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How heterogeneous is the impact of energy efficiency on dwelling prices?

Evidence from the application of the unconditional quantile hedonic model to the Portuguese residential market[◊]

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Abstract

This paper investigates the impact of energy efficiency along the unconditional distribution of residential property prices in Portugal. Using a dataset of more than 256,000 residential property sales from 2009 to 2013, a period that covers an economic depression, unconditional quantile regression analysis reveals that the responsiveness to energy efficiency improvements is different not only as we move from low- to high-priced residential units but also for apartments and houses. While the former show a downward trend in the magnitude of energy efficiency coefficient estimates, the opposite occurs for houses. The latter market segment exhibits clear market discounts at the lowest quantiles of the price distribution, something that is not observable thought conditional mean and quantile regression analysis. Results suggest the existence of a different responsiveness to energy efficiency improvements in the Lisbon region when compared to the rest of the country and that the impact of the Energy Performance Certificate label increases throughout time across all price quantiles. As a by-product of this paper, an unconditional quantile price index shows that the impact of the crisis was not the same across the different market segments, with price decreases being more severe for low- than high-priced properties.

Keywords: *energy efficiency, residential property market, hedonic price models, conditional quantile regression, unconditional quantile regression*

JEL Classification: C21, Q41, R21, R31

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1. Introduction

The impact of energy efficiency on the price of residential properties has long been investigated though hedonic models (Rosen, 1974), where the price of the properties is regressed against a measure of energy efficiency and other price-determining property attributes. The focus of the use of this revealed preference method in this research context, for which a comprehensive survey is available in Zhang et al. (2018), has been on the quantification of the impact of energy efficiency over the conditional mean estimated by standard ordinary least squares (OLS). By and large, the overwhelming majority of the studies suggest the existence of energy efficiency price premiums associated with the Energy Performance Certification (EPC) and other different energy certification labels.

Rather than focusing on conditional mean effects, a more recent line of investigation explores the heterogeneity of the impact of dwelling characteristics across the residential property price distribution. Mak et al. (2010) and Wen et al. (2019) constitute two examples, where the impact of key price-determining attributes, such as size, age, comfort and location factors (e.g. parking facilities, access to public goods), is assessed at different points of the price distribution. Notwithstanding these recent developments, the assessment of the impact of energy efficiency at various points of the price distribution is restricted to two recent papers. While Liao and Zhao (2019) analyse the impact on transaction prices of a residential unit located in a certified (green) building in Singapore, Evangelista et al. (2020) focus on the individual residential unit certification level and provides evidence that the market reaction to the EPC label in the Portuguese market is relatively stable across the price distribution.

This strand of work is based on the application of the standard conditional quantile regression (CQR) method, which draws on the seminal paper of Koenker and Basset (1978). Liao and Zhao (2019) constitute a notable exception, where the recent unconditional quantile regression (UQR) approach proposed by Firpo (2007) is used. While conditional and unconditional quantile approaches provide valid results, it should be noted that they refer to different concepts, with the latter evaluating partial effects along a theoretical or conditional price distribution, and the former assessing the overall impact on the unconditional price distribution. To highlight the difference between these two approaches notice that, while a property with high energy efficiency may be located in the upper part of the price distribution of the properties with the same area, age and other observable characteristics, it may be located in the lower part of the overall (or unconditional) dwelling price distribution. Examples of differences in the magnitude and sign of the two types of partial effects are presented in Firpo et al. (2009).

This paper provides a comprehensive analysis of the relationship between energy efficiency and prices in the residential property market using the UQR framework. The results are based on the dataset used in Evangelista et al. (2020), which covers more than 256 thousand residential property transactions. The data largely overlaps a period in which the market was depressed and provides a rich set of information on energy efficiency and other dwelling attributes at the individual unit level. The comprehensiveness of the data benefits from the fact that EPC certification was made mandatory in all transactions in the beginning of 2009.

The paper adds to the literature in three ways. Firstly, since the impact of energy efficiency along the distribution of prices is assessed at the unit level using various aggregations of the EPC scale, it offers a much detailed analysis than the one provided by Liao and Zhao (2019), which draws its conclusions from information taken from a dichotomous energy efficiency evaluation system designed for green buildings. Secondly, the paper presents a wide range of results that investigate the potential heterogeneity of energy efficiency partial effects not only across the distribution of prices, but also according to dwelling type (apartment, house, new and existing), throughout time and in the main regions of Portugal. Finally, the paper offers the results of an unconditional quantile hedonic price index, which allows to investigate whether the depressed market conditions, impacted equally across the different price quantiles of the residential market in Portugal.

This paper is organised as follows. Section 2 reviews the literature and highlights the key aspects associated with the estimation of energy efficiency quantile partial effects. Section 3 describes the available dataset and provides an analysis of the features of the data. Section 4 presents and discusses the results. This includes not only the analysis across time and regions, but also the results of an unconditional house price index. Finally, section 5 concludes.

