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Environmental Technology & International Affairs

Capitalising Energy Efficiency in Housing Markets: an Investigation into the Impact of Energy Performance Certificates (EPCs) on Transaction Prices in Selected European Countries

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 16.06.2016

Affidavit

I, **INDIRA DE GRAAF**, hereby declare

1. that I am the sole author of the present Master's Thesis, "CAPITALISING ENERGY EFFICIENCY IN HOUSING MARKETS: AN INVESTIGATION INTO THE IMPACT OF ENERGY PERFORMANCE CERTIFICATES (EPCS) ON TRANSACTION PRICES IN SELECTED EUROPEAN COUNTRIES", 72 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

This thesis investigates the current level of capitalisation of energy efficiency in housing markets in 12 European countries. Capitalisation is represented by the presence and magnitude of a price surplus in sales or rental transactions. The hedonic analysis method was used to estimate surpluses for each of the markets, with the energy performance rating given in Energy Performance Certificates (EPCs) being used as a proxy for energy efficiency. Two models were constructed: one characterising energy performance using a simple continuous variable and the other constructing a set of dummy variables for energy performance letter-ratings. The former gives an average surplus across the EPC scale and the latter allows for an analysis of how surpluses vary across the EPC scale. For the majority of analysed markets, statistically significant surpluses were observed across the scale. In addition, it was observed that surpluses were greater in the sales markets than in the rental markets, confirming the 'split incentive dilemma'. Statistically significant deficits were observed for the rental and sales markets in the Netherlands, as well as for the German rental market under the old EPC scheme. These unexpected results are likely caused by omitted variable bias, given the discrepancy between them and the other results in this thesis, as well as in the literature.

The results demonstrate the fact that energy efficiency is currently incorporated into decision-making in the housing markets of the analysed countries. However, detailed analysis into the factors influencing surpluses would require more extensive datasets with quality and location variables. Such improvements would decrease the impact of omitted variable bias. In addition, it is recommended that regular hedonic analyses are carried out in order to evaluate the success of the EPC scheme in European countries in the future.

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1 Introduction

1.1 Aim of the study

The primary aim of this thesis is to assess whether energy efficiency is capitalised in the housing market of selected European countries. The affirmative case would result in a price surplus due to energy efficiency for sales and rental transactions. The energy efficiency rating given in Energy Performance Certificates (EPCs) is used as a proxy for the energy efficiency of a dwelling. This enables a hedonic analysis to be carried out to estimate the willingness-to-pay for energy efficiency.

The motivation for this investigation resides in the potential to tackle the energy and climate challenges of the 21st century through the optimisation of energy efficiency in buildings. In particular, minimising the energy consumption of the building stock is a key policy goal of the European Union. A key indicator of the success of policies in this field is the level of capitalisation of energy efficiency in the market. As a result, a regular assessment of price surpluses due to energy efficiency should be incorporated as a fundamental component of EU policy evaluations.

Whilst similar analyses have been carried out for a limited number of EU member states, data limitations have so far prevented a comprehensive study. Data availability in this field is continually improving due to the increasing levels of implementation of the EU Energy Performance in Buildings Directive (EPBD), which requires EPCs to be advertised for rental and sales transactions. However, data limitations remain and a full study of the level of energy efficiency capitalisation in all EU and EEA member states is not yet possible. Despite this drawback, this thesis will outline a method for the assessment of price surpluses due to energy efficiency, which will be carried out on 12 countries. This will provide the foundation for future investigations that can be performed periodically to assess changes in the level of capitalisation of energy efficiency, thereby providing information that can be used to assess the success of policies in the field, such as the success of energy performance certification.

The following section will provide a more detailed background into the potential benefits that can be derived from the optimisation of the energy efficiency of residential buildings. It will also provide an overview of current EU policy in this field, with a focus on the role and requirements of EPCs.

1.2 Background

Buildings account for 40% of energy consumption in the EU, making the building sector the single largest contributing sector (European Commission 2016). This number is rising, with energy consumption having increased from approximately 400 Mtoe to 450 Mtoe in the last 20 years (BPIE 2011). As a result, improving the energy efficiency of buildings is seen as a key area in which EU and EEA member states can reach their emissions and energy consumption targets. The EU has committed itself to the following targets by 2030 (European Commission 2016b):

- 40% reduction in greenhouse gases, relative to 1990 levels
- Minimum of 27% share of renewable energy consumption
- Minimum of 27% energy savings, relative to business-as-usual projections

EEA Member States that are not members of the EU have committed themselves to similar climate and energy targets. For example, Norway adopted the EU's 40% emissions reduction target in advance of the Paris Conference in December 2015 (Norway Mission to the EU 2015).

Despite the currently increasing trend in energy consumption in buildings, the sector has been identified as having the highest cost-effective potential for energy savings by 2020 (European Commission 2006). This finding was supported on a global scale, with the review of 80 studies in the IPCC's Fourth Assessment Report concluding that 29% of projected emission by 2020 could be reduced cost-effectively in the residential and commercial building sectors, making it the sector with the highest potential in the IPCC report (Levine et al. 2007).

Transitioning towards low carbon fuels and managing emissions are two options that could be pursued as ways of meeting the first two EU targets without the need to alter energy consumption. However, emphasis has been placed on energy efficiency in the building sector as it *"encompasses the most diverse, largest and most cost-effective mitigation opportunities in buildings"* (Levine et al. 2007). This is in part due to the fact that the housing sector - unlike other energy intensive sectors - is dominated by second-hand, inefficient goods, which therefore have a high potential for efficiency improvements.

This thesis will focus exclusively on energy consumption in the *residential* building sector. The primary reason for this focus is the fact that residential buildings account for 75% of the EU building stock (BPIE 2011). As a result, residential buildings alone make up 27% of total energy consumption (BPIE 2011). Furthermore, policy regimes that target residential buildings have a number of wide-reaching potential benefits in addition to the fulfilment of energy and climate goals, including a *"blend of direct and indirect and monetary and non-monetary benefits"* (Fuerst et al. 2015, 147) to home dwellers. Primarily, if the negative externality of poor energy performance were to be fully accounted for in the market, home-dwellers would have real incentives to consider energy efficiency in transaction decisions. Such a market transformation can be equivalently conceptualised as the full capitalisation of the benefits of energy efficiency in the market. The key benefit of this transformation taking place in the residential market is that a larger proportion of the population is involved in decision-making in this sector than in the non-residential sector. As a result, additional benefits that could arise from an increased awareness in the importance of energy efficiency are likely to be further reaching in policies that target the residential sector. However, a potential negative consequence of energy efficiency capitalisation is the fact that it could prevent those in energy poverty from living in energy efficient dwellings, as energy efficiency becomes increasingly correlated with price.

In addition, this thesis will focus on the existing housing stock, rather than policies aimed at increasing the efficiency of new buildings. This is, again, primarily due to the fact that this is the area that offers that highest potential for savings due to increased energy efficiency. The IPCC's Fourth Assessment Report identified that the highest potential for emissions savings by 2030 resided in the retrofitting of existing buildings and replacement of energy-intensive equipment (Levine et al. 2007). This high potential is a direct result of the previously discussed irregular nature of the housing market, whereby houses have a relatively long lifetime as compared with assets and goods in other markets. Indeed, it is estimated that between 75-90% of the current building stock will still be standing in 2050 (European Commission DG Energy 2015). Policies focussing primarily on new buildings are therefore insufficient as they do not account for the low turnover in the housing stock.

A number of market barriers have been identified that account for the current lack of energy consumption optimisation in the residential building sector. In addition to financial, institutional and administrative barriers, a key obstacle to the capitalisation of energy efficiency in the housing market is imperfect information (IEA 2010). This market barrier primarily relates to a lack of available information regarding the most cost-effective changes that can be made to improve the energy efficiency of a dwelling. In addition, when the information is made available it is sometimes not well-understood. Furthermore, it has been observed that the impact of imperfect information is increased in an environment of rapidly developing systems; as it can be difficult for experts to keep track of the best available technologies (IEA 2010).

The two main EU policy frameworks that target energy efficiency in buildings are the recast of the Energy Performance of Buildings Directive (EPBD)[1] (2010/31/EU) and the Energy Efficiency Directive (2012/27/EU). The former is a recast of the original EPBD (2002/91/EC), which is included in the EEA agreement, and hence all EEA member states are required to transpose and implement it. The three main requirements of the EPBD are the setting of building performance standards, the application of an energy performance certificates (EPCs) scheme for buildings, and the need for all new buildings to be ‘nearly zero energy buildings’ (NZEBs). The deadline for most of the requirements was 2013; however, member states have until the end of the decade to fully implement NZEB requirements (European Commission DG Energy 2015).

The requirement to implement an EPC scheme is the most important policy in relation to market transformation, as it applies to existing buildings as well as new buildings and seeks to directly tackle imperfect information in the market. If the latter aim were successfully fulfilled, it is likely that retrofitting improvements that exceed minimum regulations would be observed, due to corresponding financial rewards.

Due to the principle of subsidiarity, member states have the freedom to develop their own measurement systems, accreditation requirements and EPC layouts, provided they comply with the EU framework policy outlined in the EPBD, as well as the minimum methodology requirements given in Annex 1 to the Directive. The main information requirements for EPCs include the presentation of an energy performance index and expert recommendations for cost-effective home improvements that could be made to improve the energy performance rating of the building. It is also required that the energy performance index includes reference values so that buildings can be compared (European Union 2010). In practice, this has led to most countries developing a letter-based rating scale that is defined either by fixed-values of energy consumption or according to reference buildings. In addition, the calculation methodology must be harmonised on a national level.

The EPC framework policy was strengthened in the 2010 EPBD, with the requirement to publish energy performance indicators at the point of advertising dwellings for sales or rental transactions. This was an improvement on the 2002 EPBD, as it had been observed that EPCs were often presented at the point of transaction, when the decision

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[1] Unless otherwise stated, all future references to ‘EPBD’ relate to the 2010 recast of the Directive

to buy or rent a dwelling had already been made (Bio Intelligence Service et al. 2013). Such a scenario does not support market transformation as EPCs are not factored into decisions and therefore cannot be capitalised in the market. In addition, quality assurance mechanisms were strengthened in the 2010 EPBD recast, with the requirement to implement an independent control mechanism as well as a random checking system (Bio Intelligence Service et al. 2013).

1.3 Outline of the investigation

The research questions and methodology for the study is outlined in the following chapter. This chapter also includes an overview of the data collection as well as a review of existing literature in the field. This will be followed by the results chapter, which presents the research outcomes of the study and is divided into sub-chapters for each country. The subsequent discussion chapter aims to synthesise findings from different country analyses and is followed by a conclusions and recommendations chapter, which outlines areas for future research and policy action.

2 Research questions and methodology

2.1 Research questions and hypotheses

Taking into account the current state of the art, this study will seek to answer the following research question for each of the countries under assessment:

> Does a statistically significant price surplus due to EPC ratings exist in the selected housing markets?
>
> a. What is the impact on sales prices
> b. What is the impact on rental prices

The results of this research question will provide an indication for the extent to which energy efficiency is capitalised in the assessed housing markets. In addition, it will give an indication of the success of the EPC scheme. However, the lack of similar hedonic analyses that predate the EPC scheme prevent the possibility of controlling for natural surplus levels. As a result, it is not currently possible to assess the extent to which observed surpluses are purely the result of the EPC scheme itself. Such an assessment can be made in future investigations, if the same methodology is used periodically with new EPC data.

Taking existing literature account, the following hypotheses are made:

> *H_0 (null hypothesis):* No surplus due to EPC rating is observed
>
> *H_1 (alternative hypothesis):* A surplus due to EPC is observed. For EPCs that use a letter-rating scale, surpluses are present between each adjacent letter shift.

Sub-research questions a, b:

> *H_0:* No clear relationship exists between the sales and rental surpluses
>
> *H_1:* Surpluses in rental prices are lower than surpluses in sales prices

The alternative hypothesis will be tested in each case using a 95% confidence interval, with the null hypothesis being rejected in cases where the alternative hypothesis is confirmed.

In addition to the second, comparative hypothesis for rental and sales surpluses, the literature suggests that surpluses in both cases are unlikely to exceed 10% of average dwelling prices.

Price surpluses due to the size and age of dwellings are not included in the central research questions. However, the literature suggests that a positive surplus due to size is expected. The presence of a surplus due to age is contested due to the trade-off between quality- and aesthetic-characteristics (Fuerst et al. 2015).

2.2 Methodology

This study will follow the hedonic method, which is ubiquitous in the literature in this field. The key benefit of this method is that it allows for the contributions of dependent variables on the independent variable to be separated and identified. The functional relationship between the dependent variables and the independent variable is not fixed. The resulting general form of the equation is given in equation (1)

$$\mathrm{Y} = \mathrm{f}(\mathbf{X}) + \varepsilon \tag{1}$$

Where Y is the independent variable, **X** is a set of dependent variables and ε is an error term that is assumed to be uncorrelated with **X** and normally distributed about zero: $\varepsilon \sim \mathrm{N}(0, \sigma^2)$

In market analysis, this method is often used to identify the contribution of different factors and characteristics to the overall price of a good or service. Equation (2) gives the further specification of the hedonic model in this case.

$$\mathrm{P} = \mathrm{f}(\mathbf{X}) + \varepsilon \tag{2}$$

Where P now represents price and **X** is a set of characteristics of the good or service.

Many hedonic studies specify a linear model. This assumption greatly simplifies the analytical process as it allows for contributions to be estimated using the multiple regression technique. In the case of the housing market, the linear assumption has been shown to be valid, leading to a number of studies that use regression analysis to decompose house prices**.**

Adopting a linear functional form, equation (3) gives a further specification of the relationship between the price and characteristics of a good or service.

$$\mathrm{P} = \alpha + \sum_{j=1}^{N} \beta_j \mathrm{X}_j + \varepsilon \tag{3}$$

Where α is a constant and β_j are the coefficients relating to independent variables, X_j.

Contributions to the overall price are determined through the estimation of the β_j coefficients, which are chosen to minimise the sum of squared errors between a dataset and the linear model.

For the case of the housing market, possible independent variables include age, size, quality, location and energy performance. Some of these variables, such as age and size are quantitative and can be analysed using continuous variables in a simple linear function as specified above. However, for quality characteristics and other qualitative factors, it is often necessary to create dummy variables, which are equal to one if the characteristic is present and zero otherwise.

The independent variables can therefore be separated, as is shown in equation (4).

$$P = \alpha + \sum_{j=1}^{N} \beta_j X_j + \sum_{k=1}^{M} \gamma_k \delta_k + \varepsilon \quad (4)$$

Where X_j are continuous variables and δ_k (with corresponding coefficients, γ_k) are dummy variables.

In cases where a qualitative variable has multiple categories, separate dummy variables have to be created. The coefficient of each of these variables represents the deviation of the intercept relative to a reference situation. It is necessary to omit one category from the set of dummy variables, which is then taken to define this reference, or 'hold-out', value.

The literature is divided as to whether to use a continuous variable or a set of dummy variables for the EPC rating of a dwelling. The letter-rating system allows for it to be categorised as a qualitative variable (Fuerst et al. 2015)**.** However, it is also valid to create a continuous variable by converting the letter-scale into a number-scale (Bio Intelligence Service et al. 2013). The disadvantage of the latter method is that it assumes that the *ceteris paribus* relationship between price and EPC rating is linear. In other words, this method assumes that the difference in marginal price between a G- and an F-rated dwelling is the same as the difference between a B- and an A-rated dwelling. This method is valid in establishing whether a clear relationship exists across the scale but gives no information as to how marginal surpluses differ across it. The dummy variable method is therefore favoured in this study, as it provides an additional insight into the different surpluses that may result from a shift between different letters on the scale.

Most of the datasets provide data for the following three categories:

- Year of construction (age variable)
- Area/number of rooms (size variable)
- EPC rating (energy efficiency variable)

The research questions will focus on the results relating to the third category; however, it has been stated that the first two categories are "essential controls for any residential hedonic price modelling" (Fuerst et al. 2016)

Equation (5) is constructed in a linear form in order to estimate the contribution of each of these variables.

$$P = \alpha + \beta_1 AGE + \beta_2 SIZE + \gamma_1(EPC1) + \gamma_2(EPC2) + \cdots + \gamma_n(EPCn) + \varepsilon \quad (5)$$

Where AGE and $SIZE$ are continuous variables and $(EPCi)$ are dummy variables. The number of letter-categories in the EPC scale varies between countries and hence so do number of dummy variables. Without loss of generality, the D category is left out from the set of dummy variables in each case, representing the reference, or 'hold-out', category.

Some studies use a semilog model, whereby the price is replaced by its natural logarithm as the dependent variable. The main advantage of this method is that it allows relative price surpluses to be estimated as percentage values. However, the linear price model given above was generally found to be a better fit for the datasets in this study. As a result, the semilog model is not used.

A simple linear model using a continuous variable for the EPC rating is also used in cases when the EPC includes a number rating for energy performance, or when it is necessary to estimate the average surplus across the scale. Furthermore, this method enables the estimation of percentage surpluses, which aids comparability with the literature. This model is specified in equation (6).

$$P = \alpha + \beta_1 AGE + \beta_2 SIZE + \beta_3 EPC + \varepsilon \quad (6)$$

Where EPC is now a continuous variable.

2.3 Data

The following countries were chosen for analysis in this study:

- Austria
- Belgium
- Czech Republic
- Denmark
- France
- Germany
- Italy
- Luxembourg
- The Netherlands
- Norway
- Slovakia
- Spain
- Sweden
- United Kingdom

The countries were selected on the basis of partnerships that currently exist between the Energy Economics Group, Vienna University of Technology and other European research groups in the EU project ZEBRA2020[2].

