continua) entonces el sobreprecio de una vivienda clase “A” en relación a otra clase “G” en Barcelona es del 10% mientras que en Valencia escala hasta el 29%, eso representa, en relación al precio medio respectivo un incremento de 18 mil y 35 mil euros respectivamente, y por ende suficiente para compensar el sobrecoste medio marginal calculado en Madrid por GARCÍA-NAVARRO & al. (2014) para una vivienda plurifamiliar. En cambio, la calificación mínima “E” para las viviendas nuevas apenas recibe un premio.

Asimismo, en Valencia, donde la oferta es menos diversificada en términos energéticos y las viviendas mejor calificadas son más escasas en relación a las peor calificadas, el impacto por escalón es del 3,35%, es decir, mayor que en Barcelona donde la oferta es más diversificada y las viviendas eficientes más abundantes en términos relativos. Este hallazgo podría tener serias implicaciones para la política energética tal como ha sido diseñada, puesto supone que, ante una mayor homogeneidad en la clase energética derivada del incremento de las clases superiores, la diferenciación de precios tiende a desaparecer, y, por ende, las ventajas que podrían tener los promotores de vivienda nueva o energéticamente rehabilitada para compensar los costes marginales de construcción energéticamente eficiente. Esta conjetura va en línea de la evidencia empírica reportada por Chegut & al. (2014) cuyo trabajo en Londres ha puesto de relieve que por cada nuevo edificio que se certifica con el sistema Breeam existe una reducción en el sobreprecio en relación al de los edificios previamente certificados en la misma zona. Exactamente la misma conclusión fue apuntada por el trabajo pionero de Winward & al. (1998) quienes documentaron que el comportamiento de los consumidores en los albores de la calificación energética de los electrodomésticos dependía de la proporción de bienes certificados en la tienda. También podría ocurrir que los ahorros energéticos en Valencia fuesen relativamente más interesantes en relación al menor precio de la vivienda en dicha AM en relación al Barcelonés (hasta un 82% más caro en términos unitarios), como ya lo hubiera apuntado el trabajo de Mudgal & al. (2013). Esta conjetura requiere una mayor profundización en los trabajos futuros que necesariamente pasa por la compleja tarea de cuantificación del gasto energético real de los hogares en los mismos entornos espaciales a los que se refiere la oferta inmobiliaria.

Finalmente, en el mercado inmobiliario alicantino los análisis denotan importantes singularidades: 1) la proporción de viviendas con información energética en sus anuncios publicitarios es muy superior que en Valencia y especialmente que en Barcelona; 2) en contra de toda lógica –y de lo que ocurre en Barcelona y en menor medida en Valencia-, las viviendas más recientes (periodo post-CTE) están peor calificadas que las más antiguas; 3) las viviendas peor calificadas tienen mejores prestaciones en el resto de sus atributos arquitectónicos, a diferencia de lo que ocurre en Barcelona en donde una peor calificación energética corresponde a una peor calidad de la vivienda en general. Esto produce que, a pesar del importante número de variables de control usadas en los modelos econométricos, el precio hedónico de la calificación energética alicantina resulte revertido. Es decir, a una peor calificación corresponde un precio más elevado todo lo demás igual. Además, las AM valencianas, a diferencia de Barcelona, la distribución de la clase energética de los anuncios inmobiliarios no coincide con la del parque certificado según los respectivos registros oficiales. Si dicha distorsión respondiese a anomalías en la publicitación de calificaciones incorrectas estaríamos asistiendo a una completa banalización de la política energética tal como ha sido diseñada en el seno de la Comisión Europea.

Así pues, emergen dos claras implicaciones para la política pública:

1. La primera, y más importante, relacionada con la eventual desaparición del sobreprecio energético a medida que las viviendas más eficientes aparezcan en el mercado y por ende la diversidad de la oferta incremente. Lo cual supondría un reto para el esquema EPC que ha confiado en el libre mercado como proveedor de inmuebles eficientes.

2. La segunda reclama una mayor atención por parte de las administraciones competentes en la verificación de la correspondencia entre la información publicitada y la contenida en los registros de certificados.

6. Agradecimientos

Los autores agradecen a la evaluación anónima sus críticas que, sin lugar a dudas, han permitido mejorar este trabajo. Asimismo, a Habitaclia por facilitar el acceso a los datos de ofertas inmobiliarias. Este artículo deriva del proyecto EnerVALOR "¿Cuánto nos importa la calificación energética? Un análisis del nivel de comprensión de los EPC, confianza percibida e impacto sobre las preferencias y valores residenciales" financiado por el Ministerio de Economía y Competitividad bajo la referencia BIA2015-63606-R (MINECO/FEDER) del cual los autores son, respectivamente, IP y parte del equipo de trabajo. Asimismo, este trabajo se inscribe en el marco de la tesis doctoral de la segunda persona autora.

Bibliografía

Addae-Dapaah, K. & Chieh, S. J. (2011): "Green mark certification: does the market understand?", *Journal of Sustainable Real Estate*, 3(1), 162-191.

Brounen, D & Kok, N. (2011): "On the economics of energy labels in the housing market», *Journal of Environmental Economics and Management,* 62(2), 166-179.

Bueno, J. (2013): *Primera sanción por falsear los datos de un certificado energético,* disponible en: http://www.elmundo.es/economia/2013/12/18/52b18334268e3e65428b4577.html (acceso 18 Diciembre 2013)

Bueno, J. (2014): *El certificado energético sigue en tierra de nadie*, disponible en: http://www.elmundo.es/economia/2014/12/19/5492bbc4268e3ecf3c8b4573.html (acceso 19 Diciembre 2014)

Chegut, A. & Eichholtz, P. & Kok, N. (2014): "Supply, demand and the value of green buildings", Urban Studies, 51(1), 22-43.

De Ayala, A. & Galarraga, I. & Spadaro, J. V. (2016): "The price of energy efficiency in the Spanish housing market", *Energy Policy,* 94, 16-24.

Eichholtz, P. & Kok, N. & Quigley, J. M. (2010): "Doing well by doing good? Green office buildings", *The American Economic Review,* 100(5), 2492-2509.

Fuerst, F. & McAllister, P. (2011): "The impact of energy performance certificates on the rental and capital values of commercial property assets", *Energy Policy,* 39(10), 6608-6614.

— & al. (2015): "Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England", *Energy economics*, 48, 145-156.

García-Hooghuis, A. & Neila, F. (2013): "Modelos de transposición de las Directivas 2002/91/CE y 2010/31/UE "Energy Performance Building Directive" en los Estados miembros de la UE, Consecuencias e implicaciones", *Informes de la Construcción,* 65(531), 289-300.

García-Navarro, J. & González-Díaz, M. & Valdivieso, M. (2014): ""Estudio Precoste»: evaluación de los costes constructivos y consumos energéticos derivados de la calificación energética en un edificio de viviendas situado en Madrid", *Informes de la Construcción,* 66(535), 26.

Hyland, M. & Lyons, R. C. & Lyons, S. (2013): The value of domestic building energy efficiency—evidence from Ireland, *Energy economics,* 40, 943-952.

Kok, N. & Jennen, M. (2012): "The impact of energy labels and accessibility on office rents", *Energy Policy,* 46, 489-497.

Marmolejo, C. (2016): "La incidencia de la calificación energética sobre los valores residenciales: un análisis para el mercado plurifamiliar en Barcelona", *Informes de la Construcción,* 68(543), 156.

— & Chen, A. (2019) "The uneven price impact of energy efficiency ratings on housing segments. Implications for public policy and private markets", *Sustainability,* 11, 372, 1-23.

— & Bravi, M. (2017) "Does the Energy Label (EL) Matter in the Residential Market? A Stated Preference Analysis in Barcelona", *Buildings*, 7 (2) 1-17

— & García-Hooghuis, A. & Garcia-Masia, A. (2017) "¿Cuánto nos importa la clase energética de nuestras viviendas? un análisis del nivel de comprensión de los EPC, disposición y motivos de pago en Barcelona", *Habitat Sustentable,* 7 (1), 55-65

Mudgal, S. & al. (2013): *Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries*: European Commission (DG Energy), Paris.

Roca, C. J. (1988): *La estructura de valores urbanos: un análisis teórico-empírico:* Instituto de Estudios de Administración Local, Madrid.

— & Marmolejo, C. R. & Moix, M. (2009): "Urban structure and polycentrism: Towards a redefinition of the sub-centre concept", *Urban Studies, 46*(13), 2841-2868.

Rosen, S. (1974): "Hedonic prices and implicit markets: product differentiation in pure competition", *Journal of political economy,* 82(1), 34-55.

Salido, J. (2013): El certificado energético para viviendas también se despacha en cupones de descuento, disponible en:

http://www.elmundo.es/elmundo/2013/07/02/suvivienda/1372752464.html (acceso 02 Julio 2013)

SÁNCHEZ, P. (2014): Picaresca en la certificación, disponible en:

https://elpais.com/economia/2014/02/06/vivienda/1391692114_309183.html (acceso 06 Febrero 2014)

Taltavull & P.; Pérez, R. & Mora, R. (2017) "Green Premium. Evidence from Spain", ACTAS DEL CONGRESO LARES 2017, SAO PAULO, BRASIL.

Viúdez, J. (2013): El caos del certificado energético, disponible en:

https://elpais.com/sociedad/2013/09/13/actualidad/1379090592_775839.html (acceso 14 Septiembre 2013)

Winward, J. & Schiellerup, P. & Boardman, B. (1998): Cool Labels: the first three years of the European Energy Label: Energy and Environment Programme, Environmental Change Unit, Oxford.

sustainability

MDPI

Article

The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments. Implications for Public Policy and Private Markets

Carlos Marmolejo-Duarte * and **Ai Chen**

Escola Tècnica Superior d'Arquitectura de Barcelona, Centre de Política de Sòl i Valoracions, Universitat Politècnica de Catalunya, 08028 Barcelona, Spain; ai.chen@upc.edu

* Correspondence: carlos.marmolejo@upc.edu; Tel.: +34-93-401-63-96

Received: 14 November 2018; Accepted: 24 December 2018; Published: 12 January 2019

check for updates

Abstract: In the literature, there is extensive, although in some cases inconclusive, evidence on the impact of Energy Performance Certificates (EPC) on housing prices. Nonetheless, the question of whether such an impact is homogenous across residential segments remains highly unexplored. This paper addresses this latter issue utilizing multifamily listing data in metropolitan Barcelona. In doing so, first the entire sample is analyzed using a hedonic model. Second, the sample is split on the basis of a multivariate segmentation. Finally, separated hedonic models are specified again. The results suggest that in general, there is a modest impact of EPC ratings on listing prices, nonetheless it is not homogeneous across housing segments: (1) for the most modern apartments, with state-of-the-art features and active environmental comfort, energy ratings seem to play a null role in the formation of prices; (2) conversely, for the cheapest apartments, apartments boasting the most basic features, and apartments located in low-income areas, the "brown discount" is enormously significant, potentially depreciating the equity of those who have the least resources to carry out an energy retrofit. These results have implications for the assessment of the EPBD and its Spanish transposition, since a very well-intentioned environmental policy could have potentially harmful social repercussions in the absence of corrective measures.

Keywords: EPC impact; residential prices; energy labeling; housing market segments; Barcelona

1. Introduction

For environmental and energy dependency reasons, improving energy efficiency in buildings is a major priority in the public agenda of industrialized countries [1]. In the European Union, the Energy Performance of Buildings Directive (2002/91/EC), also known as EPBD, is the main policy instrument aimed to promote energy efficiency in the real estate market [2]. The EPBD introduced Energy Performance Certificates (EPCs) to provide tenants and buyers with synthetic and third-party information regarding the efficiency of real estate to eliminate market asymmetries. Such a strategy is relevant since market failures, in the form of imperfect information and asymmetries, are suggested to be barriers in the diffusion of efficient buildings [3], producing an "energy gap" (i.e., a rate of adoption well below the social optimum) [4]. Therefore, the recast of the Directive in 2010 (2010/31/EU) made it mandatory to include EPC labels in the marketing of almost all new and existing buildings in order to inform prospective users.

As efficient buildings can save money in energy bills and reduce environmental impacts it is expected that informed tenants and buyers were willing to pay more for efficient real estate. Eventually, such willingness to pay for efficient buildings may capitalize into "market premiums", generating incentives for developers and owners to invest in energy efficiency [5]. In sum, the European

Commission saw the EPC scheme as "a power tool to create a demand-driven market for energy efficient buildings (p. 5) [6].

Among all the real estate markets, the residential one is a special case since, due to the size of its stock, it consumes much more energy than commercial properties [7]. In the literature, there is extensive, yet in some case inconclusive, evidence regarding the existence of market premiums for efficient homes. According to the studies reviewed in the next section, home selling prices can vary up to 30.5% (for rating A, the most efficient one, in relation to rating G as the most inefficient) in the Danish case [8] or as little as 5% (A/G) in the case of the Irish renting market [9]. However, there is evidence suggesting that EPC labels do not play any role in price discrimination in the Oslo market [1]. Differences in climate and energy costs in relation to home prices and, perhaps, environmental concerns may be behind such divergences. As such, there are no reasons to believe that the impact of EPC labels is stationary across housing segments within the same city, where household budgets, personal tastes, and priorities, as well as home attributes and prices also vary in a significant manner. As a matter of fact, in the office market, there is evidence suggesting that "green labels" are contingent to characteristics of buildings in the determination of prices [10].

The aim of this paper is to test whether the impact of EPC ratings on housing prices is the same in different market segments within a city. This analysis is relevant since the identification of divergent impacts may help to orientate specific energy and housing public policies, while simultaneously signaling opportunities for private developers. With this objective, this study uses data of listed apartments in metropolitan Barcelona. This case is worth studying due to the late and overnight transposition of the 2010 EPBD in Spain: only 47 days separated the date of the publication of the RD 235/2013 (that transposed the Directive) and the 1st of June of 2013 when it was mandatory to include the EPC labels in real estate marketing. At the same time, due to the financial crisis, the public campaigns were almost nonexistent, making it impossible to make the households aware of the meaning and utility of the EPC scheme. Broadly, the methodology consists of: (1) Acquire, geoprocess and depurate the data, (2) Calibrate a hedonic model for the entire depurated sample of 3479 apartments, (3) split the sample into housing segments using a multivariate approach, (4) calibrate specific models for each of the segments, and (5) identify whether the hedonic agenda for each of the segments is statistically different. The main novelty of this approach, in relation to the previous studies that have analyzed market segments [9,11–13], lies precisely in the segmentation of the market based on the multiple urban and architectural attributes that effectively affect the formation of real estate prices.

The results suggest that, in general, there is a modest impact of EPC ratings, being quite lower than that reported in other countries. In fact, the relationship between this surcharge and the energy rantings is not linear, but tends to be exponential, so there is a psychological effect that especially rewards the select club that makes up the "A" rated apartments (the most efficient ones). However, this premium is not homogeneous throughout the different residential segments. In fact, in the newer homes that largely featured active air conditioning systems and boasted architectural layout advantages (e.g., more bathrooms or being equipped with a condominium pool) or of being higher quality, energy rating plays no role whatsoever in the formation of real estate prices. On the contrary, in the case of dwellings built during the post-war period, which usually located in low-income areas, characterized by low prices and few architectural features, energy rating emerges as an important driver in listing price formation. Finally, for the segment of older dwellings, usually located in the 19th Century Expansion areas and wealthy neighborhoods, there is also a market premium, although it is lower than in the case of the worst dwellings. These findings have repercussions that lie at the very heart of energy policy and, also, in the strategies of private developers as discussed in the concluding section.

The remainder of this paper is organized as follows: first, a review of the studies identifying the marginal price of EPC rating; next, a description of the scope of the study, materials and methods; followed by the discussion of the results; and, as a conclusion, the presentation of the findings in the framework of energy policy and private markets.

2. The Impact of Energy Ratings on Prices

The positive relationship between the green labels introduced before the EPC scheme (e.g., BREEAM-Building Research Establishment Environmental Assessment Method, HQE-High Quality Environmental standard, LEED-Leadership in Energy and Environmental Design, Green Mark, Energy Star and Minergie) and both rental and sales prices is well studied in the literature and stands in contrast with the relatively reduced number of studies focused on the EPC scheme. These papers share a common methodology (based on the hedonic analyzes of marginal prices) and the same information sources (in the absence of transaction prices, they refer mainly listing data).

The reform of the EPBD (2010/31/EU) and Directive 2012/27/31 set the current framework for the transposition of energy certification into the Member States. Within this context, the pioneering study by Brounen & Kok [14] analyzed the impact of these new "green labels" on residential prices in the Netherlands; although the data used comes from the period in which the buyer could exempt the seller from providing the EPC. The results of this study found a positive correlation between the best rated dwellings and sales prices verified in real estate transactions. Such authors, like almost all others whose work has been summarised in Table 1, assume that energy ratings constitute a categorical measure of energy efficiency. Therefore, considering the intermediate rate "D" as the basis for comparison, they found that the marginal price moves from +10% for rate "A" to −5% for rate "G", i.e., "market premiums" are formed above the reference situation, while below such threshold market penalties or "brown discounts" (i.e., price reductions) emerge. The study conducted by Hyland et al. [9], in different Irish cities, was the first to simultaneously compare the impact of EPCs on the rental and sale listing prices. In general, they found that the impact of the energy labelling is higher in the sale market than in the rental market. For example, a dwelling for sale ranked as "A" (in relation to "D") has a market premium of +9.30%, and only a premium of +1.80% if it is in the rental market, holding everything else equal. Similarly, the "brown discount" for a home rated as class "F" or "G" (in relation to "D") is significantly larger (−10.60%) than another one on the rental market (−3.20%). The larger impact of green labels on sales prices in relation to rental prices is a finding that had already been reported by previous work based on other certification schemes. Examples of such research are the work regarding LEED offices in the US (+31.40% for sale and only +9.20% for rent) [15]; LEED offices (+11.10% for sale and only +5.80% for rent) and Energy Star (+13.00% for sale and only + 2.10% for rent) [16]. The unequal impact of energy labels on rental and sale prices has an impact on yields, for example, Fuerst & McAllister [15] demonstrated the inverse relationship between yields and energy ratings of the BREEAM scheme for the English office market. It seems, therefore, that investors do value efficient buildings as a result of a better marketability, lower vacancy rates, and lower depreciation [17,18]; in relation to office tenants for whom the savings in energy bills are marginal in relation to operating expenses (e.g., salaries).

From Table 1, the work of the Biointelligence Service [5] stands out. This organization was commissioned directly by the European Commission as part of the studies aimed at assessing the effectiveness of the EPBD. It shows the impact of EPC in several countries, with the novelty that the energy rating has been taken as continuous and not categorical. Yet again, the impact of EPC is sharper in selling prices than in rental prices. From this study, it should be noted that EPC ratings seem to have a larger impact on hinterlands (e.g., Belgium and Ireland, with Austria as an exception) than in capital cities. According to the authors, this differential impact is explained by the fact that savings in energy bills are more important, in relation to the base price, in dwellings in smaller urban areas (where housing is cheaper) than in capital cities. Moreover, a higher energy rating does not always imply a market premium. In the Oxford rental market apparently there is a penalty for the best-rated dwellings (−4.00% per EPC class). However, the authors acknowledge the enormous deficiencies of their analysis since in this city, the older, better located and high-priced mansions do rank low in the efficiency ladder. In general, the very poor control of urban characteristics (e.g., accessibility, quality of urbanization and neighborhood effect affecting residential values as studied since Roca [19]) is a deficiency of such work and can bias the coefficients of their models.

Table 1. Selected Studies on EPC Marginal Prices.

Study Cases	Market	Scale Type as Interpreted by EPC Ratings	Marginal impact of EPCs on Sale	Marginal impact of EPCs on Rent	From Energy Rating X to Y (X/Y)	Type of Prices	Authorship
Netherlands	Residential	Categorical	10.00%		A/D	Closing	[14]
			5.50%		B/D		
			2.00%		C/D		
			−0.50%		E/D		
			−2.50%		F/D		
			−5.00%		G/D		
Ireland	Residential	Categorical	9.30%	1.80%	A/D	Listing	[9]
			5.50%	3.90%	B/D		
				−1.90%	E/D		
			−10.60%	−3.20%	F,G/D		
Vienna	Residential	Continuous	Between 10% & 11%	Between 5% & 6%	step	Listing	[5]
Lower Austria			Between 5% & 6%	4.40%	step		
Brussels (Flandes)			4.30%	3.20%	step		
Brussels (Capital)			2.90%	2.60%	step		
Brussels (Wallonia)			5.40%	1.50%	step		
Lille			3.20%	nd	step		
Marseille			4.30%	nd	step		
Ireland (cities)			1.70%	1.40%	step		
Ireland (not cities)			3.80%	1.40%	step		
Oxford (United Kingdom)			0.40%	−4.00%	step		
United Kingdom	Residential	Categorical	5.00%		A,B/D	Closing	[12]
			1.80%		C/D		
			−1.00%		F,E/D		
			−7.00%		G/D		
Denmark	Residential before 1st July 2010		2.40%		A,B,C/D,E,F,G		
	Residential after 1st July 2010	Categorical	10.10%		A,B,C/D,E,F,G	Closing	[8]
			6.20%		A,B/D		
			5.10%		C/D		
			−5.40%		E/D		
			−12.90%		F/D		
			−24.30%		G/D		

Finally, from Table 1, it is also worth mentioning the work by Jensen et al. [8] has found that a clear increase of the energy rating premium in Denmark as the inclusion of the EPC label became mandatory in 2010. Denmark was the first country to introduce, in 1997, an "A"–"G" energy label for buildings, well before the first EPBD came into force; nonetheless, according to such authors, only in 2011 did Danish real estate agents begin to claim that properties with higher EPC rating were the easiest properties to sell.