2. Energy efficiency quantile partial effects

The impact of energy efficiency on property prices has been essentially studied from the conditional mean perspective. However, having information on this impact across the entire spectrum of the price distribution is important not only to carry out robustness checks (e.g. comparison of mean and median values), but also to have a clearer view of the impact of energy efficiency improvements in different price market segments. In this vein, quantile regression emerges as an appropriate technique that could help providing a full picture of the impact of energy efficiency and as an important instrument for all those interested in tailoring policy measures according to the different segments of the residential property market.

2.1. Use of conditional and unconditional quantile partial effects

The literature providing evidence on residential property market attributes across the price distribution is relatively scarce, focused on small homogeneous markets, and essentially restricted to the use of the CQR framework. An earlier example is Zietz et al. (2008), who focus their analysis on a particular region of Utah, US. Further examples are given by Mak et al. (2010) and Wen et al. (2019), which address the Hong Kong and Hanzhou markets in China, respectively. Fuerst and Warren-Myers (2018) also apply conditional quantile regression models to assess the effect of energy rating non-disclosure across the price distribution of rents in the Australian Capital Territory. More recently, Evangelista et al. (2020) provide evidence on conditional quantile energy efficiency partial effects in the sales market for Portugal.

As mentioned before, the CQR framework provides a particular interpretation of quantile impact changes on the distribution of the dependent variable, as these are conditional on the values of the covariates included in the model. As highlighted by Borah and Basu (2013), this prevents the generalisation of CQR results to a policy or population context. In fact, while the OLS conditional mean partial effects can be interpreted as unconditional (or generalizable) partial effects, through the law of iterated expectations, this equality does not hold for CQR. Some applications of the application of the UQR framework are Peeters et al. (2017) and Seya et al. (2020), which deal with farmland prices in Belgium and parking lot prices in Japan. Although in a stated preference context, Lang and Lanz (2021) also make use of the unconditional quantile framework to investigate whether the tenant’s willingness to pay for energy efficiency improvements is homogeneous across the distribution of potential rent increases.

Liao and Zhao (2019) constitute the only example providing evidence on conditional and unconditional quantile energy efficiency partial effects. These authors find fundamental differences in conditional and unconditional estimates of the effect of an individual residential unit being located in a certified green building in Singapore. Two points are worthwhile to highlight in relation to this study. Firstly, given that certification is concentrated in some locations, types of properties, and developers, there was the need to address in the paper the issue of sample selection. Secondly, while the quantile evaluation is done at the residential unit level, the green certification is only captured at the aggregated building level. This fact precludes a finer investigation of the effects of energy efficiency since there is no information at the residential unit level.

In the case of Portugal, the EPC label was made obligatory to all residential market transactions in January 2009. As such, sample selection problems are avoided in this study. Moreover, the evaluation system used in Portugal and the data used in this study has information at the individual residential unit level, which allows for the exploration of the nine-level ranking scale available to evaluate energy efficiency of properties; for similar data conditions in the analysis of the effect of several levels of EPC labelling on housing transaction prices in a mandatory labelling system applied in the Australian Capital Territory, see the conditional mean models of Fuest and Warren-Myers (2018). Finally, it should be said that the present study is the first that applies the UQR framework to an entire country. Modelling this heterogeneity is a challenging issue to address, which is possible given the size and the random nature of the available dataset (see section 3 for more on the data).

2.2. Methodology and estimation strategy

The interest of the paper lies in understanding the effect of the energy efficiency (EE) on the dwelling price at the τth quantile of its distribution, $0 < \tau < 1$. Following Koenker and Basset (1978), the conditional effect of EE on the transaction price P at the τth price quantile, $\frac{dQ_\tau(P|z)}{dEE}$, $z = (EE, x)$, can be derived as the argument that minimises the following sum of weighted absolute residuals:

$$\hat{\beta}_{\tau,CQR} \equiv \arg\min_{\beta} \sum_{i=1}^{n} \rho_\tau . (P_i - z_i'\beta_\tau) \quad (1),$$

where $\rho_\tau = u_i . (\tau - \mathbb{I}\{u_i < 0\})$ corresponds to the reweighting (*alias* check) function of the residuals u_i, and $\mathbb{I}$ is an indicator function assuming the value 1 when the condition between brackets holds, and 0 otherwise. The x corresponds to the k property attributes that, in addition to EE, are included in the specification of the hedonic model establishing a functional relationship between prices and dwelling attributes. With the exception of $\tau = 0.5$, which corresponds to the least absolute deviation regression case, the reweighting of residuals by the check function is done asymmetrically for all price quantiles.

The estimation of the unconditional partial effect of EE, $\frac{dQ_\tau(P)}{dEE}$, is done using two different approaches, which depend on how energy efficiency is specified. In the first approach, when EE is defined as continuous or as assuming several discrete values, the estimation of the energy efficiency partial effect at the τth unconditional quantile is done following Firpo et al. (2009).