Data on the characteristics of dwellings in these countries (including EPC ratings) was collected from estate agency websites, which can be found in appendix 1. This downloading process is currently set to run every six months. This will provide the opportunity to extend the scope of the current study to include a temporal component. Data was collected for both sales and rental transactions in each country. In addition to EPC ratings and advertised prices, the useable area was collected for each dwelling and in most cases the construction year.

The use of data on advertised-, rather than final transaction-, prices could lead to overestimations in this data field. This is due to the fact that negotiations often drive down transaction prices. Information relating to cases where EPCs are used directly during such negotiations will not be captured by our analysis

Once the data had been collected, it had to be sorted. This process is important to ensure that false data entries are removed from the dataset. These entries can be the result of inputting errors at the data entry level, as well as incorrect categorisation at

[2] www.zebra2020.eu (accessed: 27/05/16)

this level and at the data collection level. This can lead to offices and apartment blocks being categorised as single-family dwellings. Some false entries also arise from formatting errors in the spreadsheets. In order to identify probable false entry points, cut-off values were established for each data category.

Two of the selected countries (Belgium and Italy) were excluded from the main body of this study due to insufficient data quality. Results from these countries can be found in appendix 2.

2.4 Literature review

A growing number of studies have emerged that investigate the extent to which EPCs have been successfully implemented in EU Member States. In particular, these studies investigate the level of public understanding and awareness of EPC labels, the extent to which EPCs have been taken into consideration in transactions and home improvements, and the effect that EPCs have had on property prices. This adds to existing literature on the market effects of other energy performance labels that have been developed for commercial and residential buildings. These include the Green Market Certificate (GMC) in Singapore and ENERGY STAR® in the United States, both of which differ from the EPC system in that a minimum green standard must be met in order for a label to be awarded.

This section of the literature review will proceed as follows. First the literature that specifically investigates price surpluses due to EPC ratings in EU countries will be examined, as this relates directly to the current investigation. The most important studies in this field represent the body of work that the results of this thesis will contribute to directly and will therefore be elaborated in detail. Key findings of similar studies that investigate price surpluses due to other, non-EU labelling systems will then be evaluated, followed by a review of the research that has been carried out on the success on EPC implementation through survey analysis. The latter section aims to contextualise the quantitative studies on the level of market capitalisations of EPCs. Finally, the split-incentive dilemma will be summarised, including an evaluation of its observed impact on the capitalisation of energy efficiency.

Almost all of the studies that estimate price surpluses due to energy efficiency ratings use a form of Rosen's hedonic method. The basic model assumes that goods can be differentiated by the number of attributes they contain. In a purely competitive market, the price of this good at market equilibrium then represents a combination of supply and demand side attributes. Such a formulation allows for the value of unobserved attributes to be estimated (Rosen 1974). The benefits and limitations of different formulations of the hedonic method will be discussed in the methodology chapter.

One of the earliest quantitative studies into the market impact of EPCs was carried out by Brounen and Kok (Brounen and Kok 2011). The study focussed on the Netherlands and investigated both the level of implementation of the EPC scheme and the resulting price surpluses, which were estimated using the hedonic method. Whilst the level of implementation was observed not only to be low, but also to be declining, the authors calculated statistically significant price surpluses for EPC ratings. The Netherlands national EPC rating system uses an A-G scale, where A is the most efficient and G is the least. Compared with a D rating, the study found price surpluses of 10%, 5.5% and 2.0% for the sales prices of homes with A, B and C ratings respectively. In addition, the study calculated relative sales price deficits of 0.5%, 2.5% and 5% for E, F and G rated homes. This positive relationship between house price and EPC rating demonstrated an early indication that energy efficiency was being capitalised in housing transactions where EPC labels were present.

A joint research group from the University of Cambridge and the University of Reading have carried out two studies that investigate price surpluses due to EPC ratings in the UK. The first study uses data from England (Fuerst et al. 2015) and the second from Wales (Fuerst et al. 2016). Both used a semi-log hedonic model that allowed for average relative surpluses to be calculated as percentages. In addition, data of dwellings with repeat sales were obtained and used to control for factors specific to individual dwellings. In England, statistically significant surpluses of 5% and 1.8% were found for sales prices for A/B and C ratings respectively, when compared with D ratings. In addition, deficits of 0.7% and 0.9% were found for E and F ratings. In Wales, relative again to dwellings with D ratings, surpluses of 11.3% and 2.1% were found for sales prices for A/B and C ratings respectively and deficits of 2.1%, 4.7% and 7.2% were found for sales prices for E, F and G ratings. Whilst these two studies appear to suggest that sales prices in Wales have been more greatly affected by the introduction of EPCs, the authors warn that this effect may be largely down to the lower average house prices in Wales. This finding demonstrates the potential limitations of presenting surpluses in relative terms, as the added value of energy efficiency improvements may be an absolute quantity.

The EU Commission DG Energy published a report in 2013 on price surpluses resulting from EPCs (Bio Intelligence Service et al. 2013). This study was one of the first to analyse price surpluses for multiple EU countries in a single investigation. Furthermore, the study was able to make estimations of rental surpluses in Austria, Belgium and Ireland and therefore to compare rental and sales surpluses in these countries. In all three countries, the rental surplus was found to be smaller than the sales surplus, which provides empirical confirmation of the well-documented split incentive problem, which will be further elaborated below. The study used a hedonic method; however, it made the assumption that the increase in the price surplus due to a one-letter improvement remained constant across the EPC scale and hence did not estimate the different surpluses resulting from improvements between different letters (e.g. from G to F vs. from B to A). Whilst this represents a simplification, as most quantitative studies have confirmed the fact that the relationship between rating and price surplus is "not expected to be uniform" (Fuerst et al. 2016, 29), the method is valid in giving an average indication of surpluses in each country. The numerical results obtained are summarised in Table 1.

Table 1: Property price surpluses due to EPC ratings, summary of results from the Bio Intelligence Service Study (Bio Intelligence Service et al. 2013)

Country (region)	Sales surplus for one-letter improvement (%)	Rentals surplus for one-letter improvement (%)
Austria (Vienna)	10 - 11	4.4
Austria (Lower Austria)	5 - 6	4.4
Belgium (Flanders)	4.3	3.2
Belgium (Wallonia)	5.4	1.5
Belgium (Brussels)	2.9	2.2
France (Marseille)	4.3	-
France (Lille)	3.2	-
Ireland	2.8	1.4
UK (Oxford)	-4	-

Inter-country comparisons are made by the authors; however this should be done with caution. This is because the differences between EPC mechanisms and housing markets in each of the countries may greatly impact the magnitude of surpluses.

The most surprising result from the study is the deficit recorded for Oxford, UK. However, the authors stress that care must be taken with the interpretation of this result, since the sample size was limited and a key explanatory variable, age, was omitted in the data set. The latter is likely to have led to a bias in results, as the age of a dwelling is often correlated with its energy efficiency rating. As a result, Franz Fuerst et al. state that *"two attributes that are essential controls for any residential hedonic price modelling are size… and age"* (Fuerst et al. 2016).

Another study carried out in 2013 investigated sales and rentals surpluses in Ireland due to EPC ratings (Hyland et al. 2013). This study confirmed the findings of the EU Commission study of greater surpluses for sales than for rental transactions. It is difficult, however, to compare the quantitative results as the EU Commission study gives surpluses in absolute percentages, whereas this study uses relative percentages compared with a dwelling with a D rating. This serves to demonstrate a difficulty in interpreting and comparing quantitative results in existing literature

The above studies represent the most prominent work published on the quantitative impact of EPC ratings on house prices. Whilst other investigations have also been made into the impact that energy efficiency has on selected EU housing markets (de Ayala et al. 2016) (Cajias and Piazolo 2013), these do not use EPC data as a proxy for energy efficiency attributes and hence are not directly comparable to our research. In addition, many studies have carried out the same hedonic analysis of EPCs in the commercial buildings market (Fuerst and McAllister 2011) (Kok and Jennen 2012). These generally also find a positive relationship between EPC rating and price surplus; however, caution must be taken when using these findings as an evidence-base for predictions in the housing market. It is beyond the scope of the current analysis to control for the differences between the two markets, as well as the differences in legislations for the two buildings types under the EPBD. As a result, a detailed literature review in this area is not included.

The existing literature clearly finds a positive relationship between EPC ratings and price surpluses in the housing market. All of the findings presented above are statistically significant and have been subjected to robustness checks. However, it is instructive to compare these findings to those of similar studies carried out into the effect of non-EU energy rating schemes on housing prices. This comparison acts as a control against other factors that may be causing a positive relationship between house price and EPC rating. If the other studies confirm the positive relationship between the two attributes, greater confidence can be attributed to the assertion that it is the label itself that is causing observed market changes. The key findings from a selection of these studies are presented in Table 2.

Table 2: Summary of key findings for hedonic studies on the impact of non-EU energy efficiency labels on housing prices

Reference	Focus country/region	Energy efficiency labelling scheme	Key findings
(Addae-Dapaah and Chieh 2011)	Singapore	Green Mark Certification (4 levels: GMC (lowest), GMG, GMGP, GMPL (highest))	12 hedonic models developed to estimate surpluses. Surplus identified for sales prices with GMC label (relative to non-GMC) but mixed results were found for higher rated labels (market confusion)
(Australian Bureau of Statistics 2008)	ACT (Australia)	EER (scale: 0-6)	Surpluses (sales) relative to a 0-rated home: 1.6% (EER1), 3% (EER2), 5.9% (EER3), 6.3% (EER4), 6.1% (EER5)
(Bloom et al. 2011)	Colorado (US)	ENERGY STAR®	Price surplus for homes with an ENERGY STAR® label: $8.66/ft^2$ (relative to homes without one)
(Deng and Quigley 2010)	Singapore	Green Mark Certification	Average price surplus (sales) of GMC homes relative to non-GMC: 15%
(Kok and Kahn 2012)	California (US)	ENERGY STAR®	Price surplus for homes with an ENERGY STAR® label: 9% (relative to homes without one)
(Salvi et al. 2010)	Zurich (Switzerland)	Minergie labelling scheme	Sales surplus of labelled homes compared with unlabelled homes: 7% (single family homes) 3.5% (flats)
(Yoshida and Sugiura 2010)	Tokyo, Japan	TGLSC	Sales *deficit* of labelled (compared with unlabelled) condominiums: 5.6%
(Zheng et al. 2011)	Beijing (China)	"Green" index (developed by authors)	Sales price surplus of "green" homes compared with non-"green" homes: 17.7% (initially) But: -11% (resale price) -8.5% (rental price)

The above studies, which cover a range of global energy efficiency labelling schemes, show that statistically significant surpluses are observed in most cases. Two outstanding findings that do not follow the pattern are found in the studies carried out by Zheng et al. (Zheng et al. 2011) and Yoshida and Sugiura (Yoshida and Sugiura 2010). Both studies are often included in the analysis of other hedonic model investigations, which seek to explain the discrepancy between these findings and the wider body of literature that consistently estimates price surpluses in relation to higher levels of energy efficiency. It has been argued that the deficit observed in the first study by Zheng et al. could be the result of a perception of high maintenance costs in energy efficient homes (de Ayala et al. 2016). Furthermore, since the green index was developed by the authors, it transactions in this study did not benefit from the increased information that accompanied transactions with energy efficiency labels in other studies. Yoshida and Sugiura, the authors of the second study, also suggested that the deficit may be the result of perceived high maintenance costs of energy efficient homes as well as uncertainty over the quality of building material. In addition, the authors identified omitted variable bias as a potential cause, which becomes significant when explanatory variables that are correlated with energy efficiency are omitted from the regression. It can be difficult to control for this bias as it often results from a lack of data for the omitted variable. As a result independence tests between this attribute and energy efficiency usually cannot be carried out. However, control mechanisms have been developed for variables that are thought to be correlated, such as location (Fuerst et al. 2016).

The literature discussed so far in this section reflect the observation that energy efficiency labelling schemes are being capitalised in transactions in housing markets. However, the geographical scope of the studies relating specifically to the EPC scheme is limited, as quantitative analyses have only been carried out for a minority of EU Member States. This thesis will therefore build on the current body of work in this field by carrying out hedonic regressions for countries that have not yet been analysed, as well as comparing results with countries that have.

A number of studies have been carried out that use survey data to assess the success of the EPC scheme. This methodology seeks to better understand the way in which consumers interact with EPC labels in the housing market. Studies have focussed on five key areas:

- The level of understanding of EPCs
- The extent to which the labels have been incorporated into decision-making processes
- The significance of EPC labels as compared with other attributes in the decision-making process
- The level of implementation of improvement recommendations provided in EPCs

- The level of trust of the information contained within EPCs

Investigations into the level of understanding of the information provided in EPCs have generally found that the most important information is well understood (Lainé 2011). However, many studies have identified issues relating to a lack of understanding of more complex information. In a survey carried out in Germany, respondents were asked to give a rating (out of seven) for the level to which they found the information provided in EPCs understandable. A mode response of five was reported, which was classed as by the author as *"fairly understandable"* (Amecke 2012, 8). However, only 58.1% of respondents were correctly able to identify and distinguish between the two types of certifications schemes offered in Germany, which signified a lack of understanding of the EPC valuation method. Furthermore, a survey carried out as part of the previously mentioned EU Commission study found that the level of understanding across surveyed states was generally high; however, evidence also suggested a lack of understanding of more complex information such as the meaning behind different ratings and the method used to calculate them (Bio Intelligence Service et al. 2013). In addition, Amecke stated that the main cause behind the ineffectiveness of EPCs was the fact that the certificates were insufficient in helping consumers to understand the financial costs and benefits relating to energy efficiency (Amecke 2012). This is supported by the EU Commission report that stresses the importance of making financial forecasts easier to calculate for home-dwellers. In particular, the report highlights the fact that the amount of money that can be saved in the future is a lot more difficult to calculate than upfront investment costs.

Investigations into the extent to which EPCs affect decision-making in the housing market have tended to find that they play a minor role (Amecke 2012) (Backhaus et al. 2011) (Murphy 2013). Key factors behind this include lack of implementation of EPCs, complexities within the housing market and poor coordination with other policy measures. Research has been done into the reasons behind consumers opting for houses with lower ratings in order to further understand the lack of consideration of EPCs in purchase decisions. One factor that has been identified is a fear that potential house buyers will appear difficult if they demand an EPC rating where it has not been provided (Lainé 2011). In addition, Gram-Hanssen et al. found evidence that EPCs were used to decide what changes to make after a house had been purchased, rather than in the pre-purchase decision-making process (Gram-Hanssen et al. 2007). However, this finding was based on interviews with a small sample of 10 Danish households and cannot necessarily be generalised. In contrast with the negative outcomes of the above studies, Amecke et al. reported that 78% of respondents had used EPCs at some point during their search process. Whilst this does not necessarily mean that EPCs formed part of the decision-making process in all cases, it demonstrates an awareness of their existence and purpose (Amecke 2012). Finally, investigations into price negotiation processes have found that EPCs tend to play a minor role, if any (Lainé 2011). However, since many of the previously discussed hedonic studies use datasets with advertised prices rather than final transaction prices and still find statistically significant surpluses, it is possible that the EPCs are being capitalised in the housing market even if they are not used in price negotiations.

In order to contextualise the apparent lack of importance of the EPC scheme in decision making, it is instructive to compare it against other factors that influence the decision to buy a house. Amecke et al. report that respondents rated location, outdoor spaces, price and dwelling condition as the most important criteria, while EPC rating was "only a minor purchasing criterion" (Amecke 2012, 4)**.** In addition, it was reported that EPCs were seen to be less useful than utility bills, which were thought to relate more directly to energy efficiency. Murphy explains the dominance of features such as size, location and price above energy efficiency as resulting from the fact that they are considered to be unalterable features of a dwelling (Murphy 2013). Whilst the quantitative hedonic studies also provide estimations of the relative importance of different factors such as size, age, EPC rating and location, it is important to compare this with the above survey results that provide an insight into the factors that consumers perceive to be affecting their decisions.

Although our research will focus purely on the market effects of EPCs for sales and rental transaction and will not investigate the extent to which retrofitting recommendations are enacted, it is important to have an overview of this area of the literature. In particular, this is because it aids the assessment of whether observed price surpluses relate to overall energy efficiency improvements of the existing housing stock or whether they are just connected with a redistribution of home-owners with wealthier people moving to more energy efficient dwellings. Studies in this field have found evidence of home-owners carrying out energy efficiency measures as a result of the EPC of their dwelling (Murphy 2013) (Tigchelaar et al. 2011) (Kjaerbye 2009) (NHER 2009)**.** However, Murphy et al. did not find a statistically significant difference between EPC-recipients and non-EPC-recipients in terms of likelihood to have carried out an energy efficiency measure (Murphy 2013). Furthermore, a study carried out in the UK found that 32% of households with EPCs had implemented energy efficiency measures; however, they observed a discrepancy between the most recommended cost-effective measures in EPCs and the most implemented measures, which casts doubt over the extent to which EPCs formed the primary information source for these renovations (NHER 2009). In contrast with these findings, the IDEAL EPBD multi-country study reported that households with EPCs were twice as likely to carry out energy efficiency renovations (Murphy 2013). The contradiction between this result and the previously mentioned studies that fail to find a statistically significant difference between EPC- and non-EPC-recipients may be demonstrative of the influences of country-specific factors and biases due to the samples used in different studies. Taking this into account, it is concluded that weak evidence exists to suggest that EPC-recipients carry out more energy efficiency renovations.