However, the positive impact on prices reviewed before contrasts with the outcomes of opinion-based research. Murphy [20] conducted a survey in the Netherlands in order to identify the impact of EPC information on price negotiation in the context of home purchasing. Her results suggest that "a higher EPC fails to have a direct influence during negotiation and decision making" (p. 666). In the same line, Parkinson et al. [21] have found no correlation between EPC ratings and rental values while surveying commercial office occupants in the UK. Their findings suggest that facilities' aesthetics are the main driver of rents. Compatible evidence can be found in the study of Pascual et al. [22] based on surveys applied to real estate agents in eight countries. According to their results, EPC ratings exert a negligible impact on housing prices, this conclusion is especially valid in the case of Spain where only 15% of the surveyed agents confirmed the existence of a premium for efficient flats. Departing from such contradictory evidence, that is: on the one hand a positive market premium for efficient properties suggested by hedonic models; and on the other hand, no strong evidence on EPC impact on prices and rents coming from demand and agents' surveys, Olaussen et al. [1] have carried out an interesting quasi-natural experiment in order to identify whether omitted variables in model specifications can lead to spurious results. Their study, based on Oslo's residential market, consists of analyzing the price of homes sold before and after July 2010 when it became mandatory to include the EPC labels in advertisements, so as to identify whether such labels did actually produce a price increase in the case of efficient homes. In doing so, they assigned the EPC class to each home in the pre-2010 sample according to the class the same home had in the post-2010 sample. Their hedonic results show similar market premiums and penalties on EPC ratings for the pre and post 2010 samples, allowing them to conclude that "price premium of the energy labels clearly captures something else rather than an effect caused by the labels themselves" (p. 251). Nonetheless, such authors warn that even though EPC rating does not matter in Norway, they could matter in other countries, possibly where trust and honesty in the building industry are lacking. All in all, it is necessary to carefully incorporate control variables, as is done in this paper, in order to reduce the risk of omitting relevant attributes.

So far, there is a great divergence, yet inconclusive evidence, regarding the impact of EPCs on residential values across Europe, perhaps explained by the important differences in terms of income, energy costs, construction regulations/traditions, climate, and environmental concerns. Furthermore, the way the EPBD has been transposed across the countries has resulted in divergent calculation methods, often supported by previous national regulations, making it difficult to assess cross-border comparisons [23]. In this context in Spain there are two pioneering works in the study of the hedonic agenda of the EPC ratings. De Ayala et al. [24] base their study on opinion-values declared by a sample of non-specialist respondents from 5 cities (Madrid, Bilbao, Seville, Vitoria and Malaga). In their study energy rating is produced by their own estimation. They determine 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. On the other hand, Marmolejo [25] uses listing selling prices in Barcelona, finding a marked premium of +5.11% from the G to A rates, or of +9.62% if it is accepted that buyers perceive the rating scale to be nominal. Both studies need revisiting, the former not only because it analyzes opinion values but also because it makes little control of micro-locational and structural factors that have a paramount influence on values, and their omission can bias the coefficients; and the latter, because precisely these micro-locational factors make the variable "EPC rating" become statistically significant in the models, and therefore suggests a heterogeneous impact of this factor along the real estate market. Further EPC research in Spain includes: the work by Bian & Fabra [26] regarding the incentives that owners have to deliver EPC information; the work by González [27] on the shortcomings in the EPC scheme based on in-depth interviews to energy certifiers; and Taltavull et al. [28] on the hedonic agenda of EPCs in Alicante. Therefore, this paper aims to explore this aspect in greater detail.

2.1. The Impact of the EPC Rating may Differ between Market Segments

The studies researching the impact of EPC ratings among segments depart from univariate segmentations using variables such as area, age or typology of homes. In Sweden, Pontus et al. [11] have made a particular study in which the sale price of housing has been correlated directly with the energy consumption stated in the very EP certificate. The coefficient of energy consumption in their hedonic model, built on the entire housing sample, appears with a contradictory sign (Bx = 0.06, p = 0.000, where "x" is the log of consumption in kWh/year/sq. m. and "Y" the log of the price per sq. m.): that is, the higher the consumption in kWh/year/sq. m., the higher the price of housing, with everything else being equal. However, they conclude exactly the opposite when the sample is segmented, that is, the higher the energy consumption the lower the price. This conclusion is especially valid for the quartile of cheaper housing, which indicates that households with tight budgets that can only access the cheaper housing seem to value energy-bill savings from efficient dwellings. In contrast, those who can afford the purchase of dwellings with unit prices in the upper quartile seem to attribute zero importance to the EPC rating. Likewise, these authors find a market premium for dwellings built before 1960, since in general these houses have less quality and therefore those rehabilitated (with a better rating) are distinguished among houses of equal age. In the same sense, in Ireland, the impact of an EPC step on a 2-room apartment equals an increase of 2.3%, whereas in the 3-room and 4–5-room apartments this increase is lower and stands at 1.70% and 1.60% respectively [9]. Fuerst et al. [12] have found that the greatest impact of the EPC on the English residential market occurs in townhouses and that the impact on apartments is larger than that on detached houses. This situation might imply several things, among others that the potential consumption savings are more important for the cheaper houses occupied by people of lower income levels, conclusions that are convergent, with the results of Pontus et al. [11]. However, the previous results are contradictory to the results of Salvi et al. [13] who studied the impact of the Minergie certification in Switzerland and found a larger impact in the single-family dwellings in relation to apartments. They argue that this finding is compatible with larger energy savings produced by larger energy demand in single-family dwellings.

So far, the studies reviewed performed univariate segmentation, neglecting the fact that market segments are made of the combination of multiple attributes regarding architectural and locative features and therefore it is necessary to take them into consideration simultaneously as is done in this paper.

3. Methods and Materials

This chapter describes the methods and materials used in two different subsections. It is worth stating that the hedonic procedure followed in this paper requires using housing prices in order to identify marginal prices of energy ratings. In Spain transaction data, at an individual level, portraying all the structural and architectonic features of homes is not available. In absence of such data, we use listing prices as discussed in Section 3.2. Also, the hedonic procedure requires the introduction of control variables in order to isolate the effect of energy ratings. Section 3.2 contains the control attributes used.

3.1. Methods

The methodology was established in five stages (see details, data sources and flow procedure in Figure 1):

(1). Data acquisition, preliminary indexes computation, geoprocessing, depuration and representativeness analyses. This stage consists of:

(a) Data gathering from different sources of information regarding listing apartment data and urban and territorial features. Each of the data sources has a specific geographic unit.
(b) Computation of preliminary urban indicators. Using job positions data from census information, a principal component analysis (PCA) has been performed in order to eliminate concomitant information. Thus, the larger the value of "CP-high-socioeconomic-level" index, the larger the proportion residents holding managerial, officers and intellectual job positions. Utilizing trip-chain information and following the example of reference [29], two indicators for centrality have been computed: time-density stands for the number of hours per urbanized km^2 that people spend in a given transport zone; the centrality index accounts for the time-density, diversity of activities performed by people and nodality in transport zones. The floor area ratio is calculated from the built area and the urbanized surface from the cadastral dataset. Finally, the land use diversity is computed using the Shannon index and data from the utilization of built premises at street level.

(c) Transferring of territorial and urban data to an apartments database. By means of a geoprocess the original data and the preliminary urban indicators have been transferred to each of the apartments in the dataset. This specific process consists of using a buffer analysis where data is transferred according to the intersected area. In order to determine the radius of the buffer, a cross-validation procedure has been implemented. Such procedure consists of calibrating preliminary hedonic models and identifying the radius that leads to the largest covariance. After testing a 300, 600 and 900 m. radius, the first was selected.

(d) Depuration of the dataset and representativeness analyses. Following reference [30], the Mahalanobis distance has been used so as to eliminate outliers on a multi-attribute basis. Also, apartments with no EPC information have been discarded. In order to test whether the depurated sample is representative of the original non-depurated sample and representative of the EPC rating distribution contained in the EPC Catalan Official Register, two tests have been implemented. The first accounts for the statistical representativeness of the *number* of apartments, the second, using the ANOVA (Analysis of Variance) accounts for the representativeness of the *distribution* of EPC ratings.

(2). Specification and calibration of a hedonic model for all the depurated sample.

(a) Departing from the depurated sample, a hedonic model has been implemented as being further detailed.

(b) In order to assure the robustness of the results regarding a possible selection bias, the 2-step Heckman procedure has been implemented, see below.

(3). Segmentation of the depurated sample.

First, a principal component analysis has been implemented so as to eliminate redundant information, such analysis has departed from the variables found to be correlated with prices in the model specified in (2) except for the EPC ratings in order to avoid endogeneity issues. Next, the apartments have been classified using a 2-step cluster analysis, considering the principal components previously calculated as segmentation variables.

(4). Specification and calibration of hedonic models for each of the segments.

The same procedure described in (2) has been repeated for each of the housing segments.

(5). Finally, structural differences in the hedonic agenda for each of the segments have been identified using the Test of Chow.

The hedonic analysis assumes that the value of a dwelling can be broken down into the implicit value of each of the residential attributes [12]. Therefore, it is based on the hypothesis that households make their residential choices by matching the marginal utility of housing attributes with their marginal price. Through a multivariate statistical procedure, the implicit price of each of these factors can be delineated [31]. In the literature, it is usual for this marginal value to be calculated through a regression model using, in the absence of a clear theoretical posture, a log-linear specification [32]. This procedure has several virtues, on one hand, it facilitates that the distribution of the dependent variable (the price) approaches normality, thus enabling calibration using OLS (Ordinary Least Squares) while also reducing the statistical problem of heteroscedasticity [33] and on the other, it allows for interpreting the coefficients as semi-elasticities: the percent change in price produced by a unitary increment of the independent variable.

In this paper the functional expression being used is:

$$\ln(P) = k + \sum_{A=1}^{n} BA + \sum_{E=1}^{n} BE + \sum_{L=1}^{n} BL + e \quad (1)$$

In Equation (1), *ln(P)* is the natural logarithm of the listing price of the depurated sample; *A* is a vector that includes the architectural characteristics of each of the studied dwellings (including energy rating); *E* is the same but referred to the building, while studied dwellings are multi-family type, so that there are common services (e.g., lift or swimming pool) that can influence the price of these; *L* is a vector that internalizes the spatial factors of urban and socioeconomic nature that impact on the formation of residential prices through land rent; finally *B* are the coefficients representing semi-elasticities and *e* is the error term.

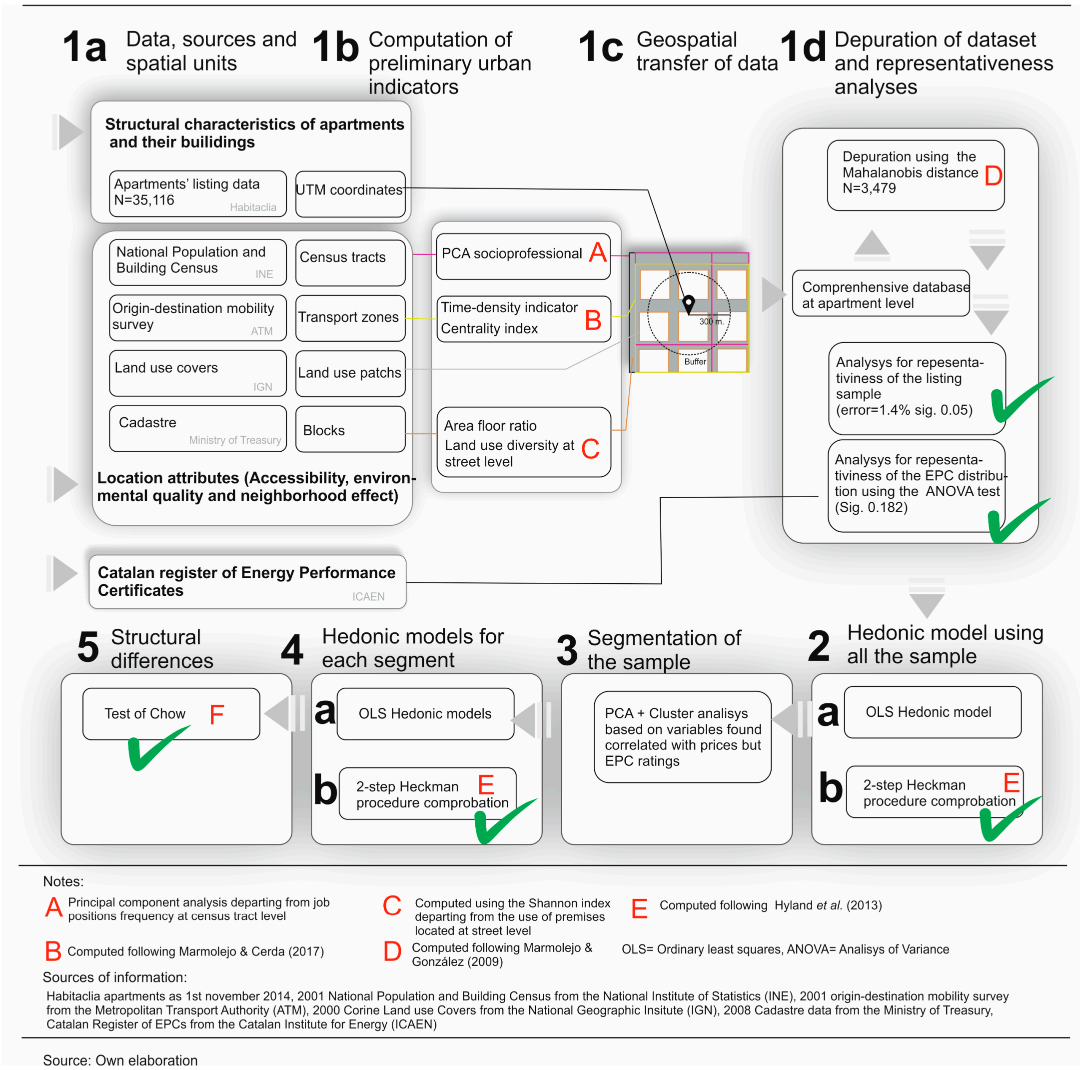


Figure 1. Methodological summary scheme.

As will be explained in the next subsection, a large proportion of apartments does not contain an EPC rating. This fact reflects sellers not adhering to the obligation to exhibit the EPC label in the advertising as the Royal Decree 235/2013 mandates. This issue may introduce a sample selection bias if the sellers exhibiting the EPC label are not randomly distributed among the non-depurated sample. So, in order to fully assure the robustness of the analysis, as suggested in reference [9], the 2-step Heckman model has been implemented. Such a model has been built as follows:

- First, a logistic model has been specified with the variables correlated with the presence of an EPC energy rating. The variables found to influence the probability of the presence of such information are: area, swimming pool, lift, air conditioner, heating, and socioeconomic indicators of the location of the apartments. In general, the poorer apartments exhibit a larger probability of including the EPC information in its advertisement.

- Second, using the above-stated variables as "selection variables" the 2-steps Heckman procedure has been implemented.

3.2. Case Study and Materials

The area of study comprises the 178 municipalities of the Metropolitan Transport Authority of Barcelona (3760 sq. km; 5.2 million residents in 2015) containing multifamily-dwelling listing data. Listing data was retrieved from Habitaclia, one of the largest real estate advertising websites in Catalonia, and refers to the first quarter of 2015. It is worth stating that multifamily housing is the predominant dwelling typology in the case study.

Data on urban and socioeconomic characterization come from: Cadastre (2008), Census (2001), (the use of the 2011 Census has been discarded due to its poor representativeness at census tract scale), Origin-Destination Daily Mobility Survey (2001); and land use data from the CORINE Land Cover 2000 project. Data from the Official EPC Register of the Catalan Institute of Energy (2014) has been retrieved to test whether our sample fits the general EPC rating distribution.

The non-depurated universe is made up of 35,116 apartments. After discarding the cases with no EPC information and eliminating outliers on a multivariate basis, the depurated sample is made up of 3,479 apartments. Yet it is still representative of the universe of listed apartments (error = 1.4% sig. = 0.05). Also, according to the ANOVA test (sig. = 0.182) it is representative of the EPC rating distribution contained in the Official EPC Register. All in all, the depurated sample represents both the listed apartments and the energy efficiency performance of the certified housing stock.

Table 2 contains the descriptive statistics of the depurated sample. The average apartment is sold for 160 thousand Euro and has 84 sq. m, with 1.29 bathrooms and 2.9 bedrooms. In general, 29% of the sample have air conditioning, 42% have heating and 45% have elevators, while only 4% have a communal swimming pool. The people with a university degree living in the housing environment range from 2.34% to 66.10%. Finally, on an ordinal scale (A = 7, G = 1), the average EPC rating is 2.7. The dichotomous indicator "quality/retrofit" is constructed upon a semantic analysis of the description included in the advertisements, highlighting the high quality of the finishing, outstanding design or the fact that properties have been retrofitted. Only 10% of the depurated sample can be considered as "qualified/retrofitted". Finally, the important dispersion of variables stresses the large differences in housing and locative attributes across the city.

Table 2. Descriptive Statistics of Architectural (structural) and Spatial Variables (location) of the Depurated Sample.

	Variable	N	Min	Max	Average	Std. Dev.
Structural characteristics of dwelling	Price (Euro)	3479	34,000	715,000	159,707	88,017
	Unit price (Euro/sq. m)	3479	845	3542	1885	662
	Area (sq. m)	3479	25	234	84	28
	Number of bathrooms	3479	1	4	1.29	0.51
	Number of rooms	3479	–	15	2.91	0.90
	Ratio bathrooms/room	3479	–	2	0.48	0.23
	Energy Rating (ordinal) *	3479	1	7	2.70	1.25
	Level of the apartment in the building	3479	–	13	2.14	1.63
	Balcony or terrace area (sq. m)	3479	–	256	9.73	14.53
	Living room area (sq. m)	3479	–	90	12.04	9.83
	Air conditioner (dummy)	3479	–	1	29.00%	0.46
	Heating (dummy)	3479	–	1	42.00%	0.49

Table 2. *Cont.*

	Variable	N	Min	Max	Average	Std. Dev.
Structural characteristics of dwelling	Price (Euro)	3479	34,000	715,000	159,707	88,017
	Quality/retrofit (dummy) **	3479	–	1	10.00%	0.30
	Penthouse (dummy)	3479	–	1	3.50%	0.18
	Duplex/triplex (dummy)	3479	–	1	6.00%	0.23
	Year of construction	3479	1890	2015	1969	19.79
Structural characteristics of building	Communal swimming pool (dummy)	3479	–	1	4.00%	0.05
	Communal garden (dummy)	3479	–	1	9.00%	0.28
	Lift (dummy)	3479	–	1	45.00%	0.50
Accessibility indicators	Built density (area floor ratio)	3479	0.19	5.90	1.93	1.24
	Time-density ***	3479	324	1,134,098	118,964	146,950
	Centrality Index ***	3479	2.52	20.41	11.29	2.29
	Land use diversity (of the context) +	3479	0.35	1.64	1.02	0.21
	Diversity of activities (of the context)	3479	–	2.92	2.03	0.38
	Average time to work (minutes)	3479	8.94	37.01	23.47	4.59
	Land use diversity at street level ++	3479	–	1.77	1.11	0.23
Environmental quality indicators	Average age of buildings (of the context)	3479	21	124	53.99	14.33
	% households that identify a greenery lack (of the context)	3479	12.45	97.89	64.37	13.58
	% Health facilities (of the context)	3479	–	42	2.01	2.89
	% Educational premises (of the context)	3479	–	93.00	2.13	2.97
	% Social services premises (of the context)	3479	–	66.66	1.85	4.32
	% Cultural premises (of the context)	3479	–	95	1.52	3.35
	% Premises for trade (of the context)	3479	–	89.93	41.45	13.47
	% Premises for offices (of the context)	3479	–	100.00	14.09	11.11
	% Industrial premises (of the context)	3479	–	97	9.51	11.57
Indicators of social hierarchy	% people holding university degree (of the context)	3479	2.34	66.10	19.07	11.25
	% buildings with doorman service (of the context)	3479	–	52.55	6.37	6.77
	CP low socioeconomic level +++	3479	−1.70	7.42	0.13	0.93
	CP high socioeconomic level +++	3479	−3.26	3.24	−0.32	0.77

* Energy rating A = 7, G = 1, according to the ratings of the EPC label contained in RD 235/2013;
** This variable adopts 1 when the descripte text of the advertisements signals a high level of quality, design or a recent retrofit;
*** These indicators depart from spatial-temporal patters of people calculated from origin-destination survey as suggested by Marmolejo & Cerda (2017) [29];
+ This indicator has been computed using the Shannnon index departing from the land use covers contained in CORINE;
++ This indicator has been computed the Shannon index departing form the use of premises located at street level contanained in Census;
+++ These indicators are the principal componets coming from a Principal Component Analysis built on the job position of occupied residents living around the apartment according to census data.