The final area that has been investigated by studies using survey data is the extent to which the information contained in EPCs is trusted. A country that has suffered from a lack of trust is the Netherlands, which is reflected by the fact that adoption rates of the EPC scheme was observed to decrease over time after an initially strong level of implementation (Brounen and Kok 2011). In their study, Brounen and Kok were able to match this downward pattern with the level of negative press printed about the EPC scheme, suggesting that lack of trust was an important factor. This is supported by Murphy et al. who attributed the sharp decrease in public acceptance of the scheme in the Netherlands to a consumer programme, which showed that a single dwelling could receive a wide range of EPC ratings (Murphy 2013). In addition to a lack of trust in the valuation method, a survey carried out in the Netherlands in 2011 reported that 40% did not trust recommendations given in the EPCs (Tigchelaar et al. 2011). This issue has also been reflected in studies carried out in other countries, with Amecke et al. reporting a mode response of four (out of seven) for a survey question on the level of trust in EPC information in Germany (Amecke 2012). In addition, the NHER study in the UK reported that the main reason for recipients not implementing retrofit recommendations was due to disagreement that the recommendations provided in EPCs were the best measures to implement (Amecke 2012). The example from the Netherlands highlights the importance of strict valuation standards and training of personnel. In addition, it is possible that in cases where the correct recommendations have been made, insufficient reasoning has been given to support these recommendations, which can also lead to a lack of trust.

The final area of the literature that provides an important background to this studies' analysis relates to the well-documented split-incentive dilemma. This dilemma encompasses situations in which investment decisions are hindered due to the fact that the flow of benefits and investments are unequally divided among actors in a given transaction. In the case of energy efficiency improvements in the housing market, the split incentive dilemma surrounds the differing interests and incentives of landlords and tenants. Since landlords generally do not pay energy bills, it is in their interest to provide house components as cheaply as possible. On the other hand, tenants have the incentive of maximising the energy efficiency of their home so as to minimise energy bills. However, tenants generally lack control over home improvements (Bird and Hernández 2012). As a result of this market barrier, the market transformation impact of the EPC and other energy efficiency schemes are predicted and recorded to be less for rental markets than for sales markets (Fuerst et al. 2016) (Cajias and Piazolo 2013) (Kholodilin et al. 2014).

3 Results

3.1 Chapter overview

This chapter is divided into sub-chapters for each of the countries under analysis. Each of these sub-chapters begins with a brief overview of the current national legal transposition of EPC regulations, as well as the level of implementation. This information is important in understanding the extent to which the policy has penetrated the market in each country, as well as in understanding the rating and measurement systems, which differ between countries.

This is followed by a presentation of the regression results. Results tables are preceded by bar charts presenting the distribution of energy labels in the sample. These are expected to follow a log-normal distribution and the bar charts provide information as to which rating classes are represented more in the sample. Results tables are then presented and are first given for sales data and then for rental data. The dummy variable model is favoured and in most cases this is the only model that is presented. In cases where there is an ambiguity as to whether a statistically significant surplus or deficit exists when averaged over the whole EPC scale, regression results using the linear model are also given.

The linear model is also useful in enabling the estimation of the average surplus across this scale as a *percentage* of the average dwelling price in the sample. This estimation is particularly valuable in increasing the comparability of the results of this study with the literature, in which results are commonly given as percentage values. As a result, linear models are also run for the sales and rental markets in all countries. These results can be found in appendix 3. The only exception to this is for cases mentioned in the above paragraph, in which it is necessary to present the linear results in the current chapter, in order to resolve ambiguities in the dummy variable model results. In these cases, surplus values as percentages of average dwelling prices will also be presented in the results tables and analysed in the *discussions* chapter.

The level of statistical significance of each of the price contributions is indicated using the code given in table 3.

Table 3: key for the coding of p-values in the results chapter

P-value	Code
<0.001	***
<0.01	**
<0.5	*

A 95% significance level has been chosen as the cut-off value for statistically significant results. As a result, p-values above 0.05 are not reported and the corresponding price contributions are not considered to be statistically significant. The t-statistic for each price contribution is also reported in parentheses. Finally, for countries that do not have the euro currency, conversions into the euro are presented. The exchange rates for all of the conversions were taken at 10am on 28th May[3]. These do not represent the actual transaction prices in Euros, as the exchange rate is likely to have been different at the time of transaction. However, the values give an indication of the magnitude of the surpluses to the reader that is unfamiliar with non-euro currencies.

The literature on the minimum sample size per number of variables contains greatly varying recommendations. This value is commonly referred to as the number of subjects per variable (SPV) and suggested minimum values vary from two (Steyerberg et al. 2015) to 15-25 (Green 1991). A rule of thumb of a minimum sample size of 50 falls within this range and represents similar SPV values for each regression, since the number of available variables are similar between countries. This rule is therefore adopted and EPC classes are grouped in cases where dummy variable classes contain fewer than 50 data points in a sample.

The limitations in the number of explanatory variables mean that the numerical results will mainly be used to analyse general trends. As a result, numerical analysis will not penetrate far beyond the precision level of orders of magnitude. All price contributions are therefore given to two significant figures. In addition, t-statistics are given to four significant figures and the p-values are given to 6 significant figures.

The *observations* sub-chapter will summarise the regression results. Possible causes for observed trends will also be discussed. This sub-chapter will focus on the results from the dummy variable model, except for in cases of ambiguity, when the linear

[3] Conversion rates were taken from the website: http://www.x-rates.com/table/?from=EUR&amount=1 (10:00, 28/05/16). The following conversion rates were used. 1 EUR: 0.760158 GBP, 27.030878 CZK, 7.347814 DKK, 9.265874 NOK, 9.279431 SEK

results will provide extra clarification of overall trends. An analysis and overview of all linear results not discussed in the observations sub-chapters will be left for the *discussion* chapter at the end of the study.

3.2 Austria

3.2.1 National EPC scheme

Austria is divided into nine federal states. Certain areas of legislation are managed at a state - rather than national - level. This includes building regulation policy, which covers the calculation methodology for EPCs. However, whilst the policy is managed regionally, a harmonisation process took place in 2006 at the national level to ensure the full transposition and implementation of the EPBD. This resulted in a set of guidelines, which are followed by all states (OIB 2015). As a result, the impact of EPCs can be analysed on a national level, without the need to adjust for different state measurement systems. However, it is possible that some regional differences could occur as a result of staggered implementation. The guidelines were updated in 2011 to account for the recast of the EPBD and were first implemented in the state of Carinthia at the end of 2012. The final state to fully implement them was Salzburg in October 2013 (CA EPBD 2016).

The main indicator that is used to determine the energy efficiency of a home for Austrian EPCs is the total energy efficiency factor. This is calculated using a fixed-value method, which converts energy usage in kW/m^2 into categories on a scale from A++ (most efficient) to G (least efficient). By 2011, it was estimated that 20% of the Austrian building stock had obtained valid EPCs (CA EPBD 2016b).

3.2.2 Regression results

EPC class distributions in the sample:

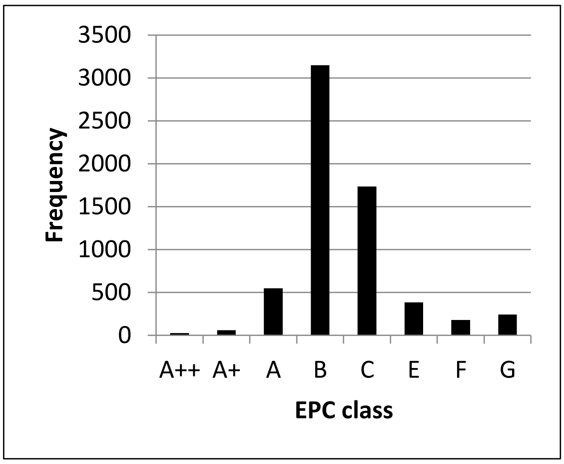

Figure 1: Bar chart of the distribution of EPC classes in the Austrian sales market sample

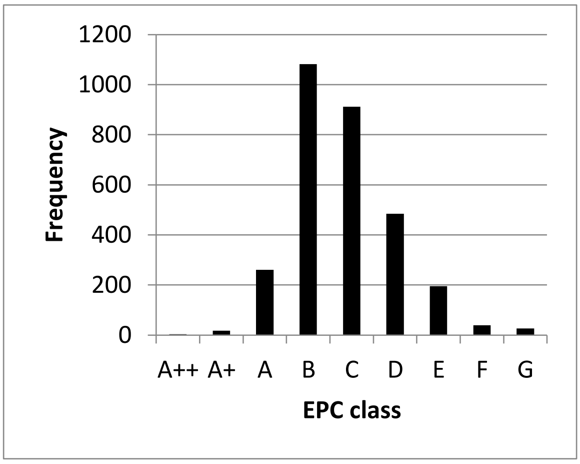

Figure 2: Bar chart of the distribution of EPC classes in the Austrian rental market sample

Table 4: Regression results for the Austrian sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Total Area (m^2)	3,100*** (53.42)
Construction Year	− 480*** (− 4.360)
A++, A+	67,000 (1.420)
A	170,000*** (7.410)
B	200,000*** (11.90)
C	70,000*** (4.181)
D	*Hold out*
E	− 79,000** (− 3.201)
F	− 180,000*** (− 5.343)
G	− 210,000*** (− 6.953)
Intercept	910,000*** (4.224)
Regression and Sample Statistics	
Adjusted R^2	0.287403
Sample size	7335
Average price of a dwelling (€)	395,016.90

Table 5: Regression results for the Austrian rental market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Total Area (m^2)	16*** (90.71)
Construction Year	− 0.91*** (− 6.186)
A++, A+, A	120** (3.192)
B	94*** (3.311)
C	17 (0.6264)
D	*Hold out*
E	− 180*** (− 4.583)
F, G	− 340*** (− 5.500)
Intercept	1,600*** (5.448)
Regression and Sample Statistics	
Adjusted R^2	0.748568
Sample size	3023
Average rent of a dwelling (€/month)	1,361.44

3.2.3 Observations

3.2.3.1 Sales market observations

For the sales market, the statistically significant EPC coefficients follow the expected trend in the range between B- and G-rated dwellings. It is observed that the coefficients increase relative to the hold-out category for C- and B-rated dwellings, and decrease for E-, F- and G-rated dwellings. However, there is an unexpected trend at the higher-end of the scale, whereby the price contribution decreases between B- and A-rated dwellings, and again between A- and A+-/A++-rated dwellings. This suggests that the price surplus effect ceases to exist in this region of the EPC-scale. In addition, since a statistically significant discount has been observed, it is possible that there is a negative price effect associated with dwellings that are perceived to be highly energy efficient, such that the willingness-to-pay for energy efficiency actually decreases for these homes in the sales market. However, caution should be taken with this conclusion, since the adjusted R^2 value shows that the model is about 29% described and it is therefore possible that other factors that have not been included are affecting dwelling prices at the highest end of the EPC scale.

The area coefficient for the sales market is highly statistically significant and positive, as expected. However, a negative correlation between price and construction year is observed, suggesting that older dwellings are more desirable. Provided that energy efficiency is fully described by the EPC variables, it is likely that aesthetic factors contribute to this effect, as well as other factors including the regional distribution of the sample. However, other negative quality characteristics that may be present in older homes and are not connected to energy efficiency would also be expected to cause a positive correlation between price and age. Further investigation with better data on the quality- and aesthetic-characteristics of the dwellings in the sample is necessary to ascertain the extent to which the construction year coefficient is consistent with expectations.

3.2.3.2 Rental market observations

For the rental market, a positive correlation between price and EPC-rating is observed across the whole scale. This suggests that if a negative effect does exist at the higher end of the scale in the sales market, it has not been transferred to the rental market. A possible cause of this is the fact that tenants generally do not expect to bare the maintenance costs for energy efficient-mechanisms and hence will usually only consider bills in their energy-related considerations.

3.3 Czech Republic

3.3.1 National EPC scheme

The EPBD has been implemented and transposed in the Czech Republic on the national level. The most recent amendment in April 2013 involved a change to the measurement method of the EPC. As a result, EPCs issued after this date use a reference building approach to classify the energy performance of buildings, instead of the previously used calculated asset rating. The classification system takes the form of a letter scale between A (most efficient) and G (least efficient). By the end of 2014 it was calculated that 3% of the building stock had been certified (CA EPBD 2016).

3.3.2 Regression results

EPC class distributions in the sample:

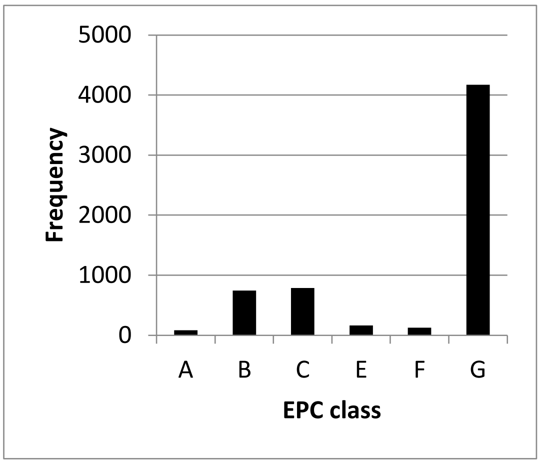

Figure 3: Bar chart of the distribution of EPC classes in the Czech sales market sample

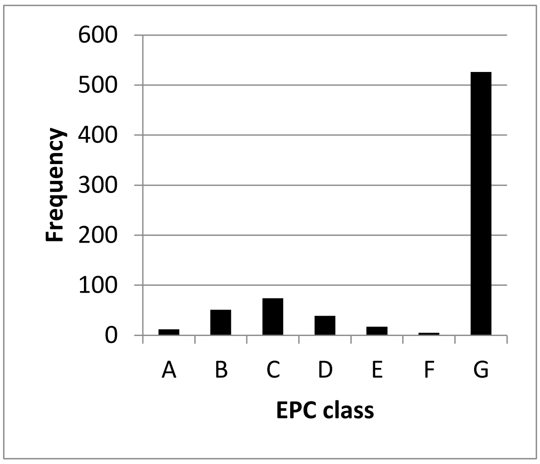

Figure 4: Bar chart of the distribution of EPC classes in the Czech rental market sample

Table 6: Regression results for the Czech sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (Kč)	Price Contribution (€)
Useable Area (m^2)	14,000*** (43.33)	520***
Construction Year	12,000*** (6.549)	440***
A	2,000,000*** (5.173)	74,000***
B	1,400,000*** (6.338)	52,000***
C	580,000** (2.611)	21,000**
D	*Hold out*	*Hold out*
E	− 440,000 (−1.452)	−16,000
F	−780,000* (−2.380)	−29,000*
G	−830,000*** (−4.213)	−31,000***
Intercept	−22,000,000*** (−6.064)	−810,000***

Regression and Sample Statistics	
Adjusted R^2	0.258238
Sample size	6322
Average price of a dwelling (Kč)	3,590,628.34
Average price of a dwelling (€)	132,834.32

Table 7: Regression results for the Czech rental market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (Kč)	Price Contribution (€)
Useable Area (m^2)	91*** (19.04)	3.40***
Construction Year	− 20 (−0.6668)	−0.74
A, B	−7,400** (−2.628)	−270**
C	−4,900* (−1.782)	−180*
D	*Hold out*	*Hold out*
E, F, G	− 8,100*** (−3.535)	−300***
Intercept	53,000 (0.8781)	2000
Regression and Sample Statistics		
Adjusted R^2	0.342613	
Sample size	724	
Average rent of a dwelling (Kč/month)	15,667.06	
Average rent of a dwelling (€/month)	579.60	

Table 8: Regression results for the Czech rental market using the linear model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (Kč)	Price Contribution (€)
Useable Area (m^2)	91*** (19.16)	3.37***
Construction Year	− 27 (−0.9130)	−1.00
EPC rating	620* *surplus* (2.193)	23*
Regression and Sample Statistics		
Adjusted R^2	0.335202	
Sample size	724	
Average rent of a dwelling (Kč/month)	15,667.06	
Average rent of a dwelling (€/month)	579.59	
Surplus as a percentage of average price (%, 2sf)	4.0	

3.3.3 Observations

3.3.3.1 Sales market observations

The observed trend for the sales market in the Czech Republic is consistent with the hypothesis of a price surplus existing across the EPC scale. This trend is strongest in the shift between C- and B-rated dwellings and weakest between G- and F-rated dwellings. It is possible that the latter effect is due to the fact that dwellings in both categories have poor energy efficiency and hence the marginal difference is incorporated to a lesser degree in decision-making.

In addition, the area variable is observed to have a strongly significant positive correlation with price. In contrast with the results for the Austrian sales market, a positive correlation is found between construction year and price, which may result from the increased quality of newer dwellings.

3.3.3.2 Rental market observations

The results for the rental market using the dummy variable method yielded unexpected, statistically significant results for the effect of EPC-ratings on house prices. Whilst dwellings rated below the ‘hold out’ category D were observed to have the expected price discount, a price discount was also observed in the shifts between D- and C-, C- and A-/B-rated dwellings. The latter result directly contradicts the studies’ hypothesis. It is possible that missing variables or sample biases have distorted the results at this end of the scale. Given the ambiguity in the first set of results, a linear model was run to identify whether the observed surplus or the observed deficit dominates when averaged over the full EPC scale. These results give a statistically significant surplus; however, the dummy variable model results demonstrate the fact that this is unlikely to be distributed across the scale.

Neither model yielded a statistically significant result for the effect of construction year on price; however, both models confirmed a positive area contribution.

3.4 Denmark

3.4.1 National EPC scheme

The transposition and implementation of the EPBD takes place on the national level in Denmark. EPCs are calculated using a fixed-value approach, in which different value classes are used for different types of buildings. The energy efficiency factor is given as a letter rating on a scale between A (most efficient) and G (least efficient). The A band is subdivided into three categories: A2020 (most efficient), A2015 and A2010 (least efficient). In 2012, it was calculated that 19% of the building stock was certified (CA EPBD 2016b). More specifically, it has been estimated that 29% of single-family houses have a certificate (CA EPBD 2016). Denmark already had an energy performance certification scheme before the transposition of the first EPBD in 2006. This made implementation relatively simple compared with other countries that did not have existing schemes (BPIE 2010). A new law came into force in July 2012 to account for the EPBD recast. The main change to EPC policy was the inclusion of the mandatory advertising requirement, which was required to be implemented by 1 January 2013 (BPIE 2016).

3.4.2 Regression results

EPC class distributions in the sample:

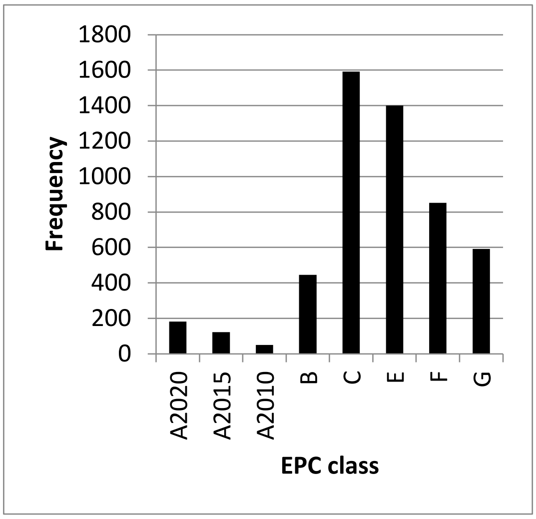

Figure 5: Bar chart of the distribution of EPC classes in the Danish sales market sample

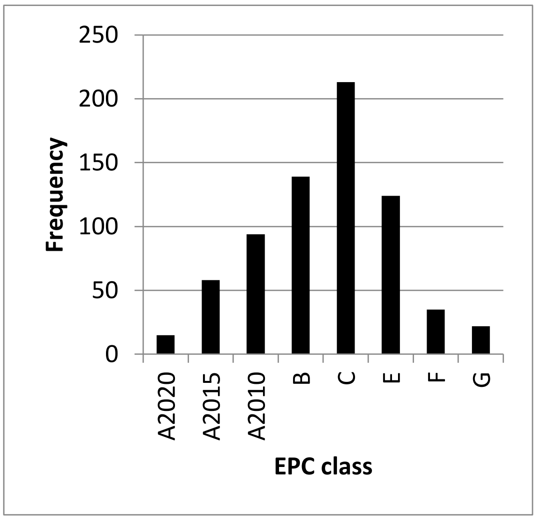

Figure 6: Bar chart of the distribution of EPC classes in the Danish rental market sample

Table 9: Regression results for the Danish sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (kr.)	Price Contribution (€)
Area (m^2)	12,000*** (36.45)	1,700***
A2020	1,500,000*** (10.75)	200,000***
A2015	3,000,000*** (18.44)	410,000***
A2010	480,000 (1.890)	65,000
B	370,000*** (4.008)	50,000***
C	74,000 (1.261)	10,000
D	*Hold out*	*Hold out*
E	− 280,000*** (− 4.577)	− 38,000***
F	− 390,000*** (− 5.389)	− 53,000***
G	− 830,000*** (− 10.03)	− 110,000
Intercept	400,000*** (6.313)	54,000***

Regression and Sample Statistics	
Adjusted R^2	0.209607
Sample size	7449
Average price of a dwelling (kr.)	2,162,898.25
Average price of a dwelling (€)	294,359.842

Table 10: Regression results for the Danish rental market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (kr.)	Price Contribution (€)
Area (m^2)	45*** (21.83)	6.10***
A2020, A2015	1,800*** (3.866)	240***
A2010	330 (0.7610)	45
B	950* (2.493)	130*
C	20 (0.06074)	2.70
D	*Hold out*	*Hold out*
E	− 320 (− 0.8133)	− 44
F, G	− 1,300* (− 2.482)	− 180*
Intercept	2,700*** (8.800)	370***
Regression and Sample Statistics		
Adjusted R^2	0.343969	
Sample size	947	
Average rent of a dwelling (kr./month)	7240.57	
Average rent of a dwelling (€/month)	985.40	

3.4.3 Observations

3.4.3.1 Sales market observations

The trend for the price contribution due to EPC rating in the Danish sales market is similar to the trend observed in the Austrian sales market. A price surplus is estimated in shifts between all EPC ratings except for at the highest end of the scale (in the shift between A2015- and A-2020-rated dwellings), where a deficit is detected. Another significant observation is the fact that the order of magnitude of the shift between B- and A2015-rated dwellings (even if averaged over the two steps taken with the intermediate shift to A2010) is higher than in any of the other adjacent letter shift. This would suggest that the surplus effect is strongest at the higher end of the spectrum, until the highest level, at which point an opposing negative effect is observed. It is possible that a ‘tipping point’ exists, where the increased benefits of energy efficiency are capitalised at a heightened rate at the higher end of the EPC scale until the point at which energy efficiency ceases to be capitalised in the market. However, the results could also be biased due to the small sample sizes for A2015- and A2020-rated dwelling. Furthermore, the relatively low adjusted R^2 value means that other factors not related to the EPC value may be causing this pattern. Data for construction year was not obtained for the Danish sales market; however, a positive contribution is observed due to area.

3.4.3.2 Rental market observations

Statistically significant results are only observed for three of the dummy variable categories in the Danish rental sector. However, each of these results is consistent with the hypothesis of a positive relationship between price and EPC rating. In addition, a positive relationship is observed for area.

3.5 France

3.5.1 National EPC scheme

EPCs are managed at the national level in France. The implementation process was updated in 2010 along with new regulations that have greatly improved the EPC procedure (CA EPBD 2016). The relevant indicator for energy efficiency is the primary energy consumption factor. Energy consumption is either calculated or measured, depending on the building type and the year of construction. This value is then compared to fixed-value bands that relate to a letter-scale, ranging from A (lowest energy consumption) to G (highest energy consumption). It was calculated in 2012 that 17% building stock was certified (CA EPBD 2016b). It is estimated that this number had grown to 20% by 2014 (CA EPBD 2016).

3.5.2 Regression results

EPC class distributions in the sample:

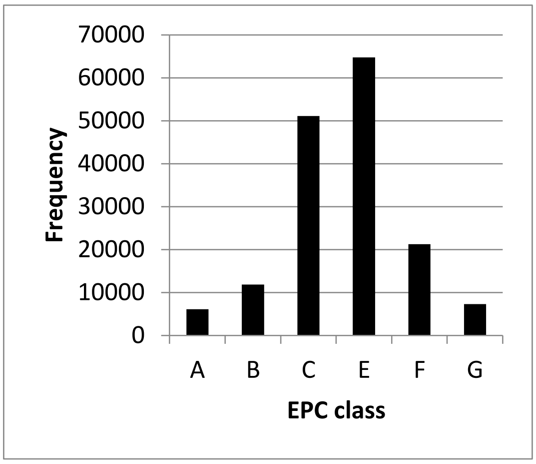

Figure 7: Bar chart of the distribution of EPC classes in the French sales market sample

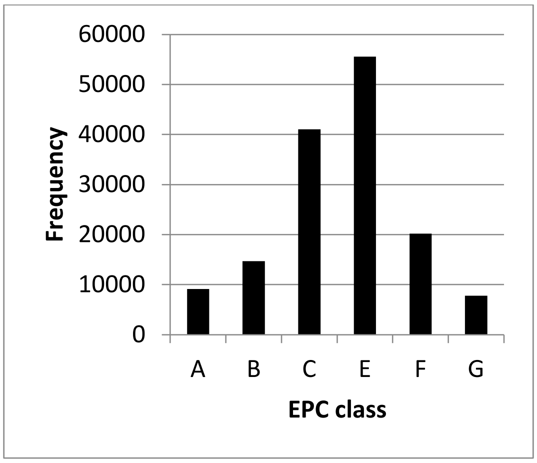

Figure 8: Bar chart of the distribution of EPC classes in the French rental market sample

Table 11: Regression results for the French sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Area (m^2)	1,600*** (330.1)
A	32,000*** (15.22)
B	74,000*** (47.08)
C	33,000*** (37.54)
D	*Hold out*
E	− 21,000*** (− 25.33)
F	− 39,000*** (− 31.60)
G	− 52,000*** (− 26.35)
Intercept	66,000*** (89.17)
Regression and Sample Statistics	
Adjusted R^2	0.329191
Sample size	265143
Average price of a dwelling (€)	245,545.80

Table 12: Regression results for the French rental market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Area (m^2)	5.10*** (128.7)
A	53*** (8.019)
B	47*** (8.740)
C	12** (3.257)
D	*Hold out*
E	− 11*** (− 3.378)
F	− 7.084 (− 1.649)
G	− 8.572 (− 1.206)
Intercept	300*** (95.92)
Regression and Sample Statistics	
Adjusted R^2	0.072385
Sample size	224341
Average rent of a dwelling (€/month)	589.32

3.5.3 Observations

3.5.3.1 Sales market observations

The French sales market is also observed to display the previously-discussed trend of a price surplus across the scale up until the highest shift (in this case between B- and A-rated dwellings) at which point a deficit is observed. Orders of magnitudes of shifts between adjacent letters are fairly consistent across the scale. In addition, the area variable contributes positively to price.

3.5.3.2 Rental market observations

Statistically significant results are not observed at the lower end of the EPC scale for the French rental market. However, shifts between letters ratings above E-rated dwellings correspond to the expected price surplus. A positive area contribution is also observed. Nevertheless, the extremely low adjusted R^2 value for this set of results (<0.1) means that over 90% of price contributing-characteristics are not covered by the model and corresponding data. As a result, caution must be made when using these results to make further inferences about the French rental market.

3.6 Germany

3.6.1 National EPC scheme

The transposition of the EPBD in Germany took the form of an amendment to the existing Energy Saving Ordinance. Further amendments were made to account for the 2010 EPBD recast; however, the decision to adopt the *'Energiewende'* policy led to a legislative delay, as it was necessary to strengthen energy efficiency requirements. As a result, the deadline for the implementation of the majority of provisions relating to EPCs was May 2014 (CA EPBD 2016). A key change in EPC policy for non-residential buildings was the transition from a continuous number scale to a letter-rating system (BPIE 2016). Although EPC policy is controlled and implemented at the state-level, it is formulated nationally and hence it can be assumed that the EPC rating that a given dwelling receives is largely independent of the state in which it is located. It is difficult to estimate the proportion of buildings that are certified, as EPCs that were issued before the 2014 amendment were not registered (CA EPBD 2016). The current EPC measurement system uses a reference building comparison approach.

3.6.2 Regression results

The dataset for Germany is unusual in comparison to the other datasets as it is possible to distinguish between the EPC entries that were implemented before and after the 2014 amendment that accounted for the 2010 EPBD recast. This is because of the transition from a number- to a letter-based rating system. By contrast, all of the other countries assessed in this study maintained the same rating scale before and after the implementation of the 2010 EPBD recast.

This feature of the German dataset enables a comparison between the new and old systems. However, it is necessary to limit this exercise is limited to a comparison of general trends rather than a comparison of numerical surpluses. This is because the new legislation for the energy efficiency requirements for buildings in 2014 resulted in a stricter scale, with H-rated buildings in the new regime relating to the entire lower half of the scale in the pre-2014 legislation. Figure 3 demonstrates how the primary- and end-energy of the same building are rated differently according to the different scales. A key reason behind the decision to refrain from converting between these scales in the analysis of this study is the fact that a given building, such as the one in this figure, can be perceived to be efficient according to one scale, and only moderately efficient according to the other. This effect is enhanced through the colour-coded presentation of the EPC.

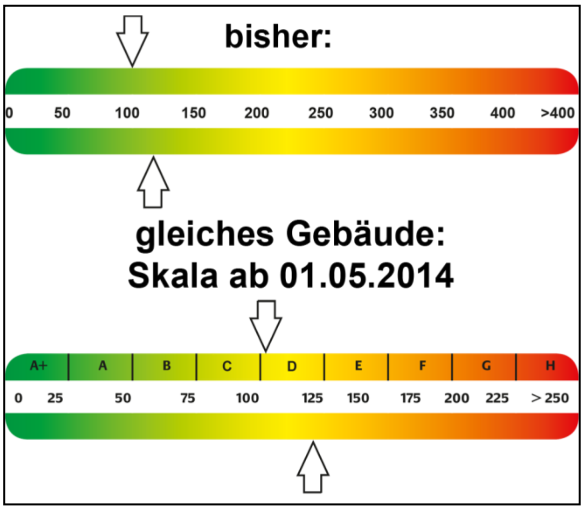

Figure 9: A comparison between the EPC scales in Germany in the pre-2014 legislation (above) and the post-2014 legislation (below). 'Gleiches Gebäude' indicates the fact that the arrows for each scale relate to the ratings of the same buildings. The arrow above each scale indicates final energy demand (kWh/m^2*a) and the arrow below indicates primary energy demand (kWh/m^2*a) (Thermomess Wärmemessdienst AG 2014).

EPC rating distributions in the sample:

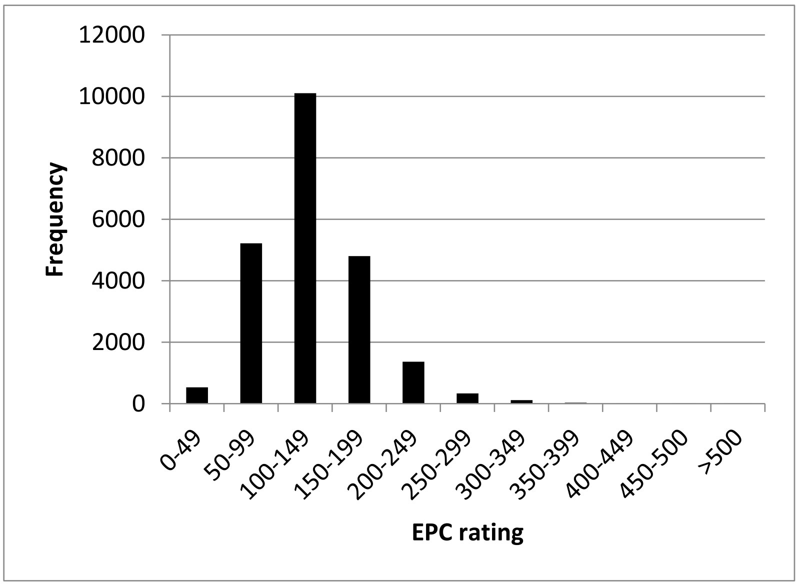

Figure 10: Bar chart of the distribution of EPC classes in the German sales market sample for the pre-2014 number-rated EPC system

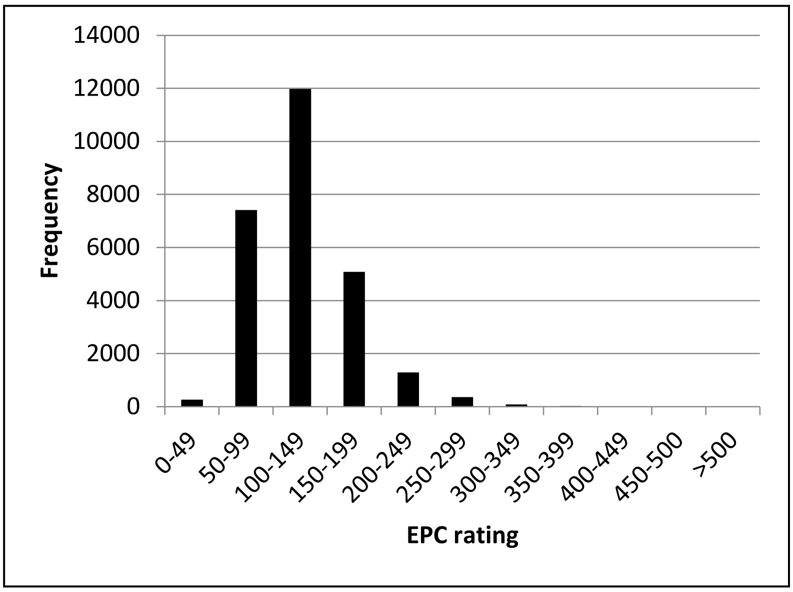

Figure 11: Bar chart of the distribution of EPC classes in the German rental market sample for the pre-2014 number-rated EPC system

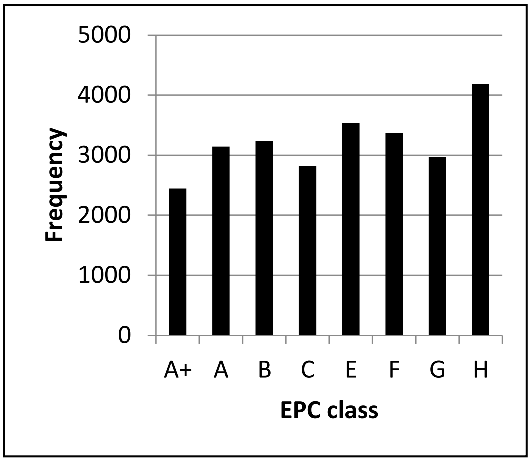

Figure 12: Bar chart of the distribution of EPC classes in the German sales market sample for the post-2014 letter-rated EPC system