Data sources: Habitaclia listing (2015), 2001 National Population and Housing Census from the National Institute of Statistics (INE), 2001 origin-destination mobility survey from the Metropolitan Transport Authority (ATM), 2000 Corine Land use Covers from the National Geographic Insitute (IGN), 2008 Cadastre data from the Ministry of Treasury, 2015 Catalan Register of EPCs from the Catalan Institute for Energy (ICAEN).

4. The Energy Performance of Housing in the Case Study

This chapter portrays the distribution of energy ratings in the case study as a preliminary stage before explaining the results coming from hedonic analyses. Figure 2 depicts the distribution of EPC ratings, the vast majority of dwellings are rated "E" (48.30%), followed in this order by letters "G" (21.80%), "F" (13.50%), "D" (9.70%) and "C" (4.30%), while the best "A" is reserved only for a select club of properties that represent 2.30% of the sample. It is worth saying that the depurated sample does not contain "B" rated homes, as in general there are very few cases holding such a rating. The reason for this is that developers willing to invest in efficient homes do prefer to pay for the small marginal cost that enables upgrading the performance of the homes up to rating "A".

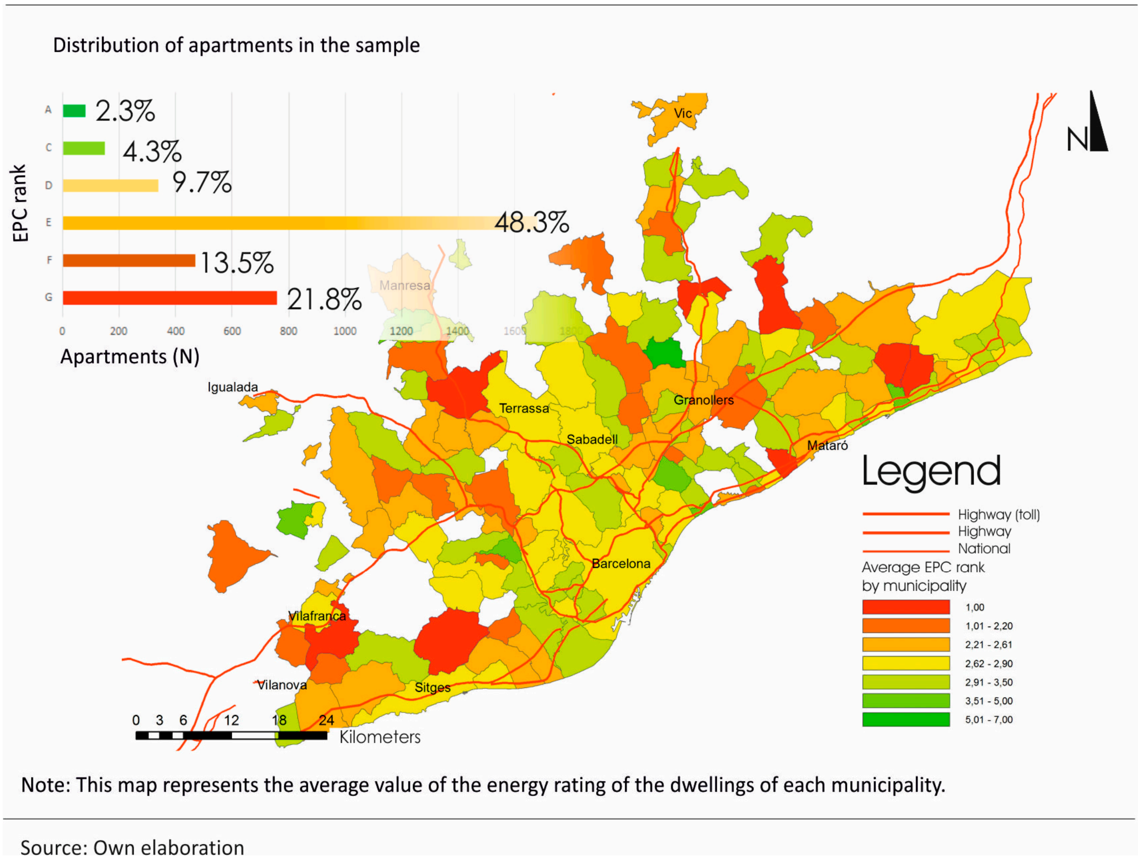
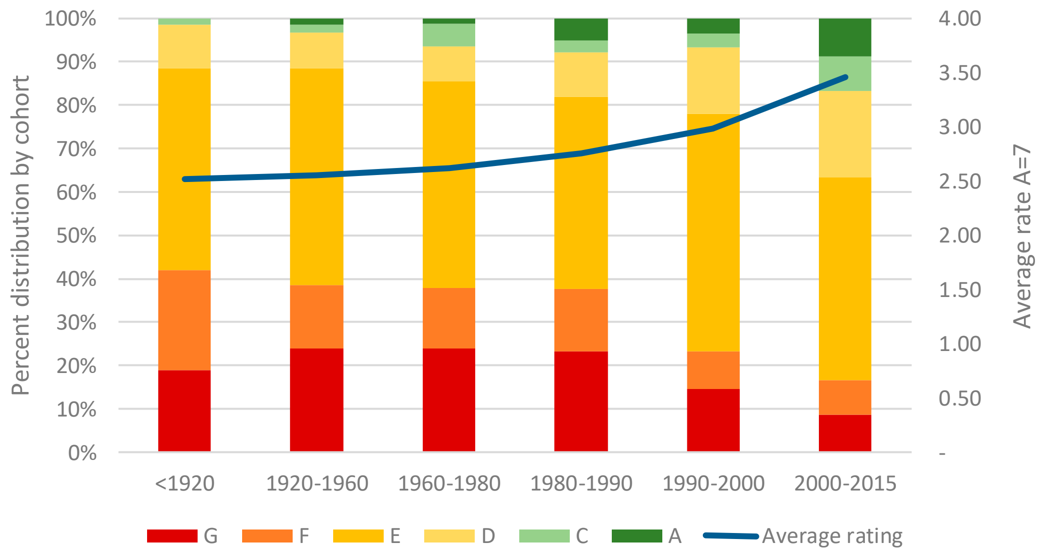


Figure 2. Distribution of the EPC Ratings in the Case Study.

Figure 2 also shows the spatial distribution of the analyzed sample according to its energy efficiency. Urban centres (labelled on the map) such as Barcelona and sub-centres exhibit medium and low-medium efficient dwellings. In contrast, the peripheral municipalities, especially those located in the suburbs of the previous sub-centres, have better-qualified stock. Rural municipalities (functionally integrated to Barcelona) depict the least efficient housing. In these ultra-peripheral municipalities, during the 1960s and 1970s a large number of low-quality dwellings were built, often in suburbs of illegal origin. Thus, paradoxically, peripheral areas with low-density layouts (i.e., urban sprawled) which are energy-intensive in terms of transportation due to their car dependency have many energy efficient dwellings.

Behind the aforementioned spatial distribution, the construction year does play a role, since the first thermal isolation legislation in Spain dates back only to 1978 (becoming effective in 1981). Figure 3 shows the declining proportion of buildings ranked with "G"+"F"+"E", especially after the "Oil Crisis" and the end of the post-war period where there is a proportional increase of the best-ranked dwellings. Thus, the average score (A = 7, G = 1) increases from 2.52 for dwellings built before 1920 to 3.46 for those built after the year 2000. In this last cohort, the minimum energy efficiency requirements DB-HE of the Spanish Technical Construction Code (RD 314/2006, RD 1371/2007, OM FOM 1635/2013) have had little impact due to a large reduction of new dwellings after the crisis of the construction industry started in 2007.



Source: Own elaboration

Figure 3. EPC Rating of the Sample According Its Year of Construction.

In short, the residential stock listed in the Metropolitan Area of Barcelona is characterized by a very poor energy efficiency. Although this situation is not significantly worse than that reported by Fuerst et al. [12] for the English residential market, their study based on sales data shows that 48% of the apartments are ranked "D", while only one of the 85,007 apartments analyzed is rated as "A". In this study, the average ordinal score is 2.7, better than the rating of the houses located in the cities of the south of Spain that were studied by De Ayala et al. [24].

5. Results and Discussion

Regarding the possible selection bias discussed in Section 3.1, it seems to be minimal just as expected (due the similar distribution of EPC ratings in the depurated dataset and in the official register). Despite the fact that the inverse of the Mill's ratio appears to be significant (B = 0.47; sig. = 0.02) in the second stage of the 2-step Heckman procedure, the coefficients of the remaining variables are practically the same than those obtained in the OLS model. For the sake of simplicity, the results are focused in the OLS models, nonetheless, at the bottom of each table, the coefficients for EPC classes coming from the Heckman procedure are detailed.

Figure 4 shows the best of the models able to explain upon 65.5% of the variance, the significant variables (sig. < 0.1) are organized by conceptual dimensions.

MODEL SUMMARY

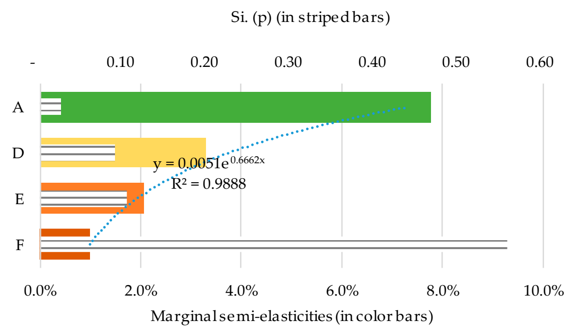
R	R squared	Adjusted R squared	Standard error of estimation
0.811	0.657	0.655	0.28444

ANOVA

		Sum of squares	df	Quadratic mean	F	Sig.
	Regression	536.787	20	26.839	331.739	-
	Residuals	279.770	3458	0.081		
	Total	816.557	3478			

Coefficients

		Non-standardized coefficients		Standardized coefficients		
		B	Std. Error	Beta	t	Sig.
	(Constant)	10.222	0.050		205.146	0.000
Structural characteristics of dwellings	Area (sq.m)	0.018	0.001	1.02	23.46	0.00
	Air conditioner	0.095	0.013	0.09	7.03	0.00
	Number of bathrooms	0.056	0.012	0.06	4.68	0.00
	Heating	0.026	0.014	0.03	1.89	0.06
	Quality-retrofit indicator	0.035	0.017	0.02	2.05	0.04
	Area^2	-4.14E-05	0.000	-0.51	-12.01	0.00
	Construction year 1981-2006	0.078	0.016	0.05	4.78	0.00
	Construction year> 2006	0.118	0.024	0.05	4.82	0.00
Structural characteristics of the	Lift x floor level	0.011	0.002	0.06	5.11	0.00
	Communal swimming pool	0.128	0.026	0.05	4.92	0.00
Energy rating	A	0.078	0.035	0.02	2.25	0.02
	C	-0.029	0.026	-0.01	-1.11	0.27
	D	0.033	0.019	0.02	1.70	0.09
	E	0.021	0.013	0.02	1.63	0.10
	F	0.010	0.017	0.01	.59	0.56
Accessibilty	Floor area ratio	0.042	0.006	0.11	6.87	0.00
	Centrality indicator	0.011	0.003	0.05	3.66	0.00
Social hierarchy	% people holding a university degree	0.005	0.001	0.12	4.71	0.00
	CP high socioeconomic level	0.059	0.013	0.09	4.38	0.00
	% buildings with doorman service	0.005	0.001	0.07	4.27	0.00



Coefficients for EPC classes according to the second stage of the 2-steps Heckman procedures

		B	Std. Error	Beta	t	Sig.
Energy rating	A	0.077	0.035	0.024	2.219	0.03
	C	-0.029	0.026	-0.012	-1.135	0.26
	D	0.032	0.019	0.019	1.640	0.10
	E	0.020	0.013	0.021	1.566	0.12
	F	0.009	0.017	0.006	0.538	0.59

Notes: Dependent variable ln of the price, variables introduced by stepwise method, except those related to the energy rating. In gray are the non-significant variables at 90% of confidence. Energy reference rating = G; Age reference cohort $\leq$ 1981; Source: Own elaboration.

Figure 4. Model for the complete depurated sample.

In the dimension of structural features:

- The area is introduced with the expected positive sign, in fact, the introduction of its square (with the negative sign) is indicative of the existence of decreasing returns in the formation of prices.
- Three quality indicators are utilized, such as the presence of air conditioning, heating and the qualitative indicator of quality/retrofit.
- The number of bathrooms is not a factor. It seems reasonable that the number of rooms does not enter in the model, since the area, which is highly correlated with this indicator, has been taken into account.
- The age of the home also has an expected impact on prices. The age has been introduced as a dummy variable for construction periods. The limits of each of the period is related to the introduction and upgrading of the energy performance legal requirements, which in turns are also associated with improvements in other building aspects.

In the dimension of the common services present in the buildings where apartments are located:

- The interaction variable between the story in which the apartment is located and the presence/absence of elevators. The positive sign of the coefficient implies that price increases the apartment's level in the building rises only applies when an elevator is present.

In the energy efficiency dimension:

- Of the 5 possible EPC ratings (the control rating is "G"), only "A" and "D" are significant. Thus, for the best ratings, there is a market premium of 7.8% (in relation to the worst "G" situation), while for the "D" rating the premium is 3.3% and 2.1% for "E" (although it is almost significant at 90% of confidence). Therefore, the appreciation of the best rated dwellings is not linear; as the rank increases the marginal price increases progressively, following an exponential pattern. This finding has enormous potential for the promotion of efficient dwellings, *since the larger premium for these dwellings might counterbalance the excess of construction costs.* The remaining of the ratings are not significant; however, with the exception of "C", these would have logical sing/value depending on the above mentioned pattern. Energy-efficiency ratings do not always have the expected impact. Addae-Dapaah & Chieh [32] report in their pioneering study on the impact of the Green Mark on sale residential prices in Singapore a higher positive impact for the lowest ratings compared to the most efficient ones. These authors argue a confusion of the Singapore market exists, perhaps because the scheme raises nominal ratings ("certificate", "gold", "superior gold" & "platinum") and not ordinal ("A" –> "G ") as the EPC scheme does.

In the locational dimension:

- Two indicators are related to urban centres accessibility: the floor-area-ratio and the centrality indicator, both with the expected positive sign which is indicative of the trade-off between sale prices and transport costs.
- Three indicators related to the socio-economic stratification of the city appear, so the higher the apartment's price: (1) the larger the proportion of people holding a university degree, (2) the larger the proportion of residents in qualified job positions, and (3) the larger the proportion of buildings with doorman service. It is worth noting that this latter service is commonly present in wealthy areas of the city. According to the coefficient of the typified variables, *social hierarchy indicators are the main explanatory variables of real estate prices*. This is both because the population has a higher purchasing power, and because it seems they are willing to pay a *market premium* for locations dominated by similar socio-economic groups (i.e., neighborhood effect).

In short, the EPC energy rating, despite its very late universalization in Spain, seems to matter at least to owners willing to be compensated for the sale of their equity. In Spain, given the predominance of housing ownership, the behavior of sellers tends to be the same as buyers. Nevertheless, the asking market premium for the most efficient apartments (+7.8% or +12,409 Euros for the average dwelling in the sample) is surprisingly lower than the marginal value of comfort attributes such as air conditioning (9.5%), which in the light of the results obtained seems to play a more important role in price formation than the possible energy savings and environmental preservation that are implicit in efficient buildings.

5.1. Is the Energy Premium the Same Across Real Estate Segments?

As has been explained in Section 3.1, the depurated sample has been split in hosing segments. The housing attributes found to be correlated with prices, in the model contained in Figure 4, but with energy ratings. Figure 5 shows the main features of each of the identified housing segments:

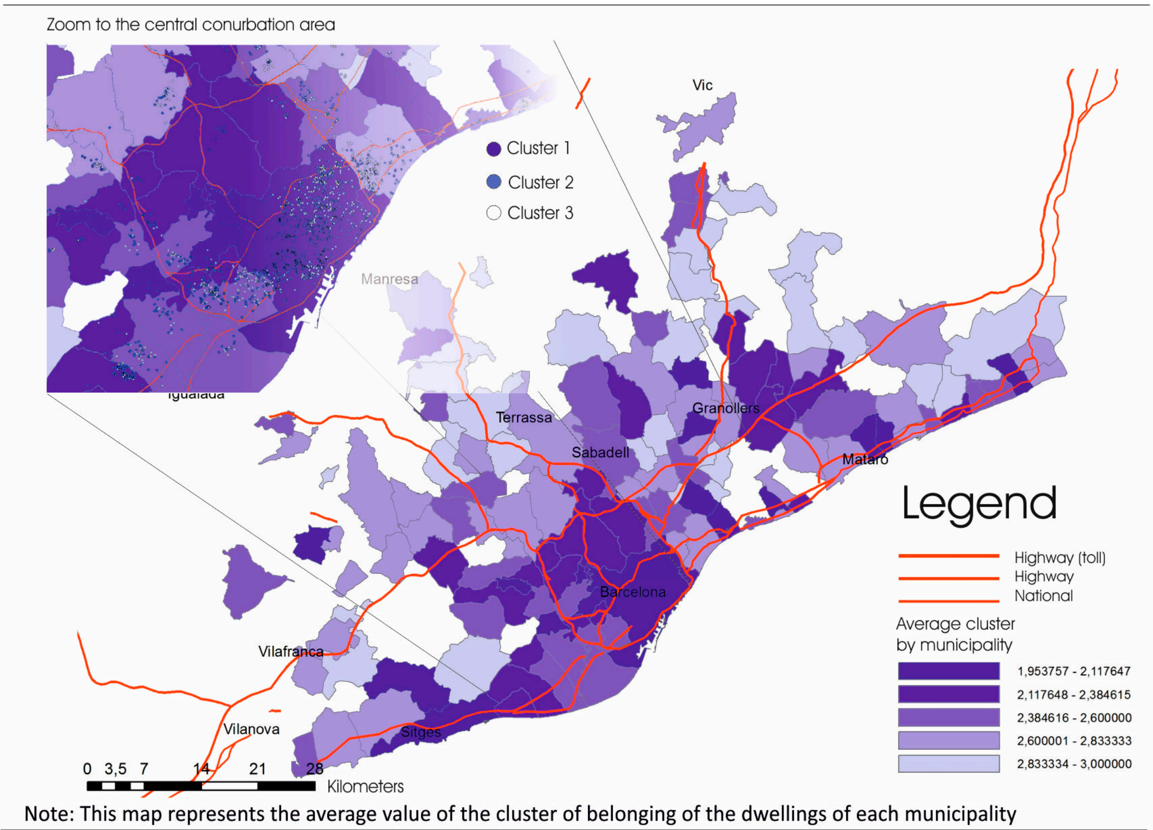
- *Cluster 1* (the smallest) is characterized by expensive dwellings (in absolute and unitary terms), with the largest area located in central zones, where the population with higher education levels employed in qualified positions live. However, the dwellings contained in this cluster do not exhibit the larger proportion of services such as heating, air conditioner or swimming pool due to their age and central location.
- *Cluster 2* consists of dwellings characterized by a medium price in absolute and unitary terms, as well as its area also being intermediate. Among the three groups, these are the most recent dwellings, and for that reason, these have a larger proportion of active-comfort systems: 92% are equipped with heating and 59% air conditioning systems, while in 24% of cases their advertisements highlight exceptional quality and/or design. The location of this second cluster is mesocentral, and the proportion of people with a university degree is intermediate (in relation to the three groups). It is noted that 10% of them have a communal swimming pool, which suggests that they are oriented towards the middle-upper class and respond to most recent residential trends.
- *Cluster 3* is the largest, and the apartments contained in this cluster were built in the post-war period characterized by a low-quality urban growth fed by rural immigration. Housing in this group is small in size, cheap in price, with no amenities and services (only 3% are air conditioned and none of the apartments are heated). None have a swimming pool and an elevator is only present in 15%, although they are multi-family buildings located in multi floors zones (average floor area ratio is 1.67). Socioeconomic indicators suggest that this cluster is located in areas where the less educated population lives, occupying less qualified positions (e.g., salesmen/women, unskilled jobs, etc.).

		Cluster 1	**Cluster 2**	**Cluster 3**
Number of cases		338	1336	1805
Structural characteristics of dwellings	Price (Euro)	304,056	169,870	125,188
	Unit price (Euro/sq. m)	2783	1988	1641
	Area (sq. m)	109	86	77
	Air conditioner (%)	51%	59%	3%
	Number of bathrooms (average)	1.6	1.4	1.2
	Heating (%)	65%	92%	0%
	Quality/retrofit indicator (%)	10%	24%	0%
	Construction year (average)	1954	1978	1965
Structural characteristics of the building	Lift (%)	86%	75%	15%
	Communal swimming pool (%)	1%	10%	0%
Energy rating	A	2%	5%	0.2%
	C	3%	5%	4%
	D	13%	16%	4%
	E	56%	49%	46%
	F	11%	11%	16%
	G	15%	14%	29%
	EPC ordinal	2.84	3.09	2.39
Accessibility	Floor area ratio (average)	4.19	1.72	1.67
	Centrality indicator (average)	14.84	10.98	10.86
Social hierarchy	% people holding a university degree	41%	19%	15%
	CP high socioeconomic level	0.68	- 0.24	- 0.56
	% buildings with doorman service	20.3%	5.1%	4.7%

Figure 5. Architectural and locative characteristics of the market segments.

The energy rating of the three clusters is consistent with the age and architectural performance of housing, so on an ordinal scale (A = 7, G = 1) the average rating is: 2.84, 3.09 and 2.39 respectively; that is, the newest dwellings, with better active-comfort conditioning, are the most efficient, while post-war dwellings are the most inefficient. The dwellings of the centres are located in an intermediate energy-efficiency situation.