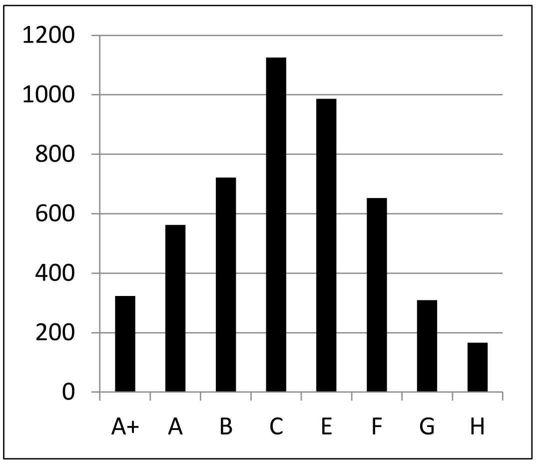

Figure 13: Bar chart of the distribution of EPC classes in the German rental market sample for the post-2014 letter-rated system

Table 13: Regression results for the German sales market for the pre-2014 number-rated EPC system. The linear model is used. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Number of rooms	39,000*** (75.87)
Construction Year	560*** (11.88)
Energy consumption characteristic value (higher number: higher consumption)	− 110*** *surplus* (− 3.337)
Intercept	− 1,000,000*** (− 11.02)
Regression and Sample Statistics	
Adjusted R^2	0.203651
Sample size	22513
Average price of a dwelling (€)	209,172.85

Table 14: Regression results for the German sales market for the post-2014 letter-rated EPC system. The dummy variable model is used. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Number of rooms	33,000*** (51.54)
Construction Year	540*** (14.50)
A+	63,000*** (8.109)
A	30,000*** (4.128)
B	53,000*** (7.542)
C	33,000*** (4.595)
D	*Hold out*
E	− 12,000 (− 1.790)
F	− 42,000*** (− 6.018)
G	− 84,000*** (− 11.64)
H	− 130,000*** (− 18.97)
Intercept	− 940,000*** (− 12.74)
Regression and Sample Statistics	
Adjusted R^2	0.115517
Sample size	29579
Average price of a dwelling (€)	289,754.90

Table 15: Regression results for the German rental market for the pre-2014 number-rated EPC system. The linear model is used. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Number of rooms	220*** (105.3)
Construction Year	0.59*** (10.05)
Energy Consumption Characteristic Value (higher number: higher consumption)	0.39*** *Deficit* (9.070)
Intercept	− 1,200*** (− 9.996)
Regression and Sample Statistics	
Adjusted R^2	0.300827
Sample size	26527
Average rent of a dwelling (€/month)	624.62

Table 16: Regression results for the German rental market for the post-2014 letter-rated EPC system. The dummy variable model is used. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Number of rooms	260*** (48.39)
Construction Year	1.7*** (8.988)
A+	360*** (10.63)
A	230*** (8.460)
B	160*** (6.521)
C	56** (2.647)
D	*Hold out*
E	30 (1.394)
F	54* (2.158)
G	4.10 (0.1241)
H	− 17 (− 0.4027)
Intercept	− 3,300*** (− 9.979)
Regression and Sample Statistics	
Adjusted R^2	0.325220
Sample size	6223
Average rent of a dwelling (€/month)	866.61

3.6.3 Observations

3.6.3.1 Sales market observations

A statistically significant price surplus due to EPC rating is observed for the pre-2014 number-rated data. However, at around 0.05% of the average house price, this surplus is several orders of magnitude below surpluses observed for other datasets in this study, as well as in the literature. A possible cause for this could be a damping effect due to the presence of a statistically significant deficit for sections of the EPC rating scale, as was observed in the Czech rental results. The number of rooms was used as the size variable and demonstrated a positive contribution, as did construction year.

A price surplus is also observed due to the letter-based EPC ratings in the sales market for all statistically significant, adjacent letter shifts, with the exception of the shift between B- and A-rated dwellings, where a deficit is observed. Since this is the penultimate highest shift in the scale, the pattern is distinct from the previously observed deficit at the highest end of the spectrum for the sales markets of other countries. The low adjusted R^2 value (just above 0.11) suggests that it is highly likely that the explanation is connected to an omitted variable bias. More data covering a wider number of explanatory variables would be necessary to further explore this potential explanation. As with the pre-2014 dataset, the number of rooms and construction year variables display a positive price contribution.

3.6.3.2 Rental market observations

The results for the section of the rental dataset with number-rated EPCs demonstrate a statistically significant deficit due to EPC rating, which directly contradicts this studies' hypothesis. By contrast, the rental results for letter-rated EPCs display the expected price surplus for shifts in letter ratings above the D hold-out category. However, these results contain a level of ambiguity as only one of the shifts below the hold-out EPC category is statistically significant and it suggests a deficit in the shift between F- and D-rated dwellings. It is possible that the presence of a deficit in this section of the EPC scale is also the causal factor behind the observed deficit for the pre-2014 results. For both sets of results, positive contributions are the observed for number of rooms and construction year, in agreement with the sales market results.

3.7 Luxembourg

3.7.1 National EPC scheme

The EPBD was transposed into Luxembourgish law by means of a modification of the existing legal framework governing the energy performance of buildings. A policy timeline was established in 2012 in response to the EPBD recast, which outlined the necessary adjustments that needed to take place. These have now mostly entered into force. The EPC contains an energy performance letter-indicator, which is calculated using a reference-building approach. The scale ranges from A (most efficient) to I (least efficient). Since the central database for EPCs is still being developed, statistics on the proportion of the building stock that is certified are not currently available (CA EPBD 2016).

3.7.2 Regression results

EPC rating distributions in the sample:

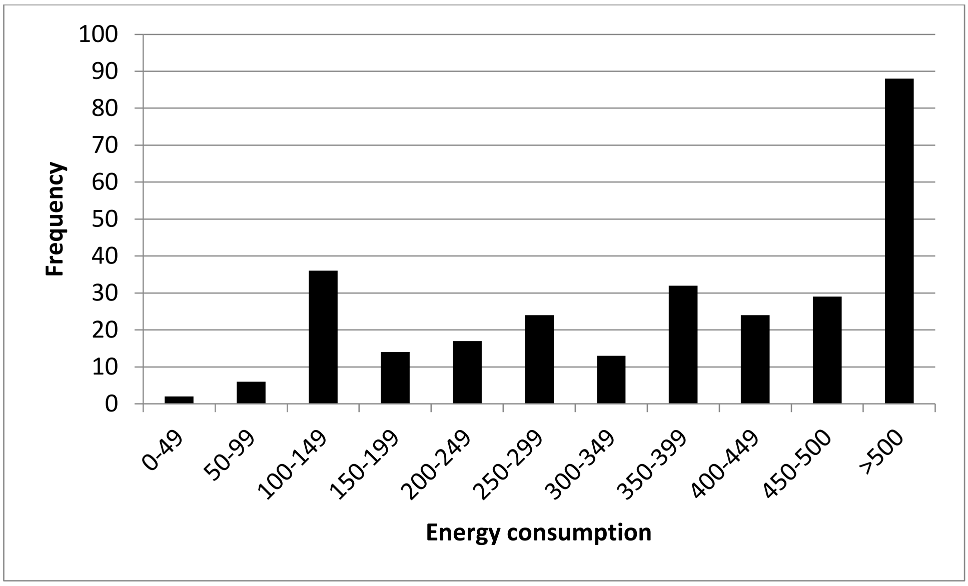

Figure 14: Bar chart of the distribution of EPC ratings in the Luxembourgish sales market sample

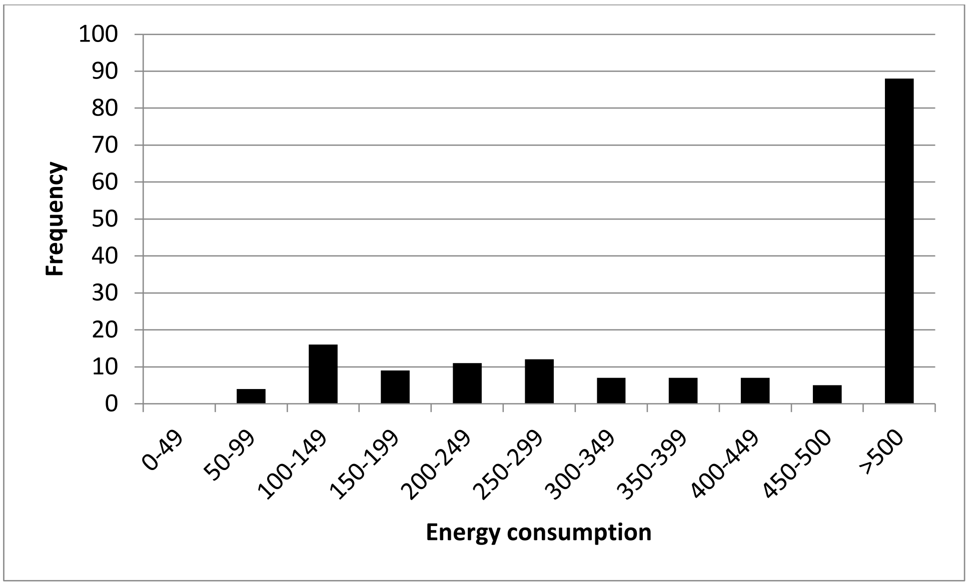

Figure 15: Bar chart of the distribution of EPC ratings in the Luxembourgish rental market sample

The Luxembourgish EPC rating is given as a number with a corresponding letter-class. However, the dataset used for this study only contains the number class and a conversion to letter classes was not possible, due to the reference-building categorisation method used for EPCs in Luxembourg. As a result, a linear model was used to measure the impact of the number ratings.

Table 17: Regression results for the Luxembourgish sales market using the linear model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Livable surface area (m²)	460*** (10.01)
Construction Year	160 (1.123)
Energy Consumption (higher number = higher consumption)	− 98*** (4.601) *surplus*
Intercept	− 140,000 (− 0.5100)
Regression and Sample Statistics	
Adjusted R^2	0.351598
Sample size	285
Average price of a dwelling (€)	194,472.30

Table 18: Regression results for the Luxembourgish rental market using the linear model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Livable surface area (m^2)	1.7***
Energy Consumption (higher number = higher consumption)	− 0.01** *surplus*
Intercept	440*** (11.85)
Regression and Sample Statistics	
Adjusted R^2	0.310141
Sample size	88
Average rent of a dwelling (€/month)	589.32

3.7.3 Observations

3.7.3.1 Sales market observations

The sales market demonstrated a statistically significant price surplus due to EPC rating across this scale, despite the small sample size. A positive contribution due to area was also observed; however, a significant result was not obtained for the contribution of construction year.

3.7.3.2 Rental market observations

The construction year variable was not included in the rental model, since data was only available for 18 of the useable data entries. Nonetheless, the remaining model displayed a small surplus due to EPC rating. The expected positive area contribution was also observed.

3.8 The Netherlands

3.8.1 National EPC scheme

The transposition and implementation of the EPBD is managed on the national level in the Netherlands. The first law including EPC measures entered into force in 2008. This was followed by an improved system that was implemented in January 2015. The new EPC system puts a strong emphasis on usability and takes the initial form of an interactive web application. All dwelling owners have been issued with 'temporary' web-based EPCs based on cadastral data. These can then be adjusted by the owners themselves through the input of new data. In order to obtain an official EPC, this adjusted model has to be checked by a qualified professional. The energy performance rating is calculated using this web application, following the input of 20 building characteristics by the owner (CA EPBD 2016). The new web-based system has led to an increase in the number of issued EPCs from 300,000/year to 460,000/year and this number is expected to increase further (CA EPBD 2016).

3.8.2 Regression results

EPC class distributions in the sample:

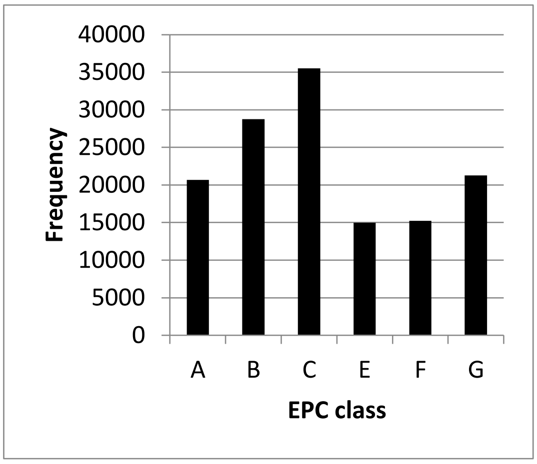

Figure 16: Bar chart of the distribution of EPC classes in the Netherlands sales market sample

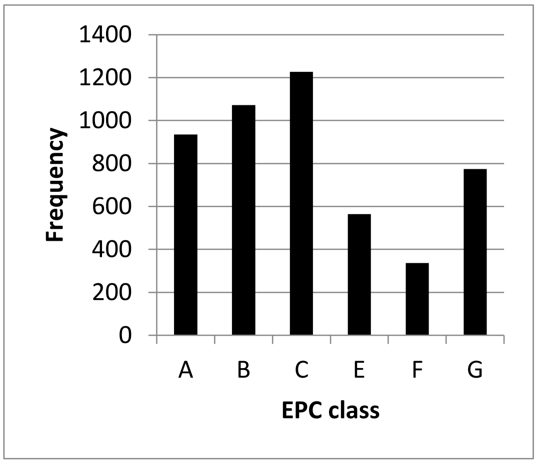

Figure 17: Bar chart of the distribution of EPC classes in the Netherlands rental market sample

Table 19: Regression results for the Netherlands sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Area (m^2)	2,800*** (423.6)
Construction Year	160*** (10.31)
A	17,000*** (9.590)
B	15,000*** (9.166)
C	− 15,000*** (− 9.893)
D	*Hold out*
E	− 3,900* (− 2.184)
F	28,000*** (15.94)
G	25,000*** (14.46)
Intercept	− 400,000*** (− 12.72)
Regression and Sample Statistics	
Adjusted R^2	0.570168
Sample size	150323
Average price of a dwelling (€)	294,728.50

Table 20: Regression results for the Netherlands sales market using the linear model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Area (m^2)	2,800*** (440.7)
Construction Year	160*** (10.14)
Energy label	− 2,400*** *deficit* (− 8.362)
Intercept	− 400,000*** (− 12.39)
Regression and Sample Statistics	
Adjusted R^2	0.565894
Sample size	150323
Average price of a dwelling (€)	294,728.50
Surplus as a percentage of average price (%, 2sf)	− 0.81

Table 21: Regression results for the Netherlands rental market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Area (m^2)	12*** (77.07)
Construction Year	− 1.00** (− 2.741)
A	110* (2.494)
B	130** (3.023)
C	33 (0.8168)
D	*Hold out*
E	190*** (4.111)
F	480*** (8.971)
G	440*** (9.595)
Intercept	1,700* (2.335)
Regression and Sample Statistics	
Adjusted R^2	0.582352
Sample size	5263
Average rent of a dwelling (€/month)	1,316.17

Table 22: Regression results for the Netherlands rental market using the linear model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Area (m^2)	13*** (80.01)
Construction Year	− 1.50*** (− 3.945)
Energy label	− 53*** *deficit* (− 7.967)
Intercept	2,600*** (3.390)
Regression and Sample Statistics	
Adjusted R^2	0.573943
Sample size	5263
Average price of a dwelling (€/month)	1,316.17
Surplus as a percentage of average price (%, 2sf)	− 4.0

3.8.3 Observations

3.8.3.1 Sales market observations

The results for the sales market in the Netherlands are mixed across the EPC scale. The expected surplus due to EPC rating is observed in the following adjacent letter shifts: G to F, E to D, C to B and B to A. However, the shifts from F to E and D to C display relatively strong deficits. This suggests that if a surplus does exist in this market, the results have been distorted by another effect or characteristic that is not accounted for in the model. The fact that the deficits are observed for specific shifts, rather than across the whole scale, implies that the effect relates to dwellings within these bands, either in general in the Netherlands housing market or within the sample. It should also be noted that whilst the adjusted R^2 value indicates that the model is little over 56% described, this is one of the highest observed values among this studies' results. This would suggest that the causes of the unexpected results are at least in part specific to the Netherlands and cannot be fully described by the same omitted variable bias affecting the other countries' results.

A linear model was also run to establish whether the surplus or deficit effect is dominant across the sample. A statistically significant deficit is observed. This is not a surprising result given the relative magnitudes observed for the dummy variable coefficients in the earlier model. The models also indicate a positive price contribution of both construction year and area.

3.8.3.2 Rental market observations

The results for the rental market are also mixed, with surpluses being observed for the following shifts: G to F and C to B. No significant result was observed for the shift from D to C and all of the other shifts displayed deficits. The linear model was run and displayed an overall deficit. The fact that such unexpected and mixed results were also observed in the rental market further indicates a lack of both information and understanding in the Dutch datasets.

The area coefficient for the rental market was positive as expected. However, the construction year coefficient was negative, despite the fact that the coefficient for the sales market is positive. This is unexpected, given the fact that the sign of the coefficient for this variable has been observed to be consistent between rental and sales results for other countries. However, it is possible that negative quality characteristics that cause a positive relationship for the sales markets is less prevalent in the rental markets, where tenants are not expected to bear the costs of maintenance and repair. In this case, aesthetic considerations may dominate in favour of older buildings.

3.9 Norway

3.9.1 National EPC scheme

As a member of the European Economic Area (EEA) but not the EU, Norway is only obliged to transpose and implement the initial 2002 EPBD Directive. This is because the 2010 EPBD recast was not included in the Agreement on the EEA (CA EPBD 2016). The 2002 Directive was fully implemented by 2013 and the 2010 Directive has since been used as a guide for policy formation. Current Norwegian legislation requires EPCs to be displayed at the point of marketing, as is specified in the 2010 EPBD recast; however, it is possible to supply it in its shortened form. In addition, the legislation exceeds the requirements of the Directive by stating that all dwellings must acquire an EPC. An energy grade is given on the EPC according to the calculated energy needs, which ranges from A (lowest energy needs) to G (highest energy needs). New buildings that meet - but do not exceed – requirements, are usually given a C rating (CA EPBD 2016). Given the requirement for all dwellings to be certified, the percentage of the building stock with valid EPCs is relatively high. In 2012, it was estimated to be 75% (CA EPBD 2016b).

3.9.2 Regression results

EPC class distributions in the sample:

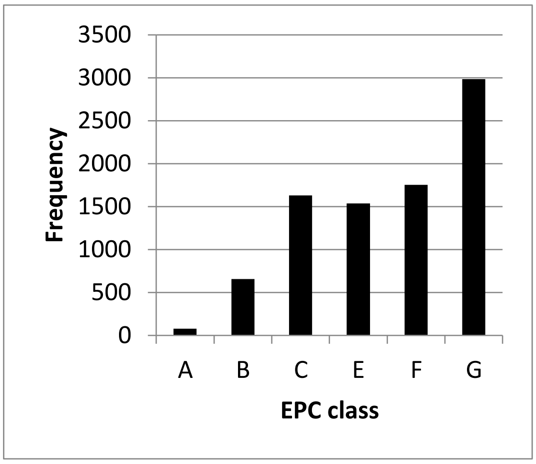

Figure 18: Bar chart of the distribution of EPC classes in the Norwegian sales market sample

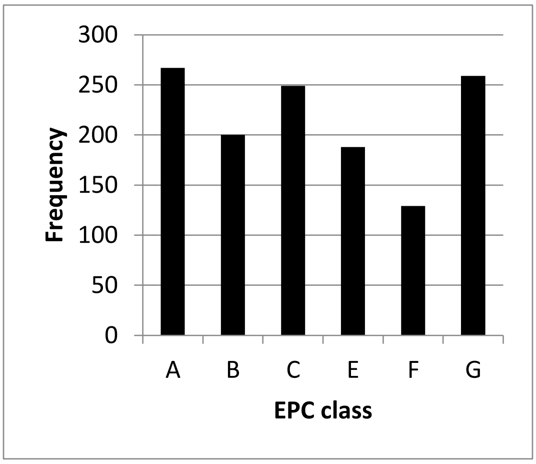

Figure 19: Bar chart of the distribution of EPC classes in the Norwegian rental market sample

Table 23: Regression results for the Norwegian sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (kr)	Price Contribution (€)
Area (m^2)	17,000*** (60.12)	1,800***
A	940,000*** (4.152)	100,000***
B	430,000*** (4.710)	46,000***
C	260,000*** (3.718)	28,000***
D	*Hold out*	*Hold out*
E	− 450,000*** (− 6.303)	− 49,000
F	− 560,000*** (− 8.212)	− 60,000
G	− 480,000*** (− 7.787)	− 52,000
Intercept	1,300,000*** (22.66)	140,000
Regression and Sample Statistics		
Adjusted R^2	0.274192	
Sample size	10176	
Average price of a dwelling (kr)	3,127,709.76	
Average price of a dwelling (€)	337,551.51	

Statistically significant results were not obtained for the price contribution due to EPC rating in the Norwegian rental market. As a result, these results have been omitted from the study.

3.9.3 Observations

3.9.3.1 Sales market observations

The results for the Norwegian sales market indicate the expected statistically significant surpluses due to EPC ratings for all shifts except for at the lowest end of the scale, between G- and F-rated dwellings. It is possible that the barriers to improving energy efficiency are higher, or perceived to be higher, for the least efficient dwellings. However this effect has not been observed for other countries. Data on the construction year was not available. However, the area variable displays a positive correlation with price.

3.10 Slovakia

3.10.1 National EPC scheme

The Slovakian transposition of the 2002 EPBD entered into force between 2006 and 2007 and is managed on the national level. However, EPCs only started to be issued in January 2008. The calculation method of the EPC was altered in October 2009 and the template was changed in the new Decree that entered into force in January 2013, which accounted for the changes present in the 2010 EPBD recast. The current energy performance index consists of a letter-rating scale that ranges from A (most efficient) to G (least efficient) and uses a fixed value calculation method. So far, the rate of certification has been relatively low. It was estimated in 2012 that only 4% of the building stock was certified (CA EPBD 2016).

3.10.2 Regression results

EPC class distributions in the sample:

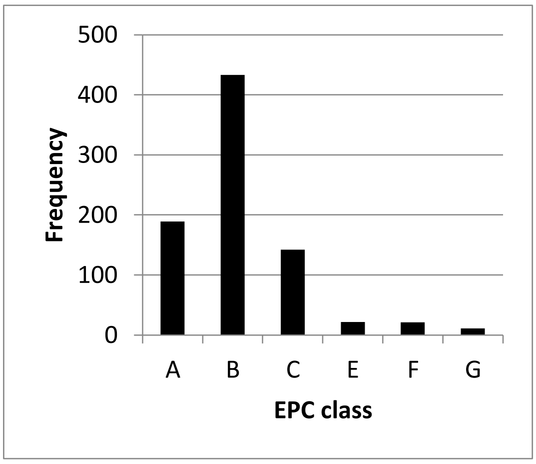

Figure 20: Bar chart of the distribution of EPC classes in the Slovakian sales market sample

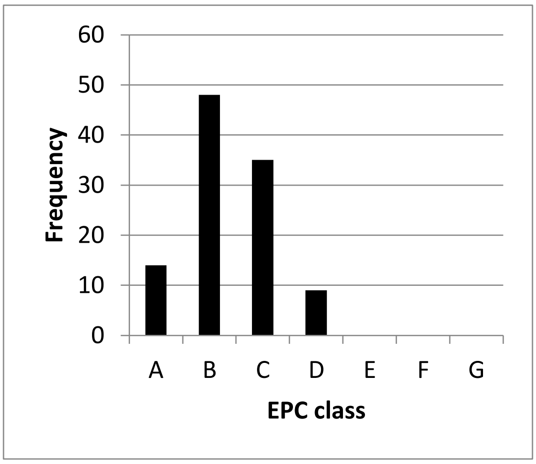

Figure 21: Bar chart of the distribution of EPC classes in the Slovakian rental market sample

Table 24: Regression results for the Slovakian sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Living Area (m^2)	1,100*** (22.84)
A	63,000** (3.252)
B	81,000*** (4.456)
C	23,000 (1.172)
D	*Hold out*
E, F, G	− 15,000 (− 0.6470)
Intercept	− 50,000** (− 2.742)
Regression and Sample Statistics	
Adjusted R^2	0.394425
Sample size	867
Average price of a dwelling (€)	133,866.74

Table 25: Regression results for the Slovakian sales market using the linear model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Living Area (m^2)	1,100*** (22.41)
EPC rating	22,000*** *surplus* (6.304)
Intercept	59,000*** (5.629)
Regression and Sample Statistics	
Adjusted R^2	0.383564
Sample size	867
Average price of a dwelling (€)	133,866.74
Surplus as a percentage of average price (%, 2sf)	16

The dataset for the rental market was too small and limited to carry out meaningful analysis.

3.10.3 Observations

3.10.3.1 Sales market observations

Significant results were only found for the A and B EPC categories in the results of the dummy variable model analysis of the sales data. However, whilst both show a price surplus relative to the D hold-out category, the shift between them (from B to A) indicates a price deficit. This effect has been observed between the top two EPC categories for other countries; however, the lack of meaningful results in the other categories makes it difficult to ascertain whether or not a surplus exists across the lower part of the scale. A linear model was therefore also run. The results from this model show a statistically significant surplus, which supports the hypothesis that a surplus exists across the scale, other than at the highest end where a deficit has been observed. As with the results in other countries, the expected surplus due to area was also observed.

3.11 Spain

3.11.1 National EPC scheme

Energy certification for buildings in Spain dates back to 2002, when a number of different methodologies were used to assess the energy performance of new buildings. In order to transpose the 2002 EPBD, a national Decree was issued in 2007 that required the use of a newly developed simulation and evaluation tool in the certification process. Until 2013, certification was only required for new buildings. This was updated by a new Decree that fully transposed the 2010 EPBD recast and included the need to certify existing buildings prior to sale or rental transactions. Whilst the EPC policy is formulated on the national level, registration and quality control come under regional jurisdiction (CA EPBD 2016). The energy efficiency index used in Spanish EPCs reports energy consumption in kWh/m^2yr and matches this to its corresponding letter on a fixed-value scale that is determined by a reference building. This scale ranges from A (most efficient) to G (least efficient). Data on the proportion of the building stock that is currently certified is not available; however, proportions of EPCs among the regions have been published and show an imbalance in activity (CA EPBD 2016).

A lack of publicly available information has made the analysis of the effect of EPCs on the Spanish housing market difficult in the past. In particular, the most recent and prominent hedonic study uses proxy data to estimate EPCs (de Ayala et al. 2016)**.** The results in the current study therefore represent a significant contribution to this field of research in Spain.

3.11.2 Regression results

EPC class distributions in the sample:

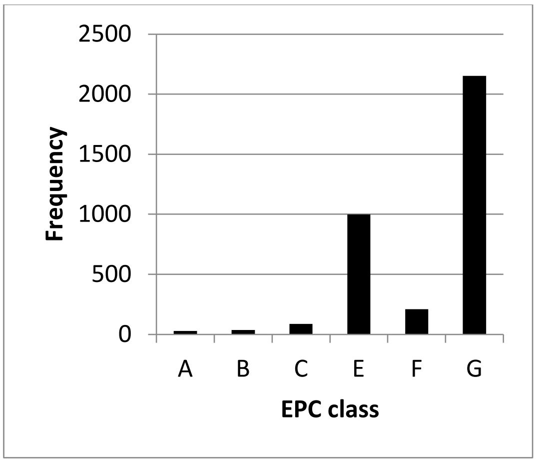

Figure 22: Bar chart of the distribution of EPC classes in the Spanish sales market sample

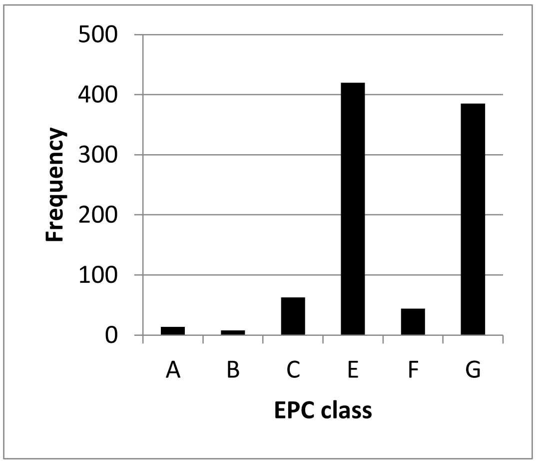

Figure 23: Bar chart of the distribution of EPC classes in the Spanish rental market sample

Table 26: Regression results for the Spanish sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Area (m^2)	3,100*** (53.51)
Construction Year	− 710*** (− 5.267)
A, B	130,000*** (4.315)
C	160,000*** (5.734)
D	*Hold out*
E	− 55,000*** (− 3.341)
F	− 92,000*** (− 4.353)
G	− 190,000*** (− 12.11)
Intercept	1,400,000*** (5.344)
Regression and Sample Statistics	
Adjusted R^2	0.491028
Sample size	3719
Average price of a dwelling (€)	251,843.67

Table 27: Regression results for the Spanish rental market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Area (m^2)	9.40*** (19.94)
Construction Year	− 0.45 (− 0.9077)
A, B, C	130 (0.9620)
D	*Hold out*
E	110 (0.9620)
F, G	− 530 (− 4.673)
Intercept	1,100 (1.131)
Regression and Sample Statistics	
Adjusted R^2	0.328465
Sample size	978
Average price of a dwelling (€/month)	968.24

Table 28: Regression results for the Spanish rental market using the linear model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (€)
Area (m^2)	9.30*** (19.61)
Construction Year	− 1.20** (−2.598)
EPC rating	210*** (12.44) *surplus*
Intercept	3,700*** (3.954)
Regression and Sample Statistics	
Adjusted R^2	0.318142
Sample size	978
Average price of a dwelling (€/month)	968.24
Surplus as a percentage of average price (%, 2sf)	22

3.11.3 Observations

3.11.3.1 Sales market observations

The results for the Spanish sales market confirm the predicted surplus due to EPC rating for the range: C-G. Insufficient data was available to distinguish between A- and B-rated dwellings. However the shift from C to A/B exhibits a price deficit, as observed at the higher end of the scale in other countries. A surplus was also observed due to area and a deficit was observed due to construction year.

3.11.3.2 Rental market observations

The dummy variable model was used to analyse the Spanish rental market. However, no significant results were found for the EPC-rating coefficients. The linear model was also run and this gave a statistically significant surplus averaged across the EPC scale. The existence of a surplus in the market can therefore be deduced; however, the pattern of this surplus across the EPC scale cannot be analysed. The results show a positive price relationship and a negative price relationship for area and construction year respectively. The latter is consistent with results in the sales market.

3.12 Sweden

3.12.1 National EPC scheme

EPC transposition and implementation takes place on a national level in Sweden. The original transposition took the form of an amendment to existing regulations, which were further updated in 2009 and 2012 to account for the requirements in the EPBD recast. The National Board of Housing, Building and Planning is responsible for supervising and controlling the EPC system and the national EPC database, the latter of which includes an online service where all EPC ratings are can be obtained through the address of the dwelling (CA EPBD 2016).

A new rating system using letter-classes entered into force in 2014, with the scale ranging from A (most efficient) to G (least efficient). The top of the C band represents the minimum rating permitted for new buildings. The other classes are then determined by the calculated final energy of a building as a percentage of the minimum requirements for new buildings (CA EPBD 2016). In 2012, it was calculated that 20% of the building stock had obtained an EPC (CA EPBD 2016b).

3.12.2 Regression results

EPC class distributions in the sample:

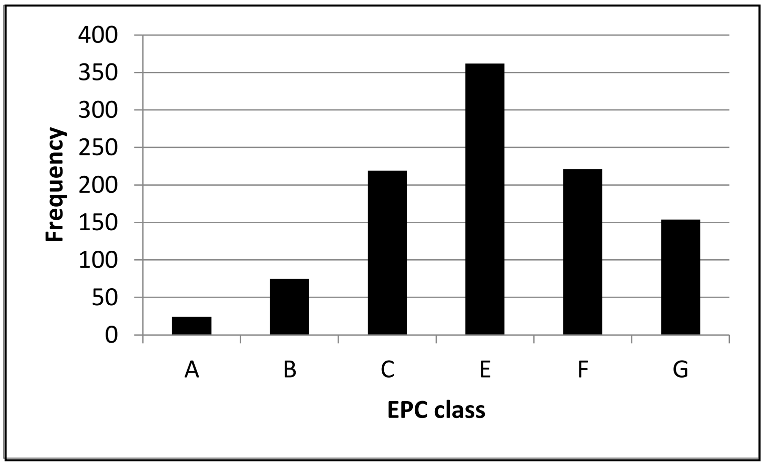

Figure 24: Bar chart of the distribution of EPC classes in the Swedish sales market sample

Table 29: Regression results for the Sweden sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (kr)	Price Contribution (€)
Area (m^2)	8,600*** (12.54)	930***
A, B	− 670,000** (− 2.715)	− 72,000**
C	− 41,000 (0.2217)	− 4,400
D	*Hold out*	*Hold out*
E	− 400,000* (− 2.441)	− 43,000*
F	− 500,000** (− 2.690)	− 54,000**
G	− 670,000** (−3.152)	− 72,000**
Intercept	1,900,000*** (12.10)	− 200,000***

Regression and Sample Statistics	
Adjusted R^2	0.115560
Sample size	1416
Average price of a dwelling (kr)	2,844,574.31
Average price of a dwelling (€)	306,546.20

Table 30: Regression results for the Sweden sales market using the linear model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (kr)	Price Contribution (€)
Area (m^2)	8,500*** (12.46)	920***
EPC rating	90,000* (2.190) *surplus*	9,700*
Intercept	2,000,000*** (8.515)	220,000***

Regression and Sample Statistics	
Adjusted R^2	0.108788
Sample size	1416
Average price of a dwelling (kr)	2,844,574.31
Average price of a dwelling (€)	306,546.20
Surplus as a percentage of average price (%, 2sf)	3.2

Rental data was not obtained and therefore results on the rental market are not included in the study

3.12.3 Observations

3.12.3.1 Sales market observations

Significant surpluses are observed for categories below the ‘hold out’ category, D, in the dummy variable model results. However, the only significant shift above the hold out category relates to a significant deficit. A linear model was therefore run to ascertain whether the surplus or deficit effect dominates when averaged over the scale. The results in table 29 show that the former effect is dominant. Both sets of results show a significant surplus due to area, as expected

3.13 United Kingdom

3.13.1 National EPC scheme

The UK is made up of four jurisdictions: England, Northern Ireland, Scotland and Wales. The transposition and implementation of the EPBD is managed independently in each of the jurisdictions as a result of power devolution. However, before to 31 December 2011 (CA EPBD 2016), the devolution of powers agreement between England and Wales did not include building regulations. As a result, England and Wales were governed by the same EPC regulations before the EPBD recast. However, despite the fact that the EPBD recast has been transposed and implemented separately by each jurisdiction, all of the jurisdictions follow the same UK Standard Assessment Procedure (SAP) to calculate EPC ratings. Furthermore the regulations governing the advertisement and scope of EPCs are broadly consistent (BPIE 2016)**.** As a result, a mixed dataset of dwellings from the UK can be used without the need to treat each of the jurisdictions separately. Nevertheless, as is the case with other countries that formulate EPC legislation on a regional level, the staggered rate of implementation of regulations must be taken into consideration. In the case of the UK, new regulations due to the EPBD were implemented at a staggered rate between 2012 and 2014 across the jurisdictions (BPIE 2016).