Figure 6 shows the spatial distribution of the sample: the darker the colour, the greater the ascription of the sample to cluster 1, standing out especially in the municipality of Barcelona. The central urbanized zone highlights the predominance of dwellings typified as Cluster 3 in the low-income neighborhoods, whereas in the 19th-century Enlargement zones the dwellings typified as Cluster 1 are predominant.



Source: Own elaboration

Figure 6. Spatial Distribution of the Sample according to the Cluster Membership.

Finally, regarding the main objective of this paper, Figure 7 contains the results of the calibrated models for each one housing segments. It is important to note that according to the Chow Test (F = 8.20 > F crit. 1.16 to 99% of confidence), structural differences do exist in the explanation of the prices of the different segments and therefore indicate divergent hedonic agendas. In this figure only the statistically significant (sig. < 0.05) variables are reported, except for those related to the different energy ratings, where again the letter "G" is the comparison situation. In all cases, the sign of the coefficients is as expected and match that of the complete sample explained in the last section, with the exception of Cluster 1 where, paradoxically, the sign of the high socioeconomic indicator is reversed, even after having verified the absence of multi-collinearity issues. This issue likely occurs because the sample (the smallest of the three) is very homogeneous in locative terms due to the segmentation procedure used.

Focusing on the interest of this study, three interesting conclusions emerge:

1. The energy rating seems to affect the older dwellings, both those located in the centers/19th-Century Enlargement zones, and those located in poor neighborhoods that emerged from the expansion of the metropolis during the post-war. Conversely, in the case of the state-of-the-art dwellings depicting amenities and active-comfort systems, energy efficiency seems to play a null role from the perspective of price formation.
2. However, the impact of the rating is not equal in the two segments in which it appears as significant. Thus, the "A" rating has an impact of +12.2% (but with a level of significance on the edge of the limit demanded in our analysis) in the most expensive, central and well-endowed housing segment. On the other hand, the impact of the "A" rating is almost three times larger +33.2% (with a higher statistical significance) in the cheaper segment, located in working-class neighborhoods and with worse active air conditioning services and in general with the poorest

architectural quality. In this last cluster, the "D" rank also appears with an impact of +7.8% and in a reversed sense, the "C" rank with an impact located at −8.6%.

3. All in all, these findings suggest that real estate differentiation in the segment of the newest dwellings does not respond to the rationale behind the EPC scheme. On the contrary, in the case of the (very abundant) dwellings located in the lower tier, in the absence of attributes of architectural quality and amenities, the EPC produces a distinctive effect strongly influencing price differentiation.

These findings are consistent with the discussion of Encinas et al. [34], since sustainability attributes seem to play different roles across residential segments. In short, the impact of energy ratings, in the light of the aforementioned results, does not seem to equally affect the segments of the multi-family market. Real estate differentiation, from the perspective of the supply price formation mechanism, and in relation to the energy ranking seems to occur in the lower segment. Thus, in the dwellings with less architectural attributes related to residential quality, this ranking has a significant impact on prices. Such "brown discounts" may have enormous social repercussions on the conformation of energy submarkets, as discussed in the conclusions.

		Mod Cluster 1			Mod Cluster 2			Mod Cluster 3		
		r^2	r^2 aj	Sig.	r^2	r^2 aj	Sig.	r^2	r^2 aj	Sig.
		84.68%	84.16%	0.000	55.89%	55.36%	0.000	44.12%	43.78%	0.000
		B	Beta	Sig.	B	Beta	Sig.	B	Beta	Sig.
Structural characteristics of dwellings	Constant	10.749			10.312			10.243		
	Area (sq. m)	0.018	1.721	0.000	0.017	1.07	0.00	0.022	1.20	0.00
	Air conditioner	0.062	0.072	0.002	0.134	0.16	0.00			
	Number of baths				0.114	0.15	0.00			
	Heating				0.096	0.06	0.00			
	Quality/retrofit Indicator				0.055	0.06	0.00			
	Area^2	0.000	-0.885	0.000	- 0.000	- 0.61	0.00	- 0.000	- 0.59	0.00
	Construction year 1981-2006				0.087	0.09	0.00	0.086	0.04	0.03
	Construction year> 2006				0.104	0.08	0.00	0.262	0.06	0.00
Structural characteristics of the building	Lift x floor level	0.015	0.09	0.00	0.017	0.11	0.00			
	Communal swimming pool				0.134	0.10	0.00			
Energy rating	A	0.122	0.04	0.08	0.046	0.03	0.24	0.332	0.04	0.03
	C	0.042	0.02	0.50	0.053	0.03	0.17	- 0.086	- 0.04	0.02
	D	0.052	0.04	0.14	0.015	0.01	0.58	0.078	0.04	0.04
	E	0.015	0.02	0.58	0.017	0.02	0.46	0.018	0.02	0.28
	F	0.033	0.02	0.37	- 0.021	- 0.02	0.50	0.023	0.02	0.30
Accessibility	Floor area ratio				0.058	0.14	0.00	0.023	0.06	0.01
	Centrality indicator							0.007	0.04	0.10
Social hierarchy	% people holding a	0.009	0.23	0.00	0.006	0.12	0.00			
	CP high socioeconomic	- 0.156	- 0.14	0.00	0.079	0.14	0.00	0.101	0.17	0.00
	% buildings with doorman							0.010	0.10	0.00
Coefficients for EPC classes according to the second stage of the 2-steps Heckman procedure										
		B	Beta	Sig.	B	Beta	Sig.	B	Beta	Sig.
Energy rating	A	0.120	0.04	0.09	0.046	0.03	0.24	0.332	0.04	0.03
	C	0.037	0.01	0.55	0.053	0.03	0.17	- 0.086	- 0.04	0.02
	D	0.049	0.04	0.17	0.012	0.01	0.66	0.078	0.04	0.04
	E	0.014	0.02	0.59	0.015	0.02	0.51	0.018	0.02	0.28
	F	0.034	0.03	0.360	- 0.022	- 0.02	0.48	0.023	0.021	0.298

Notes: Dependent variable ln of the price, variables introduced by stepwise method, except those related to the energy rating. In gray are the non-significant variables at 90% of confidence. Energy reference rating = G; Age reference cohort ≤ 1981.

Figure 7. Models for the Segmented Sample.

6. Conclusions, Policy Implications and Limitations

15 years ago, the Energy Performance of Buildings Directive (EPBD) joined the mainstream of green labels through its Energy Performance Certificates (EPC). Through this policy the European Union opted to fade out informational asymmetries in energy efficiency in real estate transactions. The aim of such policy has been to foster the acquisition and lease of efficient buildings by means of energy-informed transactions.

Nonetheless, in Spain the universalization of EPC is quite recent (it is mandatory only as of the 1st of June 2013), the research reported here determined for the first time, conjointly with those works [24,25] if EPC ratings imply "market premiums" and "brown discounts". The main contribution of this research is to explore whether such impact on prices, if any, is homogenous across multivariate housing segments. With this objective, in the absence of transaction prices, a sample of 3479 multi-family dwellings listed in metropolitan Barcelona is analyzed. This analysis, as is usual in international studies, has been based on the hedonic price method, which assumes that households equalize the marginal utility of the urban and architectural attributes of dwellings, to the marginal price they pay for benefit of them. Likewise, in order to identify market segments, a multivariate analysis is carried out departing from variables correlated with selling prices.

In general, the residential listed stock in Barcelona exhibits a poor energy performance, with an average EPC rating of 2.70 ("G" = 1, "A" = 7), with rating "E" being the most abundant (48.30%). Data showed a positive correlation between the year of construction of the dwellings and EPC ratings, with a sharp increase after the year of 1980 (when the first national energy efficiency legislation came into force). From a spatial perspective, the best-rated dwellings are located in the immediate suburbs of the metropolitan centralities, while the worst rated are in the more distant suburban areas, some of a rural character, and others in urbanizations of illegal origin, with constructions of very poor architectural quality.

The results of the hedonic models suggest that there is a market premium for efficient rated dwellings. Thus, sellers of the best-rated dwellings are willing to be compensated for a higher amount, everything else equal, when selling their assets. As such, results suggest a market premium of +7.8%, +3.3% for "A", "D" ratings respectively in relation to the most inefficient rating "G". For the average apartment, these impacts can be translated into approximately 12 thousand and 5 thousand Euros, respectively. In addition, it is observed that such overpricing tends to increase exponentially as the energy efficiency increases. *This finding has a special interest in the private development of "green" dwellings, since the prize for the most efficient apartments "A" increases exponentially regarding lower ratings*. Nevertheless, it is still necessary to verify whether such a market premium can offset the over costs produced by new and most efficient building techniques, as has been studied by García-Navarro et al. [35].

In any case, the impact of the energy ranking in Spain on residential prices is lower than the 15.00% ("A"/"G") reported by Brounen & Kok [14] for the Netherlands case, as well as below the 19.90% ("A"/"G") detected by Hyland et al. [9] for the Irish market and the 12.00% for "A" dwellings compared to "G" in the English case according to Fuerst et al. [12]. It is possible that behind these divergences are the differences in real estate prices, cost of energy, income level (in relation to the previous two), climatic differences and environmental concerns. These comparisons should be made with caution, because although the European legal framework is the same, there are differences in the national transposition of the regulations and more specifically in the way of calculating energy EPC ratings [23].

Interestingly, the EPC asking market premium is not uniform across the residential segments:

1. In the segment of *more recent apartments*, the EPC rating does not seem to play any role in the differentiation of real estate prices, which obscures the pursued objectives of the EPBD. In this market, with multiple architectural features and active technologies for environmental comfort, energy rating does not represent a differential element.

2. In the case of the *deficient housing*, the enormous price discrimination that appears, the energy rating, in the absence of other attributes of differentiation, does produce a significant "brown discount". Specifically in this segment, the worst rating "G" reduces the price of the dwellings by −33.20% in relation to "A" rated apartments.
3. In the case of *older dwellings*, located in middle/middle-high class areas, the results suggest that a moderated premium market is also formed that is equivalent to +12.2% ("A"/"G") which opens room for energy retrofitting since most of such apartments are located in Enlargement zones which started to be built at the end of the 19th century.

In short, despite the recentness of the EPC policy in Spain, it seems to affect listing prices, although as has been seen, with uneven intensity throughout the residential segments. Thus, *in the segment of recent homes with higher benefits, the rating plays a null role in the formation of prices. In this segment, private developers have to make an extra effort to communicate the economic and environmental benefits of efficient homes*. Whereas, in the segment of lower price and quality dwellings, the energy rating institutionalized by the EPBD and its transposition is a true element of residential differentiation, in the absence of other architectural attributes. This finding is compatible with the conclusion of Olaussen et al. [1] since EPC labels might be capturing omitted variables. In our case, it may be wrongly interpreted as quality in the case of the homes boasting the lowest attributes. In the Netherlands as the first country to transpose the EPBD, in the time when EPC was optional, the certification rate was higher in neighborhoods with more deficient residential stock according to the study by Brounen & Kok [14]. That is, getting an EPC in low-quality areas was seen as a positive attribute in the marketing process of homes irrespective of the EPC rating they obtain. The same seems to occur in Spain: as has been said, in Section 4, the probability that a listed apartment includes EPC information is directly correlated with its low-quality.

Our findings are also in line with other studies analyzing the impact of EPC ratings on residential univariate-segments [9,12,13]. In most of those cases, their authors argue that the larger impact found in the low-tier segment is explained by the fact that these dwellings are targeted towards households with tighter budgets, for whom the possible energy savings are relevant. Nonetheless, such a rationale is not verified in Spain. Marmolejo et al. [36] have been conducted, in Barcelona, a survey aimed to explore whether people do understand the EPC scheme. Their findings indicate that low income and poorly educated people, as residents of the deficient homes segment, have little knowledge on such a scheme, which in turns translates into an unwillingness to pay for efficient homes. As a matter of fact, such authors have found that, in general, people misunderstand the objective of the EPC rating, since they consider it an indicator of the global quality of homes. Such conclusions are not surprising due to the overnight implementation of the EPC scheme in Spain pointed out in the introductory section. Furthermore, their results are in line with preconditions Backhaus et al. [37] indicated are required before expecting any impact of EPC scheme on home prices: homeowners should be aware of its existence; find the information about energy ratings useful and trust the information on EPCs. The practical absence, in Spain, of informative campaigns on the implementation of the scheme, on the one hand, and a generalized perception of EPCs as a bureaucratic formality and even a distrust of the technical procedure, on the other, make such preconditions difficult to meet.

In any case, from a social perspective, a larger "brown discount" for the less efficient dwellings implies a devaluation of the main equity of the poor population in countries, such as Spain, where ownership is the main tenure regime (over 71% according to INE). Such population living in inefficient homes are at risk of fuel poverty, and at the same time, for cognitive and financial reasons (aggravated by the energy efficiency "brow discount") have little opportunity to perform a retrofit in their dwellings. Therefore, a well-intentioned environmental policy might have unexpected pernicious effects from a social perspective, if relevant corrective measures are not introduced (e.g., retrofit subsidies). Fortunately, in Spain legislative initiatives crystallized in Law 8/2013 of Urban Rehabilitation, Regeneration and Renewal (now recast in the main corpus of land legislation), which, together with the autonomous legislations in matters of urban planning and housing, provide the necessary instruments to carry out actions in the most degraded areas. An example of this is the area of conservation and retrofitting of the "Carrer Pirineus" located in the working-class municipality of Santa Coloma de Gramenet (province of Barcelona), where, on the basis of the aforementioned legislation, a rehabilitation of the private residential stock with energetic implications has been developed using municipal treasury as a "local bank" [38]. These actions, however, require the political will, technical capacity, and a multidisciplinary approach.

6.1. Limitations and Further Research

This research uses listing prices since, as it has been disclosed, transaction prices containing enough information on sold prices are not available in our case. Therefore, it is necessary to further explore whether the concussions drawn here are held when closing prices are used to identify the hedonic agenda of EPC ratings. However, it is expected to have few divergences, especially for the results coming from the segmented model, since negotiation ratios (i.e., closing/listing price) are contingent to the quality and location of homes. Also, it is necessary to advance towards the incorporation of energy efficiency aspects in the valuation of real estate as has been done by De Ruggeiro et al. [39] (see supplementary materials). Finally, despite the large efforts to control quality attributes of homes and locations, there is still the possibility that omitted variables, such as decorations or specific finishing, possibly spuriously concomitant to EPC ratings, do play a role in price formation. Using expert assessed homes in the context of valuation reports may also contribute to solving this latter issue.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/2/372/s1, Table S1: Data Description for segment 1 (older dwellings in wealthy zones), Table S2: Adjustment process for segment 1 (older dwellings in wealthy zones), Table S3: Data Description for segment 2 (recent apartments in upper-middle class zones), Table S4: Adjustment process for segment 2 (recent apartments in upper-middle class zones), Table S5: Data Description for segment 3 (deficient apartments in working-class zones), Table S6: Adjustment process for segment 3 (deficient apartments in working-class zones).

Author Contributions: C.M.-D has written the paper, designed the research and analyzed the data. A.C. has performed the Heckman and helped in building the dataset, which is a part of such author's Ph.D. thesis.

Funding: This paper is part of the EnerValor project ref. MINECO/FEDER BIA-2015-63606-R.

Acknowledgments: The authors would like to thank the constructive criticism to be received from the peer review referees, as well as Rolando Biere and Camilo Echavarría for his assistance in getting the information and building the geographical information system. James McDonald has assisted us in the final proofreading of this piece. Finally, the authors wish to thank Habitaclia for allowing to use the data set analysed in this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Olaussen, J.O.; Oust, A.; Solstad, J.T. Energy Performance Certificates—Informing the Informed or the Indifferent? *Energy Policy* **2017**, *111*, 246–254. [CrossRef]
2. González, A.; Diaz, M. Usability of the EPC Tools for the Profitability Calculation of a Retrofitting in a Residential Building. *Sustainability* **2018**, *10*, 3159. [CrossRef]
3. Giraudet, L. *Energy Efficiency as a Credence Good: A Review of Informational Barriers to Building Energy Savings*; FAERE Policy Paper; FAERE: Paris, French, April 2018.
4. Gillingham, K.; Palmer, K. Bridging the Energy Efficiency Gap: Policy Insights from Economic Theory and Empirical Evidence. *Rev. Environ. Econ. Policy* **2014**, *8*, 18–38. [CrossRef]
5. Bio Intellinge Service; Mudgal, S.; Lyons, L.; Cochen, F. Energy Performance Certificates in Buildings and Their Impact on Transaction Prices and Rents in Selected EU Countries, Bio Intelligence Service Working Paper. April 2013. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/20130619-energy_performance_certificates_in_buildings.pdf (accessed on 9 October 2018).
6. EC. Proposal for a Directive of the European Parliament and of the Council on the Energy Performance of Buildings (recast). 2008. Available online: http://eur-lex.europa.eu/ (accessed on 14 June 2012).

7. Chau, K.; Zou, G. Energy Prices, Real Estate Sales and Industrial Output in China. *Energies* **2018**, *11*, 1847. [CrossRef]
8. Jensen, O.M.; Hansen, A.R.; Kragh, J. Market Response to The Public Display of Energy Performance Rating at Property Sales. *Energy Policy* **2016**, *93*, 229–235. [CrossRef]
9. Hyland, M.; Lyons, R.; Lyons, S. The Value of Domestic Building Energy Efficiency: Evidence from Ireland. *Energy Econ.* **2013**, *40*, 943–952. [CrossRef]
10. Das, P.; Wiley, J. Determinants of Premia for Energy-Efficient Design in The Office Market. *J. Property Res.* **2014**, *31*, 64–86. [CrossRef]
11. Pontus, C.; Hassel, L.G.; Semenova, N. Energy Performance and Housing Prices. *Sustain. Dev.* **2014**, *22*, 404–419.
12. Fuerst, F.; McAllister, P.; Nanda, A.; Wyatt, P. Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England. *Energy Econ.* **2015**, *48*, 145–156. [CrossRef]
13. Salvi, M.; Horehájová, A.; Müri, R. *Der Nachhaltigkeit von Immobilien Einen Finanziellen Wert Geben—Minergie Macht Sich Bezahlt*; University of Zurich, Center for Corporate Responsibility and Sustainability: Zurich, Switzerland, November 2008. Available online: https://www.minergie.ch/media/zkb_minergie_studie_2008.pdf (accessed on 10 April 2018).
14. Brounen, D.; Kok, N. On the Economics of Energy Labelling in The Housing Market. *J. Environ. Econ. Manag.* **2011**, *62*, 166–179. [CrossRef]
15. Fuerst, F.; McAllister, P. The Impact of Energy Performance Certificates on The Rental and Capital Values of Commercial Property Assets. *Energy Policy* **2011**, *39*, 6608–6614. [CrossRef]
16. Eichholtz, P.; Nils, K.; Quigley, J.M. Doing Well by Doing Good? Green Office Buildings. *Am. Econ. Rev.* **2010**, *100*, 2492–2509. [CrossRef]
17. Wiley, J.A.; Benefield, J.D.; Johnson, K.H. Green Design and The Market for Commercial Office Space. *J. Real Estate Financ. Econ.* **2010**, *41*, 228–243. [CrossRef]
18. Cajias, M.; Piazolo, D. Green Performs Better: Energy Efficiency and Financial Return on Buildings. *J. Corp. Real Estate* **2013**, *15*, 53–72. [CrossRef]
19. Roca, J. *La Estructura de Valores Residenciales un Análisis Teórico y Empírico*; Instituto de Estudios de Administración Local: Madrid, Spain, 1988; 251p. Available online: https://www.iberlibro.com/ESTRUCTURA-VALORES-URBANOS-ANALISIS-TEORICO-EMPIRICO/12529133261/bd (accessed on 28 September 2016).
20. Murphy, L. The Influence of the Energy Performance Certificate: The Dutch case. *Energy Policy* **2014**, *67*, 664–672. [CrossRef]
21. Parkinson, A.; De Jong, R.; Cooke, A.; Guthrie, P. Energy Performance Certification as a Signal of Workplace Quality. *Energy Policy* **2013**, *62*, 1493–1505. [CrossRef]
22. Pascuas, R.P.; Paoletti, G.; Lollini, R. Impact and Reliability of EPCs in The Real Estate Market. *Energy Procedia* **2017**, *140*, 102–114. [CrossRef]
23. García-Hooghuis, A.; Neila, F.J. Transposition of the 2002/91/EC and 2010/31/EU "Energy Performance Building Directive" in the EU Members States. Consequences and Implications. *Inf. Constr.* **2013**, *65*, 289–300. [CrossRef]
24. De Ayala, A.; Galarraga, I.; Spardo, J. The Price of Energy Efficiency in The Spanish Housing Market. *Energy Policy* **2016**, *94*, 16–24. [CrossRef]
25. Marmolejo, C. The Impact of The Energy Rating on Residential Values: An Analysis for the Multifamily Market in Barcelona. *Inf. Constr.* **2016**, *68*, 1–12.
26. Bian, X.; Fabra, N. Incentives for Information Provision: Energy Efficiency in the Spanish Rental Market (No. 13270). CEPR Discussion Papers. 2018. Available online: http://nfabra.uc3m.es/wp-content/uploads/2018/11/incentives-information-provision.pdf (accessed on 30 November 2018).
27. Gonzalez Caceres, A. Shortcomings and Suggestions to the EPC Recommendation List of Measures: In-Depth Interviews in Six Countries. *Energies* **2018**, *11*, 2516. [CrossRef]
28. Taltavull de La Paz, P.; Pérez, R.; Mora, R. Green Premium. Evidence from Spain. In Proceedings of the LARES 2017 Congress, Sao Paulo, Brazil, 26–28 September 2017. Available online: http://lares.org.br/lares2017/sessoes-paralelas-b/ (accessed on 30 November 2018).

29. Marmolejo, C.; Cerda, J. Spatiotemporal Behavior of The Population as An Approach to Analyze Urban Structure: The Case of Metropolitan Barcelona. *Cuadernos Geográficos* **2017**, *56*, 111–133. Available online: http://revistaseug.ugr.es/index.php/cuadgeo/article/view/4704 (accessed on 3 April 2018).
30. Marmolejo, C.; González, C. Does Noise have a Stationary Impact on Residential Values? *J. Eur. Real Estate Res.* **2009**, *2*, 259–279. [CrossRef]
31. Rosen, S. Hedonic Prices and Explicit Markets: Production Differentiation in Pure Competition. *J. Political Econ.* **1974**, *82*, 34–55. [CrossRef]
32. Addae-Dapaah, K.; Chiech, S. Green Mark Certification: Does the Market Understand? *J. Sustain. Real Estate* **2011**, *3*, 162–191. Available online: https://core.ac.uk/download/pdf/79524532.pdf (accessed on 10 October 2018).
33. Malpezzi, S. Hedonic Pricing Models: A Selective and Applied Review. In *Housing Economics and Public Policy*; O'Sullivan, T., Gibb, K., Eds.; Blackwell. Blackwell Science Ltd.: Oxford, UK, 2002; pp. 67–89.
34. Encinas, F.; Aguirre, C.; Marmolejo, C. Sustainability Attributes in Real Estate Development: Private Perspectives and Advancing Energy Regulation in A Liberalized Market. *Sustainability* **2018**, *10*, 146. [CrossRef]
35. García-Navarro, J.; Díaz, M.; Valdivieso, M. Assessment of Construction Costs and Energy Consumption Resulting from House Energy Ratings in A Residential Building Placed in Madrid: "Precost&e Study". *Inf. Constr.* **2014**, *66*, 1–10.
36. Marmolejo, C.; García-Hooghuis, A.; Garcia-Masia, A. How Much Does the Energy Class of Our Dwellings Matter to Us? An analysis of The Level of Understanding of EPCs, Willingness to Pay and Reasons for Payment in Barcelona. *Habitat Sustentable* **2017**, *7*, 54–65. Available online: https://dialnet.unirioja.es/servlet/articulo?codigo=6045650 (accessed on 3 April 2018).
37. Backhaus, J.; Tigchelaar, C.; de Best-Waldhober, M. Key Findings and Policy Reconmendations to Imporve Effectiveness of Energy Performance Certificates and the Energy Performance of Buildings Directive. Available online: http://www.ideal-epbd.eu/ (accessed on 30 October 2018).
38. García-Barón, A. The Role of Thermal Comfort in The Energy Efficiency Policy: Improving Quality of Life in the Pyrenees Street in Santa Coloma de Gramanet. UPCommons, 2017-10. Available online: https://upcommons.upc.edu/handle/2117/111728 (accessed on 10 October 2018).
39. De Ruggiero, M.; Forestiero, G.; Manganelli, B.; Salvo, F. Buildings Energy Performance in a Market Comparison Approach. *Buildings* **2017**, *7*, 16. [CrossRef]

The evolution of energy efficiency impact on housing prices. An analysis for Metropolitan Barcelona

La evolución del impacto de la eficiencia energética en los precios residenciales. Un análisis para la Barcelona Metropolitana

Carlos Marmolejo-Duarte (Main and Correspondence Author)
Departamento de Tecnología en la Arquitectura, Centro de Política de Suelo y Valoraciones, Escuela Técnica Superior de Arquitectura de Barcelona, Universidad Politécnica de Cataluña
Diagonal, 649,4a, Arq Legal, 08028, Barcelona (Spain) https://orcid.org/0000-0001-7051-7337
carlos.marmolejo@upc.edu

Ai Chen
Departamento de Tecnología en la Arquitectura, Centro de Política de Suelo y Valoraciones, Escuela Técnica Superior de Arquitectura de Barcelona, Universidad Politécnica de Cataluña
Diagonal, 649,4a, Arq Legal, 08028, Barcelona (Spain) https://orcid.org/0000-0002-8912-0660
ai.chen@upc.edu

Manuscript Code: 1149
Date of Acceptance/Reception: 29.01.2019/16.07.2018
DOI: 10.7764/RDLC.18.1.156

Abstract
The Energy Performance of Buildings Directive has it made mandatory to include an energy performance certificate (EPC) on real estate advertisements so as to promote efficient properties. Previous research has found a positive correlation between residential prices and EPC's energy ranks; nonetheless, the analysis of the evolution of such impact for the same market is still pending. This paper tries to shed light on this issue by analyzing the evolution of prices of the second largest urban agglomeration in Spain. In doing so, a pooled hedonic model is carried out departing from selling listing prices of apartments and a set of locative control variables. Results suggest that in a short period the energy premium for multifamily houses has positively evolved. As a result, a sharped market differentiation arises between inefficient and energy saving dwellings. Such findings have significant implications for the construction and real estate industry, since higher selling prices may compensate for higher building costs coming from energy efficient technologies.

Keywords: Hedonic price models, real estate valuation, energy efficiency, energy performance certificates, Barcelona.

Resumen
La Directiva de la Eficiencia Energética en la Edificación obliga la inclusión de la etiqueta derivada de un certificado de eficiencia energética (CEE) en la publicidad inmobiliaria con el objetivo de promover edificios energéticamente eficientes. En la literatura está bien establecida la correlación positiva entre los precios residenciales y las clases energéticas de los CEE; sin embargo, la evolución de dicha correlación en dicho mercado es un tema pendiente. Este trabajo intenta avanzar en ese sentido a partir del análisis de la evolución de los precios en la segunda aglomeración urbana en España. Para ello, se utiliza un modelo de precios hedónicos con datos provenientes de precios de oferta de apartamentos y de un conjunto de variables locativas de control. Los resultados sugieren que en un periodo corto de tiempo el sobreprecio energético de las viviendas plurifamiliares ha tenido una evolución positiva, emergiendo una diferenciación importante entre las viviendas ineficientes y aquéllas que ahorran energía. Estos hallazgos, tienen implicaciones importantes para el sector inmobiliario y de la construcción en tanto cuanto un mayor precio de venta podría compensar los mayores costes de construcción derivados de la edificación energéticamente eficiente.

Palabras clave: Modelos de precios hedónicos, valoración inmobiliaria, eficiencia energética, Barcelona.

Introduction

In order to foster energy-efficient buildings, the European Commission issued the Energy Performance of Buildings Directive (EPBD 2002/91/EC), recast in 2010/31/UE. The main hypothesis of such communitarian policy is that building users (*i.e.* buyers and tenants) should elicit in preferential conditions efficient buildings when they are informed on energy consumption and CO_2 emissions. So, individuals may be willing to pay more for taking advantage of energy savings and environmental preservation. In doing so, the Directive obligates real estate owners willing to sell or lease properties to get an Energy Performance Certificate (EPC) and include the derived energy rank in the advertising of the property. In sum, by breaking down energy information asymmetries, the EU tries to promote the construction of efficient buildings and the energy retrofit of existing ones (Encinas *et al*., 2018).

In Spain the transposition of the Directive has been implemented by means of different legal instruments, being the RD 235/2013 the most import one. According to this legal text, as from 1st of June 2013, almost all properties to be let (to a new tenant) or sell must exhibit the EPC rank when advertised (Marmolejo & Bravi, 2017). The previously published research, reviewed in the next section, has found that EPC ranks are positively correlated with housing prices both in Spain and other EU member states.

Description of the problem

The impact of EPC ranking in the Spanish residential market is sharply smaller than in other northern European countries. Behind such divergence, authors have argued differences on climatic conditions, income, property prices as well as diverging concerns on environment conservation. Whether such impact remains low along the time is still a pending question. This paper tries to shed light on it, by means of two objectives:

1) Study the evolution of EPC impacts on residential prices along the time
2) Study if such evolution is linear among energy ranks.

In doing so, a large dataset has been gathered for the Metropolitan Area of Barcelona, the second largest urban agglomeration in Spain and the sixth in Europe. Selling listing prices have been acquired from one of the largest real estate websites in Spain providing extensive coverture of the residential market. The study is constrained to apartments since this is the dominant typology of dwellings in Mediterranean cities. In order to get unbiased results, considerable efforts have been made in order to incorporate control variables related to 1) territorial, 2) urban, 3) environmental and 4) socioeconomic aspects of the micro-location of each of the apartments. Such information has been analyzed by a set of hedonic models, in order to identify the impact of energy ranking on selling listing prices and its evolution.

The remainder of the paper is organized as follows: firstly, a review of the previous research on energy efficiency and real estate prices both in Europe and Spain is offered; secondly, the case study, data, and methodology is explained; as a third part the results are discussed, and in the concluding section, an overview of the research and its implications for the building industry are included.

Brief literature review

In the literature, the positive influence of energy efficiency and more generally sustainable attributes as measured by means of environmental certifications schemes and their respective “green labels” is well established. In particular, the evidence regarding such influence coming from the EPC scheme is quite more recent concerning previously settled programs such as LEED, BREEAM or Energy Star.

The pioneering study by Brounen & Kok (2011) analyzed the impact of EPC labels on residential prices in The Netherlands; although, the data used come from the period in which the purchasing part could exempt the selling part of delivering an EPC. The results of this study found a positive correlation between the best-ranked dwellings and sale prices in real estate transactions. These authors assume that energy ranks are a categorical measure of the efficiency of housing. Therefore, considering the intermediate rank "D", as a basis for comparison, they found that the marginal price ranged from 10% for the "A" class, to -5% for the "G" class. That is, above the reference *market premiums* are formed, while below *market penalties* appear. The study by Hyland *et al.* (2013) conducted in a set of Irish cities was the first to simultaneously compare the impact of EPC in the rental and sale markets. In doing so, these authors departed from listing prices of both markets, finding that the impact of the energy ranking is greater in the market of sale than in the rental one. For example, a home for sale ranked as "A" (in relation to "D") has a *market premium* of 9.3%, and only 1.8% if it is transacted in the rental market, all the remaining attributes being the same. Likewise, the *market penalty* for a home ranked as "F" or "G" (in relation to "D") is significantly higher (-10.60%) than the penalty received in the rental market (-3.20%). The larger impact of green labels on sale prices, in relation to rental prices, is a regularity that already had been reported by previous work based on other certification schemes (Marmolejo, 2016).

In the work of Bio intelligence Service (2013) (see Table.1), the impact of EPC is higher in selling prices than in housing rents. From this study, it should be noted that EPCs appear to have a sharper impact on hinterlands (e.g. Belgium and Ireland, with Austria as an exception) than in capital cities. According to its authors, such differential impact can be explained by the fact that savings in energy bills regarding the base price of housing, are more important in rural areas where the housing price is lower. Also, not always a higher energy rating implies a *market premium*, since in the rental market of Oxford there is apparently a penalty for the best-ranked dwellings (-4% per EPC rank). The authors of this work have recognized the enormous deficiencies of their analysis, since the older and better located, high-priced stately dwellings have, in turn, a low energy rank in that city. In general, the very poor control of urban characteristics (*i.e.* accessibility, quality of urbanization and social hierarchy) driving residential values is a deficiency of such work and can bias the coefficients of its models. In Belfast Davis *et al.* (2015) have also found that efficient homes command a higher price, according to their semi-log hedonic regression, the sale price increases 0.4% for each of the EPC ranks. Nonetheless, this impact is not the same for different age (*i.e.* styles) and typologies of homes. The same conclusion has been extracted by Marmolejo & Chen (2019a) in their analysis of listing prices in Barcelona. Their analysis suggests that the impact of EPC rankings is null in the case of recently completed state-of-the-art apartments. On the contrary, in the case of postwar apartments targeted to low-income population boasting the poorest quality the impact is large. According to such authors in this latter case, EPC rankings proxy for quality of apartments in absence of amenities, playing, in that sense, an incorrect role in price differentiation. In another study Marmolejo & Chen (2019b) they have found that in some housing markets EPC rankings appear as inversely correlated with prices, proably due to lack of supervision on the advertisement of EPC labels

In Sweden, Cerin et al. (2014) have carried out a peculiar study in which the sale price of the dwellings has been correlated directly with the energy consumption contained in the EPC label. The coefficient of energy consumption in their hedonic model appears with a contradictory sign (Bx = 0.06, p = 0.000), where *x* is the log of consumption in kWh/year/m^2 and *Y* the log of the price per m^2): the higher the consumption in kWh/year/m^2, the larger the housing price, everything else equal. It is highly probable that simple energy ranks are clearer than more precise technical units.

Table 1. EPC impacts on residential prices in a selected set of European cities. Source: Own elaboration based on Bio Intelligence Service (2013*).*

	Impact of EPC ranks on prices			
Case study	Sell (%)	Lease (%)	Used prices	Data source
Wien	Between 10 and 11	Between 5 and 6	Asking	Web portal
Lower Austria	Between 5 and 6	4.40	Asking	Web portal
Brussels (Flanders)	4.30	3.20	Asking	Web portal
Brussels (Capital)	2.90	2.60	Asking	Web portal
Brussels (Wallonia)	5.40	1.50	Asking	Web portal
Lille	3.20	nd	Transaction	Notary
Marseille	4.30	nd	Transaction	Notary
Irish cities	1.70	1.40	Asking	Web portal
Irish country side	3.80	1.40	Asking	Web portal
UK (Oxford South)	0.40	-4	Asking	Web portal

So far, there is a significant divergence in the impact of EPC rankings on residential values throughout Europe, explained by the essential differences regarding income, energy costs, construction, climate, legal requirements, and environmental concerns. Moreover, Garcia-Hooghuis and Neila (2013) have pointed out that the way in how the EPBD has been transposed across the Member States has resulted in different calculation methods, making cross-border comparisons difficult. However, the positive impact on prices reviewed before contrast with the outcomes of opinion-based research. Murphy [2014] conducted a survey in the Netherlands in order to identify the impact of EPC information on price negotiation in the context of home purchasing. Her results suggest that “a higher EPC fails to have a direct influence during negotiation and decision making” (p. 666). In the same line, Parkinson *et al.* (2013) have found, surveying commercial office occupants in the UK, no correlation between EPC ratings and rental values, their findings suggest that facilities’ aesthetic is the main driver of rents. Compatible evidence can be found in the study of Pascuas *et al*. (2017) based on surveys applied to real estate agents in eight countries. According to their results, EPC ratings exert a negligible impact on housing prices, this conclusion is especially valid in the case of Spain where only 15% of the surveyed agents confirmed the existence of a premium for efficient flats. Departing from such contradictory evidence, that is: on the one hand a positive market premium for efficient properties suggested by hedonic models; and on the other hand, no strong evidence on EPC impact on prices and rents coming from demand and agents’ surveys, Olaussen *et al.* (2017) have carried out an interesting quasi-natural experiment in order to identify whether omitted variables in model specifications can lead to spurious results. Their study, based on the Oslo’s residential market, consists of analyzing the price of homes sold before and after July 2010 when it became mandatory to include in advertisings the EPC labels, so as to identify whether such labels did actually produce a price increase in the case of efficient homes. In doing so, they assign the EPC class to each home in the pre-2010 sample according to the class the same home had in the post-2010 sample. Their hedonic results show similar market premiums and penalties on EPC ratings for the pre and post 2010 samples, allowing them to conclude that “price premium of the energy labels clearly captures something else than an effect to the labels themselves” (p. 251). Nonetheless, such authors warn that even when EPC rating does not matter in Norway, they could matter in other countries, possibly where trust and honesty on building industry are lacking. All in all, it is necessary to carefully incorporate control variables, as it is done in this paper, in order to reduce the risk of omitting relevant attributes.

In Spain, there are two pioneering works in the study of the hedonic agenda of the EPC. The work of De Ayala *et al.* (2016) is based on "opinion values" declared by a sample of respondents from 5 cities (Madrid, Bilbao, Seville, Vitoria, and Málaga) with an own calculation of the energy EPC rank. It has found that dwellings with "A", "B" or "C" energy ranks have a value, in the opinion of their owners, higher by 9.8% than those rated as "D", "E", "F" or "G". Marmolejo (2016) uses listing prices for a sample of dwellings in Barcelona and found an over price of 5.11% for the G->A improvement, or 9.62% if it is accepted that people perceive the ranking scale to be nominal. All in all, the impact of EPC ranks on prices is significantly smaller in Barcelona in relation to other European cities. In Turin, the conclusions laid by the study of Fregonara & Rolando (2016) point out a null impact of EPC rankings when other architectonic attributes are taken into consideration. This evidence stresses the necessity to furtherly explore the hedonic agenda of EPC rankings in Southern Europe. Especially because, according to Marmolejo (2016), the tiny market premium found in Barcelona cannot compensate the more substantial construction costs associated to higher energy efficiency standards, which constitutes a negative signal to construction companies and real estate developers willing to promote efficient buildings. Whether such incidence is stable along the time is still an open question tried to be solved by this paper as it is next discussed.

Methodology

The study area is the Metropolitan Region of Barcelona, which is officially comprised of 164 municipalities. In Spain transaction prices are unknown since information coming from the Property Register is only provided in an aggregated manner, containing no information about structural attributes of properties but the built area; furthermore, such information comes from self-declarations in public deeds, so it may diverge from actual prices. For these reasons in this paper listing selling prices are analyzed. Listing prices and characteristics of apartments and the respective buildings have been acquired from Habitaclia, one of the leading real estate websites in Catalonia. The two dates of datasets retrieved are: the 1st November 2014 and the 1st April 2016, both of them are posterior to the RD 235/2013 and this period comprises the end of one of the largest real estate crises in the history of Spain. Architectonic features include: floor area, number of rooms, number of baths, living room area, terrace/balcony area, story where the flat is placed, heat/air conditioning systems, information regarding renewal, EPC rank, penthouse position, number of levels (in the case of duplex/triplex dwellings), etc. as well as condominium services such as lift, swimming pool, private greenery, age, etc.

In order to make a comprehensive control of other locative attributes influencing housing prices, a significant effort has been made gathering the following information:

- Regarding socioeconomic, environmental and accessibility data, information from the 2001 Housing and Population Census (Unfortunately, it was not possible to use 2011 data census since, due to the crisis in Spain, such census is based on a restricted sample survey, which is not statistically reliable at census tract level) has been retrieved at census tract level with the following detail: a) data regarding the social status of the neighborhood (e.g. education attainment, job position of resident employed population in the context or their firms, percentage of residential buildings with doorman service, etc.); information regarding the accessibility (e.g. declared time to get the workplace); data regarding the environmental quality of the neighborhood (e.g. greenery perception); information regarding the available services (health-care, education, sociocultural, retail, office-based services, etc.).
- Regarding the built-up density and area allocated from a selection of land use, information of the latest 2013 cadastral database has been retrieved at census tract level.
- Regarding the presence of transport systems and territorial externalities, an own digitalization process has been implemented so as to identify: train stations (subway, metropolitan trains, tram and other railway transports such as funiculars), highway ramps, the coastal line and the limits of natural parks (including those of submarine nature due to the externalities that might emerge from them).
- Regarding the centrality of zones, information coming from the 2001 metropolitan survey at transport zone level has been retrieved.

Using this latter information, a synthetic indicator of centrality has been built as follows:

1) Firstly, some intermediate-variables were computed. Some of such intermediate-variables are time-density (Marmolejo & Cerda, 2012; Marmolejo *et al.*, 2016); diversity of activities; socioeconomic diversity of people that perform activities in a given zone; distance traveled by people performing activities in a given zone, etc. All the variables were computed for different days in the week and 5 time-strips.

2) Secondly, intermediate-variables were encapsulated in a synthetic indicator of centrality using DP2 methodology (Pena, 1977, Zarzosa, 2009).

In Marmolejo & Cerda (2017) all the details concerning the construction of the synthetic indicator of centrality are provided and theorized in the more general framework of time-geography.

Since the geographical entities of data used are divergent: points for studied dwellings, census tract for census and cadastral data and transport zones for mobility information, it was used a geographic information system. Using a buffer of 300 m radius (In addition, it was used a buffer of 600 m radius; nevertheless, the model built with such data exhibits a lower fit in comparison to that presented in this paper) around each of the apartments and geospatial queries, all the information was transferred to each of the apartments contained in the dataset.

The complete dataset comprises 35,116 apartments for the year 2014 and 49,424 for the year 2016; the larger amount of cases in this latter year is a signal of the recovery of the real estate market after eight years of economic downturn. Nonetheless, despite the abovementioned obligation to include the energy ranking the advertisement, a large quantity of cases does not contain such information. In general we have found that apartments disclosing the EPC ranks are slightly better in terms of quality than those without such information. Nonetheless, such difference does not produce a significant bias on the estimation of the regression coefficients according to the 2-step Heckman procedure. For the year 2014-sample the compliance rate is 12% and for the year 2016 is 15%. As a result, the sample sizes are reduced. In order to eliminate outliers, the following procedure has been applied to each separated annual sample:

- Firstly, all flats with unitary prices beyond +/-1 standard deviation from the average unitary price were discarded.