The SAP uses a fixed-value measurement approach. The energy efficiency index provided in the EPC displays the level of energy efficiency of a dwelling as a numerical rating between 0 and 100, with 100 representing the highest possible energy efficiency and 0 representing the lowest. These numerical values are then matched to letter-bands, which range from A to G. In addition to the current ratings, potential ratings are displayed to reflect the improvements that would likely arise if renovation recommendations were acted upon (CA EPBD 2016).

3.13.2 Regression results

EPC class distributions in the sample:

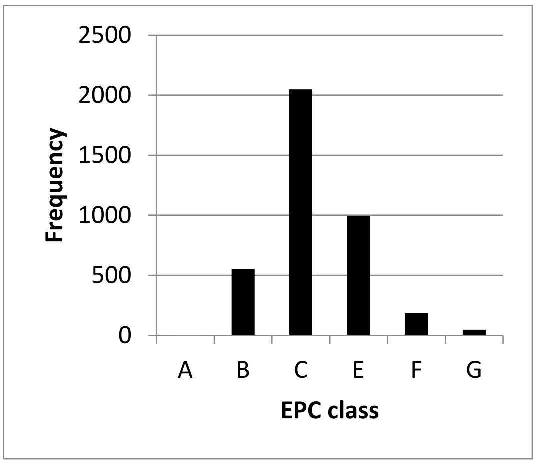

Figure 25: Bar chart of the distribution of EPC classes in the UK sales market sample

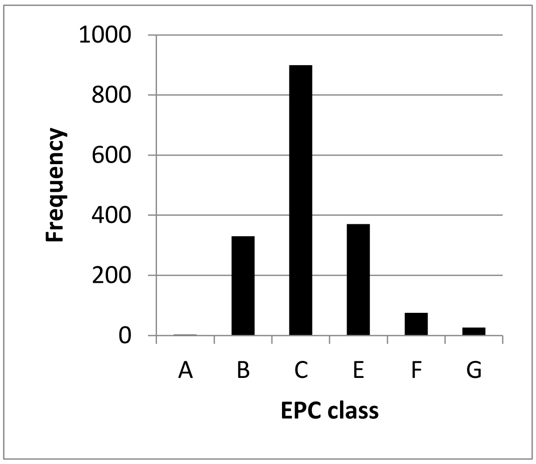

Figure 26: Bar chart of the distribution of EPC classes in the UK rental market sample

Table 31: Regression results for the UK sales market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (£)	Price Contribution (€)
Area (m^2)	8,500*** (67.61)	11,000***
A, B	95,000*** (3.529)	120,000***
C	56,000** (3.229)	74,000***
D	*Hold out*	*Hold out*
E	− 23,000 (− 1.043)	− 30,000
F	− 15,000 (− 0.3535)	− 20,000
G	− 59,000 (− 0.7087)	− 78,000
Intercept	− 35,000* (− 2.142)	− 46,000*

Regression and Sample Statistics	
Adjusted R^2	0.430918
Sample size	6148
Average price of a dwelling (£)	743,417.13
Average price of a dwelling (€)	977,977.12

Table 32: Regression results for the UK rental market using the dummy variable model. P-values are given using the code in table 3 and t-statistics are given in parentheses

Variable	Price Contribution (£)	Price Contribution (€)
Area (m^2)	5.60*** (45.90)	7.40***
A, B	− 37 (− 1.455)	− 49
C	− 13 (− 0.7109)	− 17
D	*Hold out*	*Hold out*
E	− 81*** (− 3.295)	− 110***
F,G	− 51 (− 1.225)	− 67
Intercept	170*** (10.01)	220

Regression and Sample Statistics	
Adjusted R^2	0.450810
Sample size	2608
Average rent of a dwelling (£/month)	608.10
Average rent of a dwelling (€/month)	799.97

3.13.3 Observations

3.13.3.1 Sales market observations

The UK sales market demonstrates a price surplus above the 'hold out' category. However, the results for E- and F-rated EPCs are not significant and hence conclusions can only be made for the higher end of the scale. Data was not available for the construction year of the dwellings in the data set; however, the area variable correlates positively with price as expected.

3.13.3.2 Rental market observations

The results for the UK rental market are statistically weak, since only one of the EPC coefficients was found to be statistically significant. However, this result, which reflects the presence of a price discount in the shift between D- and E-rated dwellings, is consistent with the hypothesis. In addition, the positive area coefficient confirms expectations. The results for the linear model for the UK market are not statistically significant.

4 Discussion

Cross-country comparisons must be made with caution, given the different EPC systems, as well as the fact that each country has a distinct housing market. In addition, the quality and size of samples vary between the analysed countries. Bearing in mind these limitations, the results for each of the analysed markets are presented together in table 33, with surpluses given as percentage values of the average dwelling price in each of the samples. These percentage values are therefore estimations of the added value of a dwelling due to any one-letter improvement. The adjusted R^2 values are also given, as these give an indication of how well described the models are. The surplus values used to calculate the percentages were derived using the linear variable model. In cases where the linear variable model was not presented in the main body of the text, the results can be found in appendix 3.

Table 33: Sales and rental surpluses given as percentages of average dwelling prices in the respective samples of each of the analysed countries. The linear model was used to calculate the surpluses in each case

Country	Sales surplus		Rental surplus	
	% value	Adjusted R^2	% value	Adjusted R^2
Austria	18	0.280480	5.2	0.747323
Czech Republic	11	0.256793	4.0	0.335202
Denmark	13	0.191310	5.1	0.342421
France	9.0	0.327088	2.0	0.072216
Germany (pre-2014 EPC) [4]	0.60	0.203651	−3.2	0.300827
Germany (post-2014 EPC)	7.9	0.111914	4.4	0. 317947
Luxembourg[4]	2.6	0.351598	0.084	0.310141
The Netherlands	−0.81	0.565894	−4.0	0.573943
Norway	6.4	0.270419	-	-
Slovakia	16	0.383564	-	-
Spain	27	0.486787	22	0.318142
Sweden	3.2	0.108788	-	-
United Kingdom	4.8	0.430918	-	-

[4] For countries with linear rating systems, surpluses are given for a 50-point improvement, as this is the averaged equivalent of the post-2014 letter classes. It is also fairly typical for other national systems.

The first observation that can be made from table 33 is that the alternative hypothesis for the second research question can be accepted for all countries where the rental and sales markets were analysed. This is the hypothesis that the surplus for sales markets is greater than for rental markets due to the split incentive dilemma. The decision to reject the null hypothesis is less clear for the case of the Netherlands, since both markets display deficits. However, it can be argued that the fact that the rental market deficit is greater than the sales market deficit is consistent with the hypothesis, as it can also be explained by the split incentive dilemma.

The closest literature comparison that can be made to these results is the DG Energy commissioned study that was outlined in detail in the literature review (Bio Intelligence Service et al. 2013). The highest estimated surpluses in this study, which are given in table 1, are 10-11% for the sales market and 4.4% for the rental market. These results are similarly limited due to poor data and omitted variables; however, they give a rough guide as to the order of magnitude that should be expected for the surpluses in this study. Using these maximum values as a guide, it is possible that the results for the sales markets in Austria, Slovakia and Spain have been inflated by omitted variables, as well as the results for the Spanish rental market. Furthermore, such high surplus values appear to be inconsistent with survey results, which have found EPC ratings to be *“only a minor purchasing criterion”* (Amecke 2012, 4).

Omitted variables - such as location and quality - have different effects on the final surplus results depending on the level of correlation with the variable of interest. For example, if a variable is highly positively correlated with energy efficiency, and is not included in the dataset, then the surplus due to this variable will be partly included in the energy efficiency surplus. In this study, location and quality are the most important omitted variables. Location is particularly significant as the housing market can vary between urban and rural locations, making it a potentially *“significant source of unobserved heterogeneity”* (Fuerst et al. 2015, 147). In addition, quality is likely to be highly correlated with energy efficiency, but categorisation is very subjective, making it a difficult variable to include in regression models. The adjusted R^2 values in table 33 give an indication of the number of significant variables that have been omitted, which are greater for results with lower adjusted R^2 values. However, the impact that these omitted variables have on the energy efficiency surplus depends on the level to which they are correlated with it, which cannot be tested statistically since the data for these variables is not available.

An unexpected pattern was observed in a number of the dummy variable regression results in this study. This was the pattern of a price deficit for the highest adjacent letter shift in the EPC scale, which is present in the results for the following markets:

- Austria sales market
- Denmark sales market
- The Netherlands rental market
- Slovakia sales market
- Spain sales market

Deficits observed for highly efficient dwellings in the analysed literature have been attributed to a perception of high maintenance costs (de Ayala et al. 2016) (Yoshida and Sugiura 2010). However, given the fact that dwellings in the penultimate, as well as the highest, rating class are likely to be highly energy efficient, it is unlikely that such a distinction between maintenance costs is made by prospective buyers and renters. Furthermore, the fact that the pattern was only observed for a minority of the analysed markets weakens the likelihood of perceived high maintenance costs being the causal factor of the deficits. In particular, the pattern was only observed for one rental market, despite the fact that tenants tend to bear maintenance costs. Furthermore, there is no *a priori* explanation as to why a perception of high maintenance costs for efficient products would not exist in all European markets, if it does exist in the markets that have been observed. An alternative explanation for the trend is that it results from the impact of unobserved variables, such as location. For example, it is possible that these dwellings are mostly found in rural areas where dwelling prices are cheaper. In addition, it is possible that the highest rating class is under-represented in the sample. Further investigation is needed to identify which of these explanations is the most likely cause for the observed deficits.

The country with the most unexpected results in this study is the Netherlands, for which deficits were observed for both the sales and rental markets. Hedonic studies that have previously been carried out in the Netherlands have reported surpluses due to EPC rating. However, these studies also provide evidence that suggests that the Netherlands struggled to implement the transposition of the 2002 EPBD (Brounen and Kok 2011) (Murphy 2013). In particular, it has been reported that implementation levels greatly decreased after an initially strong uptake of the EPC scheme. A key reason for this downward pattern in implementation that is stated in both studies was a lack of trust due to a negative press reception of the scheme. However, the new web-based version of the EPC that was developed for the implementation of the 2010 EPBD recast has led to a sharp increase in certification frequency. Furthermore, lack of trust and low implementation are issues that have been faced by many countries since the EPBD was first created in 2002 and all hedonic studies carried out on the EPC scheme have reported statistically significant surpluses due to EPCs. For these reasons, omitted variables such as quality and location are more likely to be the cause of the unexpected deficits. Further investigation into the causes would have to expand the scope of the model to include these variables. In particular, the study carried out by Brounen and Kok includes variables for dwelling quality characteristics, dwelling type and neighbourhood properties (Brounen and Kok 2011).

In addition to omitted variables, dataset quality can be affected by the quality of data inputting for the real estate websites. In particular, multiple cases are observed where fields are omitted in the data inputting for a dwelling. In addition, different agencies use different definitions for certain variables, such as the number of rooms and the liveable area of a dwelling. The extent to which datasets are consistent in these fields for a given estate agency depends on the training level of the agents, as well as the level to which these variables are well defined by the agency. When they are not well defined, subjective choices have to made, such as what constitutes a half-room and whether outdoor space should be included in the liveable area category. In addition to this, the quality and accuracy of EPC ratings depends on the personnel requirements, which are defined nationally. Qualified professionals are required in all cases; however, specialist training is not always needed (CA EPBD 2016).

To conclude, the results of this study confirm the alternative hypotheses for most markets. In cases where unexpected results are observed, which contradict these hypotheses, omitted variables such as location and quality are the most likely causal factors. In addition, certain markets confirm the alternative hypotheses but also display surpluses that are around two times the size given in most literature studies. These cases are most likely caused by the omission of positively correlated variables.

5 Conclusions and recommendations

This study has contributed to a small but growing field of hedonic analyses into the extent to which the EPC scheme has been capitalised in European housing markets. In particular, it has confirmed the existence of price surpluses in all but one of the analysed markets, and has also demonstrated the effect of the split incentive dilemma in these markets, which is the most likely cause for the observed discrepancy between sales and rental surpluses.

In order to increase the scope of this analysis, further investigations should aim to increase the number of explanatory variables used in the regression. In particular variables relating to location and quality are likely to greatly decrease the impact of omitted variable bias. However, difficulties can still arise in deciding how best to include these variables. For the location variable, it must be decided whether types of locations are categorised according to the level of urbanity and if so, how many different categories should be defined. Alternatively, different dummy variables can be made for different areas; however, this could decrease the extent to which results can be generalised when separate surpluses are given for different locations with similar characteristics. In addition, quality variables are difficult to include, since data relating to the quality of dwellings are likely to be highly subjective. If a more comprehensive model was achieved including these additional variables, closer analyses could be made. For example, if omitted variable bias is reduced sufficiently, cross-country comparisons can be made that investigate why surpluses are bigger in certain countries or regions. This would strengthen the evaluation of the EPC scheme, as it would be possible to identify market factors that lead to greater capitalization of energy efficiency.

The main EPC policy objective is to increase the extent to which energy efficiency is incorporated into decision-making in the housing market. The success of this aim can be measured through periodic hedonic analyses that, like this study, measure the level of capitalisation of energy efficiency in the market. As has been shown by this study, as well as in the literature, such hedonic analyses are greatly limited by data constraints. In order for the European Commission DG Energy to measure the success of the scheme to a greater level of accuracy and precision, member states should be encouraged to collect and share data for important characteristic variables in addition to EPC ratings. Furthermore, a process of regularly commissioned hedonic analyses, such as the study carried out in 2013 (Bio Intelligence Service et al. 2013), is recommended.

A key observation in the literature that has been confirmed for a wider number of countries in this study is the existence of a greater surplus for sales transactions than rental transactions. Given the significant proportion of tenants as opposed to home-owners in most of the analysed countries, true market transformation to account for energy efficiency should include measures to tackle this. The key reason given for the existence of the discrepancy in the surpluses between the two markets is the fact that landlords do not usually bear the costs of maintenance. Policies that provide incentives for landlords to invest in energy efficient improvements, such as subsidy schemes, could increase the surplus in the rental market and aid market transformation towards more efficient buildings. However, a negative consequence of such measures would be a strengthening of the energy poverty effect, whereby energy efficient dwellings can only be accessed by richer tenants and home-owners.

A key limitation with current EPC schemes is the lack of financial estimates for recommended home improvements. This leads to a further information barrier, in which home-owners are unable to weigh up the costs of making improvements on a home against the increased value of the dwelling. In addition, financial forecasts for the time frame in which home-owners can expect to see returns as well as the expected surplus that will result from specific improvements would further decrease imperfect information. Measures taken to improve access to information in this field would likely increase the level of capitalisation of energy efficiency due to the further breakdown of this market barrier.

To conclude, this thesis has demonstrated the existence of a price surplus due to energy efficiency in all but one of the countries analysed. In addition, in cases where sufficient data on the rental sector was available, an increased surplus for the sales sector was observed. However, the accuracy of the surplus values is restricted by limited datasets that cause omitted variable bias. As a result, quantitative cross-country comparisons could not be made. Nonetheless, areas for further research have been presented that would enable regular and increasingly accurate evaluations of the EPC scheme. In addition, issues have been identified with the current EPC regulations, such as the fact that the scheme does not fully break down the imperfect information market barrier, or account for the split incentive dilemma. Preliminary suggestions have been made for the improvement of the Directive’s requirements in these areas, which could either be enacted voluntarily on a national model or through the expected recast of the EPBD on the European Union level in 2017/2018.

Bibliography

Addae-Dapaah K., Chieh S. J. “Green Market Certification: Does the market understand?” *Journal of Sustainable Real Estate* 3, no.1, (2011): 162-191.

Ayala A. de, Galarraga I., and Spadaro J. “The price of energy efficiency in the Spanish housing market.” *Energy Policy* 94, (2016): 16-24.

Amecke, Hermann. “The impact of energy performance certificates: A survey of German home owners.” *Energy Policy* 46, (2012): 4-14.

Australian Bureau of Statistics. “Energy efficiency rating and house price in the ACT.” Report for Department of the Environment, Water, Heritage and Arts, Canberra: ABS, 2008.

Backhaus J., Tigchelaar C., and de Best-Waldhober M. *Key findings & policy recommendations to improve effectiveness of Energy Performance Certificates & the Energy Performance of Buildings Directive*. Report for the IDEAL EPBD project, Petten: Energy research Centre of the Netherlands, 2011.

Bio Intelligence Service, Lyons R., IEEP. *Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries.* Final Report prepared for European Commission DG Energy, Brussels: European Commission DG Energy, 2013.

Bird S., and Hernández D., “Policy options for the split incentive: Increasing energy efficiency for low income renters.” *Energy Policy* 48, (2012):506-514

Bloom B., Nobe M.C., and Nobe M.D. “Valuing green home designs: A study of ENERGY STAR® homes.” *Journal of Sustainable Real Estate* 3, no. 1, (2011): 109-126.

Brounen D. and Kok N. “On the economics of energy labels in the housing market.” *Journal of Environmental Economics and Management* 62, (2011): 166-179.

BPIE. *Data Hub.* 2016. http://www.buildingsdata.eu/ (accessed 03/06/2016).

BPIE. *Europe's buildings under the microscope: a country-by-country review of the energy performance of buildings.* Research report, Brussels: BPIE, 2011.

BPIE. *Energy Performance Certificates across Europe.* Research report, Brussels, Belgium: BPIE, 2010.

CA EPBD. *2016: Implementing the Energy Performance in Buildings Directive (EPBD).* CA EPBD III, Lisbon, Portugal: CA EPBD, 2016.

—. *Implementation Indicators.* 2016b. http://www.epbd-ca.eu/countries/indicators (accessed 03/06/2016).

Cajias M., and Piazolo D. “Green performs better: energy efficiency and financial return on buildings.” *Journal of Corporate Real Estate* 15, no.1, (2013): 53-72.

Deng Y., Li Z., and Quigley J. M. “Economic returns to energy-efficient investments in the housing market: Evidence from Singapore.” Institute of Real Estate Studies Working Paper Series, Pennsylvania: Pennsylvania State University, (2010).

European Commission. *2030 Climate & Energy Framework.* 2016. http://ec.europa.eu/clima/policies/strategies/2030/index_en.htm (accessed 03/06/2016).

—. *Buildings.* 2016b. https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings (accessed 03/06/2016).

—. "Action Plan for Energy Efficiency: Realising the Potential." *EUR-Lex.* 2006. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52006DC0545 (accessed 03/06/2016).

European Commission DG Energy. "Evaluation of the Energy Performance of Buildings Directive 2010/31/EU." *European Comission.* 2015. http://ec.europa.eu/smart-regulation/roadmaps/docs/2016_ener_023_evaluation_energy_performance_of_buildings_directive_en.pdf (accessed 03/06/2016).

European Union. "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings." *EUR Lex.* 2010. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF (accessed 03/06/2016).

Fuerst F., McAllister P., Nanda A., and Wyatt P. "Energy performance ratings and house prices in Wales: An empirical study." *Energy Policy* 48, (2016): 20-33.

Fuerst F., McAllister P., Nanda A., and Wyatt P. "Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England." *Energy Economics* 92, (2015): 145-156.

Fuerst F., and McAllister P.. "The impact of Energy Performance Certificates on the rental and capital values of commercial property prices." *Energy Policy* 39, (2011): 6608-6614.

Gram-Hanssen K., Bartiaux F., Jensen O. M., and Cantaert M. "Do home owners use energy labels? A comparison between Denmark and Belgium." *Energy Policy* 35, no.5, (2007): 2879-2888.

Green, S. B. "How Many Subjects Does It Take To Do A Regression Analysis." *Multivariate Behavioural Research* 26, no. 3 (1991): 499-510.

Hyland M., Lyons R. C., and Lyons S. "The value of domestic building energy efficiency - evidence from Ireland." *Energy Economics* 40, (2013): 943-952.

IEA. *Energy Performance Certification of Buildings: A policy tool to improve energy efficiency.* Policy Pathway, Paris: OECD/IEA, 2010.

Kjaerbye V. H. "Does energy labelling on residential housing cause energy savings?" *Proceedings of ECEEE 2009 Summer Study 1-6 June 2009*, (2009): 527-37.

Kok N., and Jennen M. "The impact of energy labels and accessibility on office rents." *Energy Policy* 46 (2012): 489-497.

Kok N., and Kahn M. E. "The value of green labels in the California hounsing market: an economic analysis of the impactof green labelling on the sales price of a home." Research funded by the San Francisco Department of the Environment and stopwaste.org, 2012, http://www.pacenation.us/wp-content/uploads/2012/08/KK_Green_Homes_0719121.pdf (accessed 03/06/2016)

Lainé L. *Room for Improvement. The impact of EPCs on consumer decision-making.* Consumer Focus Report, London: Consumer Focus, 2011.

Levine M., Ürge-Vorsatz D., Blok K., Geng L., Harvey D., Lang S., Levermore G., Mongameli Mehlwana A., Mirasgedis S., Novikova A., Rilling J., and Yoshino J. *Residential and commercial buildigns in Climate Change 2007: Mitigation.* Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge, UK and New York, US: Cambridge Universtiy Press, 2007.

Murphy L. "The influence of the Energy Performance Certificate: The Dutch case." *Energy Policy* 67, (2013): 664-672.

NHER. *Energy Performance Certificates: Seizing the opportunity.* Report 1: Research into the potential impact and take up of energy efficiency improvements recommended in Energy Performance Certificates for private homes sold in England and Wales, Milton Keynes: NHER, The National Energy Centre, 2009.

Norway Mission to the EU. *Norway's climate target for 2030.* 2015. http://www.eu-norway.org/news1/Norways-climate-target-for-2030/#.Vzr3vDWLRaQ (accessed 03/06/2016).

OIB. *OIB-Richtlinien.* 2015. https://www.oib.or.at/de/oib-richtlinien (accessed 03/06/2016).

Rosen S. "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition." *The Journal of Political Economy* 82, no.1, (1974): 34-55.

Salvi M., Horehájová A., and Neeser J. *Der Nachhaltigkeit von Immobilien einen finanziellen Wert geben- Der Minergie- Boom unter der Lupe.* Market analysis report prepared by Zürcher Kantonalbank, Zurich: University of Zurich, Center for Corporate Responsibility and Sustainability, 2010.

Steyerberg P., Austin C., and Ewout W. "The number of subjects per variable required in linear regression analyses." *Journal of Clinical Epidemiology* 68, no. 6 (2015): 627-636.

Tigchelaar C., Backhaus J., and de Best-Waldhober M.. *Consumer response to energy labels in buildings, Recommendations to improve the Energy Performance Certificate and the Energy Performance of Buildings Directive based on research findings in 10 EU countries.* Deliverable 6 of the IDEAL EPBD project, European project on consumer response to energy labels in buildings, Brussels: IDEAL EPD, 2011.

Thermomess Wärmemessdienst AG. *Verbrauchsbasierter Energieausweis gemäß EnEV 2014 (EVA).* 2014. https://www.thermomess.de/content/03_dienstleistungen/313_beratung.php (accessed 27/05/2016).

Yoshida J., and Sugiura A.. "Which "greenness" is valued? Evidence from green condominiums in Tokyo." paper presented at Green Building Finance and Investments: Practice, Policy and Research, Maastricht University, 2010. nilskok.typepad.com/files/paper-yoshida_sugiura.pdf (accessed on 03/06/2016)

Zheng S., Wu J., Khan M. E., and Deng Y. *The nascent market for "green" real estate in Beijing.* Institute of Real Estate Studies Working Paper Series, Pennsylvania: Pennsylvania State University, 2011.

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Appendices

Appendix 1: Estate Agency data sources

Austria - immobilienscout24.at

Belgium - http://immo.vlan.be

Czech Republic - http://reality.idnes.cz

Denmark - home.dk (sales) and boligportal.dk (rents, sales)

France - http://www.leboncoin.fr/

Germany - http://immobilienscout24.de

Italy- http://www.remax.it

Luxembourg - http://immo.vlan.be

Netherlands - funda.nl

Norway - finn.no

Slovakia - zoznamrealit.sk

Spain - habitaclia.com

Sweden - http://www.blocket.se, www.husmanhagberg.se

UK- http://www.foxtons.co.uk

Appendix 2: Regression results for countries with poor datasets

For each case, only linear models are given, since the EPC results from the dummy variable model are not statistically significant and hence do not reveal any extra information.

Belgium:

Appendix table 1: Regression results for the Belgian sales market using the linear model

Variable	Price Contribution (€)
Livable surface (m^2)	720*** (40.81)
Construction Year	440*** (91.08)
Energy Consumption (Number rating)	3.60 (1.812) *surplus*
Intercept	−660,000*** (−3.670)
Regression and Sample Statistics	
Adjusted R^2	0.206584
Sample size	6412
Average price of a dwelling (€)	301,571.18

Appendix table 2: Regression results for the Belgian rental market using the linear model

Variable	Price Contribution (€)
Livable surface (m^2)	6.10*** (37.63)
Construction Year	−0.67 (−1.624)
Energy Consumption (Number rating)	0.34*** (4.498) *surplus*
Intercept	1,600 (1.899)
Regression and Sample Statistics	
Adjusted R^2	0.577205
Sample size	1053
Average rent of a dwelling (€/month)	884.59

Whilst the rental results for Belgium reveal a statistically significant surplus, it was decided that the dataset was of insufficient quality to be included with the other results in the main body of the text. This is because the only value given for energy performance is a measurement of energy consumption, despite the fact that the three regions in Belgium all use different rating systems and indices for energy performance, which were not included in the dataset

Italy:

Appendix table 3: Regression results for the Italian sales market using the linear model

Variable	Price Contribution (€)
Area (m^2)	5,800*** (66.85)
EPC Rating	−13,000 (−1.712) *deficit*
Intercept	−580,000*** (−11.35)
Regression and Sample Statistics	
Adjusted R^2	0.237890
Sample size	14321
Average price of a dwelling (€)	296,981.46

Appendix table 4: Regression results for the Italian rental market using the linear model

Variable	Price Contribution (€)
Area (m^2)	11 (1.645)
EPC Rating	−240 (−1.047) *deficit*
Intercept	−1,300 (−0.7422)
Regression and Sample Statistics	
Adjusted R^2	0.001117
Sample size	1618
Average rent of a dwelling (€/month)	1,352.15

The results for Italy were not included in the main body of the text. This is due to the fact that neither the sales nor rental market datasets yielded statistically significant results. In addition, the adjusted R^2 value for the Italian rental market is incredibly low, suggesting that less than 1% of this market is described by the model.

Appendix 3: Linear model regression results

Linear model regression results have already presented for the following markets:

- Czech Republic: rental market (chapter 3.3.2)
- Germany: sales market pre-2014 EPC system (chapter 3.6.2), rental market pre-2014 EPC system (chapter 3.6.2)
- Luxembourg: sales market (chapter 3.7.2) and rental market (chapter 3.7.2)
- Netherlands: sales market (chapter 3.8.2) and rental market (chapter 3.8.2)
- Slovakia: sales market (chapter 3.10.2)
- Spain: rental market (3.11.2)

The results for markets that are not included in the main body of the study are presented below, with the exception of markets in which no significant results were found for this model. The latter have been left out, since the purpose of this appendix is to use the results to present the average surpluses as percentages of average dwelling prices in Chapter 4. In cases where the average surplus is not statistically significant, no extra information has been gained (in addition to the dummy variable model results in the main body) and a significant average percentage surplus cannot be presented.

Austria:

Appendix table 5: Regression results for the Austrian sales market using the linear model

Variable	Price Contribution (€)
Total Area (m^2)	3,000*** (52.74)
Construction Year	− 340*** (− 3.173)
EPC rating	72,000*** (17.33) *surplus*
Intercept	1,100,000*** (4.810)
Regression and Sample Statistics	
Adjusted R^2	0.280480
Sample size	7335
Average price of a dwelling (€)	395,016.90
Surplus as a percentage of average price (%, 2sf)	18

Appendix table 6: Regression results for the Austrian rental market using the linear model

Variable	Price Contribution (€)
Total Area (m^2)	16*** (90.52)
Construction Year	− 0.94*** (− 6.432)
EPC rating	71*** (8.392) *surplus*
Intercept	2,000*** (6.404)
Regression and Sample Statistics	
Adjusted R^2	0.747323
Sample size	3023
Average price of a dwelling (€/month)	1,361.44
Surplus as a percentage of average price (%, 2sf)	5.2

Czech Republic:

Appendix table 7: Regression results for the Czech sales market using the linear model

Variable	Price Contribution (Kč)	Price Contribution (€)
Useable Area (m^2)	14,000*** (43.18)	520***
Construction Year	12,000*** (6.860)	440***
EPC Rating	410,000*** (21.02) *surplus*	15,000***
Intercept	−21,000,000*** (−5.773)	−780,000
Regression and Sample Statistics		
Adjusted R^2	0.256793	
Sample size	6322	
Average price of a dwelling (Kč)	3,590,628.34	
Average price of a dwelling (€)	132,831.70	
Surplus as a percentage of average price (%, 2sf)	11	

Denmark:

Appendix table 8: Regression results for the Danish sales market using the linear model

Variable	Price Contribution (kr.)	Price Contribution (€)
Area (m^2)	12,000*** (35.32)	1600***
EPC rating	290,000*** (22.76) *surplus*	39,000***
Intercept	2,200,000*** (23.03)	300,000***
Regression and Sample Statistics		
Adjusted R^2	0.191310	
Sample size	7449	
Average price of a dwelling (kr.)	2,162,898.25	
Average price of a dwelling (€)	294,359.42	
Surplus as a percentage of average price (%, 2sf)	13	

Appendix table 9: Regression results for the Danish rental market using the linear model

Variable	Price Contribution (kr.)	Price Contribution (€)
Area (m^2)	45*** (21.80)	6.10***
EPC rating	370*** (5.317) *surplus*	50***
Intercept	4,800*** (11.48)	650***
Regression and Sample Statistics		
Adjusted R^2	0.342421	
Sample size	947	
Average rent of a dwelling (kr.)	7240.57	
Average rent of a dwelling (€/month)	985.40	
Surplus as a percentage of average price (%, 2sf)	5.1	

France:

Appendix table 10: Regression results for the French sales market using the linear model

Variable	Price Contribution (€)
Area (m^2)	1,600*** (333.8)
EPC Rating	22,000*** (82.39) *surplus*
Intercept	160,000*** (117.1)
Regression and Sample Statistics	
Adjusted R^2	0.327088
Sample size	265143
Average price of a dwelling (€)	245,545.80
Surplus as a percentage of average price (%, 2sf)	9.0

Appendix table 11: Regression results for the French rental market using the linear model

Variable	Price Contribution (€)
Area (m^2)	5.00*** (128.7)
EPC Rating	12*** (12.21) *surplus*
Intercept	360*** (71.94)
Regression and Sample Statistics	
Adjusted R^2	0.072216
Sample size	224341
Average rent of a dwelling (€/month)	589.32
Surplus as a percentage of average price (%, 2sf)	2.0

Germany:

Appendix table 12: Regression results for the German sales market using the linear model (post-2014 EPC system):

Variable	Price Contribution (€)
Number of rooms	33,000*** (52.22)
Construction Year	530*** (14.42)
Energy efficiency class	23,000*** *surplus* (29.72)
Intercept	− 830,000*** (− 10.98)
Regression and Sample Statistics	
Adjusted R^2	0.111914
Sample size	29579
Average price of a dwelling (€)	289,754.90
Surplus as a percentage of average price (%, 2sf)	7.9

Appendix table 13: Regression results for the German rental market using the linear model (post-2014 EPC system):

Variable	Price Contribution (€)
Number of rooms	270*** (48.85)
Construction Year	1.9*** (10.03)
Energy Efficiency Class	38*** *surplus* (9.911)
Intercept	− 3,400*** (− 9.105)
Regression and Sample Statistics	
Adjusted R^2	0. 317947
Sample size	6223
Average rent of a dwelling (€/month)	866.61
Surplus as a percentage of average price (%, 2sf)	4.4

Norway:

Appendix table 14: Regression results for the Norwegian sales market using the linear model

Variable	Price Contribution (kr)	Price Contribution (€)
Area (m^2)	17,000*** (59.87)	1,800***
EPC Rating	200,000*** (17.01) *surplus*	22,000***
Intercept	2,100,000*** (30.55)	230,000***
Regression and Sample Statistics		
Adjusted R^2	0.270419	
Sample size	10176	
Average price of a dwelling (kr)	3,127,709.76	
Average price of a dwelling (€)	337551.51	
Surplus as a percentage of average price (%, 2sf)	6.4	

Spain:

Appendix table 15: Regression results for the Spanish sales market using the linear model

Variable	Price Contribution (€)
Area (m^2)	3,100*** (58.04)
Construction Year	− 720*** (− 5.480)
EPC Rating	67,000*** (24.04) *surplus*
Intercept	1,720,636*** (6.649)
Regression and Sample Statistics	
Adjusted R^2	0.486787
Sample size	3719
Average price of a dwelling (€)	251,843.67
Surplus as a percentage of average price (%, 2sf)	27

United Kingdom:

Appendix table 16: Regression results for the UK sales market using the linear model

Variable	Price Contribution (£)	Price Contribution (€)
Area (m^2)	8,500*** (67.86)	11,000***
EPC Rating	36,000*** (4.899) *surplus*	47,000***
Intercept	120,000*** (4.271)	160,000***
Regression and Sample Statistics		
Adjusted R^2	0.430918	
Sample size	6148	
Average price of a dwelling (£)	743,417.13	
Average price of a dwelling (€)	977,977.12	
Surplus as a percentage of average price (%, 2sf)	4.8	