- Next, a family of regression models was calculated, using the model with the best fit the Mahalanobis Distance was computed. According to Marmolejo & González (2009), this procedure allows for the elimination of outliers in the *n*-variables used in the regression analysis.

- Finally, it was detected the Mahalanobis Distance breaking point (*i.e.* the value where the slope increases abruptly) by using a sedimentation analysis.

The final depurated sample comprises 3,246 cases for the year 2014, and 5,139 cases for the year 2016. In order to guarantee a similar size for both of the year-samples, a random selection process has been implemented in the latter annual sample. As a result, the pooled sample is made of 6,492 cases. Table 1 exhibits the descriptive statistics of the main variables organized in conceptual dimensions.

From such data, it is clear that for the year 2014 the “average apartment” exhibits: a price of 162,851 Euros, an area of 84 m^2, 1.3 bathrooms, 2.9 bedrooms, and its average height-location is 2.1 stories with an average terrace area of 12 m^2. Regarding the condominium shared spaces, it is important to note that 4% of apartments have swimming pools, 9% gardens and 46% lift service. The conditioning systems are also presented: 31% of the apartments have air conditioner while 43% central heating system.

In terms of energy efficiency, the average ordinal EPC rank (G=1, A=7) is 2.7. While class A comprises only 2% of the sample, Class B is not present after depurating the data, being Class E the most abundant (49%) followed by class G 21%. Regarding the average location, 93% are located in municipalities with access to a metropolitan highway, and 50% near to a railway station (including subway, tram, and funicular). Both the population and employment densities proxies for centrality and service presence, as it can be seen the minimum value for such attributes is 11 residents/km^2 and 5 jobs/km^2 reaching 144,421 residents/km^2 and 56,454 jobs/km^2 respectively in the most central/serviced zones. 1.2% of the apartments are located within 200 meters from the seashore which proxies for environmental quality.

Regarding the socioeconomic level of the zones where the apartments are located, 7% of the neighboring housing has doorman service as an average, 11% of neighbors hold a university degree and 8% work in managerial positions. Since these variables are closely correlated As a matter of fact, most of the variables in the dataset are correlated. Nonetheless, the models do not exhibit multicollinearity problems, since this issue has been controlled keeping the VIF well below 2.5 (except for the case of the area and the squared area since it allows to model a diminishing marginal function for this attribute), a factor analysis has been used including the job positions and education level. As a result, there are two principal components: PC1-High Income proxies for high-income job positions/high education level, the larger its value, the higher the proportion of neighbors in managerial, professional and specialized technical job positions as well as the higher the education level. PC2-Med Income proxies for medium income level, incorporating clerks, service vendors or qualified manufacturing positions. Since such synthetic indicators are produced by means a factor analysis, they are completely uncorrelated.

Table 2. Descriptive statistics for the 2014 & 2016 depurated sample and selected variables. Source*:* Own elaboration.

		2014 Sample				2016 Sample			
	N x 2	Min	Max	Mean	Std. Deviation	Min	Max	Mean	Std. Deviation
Structural architectonic characteristics of apartments									
Total price (Euros)	3,246	34,000	715,000	162,851	88,957	48,000	830,000	229,507	153,812
Unitary price (Euro/m²)	3,246	845	3,542	1,914	661	602	10,172	2,592	1,295
Area (m²)	3,246	25	234	84	28	20	380	87	32
Number of bathrooms	3,246	-	4	1.3	1	-	4	1.4	1
Number of bedrooms	3,246	-	15	2.9	1	-	10	2.9	1
Ration bathroom/bedroom	3,246	-	2	0.5	0	-	2	0.5	0
Level of the apartment	3,246	-	13	2.1	2	-	19	2.2	2
Terrace (m²)	3,246	-	256	9.5	14	-	240	9.5	21
Living room area (m²)	3,246	-	90	12	10	-	102	12	12
Large terrace (Dummy)	3,246	0	1	7%		0	1	13%	
Air conditioner (Dummy)	3,246	0	1	31%		0	1	48%	
Central heating (Dummy)	3,246	0	1	43%		0	1	68%	
Retrofited apartment (Dummy)	3,246	0	1	11%		0	1	19%	
Energy performance of apartments									
Energy class (ordinal)	3,246	1	7	2.70		1	7	2.84	
Energy class G (Dummy)	3,246	0	1	21%		0	1	19%	
Energy class F (Dummy)	3,246	0	1	14%		0	1	13%	
Energy class E (Dummy)	3,246	0	1	49%		0	1	50%	
Energy class D (Dummy)	3,246	0	1	10%		0	1	11%	
Energy class C (Dummy)	3,246	0	1	4%		0	1	3%	
Energy class B (Dummy)	3,246	na	na	na	na	0	1	1%	
Energy class A (Dummy)	3,246	0	1	2%		0	1	3%	
Architectonic characteristics of the buildings									
Swiming pool (Dummy)	3,246	0	1	4%		0	1	11%	
Garden (Dummy)	3,246	0	1	9%		0	1	16%	
Lift (Dummy)	3,246	0	1	46%		0	1	67%	
Building age	3,246	0	104	45	18	0	326	46	25
Locative attributes (transport, centrality and amenities)									
Commuting time (minutes)	3,246	12.9	41.0	24.0	4.5	12.9	41.4	24.6	3.9
Highway ramp (Dummy)	3,246	0	1	93%	26%	0	1	94%	23%
<800 m from railway station (Dummy)	3,246	0	1	50%	50%	0	1	56%	50%
Pop. density (residents/km²)	3,246	11	144,421	21,935	22,700	16	152,596	24,262	23,273
Employment density (jobs/km²)	3,246	5	56,454	9,511	9,738	7	73,563	10,548	10,078
Centrality index	3,246	3.5	20.5	11.4	2.4	4.7	20.5	12.0	2.7
Average gross area floor ratio (m²/m²)	3,246	0.2	6.0	2.0	1.3	0.2	6.0	2.3	1.6
<200m from sea shore (Dummy)	3,246	0	1	1.2%		0	1	3.9%	
Socio-economic attributes									
Doorman (%)	3,246	0%	72%	7%	10%	0%	94%	10%	14%
People with university degree (%)	3,246	1%	44%	11%	8%	1%	47%	14%	10%
Managers (%)	3,246	1%	34%	8%	4%	1%	32%	10%	5%
Professionals (%)	3,246	1%	45%	11%	8%	1%	44%	14%	10%
Technicians (%)	3,246	3%	25%	13%	4%	2%	25%	14%	4%
Clerks (%)	3,246	3%	21%	11%	3%	3%	21%	11%	3%
Service vendors (%)	3,246	3%	29%	15%	3%	5%	33%	15%	4%
Agriculture (%)	3,246	0%	8%	1%	1%	0%	10%	1%	1%
Craft & qualified manufacture (%)	3,246	2%	39%	17%	6%	1%	37%	15%	7%
Manufacturing (%)	3,246	1%	40%	13%	6%	1%	36%	11%	6%
Non qualified jobs (%)	3,246	2%	32%	10%	4%	1%	32%	9%	5%
PC1 High income (factor loadings)	3,246	-2.15	3.86	-0.11	0.81	-2.15	3.76	0.16	1.03
PC2 Med income (factor loadings)	3,246	-3.14	2.51	-0.24	0.96	-3.14	2.62	0.02	0.93

As for the year 2016, the attributes of the apartments denote an improved quality and higher price. For example, in comparison to the 2014 dataset, the 2016 apartments are: more expensive, larger, best equipped (*i.e.* air conditioner, heating and lift, swimming pool and garden), more efficient in energy performance terms, located in better zones (*i.e*. more central, closer to the seashore, transport stations and highway ramps) and wealthier zones. Why the apartments seem to be improved in all the aforementioned aspects? As it is known, 2014 year was still a moment of real estate crisis in Spain when most of the properties being offered at that time exhibited poor amenities and attributes. Furthermore, better quality properties are normally taken out from the market since their owners can get a better price quotation during the economic recovery period. Conversely, the worst apartments that usually belong to low-income population do not follow such pattern since this population niche exhibits a higher unemployment rate and mortgage evictions. This process is typical in countries such as Spain where the ownership is the dominant housing tenure.

The method used is the hedonic model (Rosen, 1974). This method assumes that the price paid for the asset from housing buyers is equal to the total utility they extract from it, being this a composite utility coming from the marginal attribute of the dwelling (e.g. area, quality, location, etc.). It is possible to calculate such marginal utility expressed in monetary terms by a regression model. In this paper, the used model used departs from the following function:

$$ln(P) = c + \sum_{i=1}^{n} X_i\, A_i + XE + \sum_{i=1}^{n} X_i B_i + \sum_{i=1}^{n} X_i L_i + \sum_{i=1}^{n} X_i\, S_i + \varepsilon \qquad (1)$$

Where
P is the asking selling price
A is a set of apartment's *i* architectonic attributes
*X*s are the coefficients for each of the variables expressed as price semi-elasticities (see below)
E is the apartment's energy rank derived from EPC
B is a set of *i* facilities and amenities of the buildings where the apartment is located
L is a set of locative *i* attributes regarding transport and environmental quality of the site where the apartment is located
S is a set of socioeconomic attributes of the population living around the apartment
ε is the error term

The functional form used is log-linear since it accomplishes with the basic statistics premises for ordinary least squares (OLS) calibrating process: normality of residuals, homoscedasticity, and multi-collinearity absence. Also, it allows to identify the marginal price of attributes expressed in semi-elasticities, it is to say the price increase in percentage terms associated with the unitary increase of the independent variables.

Due to the interest of this paper is to analyze whether the EPC rank marginal price has remained stable along the time, the procedure applied is that proposed by Sander (1992). It consists of analyzing the increase of prices using a pooled sample (*i.e.* 2014 and 2016 datasets together), controlling for the year to which each case belongs to and the eventual increase of EPC rank marginal price. As a result, equation (1) is transformed into:

$$\ln(P) = c + \sum_{i=1}^{n} X_i\, A_i + XE + \sum_{i=1}^{n} X_i B_i + \sum_{i=1}^{n} X_i L_i + \sum_{i=1}^{n} X_i\, S_i + B2016 + XE_{2016} + \varepsilon \quad (2)$$

Where

2016 is a year dummy variable equal to one if the dwelling comes from the 2016 dataset and zero otherwise
E2016 is an interaction term between the *E* energy rank and the dummy variable *2016.* In absence of an increase of the impact of energy rankings on housing prices the associated coefficient of this variable will appear as statistically insignificant.

Finally, it has been found that apartments' prices do not only respond to their locative and architectonic attributes, but also to the price of neighboring apartments (*i.e.* spatial dependence). According to the Moran's I the spatial autocorrelation of error from the OLS model of equation 2 is 0.22 (sig=0.00). The omission of this issue might lead to biased coefficients. For this reason, according to Ord (1975) the best way to correct the spatial dependence issue is looking at the largest and most significant value of the following Lagrange Multiplier Diagnostics: Lagrange Multiplier (lag); Robust Lagrange Multiplier (lag), Lagrange Multiplier (error), Robust Lagrange Multiplier (error) and Langrage Multiplier (SARMA). In our case, the Lagrange Multiplier (error) approach resulted in the largest value equivalent to 981.38 (sig=0.00)). As a result (2) is transformed into the spatial error model used in this paper:

$$\ln(P) = c + \sum_{i=1}^{n} X_i A_i + XE + \sum_{i=1}^{n} X_i B_i + \sum_{i=1}^{n} X_i L_i + \sum_{i=1}^{n} X_i S_i + B2016 + XE_{2016} + \varepsilon \quad (3)$$

Being $\varepsilon = \lambda W \varepsilon + u$

Where l is the autoregressive coefficient, *W* is the spatial matrix (in this case calculated following rook contiguity criteria) and *u* is the uncorrected error term.

Results and discussion

Table 3 contains the results for the best model coming from the calibration of equation (3) in GeoDa. In such a table, it is possible to see that the average increase in terms of asking prices has been 4.1% for the period studied (1st Nov 2014-1st April 2016). The results organized by conceptual dimensions are as follow:

Structural architectonic characteristic of apartments and buildings. In the first place appears the area of the apartment, the negative sign of the square of this variable suggest the presence of diminishing returns. In this dimension the next variable to enter is the number of bathrooms: for each additional bathroom apartment's price increases 9.8%; the presence of lift is also an important factor its average impact is 8.9% of housing prices. Other structural attributes exhibit a modest influence on prices. For example, the presence of an air conditioner contributes to an average increase of 7.4% of asking prices, while the central heating system implies an increase of 4.1% of prices. It is important to note that the presence of a swimming pool in the buildings shows the highest contribution to housing prices (18.6%). Following Olaussen et al. (2017) the age has been introduced following an inverse function. Such approach allows considering a larger impact of this attribute in the case of new and recently completed apartments, while in the case of old and very old ones the difference is smoother.

Energy efficiency attributes. There is also a positive increment of prices coming for efficient energy ranking as previous research has pointed out. In relation to rank G (the comparison base) energy class "A" increases prices in 8.6% for both years, the remainder of the classes for the base year fails to be statistically significant. This finding is plenty compatible with the results reported by Marmolejo (2016) since it confirms a scarce impact of energy efficiency on residential prices at the basis year. However, the interaction variables (*i.e.* 2016 x EPC ranks) suggest that the importance of energy ranks on price formation has clearly increased, as further discussed.

Locative attributes. The most relevant variables, regarding characteristics of transport, centrality as well as facilities and amenities, are the average gross area floor ratio (*i.e.* built up density), followed by the centrality index and commuting time. The positive sign of the first two indicators confirms that prices peak in central zones; however, the positive sign of the third indicator requires a special interpretation. The metropolitan area of Barcelona is a polycentric system gathering together, beyond the central conurbation, mature subcentres that were formerly independent centers, small towns, and rural villages. In these latter settlements, housing price is cheaper than in centralities, at the same time commuting time is smaller than in the very center (due they are largely self-contained in mobility terms). For this reason, commuting time is proxying for the location in the central conurbation, and consequently appears positively correlated with prices. The proximity to the seashore has a large impact on prices. It is important to note that housing price shows an average increase of 13.1% if the apartments are located within 200 meters from the waterfront.

Socioeconomic attributes. The synthetic indicators suggest that prices are enormously correlated with the place of residence of higher-educated people working in the best job positions (PC1-High Income). To a lesser extent, such positive correlation is also present for the case of medium income classes (PC2- Med Income).

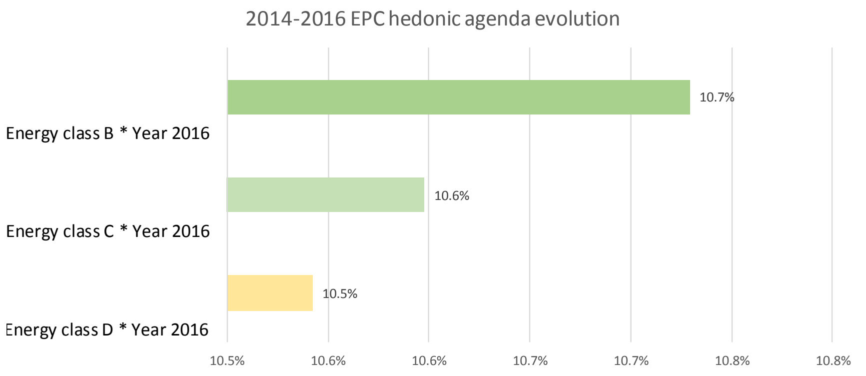
Figure 1 portrays the evolution of the impact of energy efficiency classes on prices. According to the multiplicative-interaction terms built from the energy rank and the Year 2016, the impact of more efficient ranks has increased in a monotonic coherent fashion: 10.7, 10.6 and 10.5% for ranks "B", "C", and "D", respectively. As a matter of fact, the increment of the impact of ranked "A" apartments is also positive but fails to meet the 90% confidence criteria. Overall, these results suggest that in a short period energy efficiency in Barcelona has gained importance in terms of residential prices. Green premiums and brown discounts have started to converge to what is observed in other European countries, opening new opportunities for the development of efficient housing and the retrofit of the existing stock as next discussed.

Table 3. Results of the pooled 2014 - 2016 sample model. Source: Own elaboration.

Spatial Error Model - Maximum Likelihood Estimation				
R Square	0.764	Log likelihood	-928	
Sigma Square	0.075	AIC	1917	
S.E of regression	0.274			
	Coefficients			
	B	Std. Error	Z-Value	Prob.
Lambda	0.462	0.016	28.317	-
(Constant)	10.125	0.056	182.398	-
Year 2016	0.041	0.015	2.684	0.007
Structural architectonic characteristics of apartments and buildings				
Area	0.015	0.000	37.546	-
Area^2	- 0.000	0.000	- 19.709	-
Number of bathrooms	0.098	0.008	11.842	-
Air conditioner	0.074	0.008	8.905	-
Central heating	0.041	0.009	4.686	-
Retrofited apartment	0.034	0.010	3.437	0.001
Swiming pool	0.186	0.015	11.976	-
Lift	0.089	0.008	10.452	-
Inverse of building age	0.238	0.045	5.340	-
Energy performance of apartments				
Energy class A	0.086	0.034	2.492	0.013
Energy class C	- 0.011	0.029	- 0.375	0.708
Energy class D	0.000	0.019	0.020	0.984
Energy class E	0.007	0.013	0.572	0.567
Energy class F	0.019	0.016	1.132	0.258
Energy class A * Year 2016	0.067	0.044	1.515	0.130
Energy class B * Year 2016	0.107	0.041	2.619	0.009
Energy class C * Year 2016	0.106	0.041	2.597	0.009
Energy class D * Year 2016	0.105	0.026	4.071	-
Energy class E * Year 2016	0.008	0.018	0.462	0.644
Energy class F * Year 2016	- 0.033	0.024	- 1.386	0.166
Locative attributes (transport, centrality and amenities)				
Commuting time	0.004	0.001	2.597	0.009
<200m from sea shore	0.131	0.029	4.532	-
Highway ramp	0.081	0.022	3.712	-
<800 m from railway station	0.033	0.011	3.120	0.002
Centrality index	0.025	0.003	8.680	-
Average gross area floor ratio	0.048	0.005	9.029	-
Socio-economic attributes				
PC1 High income	0.104	0.006	17.356	-
PC2 Med income	0.072	0.007	10.979	-

Note: independent variables/covariates are introduced using the stepwise method.

Figure 1. Evolution of the energy rank impact on residential prices 2014-2016. Source: Own elaboration



Conclusions

Departing from listing prices for 2014 and 2016 in this research, a set of spatial pooled regression models has been performed. Such analyses suggest that, as the time evolves, the market premium for energy efficiency (*i.e.* semi-elasticity or the percent price increase for each EPC energy rank) has increased in the main real estate market of the second largest urban agglomeration of Spain. In absolute terms (*i.e.* Euros) such market premium is still more important since market prices have increased 4.6% in the studied period due to the change of economic cycle that has marked the end of the real estate crisis in Spain. According to Garcia Navarro et al. (2014), the 2016 market premium for efficient homes found in this paper is able to overcome the increased construction costs associated with better energy-efficiency materials and building procedures. That is, matching the premia that developers can get from efficient buildings with the production cost is a critical issue in achieving the outcomes pursue by the Energy Performance of Building Directive. Our analyses suggest that in general, the more efficient ranks do exhibit an increased impact of housing prices. Such increment ranges 10.7% to 10.5% for the “B” to “D” ranks respectively. Rank “A”, also shows a positive increase but fails to meet the significance criteria.

Whether the rise of energy premiums for efficient homes in Spain is a product of the natural implementation of the EPC policy is an open question. Nonetheless, in this period of time, the significant increments in the price of energy have occurred in the country. This inflationist episode might have influenced households to penalize inefficient homes markedly. In any case, the increase of energy premiums in the Spanish residential market is a clear convergence to the European agenda of EPC hedonic prices.

Our study is limited in nature since in absence of transaction prices it has been powered by listing prices. Since the negotiation ratio (*i.e.* selling prices/listing prices) might be different across urban locations or housing qualities, there is a certain possibility that the actual impact of EPC ranking on prices may differ from that reported in our analysis. Also, it is necessary to undercover whether the evolution of the impact is the same across different submarkets since previous research has found divergent impacts.

Acknowledgments

This paper has been produced in the framework of EnerVALOR project (SPAIN MINECO FEDER BIA2015-63606-R) leaded by the first author, as well as in the doctoral dissertation of the second author. The authors wish to thank Habitaclia for allowing to use both of the datasets analyzed in this paper. The authors tanks to the remainder of the project researchers for their suggestions and help in producing this piece.

References

Bio Intelligence Service; Mudgal, S.; Lyons, L., & Cochen, F. (2013). Energy performance certificates in buildings and their Impact on transaction prices and rents in selected EU Countries. *Bio Intelligence Service* Working Paper. April 2013. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/20130619-energy_performance_certificates_in_buildings.pdf (accessed on 9 June 2018).

Brounen, D., & Kok, N. (2011). On the economics of energy labels in the housing market. *Journal of Environmental Economics and Management, 62*(2), 166-179. doi: https://doi.org/10.1016/j.jeem.2010.11.006

Cerin, P., Hassel, L. G., & Semenova, N. (2014). Energy performance and housing prices. *Sustainable Development, 22*(6), 404-419. doi: https://doi.org/10.1002/sd.1566

Davis, P. T., McCord, J. A., McCord, M., & Haran, M. (2015). Modelling the effect of energy performance certificate rating on property value in the Belfast housing market. *International Journal of Housing Markets and Analysis*, *8*(3), 292-317. doi: https://doi.org/10.1108/IJHMA-09-2014-0035

De Ayala, A., Galarraga, I., & Spadaro, J. V. (2016). The price of energy efficiency in the Spanish housing market. *Energy Policy, 94*, 16-24. doi: https://doi.org/10.1016/j.enpol.2016.03.032

Encinas, F., Marmolejo-Duarte, C., de la Flor, F. S., & Aguirre, C. (2018). Does energy efficiency matter to real estate-consumers? Survey evidence on willingness to pay from a cost-optimal analysis in the context of a developing country. *Energy for Sustainable Development, 45*, 110-123. doi: https://doi.org/10.1016/j.esd.2018.05.008

Fregonara, E., Rolando, D., & Semeraro, P. (2017). Energy Performance Certificates in the Turin real estate market. *Journal of European Real Estate Research, 10*(2), 149-169. doi: https://doi.org/10.1108/JERER-05-2016-0022

Garcia Navarro, J., González Díaz, M. J., & Valdivieso, M. (2014). Estudio PRECOST&E: Evaluación de los costes constructivos y consumos energéticos derivados de la calificación energética en un edificio de viviendas situado en Madrid. *Informes de la Construcción, 66*(535), 1-10. doi: https://doi.org/10.3989/ic.13.052

García-Hooghuis, A., & Neila, F. (2013). Modelos de transposición de las Directivas 2002/91/CE y 2010/31/UE “Energy Performance Building Directive” en los Estados miembros de la UE. Consecuencias e implicaciones. *Informes de la Construcción, 65*(531), 289-300. doi: https://doi.org/10.3989/ic.12.017

Hyland, M., Lyons, R. C., & Lyons, S. (2013). The value of domestic building energy efficiency—evidence from Ireland. *Energy economics, 40*, 943-952. doi: https://doi.org/10.1016/j.eneco.2013.07.020

Marmolejo-Duarte, C., & González, C. (2009). Does noise have a stationary impact on residential values? *Journal of European Real Estate Research, 2*(3), 259-279. doi: https://doi.org/10.1108/17539260910999992

Marmolejo-Duarte, C., & Cerda, J. (2012). La densidad-tiempo: otra perspectiva de análisis de la estructura metropolitana. *Scripta Nova: Revista Electrónica de Geografía y Ciencias Sociales, 16*. doi: http://dx.doi.org/10.1344/sn2012.16.14762

Marmolejo-Duarte, C., & Cerda, J. (2017). El comportamiento espacio-temporal de la población como instrumento de análisis de la estructura urbana: el caso de la Barcelona metropolitana. *Cuadernos Geográficos, 56*(2),111-133. Available on: http://revistaseug.ugr.es/index.php/cuadgeo/article/view/4704/5616 (accessed on 13 May 2018).

Marmolejo-Duarte, C.; Echavarria, C.; Biere, R. (2016) The value of centrality: an analysis for the Metropolitan Barcelona, ACE: Architecture, City and Environment, 11 (32): 95-112 http://dx.doi.org/10.5821/ace.11.32.4834

Marmolejo-Duarte, C. (2016). La incidencia de la calificación energética sobre los valores residenciales: un análisis para el mercado plurifamiliar en Barcelona. *Informes de la Construcción, 68*(543), 156. doi: https://doi.org/10.3989/ic.16.053

Marmolejo-Duarte, C., & Chen, A. (2019a). The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments and Implications for Public Policy and Private Markets. *Sustainability, 11*(2), 372. doi: https://doi.org/10.3390/su11020372

Marmolejo-Duate, C., & Chen, A. (2019b). The impact of EPC rankings on the Spanish residential market:an analysis for Barcelona, Valence and Alicante, *Ciudad y Territorio, Estudios Territoriales*, (LI), 199: 101-118

Marmolejo-Duarte, C., & Bravi, M. (2017). Does the Energy Label (EL) Matter in the Residential Market? A Stated Preference Analysis in Barcelona. *Buildings, 7*(2), 53. doi: https://doi.org/10.3390/buildings7020053

Murphy, L. (2014). The influence of the energy performance certificate: The Dutch case. *Energy Policy, 67*, 664-672. doi: https://doi.org/10.1016/j.enpol.2013.11.054

Olaussen, J.O., Oust, A., & Solstad, J.T. (2017). Energy Performance Certificates—Informing the Informed or the Indifferent? *Energy Policy 111*, 246–254. doi: http://dx.doi.org/10.1016/j.enpol.2017.09.029

Ord, J.K. (1975) Estimation methods for models of spatial interaction. Journal of the American Statistical Association, 70, 120-126. doi: https://doi.org/10.1080/01621459.1975.10480272

Parkinson, A., De Jong, R., Cooke, A., & Guthrie, P. (2013). Energy Performance Certification as a Signal of Workplace Quality. *Energy Policy, 62*, 1493–1505. doi: http://dx.doi.org/10.1016/j.enpol.2013.07.043

Pascuas, R.P., Paoletti, G., & Lollini, R. (2017). Impact and Reliability of EPCs in The Real Estate Market. *Energy Procedia, 140*, 102–114. doi: http://dx.doi.org/10.1016/j.egypro.2017.11.127

Pena Trapero, J. B. & Pena Trapero, X. (1977). *Problemas de la medición del bienestar y conceptos afines: una aplicación al caso español.* Madrid: España: Instituto Nacional de Estadística.

Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition. *Journal of political economy, 82*(1), 34-55. doi: https://doi.org/10.1086/260169

Sander, W. (1992). The effect of women's schooling on fertility. *Economics Letters, 40*(2), 229-233. doi: https://doi.org/10.1016/0165-1765(92)90229-r

Zarzosa-Espina, P. (2009). Estimación de la pobreza en las comunidades autónomas españolas, mediante la distancia DP2 de Pena. *Estudios de economía aplicada, 27*(2), 397-416. Available on: https://dialnet.unirioja.es/servlet/articulo?codigo=3056904 (accessed on 10 January 2019)

PAPER • OPEN ACCESS

How different are dwellings whose energy efficiency impacts price formation?

To cite this article: Ai Chen and Carlos Marmolejo-Duarte 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **603** 042015

IOP Conf. Series: Materials Science and Engineering **603** (2019) 042015 doi:10.1088/1757-899X/603/4/042015

How different are dwellings whose energy efficiency impacts price formation?

Ai Chen[1], Carlos Marmolejo-Duarte[1]

[1]Centre for Land Policy and Valuations, ETSAB, Universitat Politènica de Catalunya, Spain

ai.chen@upc.edu

Abstract. Housing energy-efficiency has become a relevant issue since it is mandatory to exhibit an Energy Performance Certificate (EPC) when transacting real estate in the European Union. A number of studies have focused on energy-efficiency marginal prices using hedonic models from cross-sectional and longitudinal perspectives. Some of them have found that the increase of relevance of EPC ranks (i.e. marginal prices) is not the same for all the A-G classes. This study aims to explore the differences in terms of architectonic and location attributes between the apartments depicting an increase of EPC ranking marginal prices regarding those where energy efficiency seems not to play a role in price formation. In doing so, a pooled spatial error hedonic model is done using selling information for multifamily housing in Barcelona for the years of 2014 and 2016. Furthermore, it is shown which EPC ranks do exhibit an increase in terms of marginal prices in the period studied. Finally, we compare the architectonic and locative attributes for the set of homes where the energy efficiency has increased in terms of price importance to the set of homes where it has not increased. The results suggest that dwellings with high and medium EPC ranks (e.g. A for 2014; and B, C and D for 2016) are more expensive, larger and boasting of better architectonic qualities than the rest of homes where EPC ranks failed to have a role in price formation. On the contrary, the location attributes are different: while A-ranked dwellings of 2014 are located on peripheries where new housing completions are placed; B, C and D-ranked homes of 2016 are located in more centric locations. These findings have implications for future analysis regarding the energy premium and energy poverty, since specific characteristics in different submarkets may have a different impact on housing prices.

1. Introduction

Since the energy consumption in the residential sector has accounted for 25% consumption of the whole world and 40% in Europe, the European Commission promulgated relevant energy directives since early 2000s. In the real estate market, the specific one is the Energy Performance of Buildings Directive. It recast in 2010 made it mandatory to exhibit Energy Performance Certificates (EPCs) when properties are rented or sold. This program aims at promoting the transparency of energy efficiency and breaking down the barriers of energy information asymmetries between buyers and sellers [1]. In Spain the transposition of such Directive has been introduced by the RD 235/2013, so as 1st of June 2013 it is also mandatory to show an EPC label on property advertisement [2].

A number of studies have researched the marginal price for energy efficiency, some of them have found that such energy premium is not the same when the market is segmented. Therefore, the concomitant architectonic and locative attributes contributing to this energy premium deserves special attention. In this regard, this paper aims to explore the differences in terms of architectonic and location attributes between the apartments depicting an increase of EPC ranking marginal prices regarding those where energy efficiency seems not to play a role in price formation. A spatial error hedonic model is applied in Barcelona Metropolitan Area in order to identify those homes where EPC labels produce an increase of price regarding those homes where such attribute plays a null role in price formation. Next, using an ANOVA test the significant attributes between both kind of homes are identified.

The results suggest that energy premiums are reserved for "A"-ranked homes in 2014 and "B,C,D"-ranked homes in 2016. So the first conclusion is that energy premium evolves in a sprawling fashion among high efficient energy classes. Nevertheless, the characteristics of homes which hedonic agenda does includes energy premiums are not the same that the remainder dwellings. Since such homes tend to be more expensive, larger and boast the best architectonic features. Interestingly, "A" ranked homes locate in peripheries where new completions are developed, meanwhile "B", "C" and "D" depict a more central location in neighborhoods of wealthy population. Such findings have relevant implications for market segmentations from energy efficiency perspective.

The remainder of this paper is organized as follows: after a short literature review, first, the scope, case study and models are detailed in the methodology section; followed by the results and discussion; and finally a brief conclusion is provided.

2. Literature review

Energy efficiency in the housing sector has become a concerning issue along with Energy Performance Certificates (EPCs) introduced by Energy Performance of Buildings Directives (EPBD) in 2002. Numerous studies have concluded the EPC impacts on housing prices by hedonic models. Brounen and Kok [3] indicated that there was an energy-efficiency premium of 3.6% with energy ranking increase in the Netherlands. Fuest et al. [4] found in England and Wales, an 11.8% housing premium increased when dwellings improved from ranking G to ranking A. Likewise, Hyland et al. [5] found the green premium was higher when selling in Ireland, rather than renting a house. Bottero and Bravi [6] indicated there was an increase of 26.44 euros per square in housing price along with each energy ranking improvement in Turin. De Ayala et al. [7] suggested that, in Spanish 5 cities, there was a green premium after asking for the opinion value using a survey applied to households. Marmolejo [8] suggested there was a 0.85% increase in housing prices around Metropolitan Barcelona Area (AMB) while in 2019, the premium increased to 1.4% with each energy ranking increase [9]. However, a few studies concluded that the impact of energy efficiency on housing prices was insignificant or even total inverse than what expected [10,11].

Considering the specific characteristics that contributed to price formation, Bourassa [12, 13] suggested the errors from the spatial dependence do matter on housing prices after using different spatial and statistical models in Auckland. Next, Hyland et al. [5] indicated that marginal impacts are different in various temporal submarkets, locations and dwelling typologies (e.g. the numbers of bedrooms) in Ireland. Also, Cerin et al. [14] estimated such marginal prices using the technical units of energy consumption (i.e. KWh/m^2). They pointed out that the dwellings with lower selling prices and older property age made negative contributions to energy saving. Subsequently, Fuerst et al. [4] classified the real estate market in England and Wales by buildings types and found the energy premium varies across these market segments. Olaussen et al. [15] and Jensen et al. [16] also found the marginal price by time-period groups in real estate markets of Oslo and Denmark. Likewise, Marmolejo and Chen [9, 17] found that the accuracy in the determination of such an energy premium is improved when controlling for the metropolitan area were the apartment is located.

In general, numerous studies have pointed out that energy label does matter on housing prices but these impacts on price formation vary widely, based on different real estate market conditions and socio-economic attributes in detail.

3. Methodology and data

3.1. Study Area and Data

This study area is the functional Barcelona Metropolitan Areas (AMB) which is comprised of 164 municipalities and contributes a considerable number of energy-labelled dwellings in Spain. Habitaclia, one of the leading real estate websites in Catalonia, offers a sample of listing prices and characteristics of apartments in AMB. Also, the relevant data are derived from the 2001 Housing and Population Census (HPC), 2013 Cadastral Database, 2001 Mobility Metropolitan Survey. The HPC in 2011 is not reliable at census tract level since it was based in a restricted sample survey.

After depurating, the sample comprises 3,246 apartments for the year 2014, and the same number of apartments in 2016. As a result, the pooled sample is consist of 6,492 apartments. Table 1 exhibits the descriptive statistics of the primary variables organised in conceptual dimensions.

It is clear that an apartment sized with 84 m^2 in 2014 were asking for 162,851 Euros. It also consists of 1.3 bathrooms, 2.9 bedrooms, and its average height of the buildings where it is located is 2.1 stories with an average terrace area of 12 m^2. Regarding the amenities, 4% of apartments have swimming pools, 9% gardens and 46% lift service. The conditioning systems are also presented: 48% of the apartments have air conditioner while 68% central heating system

Concerning indictors of energy efficiency, the average ordinal EPC rank (G=1, A=7) is 2.7. Class “A” comprises only 3% of the sample, far less than Class “E” (49%) and class “G” (21%). It is noted that Class “B” in 2014 is not presented. In terms of the average location, 93% are located in municipalities with access to highway, and 50% are near to a railway station. The average density of population and employment are 21,935 residents/km^2 and 9,511 jobs/km^2 respectively which can be regarded as the proxy variables for the centrality and serviced zones. Also, 1.2% of the apartments have sea access within 200 meters which proxies for environmental quality.

In terms of the socioeconomic level of the zones where the apartments are located, 7% of the neighbouring housing has doorman service as an average and 11% of households hold a university degree. Considering the possibility of collinearity from such variables, a factor analysis has been used including job positions and education level. As a result, there are two principal components: PC1-High Income proxies for high-income job positions/high education level with an average -0.11 scores where the lower its value, the lower the proportion of neighbours in managerial, professional and specialised technical job positions as well as the lower the education level. PC2-Med Income proxies for medium income level, incorporating clerks, service vendors or qualified manufacturing positions.

In 2016, the physical and locational quality of the apartments show superior performance and higher prices. Compared to 2014, the apartments in 2016 are: more expensive, larger, best equipped (*i.e.* air conditioner, heating and lift, swimming pool and garden), more efficient in energy performance terms, and located in centralized and well-connected zones. Since 2014 year is still in the period of real estate crisis in Spain, owners of properties with better qualities and locations are willing to transact them during the economic recovery period for better price quotations. Therefore, it is clear that the characteristics performance of homes in 2016 is better than that in 2014.

Table 1. Descriptive statistics for the 2014 & 2016 depurated sample and selected variables

	2014 Sample (N=3,246)				**2016 Sample (N=3,246)**			
	Min	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**
Architectonic Attributes								
Total price (Euros)	34,000	715,000	162,851	88,957	48,000	830,000	229,507	153,812
Unitary price (Euro/m^2)	845	3,542	1,914	661	602	10,172	2,592	1,295
Area (m^2)	25	234	84	28	20	380	87	32
Number of bathrooms	-	4	1.3	1	-	4	1.4	1
Number of bedrooms	-	15	2.9	1	-	10	2.9	1
Ration bathroom/bedroom	-	2	0.5	0	-	2	0.5	0
Level of the apartment	-	13	2.1	2	-	19	2.2	2
Terrace (m^2)	-	256	9.5	14	-	240	9.5	21
Living room area (m^2)	-	90	12	10	-	102	12	12
Large terrace (Dummy)	0	1	7%		0	1	13%	
Air conditioner (Dummy)	0	1	31%		0	1	48%	
Central heating (Dummy)	0	1	43%		0	1	68%	
Retrofited apartment (Dummy)	0	1	11%		0	1	19%	
Swiming pool (Dummy)	0	1	4%		0	1	11%	
Garden (Dummy)	0	1	9%		0	1	16%	
Lift (Dummy)	0	1	46%		0	1	67%	
Building age	0	104	45	18	0	326	46	25
Energy Performance Class								
Energy class (ordinal)	1	7	2.70		1	7	2.84	
Energy class G (Dummy)	0	1	21%		0	1	19%	
Energy class F (Dummy)	0	1	14%		0	1	13%	
Energy class E (Dummy)	0	1	49%		0	1	50%	
Energy class D (Dummy)	0	1	10%		0	1	11%	
Energy class C (Dummy)	0	1	4%		0	1	3%	
Energy class B (Dummy)	na	na	na	na	0	1	1%	
Energy class A (Dummy)	0	1	2%		0	1	3%	
Accessibility Attributes								
Commuting time (minutes)	12.9	41.0	24.0	4.5	12.9	41.4	24.6	3.9
Highway ramp (Dummy)	0	1	93%	26%	0	1	94%	23%
<800 m from railway station (Dummy)	0	1	50%	50%	0	1	56%	50%
Pop. density (residents/km^2)	11	144,421	21,935	22,700	16	152,596	24,262	23,273
Employment density (jobs/km^2)	5	56,454	9,511	9,738	7	73,563	10,548	10,078
Centrality index	3.5	20.5	11.4	2.4	4.7	20.5	12.0	2.7
Average gross area floor ratio (m^2/m^2)	0.2	6.0	2.0	1.3	0.2	6.0	2.3	1.6
<200m from sea shore (Dummy)	0	1	1.2%		0	1	3.9%	
Socioeconomic Attributes								
Doorman (%)	0%	72%	7%	10%	0%	94%	10%	14%
People with university degree (%)	1%	44%	11%	8%	1%	47%	14%	10%
Managers (%)	1%	34%	8%	4%	1%	32%	10%	5%
Professionals (%)	1%	45%	11%	8%	1%	44%	14%	10%
Technicians (%)	3%	25%	13%	4%	2%	25%	14%	4%
Clerks (%)	3%	21%	11%	3%	3%	21%	11%	3%
Service vendors (%)	3%	29%	15%	3%	5%	33%	15%	4%
Agriculture (%)	0%	8%	1%	1%	0%	10%	1%	1%
Craft & qualified manufacture (%)	2%	39%	17%	6%	1%	37%	15%	7%
Manufacturing (%)	1%	40%	13%	6%	1%	36%	11%	6%
Non qualified jobs (%)	2%	32%	10%	4%	1%	32%	9%	5%
PC1 High income	-2.15	3.86	-0.11	0.81	-2.15	3.76	0.16	1.03
PC2 Med income	-3.14	2.51	-0.24	0.96	-3.14	2.62	0.02	0.93

Notes: Energy class B in 2014 is null after depurating data. Source: Own elaboration.

3.2. Methods

The primary method used is the hedonic model [18]. However, it has been found that apartments' prices do not only respond to their locative and architectonic attributes, but also the price of nearby apartments (*i.e.* spatial dependence). According to Ord [19], the best way to correct the spatial dependence issue is

Spatial Error Model (SEM) where the largest and most significant value of the following Lagrange Multiplier Diagnostics should be used to diagnosis the spatial dependence. In our case, the Lagrange Multiplier (error) approach resulted in the largest value equivalent to 981.38 (sig=0.00). According to the Moran's I, the spatial autocorrelation of error from the OLS model is 0.22 (sig=0.00). The omission of this issue might lead to biased coefficients. For this reason, a pooled spatial error hedonic model has been implemented as the following equation (1):

$$\ln(P) = c + \sum_{i=1}^{n} X_i A_i + XE + \sum_{i=1}^{n} X_i B_i + \sum_{i=1}^{n} X_i L_i + \sum_{i=1}^{n} X_i S_i + c'2016 + XE_{2016} + \varepsilon \quad (1)$$

Being $\varepsilon = \lambda W \varepsilon + u$

Where
P is the asking selling price
X_i is the coefficient for each of the variables expressed as price semi-elasticities
A is a set of apartment's i architectonic attributes
E is the apartment's energy rank derived from EPC
B is a set of i facilities and amenities of the buildings where the apartment is located
L is a set of locative i attributes regarding transport and environmental quality of the site where the apartment is located
S is a set of socioeconomic attributes of the population living around the apartment
2016 is a year dummy variable equal to one if the dwelling comes from the 2016 dataset and zero otherwise
E_{2016} is an interaction term between the E energy rank and the dummy variable 2016. In the absence of an increase of the impact of energy rankings on housing prices the associated coefficient of this variable will appear as statistically insignificant
ε is the error term
λ is the autoregressive coefficient
W is the spatial matrix (in this case calculated following rook contiguity criteria)
u is the uncorrected error term

This approach helps to identify which energy classes for each of the years do produce an impact on property prices, and thus to segment those homes whose price is positively impacted by energy efficiency from these where energy labels play a null role in prince formation. Subsequently, using an ANOVA test it is possible to test significant differences, in terms of architectonic and locative attributes, between the aforementioned segments.

4. Results and discussions

4.1. Pooled estimation of EPC impacts on housing prices

Table 2 contains the results for the best model coming from the calibration of equation 1 in GeoDa. In such a table, it is possible to see that the average increase in terms of asking prices has been 4.1% for the period studied (1st Nov 2014-1st April 2016).

According to the multiplicative-interaction terms built from energy ranks and the Year 2016, the impact of more efficient ranks has increased in a monotonic coherent fashion: 10.7%; 10,6% and 10,5% for ranks "B", "C", and "D" respectively. As a matter of fact, the increment of the impact of ranked "A" apartments is also positive but fails to meet the 90% confidence criteria. On the contrary, energy efficient dwellings in 2014 almost fail to show significant impacts on housing prices, but "A"-ranked homes do matter with an 8.6% increase, compared to "G"-ranked ones.

Overall, these results suggest that in a short period, energy efficiency in Barcelona has gained importance in terms of residential prices. It is worth noting that the dwellings with high and medium

EPC rankings (ranked “A” in 2014 while “B”, “C” and “D” in 2016) have a significant impact on housing price formation.

Table 2. Spatial Error Estimation Results

Spatial Error Model - Maximum Likelihood Estimation			
R Square	0.764	Log-likelihood	-928
Sigma Square	0.075	AIC	1917
S.E of regression	0.274		

	Coefficients			
	B	Std. Error	Z-Value	Prob.
Lambda	0.462	0.016	28.317	-
(Constant)	10.125	0.056	182.398	-
Year 2016	0.041	0.015	2.684	0.007
Structural architectonic characteristics of apartments and buildings				
Area	0.015	0.000	37.546	-
Area^2	- 0.000	0.000	- 19.709	-
Number of bathrooms	0.098	0.008	11.842	-
Air conditioner	0.074	0.008	8.905	-
Central heating	0.041	0.009	4.686	-
Retrofitted apartment	0.034	0.010	3.437	0.001
Swimming pool	0.186	0.015	11.976	-
Lift	0.089	0.008	10.452	-
Inverse of building age	0.238	0.045	5.340	-
Energy performance of apartments				
Energy class A	0.086	0.034	2.492	0.013
Energy class C	- 0.011	0.029	- 0.375	0.708
Energy class D	0.000	0.019	0.020	0.984
Energy class E	0.007	0.013	0.572	0.567
Energy class F	0.019	0.016	1.132	0.258
Energy class A * Year 2016	0.067	0.044	1.515	0.130
Energy class B * Year 2016	0.107	0.041	2.619	0.009
Energy class C * Year 2016	0.106	0.041	2.597	0.009
Energy class D * Year 2016	0.105	0.026	4.071	-
Energy class E * Year 2016	0.008	0.018	0.462	0.644
Energy class F * Year 2016	- 0.033	0.024	- 1.386	0.166
Locative attributes (transport, centrality and amenities)				
Commuting time	0.004	0.001	2.597	0.009
<200m from sea shore	0.131	0.029	4.532	-
Highway ramp	0.081	0.022	3.712	-
<800 m from railway station	0.033	0.011	3.120	0.002
Centrality index	0.025	0.003	8.680	-
Average gross area floor ratio	0.048	0.005	9.029	-
Socio-economic attributes				
PC1 High income	0.104	0.006	17.356	-
PC2 Med income	0.072	0.007	10.979	-

Note: independent variables/covariates are introduced using the stepwise method. Energy class G is the controlled group. ‘–’ indicated the significant is less than 0.000. Variables with grey colour are insignificant at 90% of confidence. Source: Own elaboration.

4.2. How different are the dwellings which energy efficiency gains relevance in price formation?
In order to explore significant differences in terms of achitectonic and locative attributes first the 6,492 aparments are clustered in 4 groups. Group 1 (N = 73) is for the energy-labelled dwellings (ranking A) which impact significantly on housing prices in 2014 while the others are for Group 2 (N = 3,167) where no impact was found in the same year. Dwellings in the 2016 dataset are groupped in the same way, resulting in Group 3 (ranking B, C, D) where EPC ranking was found to have an impact on price formation and Group 4 where no impact was found- Each of such gropus are formed by 485 and 2,718 apartments respectively. Next, an ANOVA test (at 90% confidence level) is implemented among these groups) for each of the architectonic and locative attributes.

4.2.1. The specific characteristic performance in year periods. According to the first column of table 3, in the 2014 dataset all the architectonic attributes (excluded the number of bedrooms) are significantly different between homes clustered in Group 1 and 2. Conversely, in the remainder of accessibility and socioeconomic dimensions just the centrality index, population density and employment show significant differences. The average unit price for an "A"-ranked dwelling with a 90 square meters' size is 2,208 euros per square meter in 2014, 300 euros more per square meter than that in Group 2. Similarly, physical attributes (e.g. number of bathrooms, area of outdoor spaces and living room) and amenities (e.g. air conditioning and heating) are more present in Group 1 where the probability to find a heated dwelling doubles in Group 2 in relation to Group 1. Regarding the accessibility and socioeconomic dimensions, the "A"- ranked dwellings in 2014 are located in metropolitan peripheries where the average centrality index is 10.73, less than the referenced Group 2. The same is true for population and employment densities. All in all, energy-efficient homes in 2014 are basically located at peripheral zones where buildings are constructed under newer construction codes requiring efficient thermal performances.

Table 3. Statistical Description for the groups in 2014 and 2016

Variables	2014				2016			
	Group 1 (N=73)	Group 2 (N=3,167)	ANOVA TEST F	Sig.	Group 3 (N=485)	Group 4 (N=2,718)	ANOVA TEST F	Sig.
Architectonic Attributes								
Total_price	197,784	162,047	11.55	0.001	275,192	221,404	51.58	0.000
Unit_price	2,209	1,908	14.87	0.000	3,029	2,514	67.04	0.000
Superficie	89.84	83.94	3.20	0.074	90.64	86.40	7.37	0.007
No_bedrooms	2.89	2.92	0.06	0.801	2.82	2.89	2.21	0.137
No_bathrooms	1.52	1.29	14.82	0.000	1.50	1.33	38.34	0.000
Dum_air_conditioning	0.67	0.30	47.38	0.000	0.60	0.45	37.82	0.000
Dum_heat	0.92	0.42	75.30	0.000	0.81	0.66	41.27	0.000
Dum_reform	0.30	0.10	30.71	0.000	0.28	0.18	30.19	0.000
Dum_lift	0.86	0.46	48.34	0.000	0.79	0.65	36.59	0.000
Ages of buildings	30.84	45.55	49.25	0.000	40.70	46.45	21.66	0.000
Construction_before 1981	0.51	0.84	57.91	0.000	0.62	0.77	48.44	0.000
Construction_between 1982-2006	0.25	0.12	11.16	0.001	0.21	0.17	4.35	0.037
Construction_after 2007	0.25	0.04	68.77	0.000	0.17	0.06	69.12	0.000
Storied	2.47	2.14	2.82	0.093	2.11	2.19	0.46	0.497
Areas_outdoor	12.60	9.40	3.63	0.057	9.71	9.45	0.06	0.800
Areas_living	15.18	12.11	6.75	0.009	13.19	11.69	6.18	0.013
Dum_grand_terrance	0.18	0.07	13.35	0.000	0.12	0.14	0.48	0.487
Dum_swim_pool	0.08	0.04	3.02	0.082	0.15	0.10	8.03	0.005
Dum_gard	0.27	0.09	30.77	0.000	0.20	0.15	7.17	0.007
Accessibility Attributes								
Time_commuting	24.61	24.00	1.32	0.250	24.57	24.65	0.19	0.666
Dum_sea (in 200 meters)	0.03	0.01	1.49	0.223	0.04	0.04	0.26	0.608
Dum_highway	0.96	0.93	1.18	0.278	0.94	0.94	0.10	0.758
Dum_trans_stations	0.53	0.50	0.36	0.547	0.57	0.56	0.33	0.568
Index_Central	10.73	11.39	5.52	0.019	12.47	11.94	16.39	0.000
Ratio_floor_areas	1.84	1.99	0.87	0.350	2.43	2.33	1.54	0.214
Socioeconomic Attributes								
Proportion of university degree	9.77	10.88	1.49	0.222	15.85	14.21	11.75	0.001
Density of population	16,884	22,051	3.70	0.054	21,623	24,730	7.42	0.006
Density of employment	7,021	9,569	4.89	0.027	9,456	10,742	6.77	0.009
PCA High income	-0.23	-0.11	1.64	0.201	0.32	0.13	13.32	0.000
PCA Med income	-0.22	-0.24	0.03	0.865	0.05	0.01	0.73	0.393
Pr_Manager	7.28	7.90	1.40	0.237	10.26	9.39	10.92	0.001
Pr_professiones	9.95	11.01	1.33	0.249	15.67	14.14	10.55	0.001
Pr_technics	13.31	13.29	0.00	0.974	14.97	14.35	9.60	0.002
Pr_admin	11.14	10.98	0.25	0.614	11.32	11.31	0.01	0.935
Pr_commer	15.20	15.05	0.15	0.702	14.21	14.77	8.48	0.004
Pr_agricultura_fisher	0.67	0.75	0.64	0.425	0.67	0.69	0.33	0.568
Pr_craftman	18.06	17.47	0.62	0.430	13.69	14.82	11.51	0.001
Pr_operation	13.73	13.28	0.38	0.535	10.22	10.88	4.69	0.030
Pr_unquality	10.61	10.17	0.68	0.408	8.89	9.55	8.54	0.004

Notes: Variables with grey colour are insignificant at 90% of confidence. Source: Own elaboration.

In the 2016 dataset for Groups 3 and 4, the same significant differences in the "architectonic attributes dimension" which are found in 2014, are identified but the number of storey, area of outdoor spaces and the presence of large terraces (more than 20 m2). In Group 3, the average unit price in 2016 is 3,029 euros per square meter for a "B", "C" or "D"-ranked dwelling with 91 square meters where the probability of amenities (e.g. air conditioning, heating and lift) is 15% larger than that in group 4. Unlike the result in 2014, almost all the socioeconomic attributes show significant differences between groups. The proportion of households holding a university degree as well as the proportion of high-level positions (e.g. managers, professionals) are higher in Group 3. All in all:

- There is a clear correlation between the impact of EPC rankings on housing prices and the quality of apartments. Namely, those energy-labelled dwellings that have a significant impact on housing prices are more expensive, larger and boast the best architectonic attributes. Homes where EPC rankings have found to be significant on price formation are newer than other, although half of them were constructed before 1981 when non construction code with thermal implications existed in Spain.
- Also, the location of homes where EPC rankings have found to be impacting prices are different for the 2 analysed years. In 2014 A-ranked apartments (Group 1) were located in peripheries, conversely in 2016 "B","C" and "D"-ranked apartments (Group 2) were located in more centric locations. Such different location is reflected in the centrality index as well as urban densities. Differences in locations explain why gardened (i.e. outdoor spaces) and terraced apartments are identified in 2014 as those being impacted by energy efficiency and not in 2016 where more centric locations imply less outdoor areas.
- Finally, the different locational patterns are also reflected in the socioeconomic profile of areas: more central zones are characteised, in the case study, by an important presence of well-educated population holding privilegied job positions, which in turns proxies for large income.

4.2.2 Evolution of characteristics between housing groups where EPC rankings have found to be significant in price formation in 2014 and 2016. As stated the recast EPBD requires that the energy label information to be exhibited in the advertisement of real estate, in Spain such obligation was introduced by the transposition of the Directive in 2013. In order to explore the differences of characteristics in homes where EPC rankings have found to be relevant to the price formation, an ANOVA test has been used. The results are exhibited in table 4.

In 2016, there are 485 homes (Group 3) where EPC rankings play a role in price formation, around seven times than the corresponding cluster (Group 1) in 2014. Such divergence in group size is explained because in 2014 only "A"-ranked homes form Group 1, while in 2016 Group 3 is formed by "B", "C" and "D"-ranked apartments. According to table 4, three variables show significant differences in architectonic attributes between the two groups. The probability to find a heated home decreases from 92% in 2014 to 81% in 2016. Perhaps it is reflecting a correlation between energy class and quality. Also, by the fact that 62% of Group 3 homes was constructed before 1981while in Group 1 only 51% was built before any thermal building regulation came into force. Also, the centrality index which proxies for well-located apartments is larger, and the floor area ratio also increases up to 2.43. Finally, the proportion of households holding a university degree, the population and employment densities and the proportion of professional positions (e.g. managers, professions and technicians) shows a considerably superior performance in 2016. It is noted that in 2016 the proportion of household holding university degrees increases up to 15.85%, which is roughly the double than that in 2014.

- There are more homes with energy rankings playing an important role in housing prices after the mandatory of EPC on advertising in 2013. In other words, a larger number of homes with various energy rankings is introduced in Barcelona Metropolitan market and does matter on housing prices.

- Also, there is a worse performance on architectonic attributes of energy labelled homes related to housing prices. Namely, the qualities of physical features of energy-efficient homes impacting on housing prices are lower along with the evolution of the EPC program. Generally, it is supposed that the correlation between the physical quality of dwellings and the energy ranking is positive. Therefore, it is explicable regarding this "Worse Performance" change, considering more homes with lower energy rankings introduced.
- Finally, energy-efficient homes related to housing prices are located in a central area where the proportion of household holding a university degree and the density of population is higher. It is noted that in 2014, the homes relevant to housing prices are located in a peripheral area although they are labelled as A rank.

Table 4. Statistical Description for the groups in 2014 and 2016

Variables	Group 1 in 2014 (N=73)	Group 3 in 2016 (N=485)	ANOVA	
			F	Sig.
Architectonic Attributes				
Dum_heat	0.92	0.81	5.45	0.020
Ages of buildings	30.84	40.70	8.01	0.005
Construction_before 1981	0.51	0.62	3.26	0.071
Accessibility Attributes				
Index_Central	10.73	12.47	27.86	0.000
Ratio_floor_areas	1.84	2.43	8.01	0.005
Socioeconomic Attributes				
Proportion of university degree	9.77	15.85	24.25	0.000
Density of population	16,884	21,623	2.98	0.085
Density of employment	7,021	9,456	4.21	0.041
PCA High income	-0.23	0.32	18.34	0.000
PCA Med income	-0.22	0.05	5.65	0.018
Pr_Manager	7.28	10.26	19.92	0.000
Pr_professiones	9.95	15.67	22.83	0.000
Pr_technics	13.31	14.97	11.19	0.001
Pr_commer	15.20	14.21	3.86	0.050
Pr_craftman	18.06	13.69	27.99	0.000
Pr_operation	13.73	10.22	19.16	0.000
Pr_unquality	10.61	8.89	8.80	0.003

Notes: Variables with grey colour are insignificant at 90% of confidence. Source: Own elaboration.

5. Conclusions

Housing energy-efficiency has become a relevant issue in the Spanish residential sector since in 2013 it was made mandatory to exhibit a label coming from an energy performance certificate (EPC) when transacting real estate. As stated, many studies have identified the impact of such EPC labels on housing prices. However, few studies focus on the differences of homes where the EPC rankings are found to be important in price formation in relation to those which energy performance plays a null role. This paper, using a spatial error hedonic approach, explores this issue using listing prices for apartments located at Metropolitan Barcelona.

Results suggest that A-labelled homes do impact on housing prices in 2014, while B/C/D-labelled ones in 2016. In average, an energy performance improvement from G class to A class brings in a growth 8.6% of housing prices in 2014, and an increase of 10.6% from class G to class B in 2016. After comparing with the specific characteristics for homes related to energy premium, we find that more homes with various energy rankings are introduced in real estate market and they are located in more central areas in 2016, instead of peripheral area in 2014. It is noted that the physical features show worse performances in 2016 since more ancient dwellings are present in the B/C/D Group.

These findings have implications for future analysis regarding energy premium and energy poverty, since specific characteristics in different submarkets may have a different impact on housing prices.

Acknowledgements
This work is funded by EnerValor project grant BIA 2015-63606-R (MINECO/FEDER) and developed within the thesis of the first author.

References
[1] F. Encinas, C. Marmolejo-Duarte, F. S. de la Flor, and C. Aguirre, "Does energy efficiency matter to real estate-consumers? Survey evidence on willingness to pay from a cost-optimal analysis in the context of a developing country," *Energy for Sustainable Development*, vol. 45, pp. 110-123, 2018.
[2] C. Marmolejo-Duarte, and M. Bravi, "Does the Energy Label (EL) Matter in the Residential Market? A Stated Preference Analysis in Barcelona," *Buildings*, vol. 7, pp. 53, 2017.
[3] D. Brounen, and N. Kok, "On the Economics of Energy Labelling in The Housing Market," J. Environ. Econ. Manag., vol. 62, pp. 166–179, 2011.
[4] F. Fuerst, and P. McAllister, "The Impact of Energy Performance Certificates on The Rental and Capital Values of Commercial Property Assets," Energy Policy, vol. 39, pp. 6608–6614, 2011.
[5] M. Hyland, R. Lyons, and S. Lyons, "The Value of Domestic Building Energy Efficiency: Evidence from Ireland," Energy Econ., vol. 40, pp. 943–952, 2013.
[6] M. Bottero, and M. Bravi, "Valutaziones dei benefici conessi al riasparmio energetico degli edifice: un approccio econométrico," Ambiente e Sicurezza, pp. 15–24, 2014.
[7] A. De Ayala, I. Galarraga, and J. V. Spadaro, "The price of energy efficiency in the Spanish housing market," Energy Policy, vol. 94, pp. 16–24, 2016.
[8] C. Marmolejo-Duarte, "La incidencia de la calificación energética sobre los valores residenciales: un análisis para el mercado plurifamiliar en Barcelona," Inf Constr., vol. 68, pp. 156–168, 2016.
[9] C. Marmolejo-Duarte, and A. Chen, "The Uneven Price Impact of Energy Efficiency Ratings on Housing Segments. Implications for Public Policy and Private Markets," Sustainability, vol. 11, pp. 372–395, 2019.
[10] Bio Intellingent Service, S. Mudgal, L. Lyons, and F. Cochen, "Energy Performance Certificates in Buildings and Their Impact on Transaction Prices and Rents in Selected EU Countries," *Bio Intelligence Service Working Paper*, April 2013.
[11] E. Fregonara, D. Rolando, and P. Semeraro, "Energy Performance Certificates in the Turin real estate market," *Journal of European Real Estate Research,* vol. 10, pp. 149–169, 2017.
[12] S. C. Bourassa, M. Hoesli, and V. S. Peng, "Do housing submarkets really matter?" *Journal of Housing Economics*, vol. 12, pp. 12-28, 2003.
[13] S. C. Bourassa, E. Cantoni, and M. Hoesli, "Spatial dependence, housing submarkets, and house price prediction," *The Journal of Real Estate Finance and Economics*, vol. 35, pp. 143-160, 2007.
[14] P. Cerin, L. G. Hassel, and N. Semenova, " Energy performance and housing prices," *Sustainable Development*, vol. 22, pp. 404-419, 2014.
[15] J. O. Olaussen, A. Oust, and J. T. Solstad, "Energy performance certificates–Informing the informed or the indifferent?" *Energy Policy*, vol. 111, pp. 246–254, 2017.
[16] O. M. Jensen, A. R. Hansen, and J. Kragh, "Market response to the public display of energy performance rating at property sales," *Energy Policy*, vol. 93, pp. 229-235, 2016.
[17] C. Marmolejo-Duarte, and A. Chen, "La incidencia de las etiquetas energéticas EPC en el mercado plurifamiliar español: un análisis para Barcelona, Valencia y Alicante," *Ciudad y Territorio Estudios Territoriales (in press)* vol. 199, 2019.
[18] S. Rosen, "Hedonic prices and implicit markets: product differentiation in pure competition," *Journal of Political Economy*, vol. 82, pp. 34-55, 1974.
[19] K. Ord, "Estimation methods for models of spatial interaction," *Journal of the American Statistical Association*, vol. 70, pp. 120-126, 1975.

TECHNICAL TRANSACTIONS 7/2018
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.18.097.8792
submIssIOn Of The fInal versIOn: 28/06/2018

Ai Chen (ai.chen@upc.edu)
Carlos Marmolejo-Duarte (upc.carlos.marmolejo@gmail.com)
Centre for Land Policy and Valuations, Barcelona School of Architecture (ETSAB), Polytechnic University of Catalonia

Is the energy price premium spatially aggregated? a listing price analysis of the residential market in Barcelona

Czy ceny za energoszczędność są jednolicie rozłożone przestrzennie? analiza cen rynku mieszkaniowego w Barcelonie

Abstract

building energy efficiency has aroused much discussion around the world. energy Performance Certificates (ePCs) and relevant regulations and legislation have been established and enforced in the past 15 years due to the extreme 40% consumption of total energy and 38% of total CO_2 emissions caused by residential buildings in europe. This paper aims to confirm the energy premium in the metropolitan area of barcelona (amb) and the presence of spatial homogeneity of this energy premium with Ols hedonic prices and the GWr model. The results suggest that the energy premium causes a 12.2% housing price increase from Class G to Class a, or an implicit housing price rise of 1.9% with every ranking of ePC ordinal scale improvement. furthermore, the areas with a higher incidence of energy labelling are situated in the middle and north-eastern parts of amb that are inhabited by skilled professionals who more commonly have a higher university education.

Keywords: Energy Performance Certificates (EPCs), housing price, spatial aggregation

ATTENTION¡¡

Pages 442 to 456 of the thesis, containing the article mentioned above, are available at the editor's web

http://www.ejournals.eu/Czasopismo-Techniczne/Volume-7/art/12139/