In this approach, the partial effect corresponds to that emerging from the OLS regression of the covariates on the (recentered) influence function of the unconditional quantile on the explanatory variables.[2] The recentered version of this function is given by:

$$RIF(P_i, Q_\tau) = \alpha_{1,\tau}\mathbb{1}\{P_i < Q_\tau\} + \alpha_{2,\tau} \quad (2),$$

where $\alpha_{1,\tau} = {}^{1}/_{f_P(Q_\tau)}$ and $\alpha_{2,\tau} = Q_\tau - (1-\tau)\alpha_{1,\tau}$, and $f_P(Q_\tau)$ is the marginal density of P, has a conditional expectation given the covariates linear on the covariates.

In the second approach, when EE is defined as a dummy variable, the estimator proposed by Firpo (2007) applies. In this case, it is assumed that the data generating mechanism of EE is governed by the set of X observable characteristics, and use an estimator based on propensity scores (Rosenbaum and Rubin, 1983), which is used to reweight the sum of check functions in Koenker and Basset's (1978) minimisation procedure presented above. In this approach, the effect of a change at the τth price quantile from 0 to 1 in EE on P, $\hat{\Delta}_\tau \equiv \hat{P}_{1,\tau} - \hat{P}_{0,\tau}$, reflects the difference between the distributions of the most and the less energy efficient transacted properties, where the $\hat{P}_{l,\tau}$, $l = (0,1)$, are obtained as:

$$\hat{P}_{l,\tau} \equiv \arg\min_{\beta} \sum_{i=1}^{n} \omega_{l,i} \cdot \rho_\tau \cdot (P_i - z_i'\beta_\tau) \quad (3),$$

where $z_i'\beta_\tau = P_{l,\tau}$ and $\hat{\omega}_{1,i}$ and $\hat{\omega}_{0,i}$ are the estimated propensity score weights, calculated as $\frac{EE_i}{n\widehat{pr}(x_i)}$ and $\frac{1-EE_i}{n(1-\widehat{pr}(x_i))}$, respectively.

The estimation followed the same baseline OLS and CQR models used in Evangelista et al. (2020) in the sense that the same x vector of hedonic covariates are applied for the estimation of the impact of energy efficiency in existing apartments, new apartments, existing houses and new houses. The description of the variables is available from the supplemental appendix to this paper. As in this work, the dependent variable is also the natural logarithm of residential property prices. However, in order to explore all levels of the EPC scale and to provide a clearer view of the impact of this label on dwelling prices, it was decided to use three different ways of incorporating the EE variable into the hedonic models.[3]

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[2] An influence function, which has an unconditional expectation of zero, is used in the literature dealing with robust statistics to assess the influence of removing or adding an observation on the value of a statistics.

[3] In Portugal, the EPC rating system that was used until November 2013 consisted of a 9-level scale (A^+, A, B, B^-, C, D, E, F, and G). The change that took effect from December 2013 onwards eliminated the G rating. The A^+ and A ratings represent 0% to 50% of annual energy consumption needs relative to reference values, B and B^- 51% to 100%, and the G rating 301% or more of these same standard values.

The first one follows Evangelista et al. (2020) in that it defines EE as a binary variable, designated as AB, which assumes the value 1 for the four EPC most energy efficient ratings (A^+, A, B, B^-), and the value 0 otherwise. According to the EPC system used in Portugal, these four ratings identify all residential units having annual consumption energy needs that are the same of or lower than those of reference standard consumption value (i.e. identify all properties that perform the same or better than a standard energy efficiency performance). The second one incorporates EE in the model using 7 levels, representing the (A^+, A), B, B^-, C, D, E, and (F, G) EPC ratings. In this setting, extreme ratings are put together in single dummies due to the fact that these account for a low value of transactions (see section 3 for more on this), and the D rating is used as reference and not included in the models. Finally, a third measurement for EE consists of the inclusion of a discrete variable, defined as EED, which translates the 9-level EPC scale used in Portugal, $\{A^+, A, B, B^-, \ldots, F, G\}$, into the values $\{9,8,7,6,\ldots 2,1\}$. Following Lyons et al. (2013), this discrete approach of measuring the effect of energy efficiency was applied in Evangelista et al. (2020) in OLS models. As far as we know, there are no other empirical applications of this variable in the housing market (see Zhang and Tao, 2020, for an application of a 3-level discrete energy efficiency variable in the explanation of the price of refrigerators). This way of interpreting the effects of energy efficiency along the price distribution has not been used in quantile regression analysis in this research context despite the appealing feature of circumventing the estimation problem related to the scarcity of observations for the different price quantiles and the ratings of the EPC label. The analysis of the impact of energy efficiency is centred around these models with those using other scales acting as complement.

The design of the estimation exercise consisted of using the OLS, CQR and two versions of the UQR estimators for three different EE variables in four different market segments (existing apartments, new apartments, existing houses and new houses). The results were obtained in StataCorp (2017). The Firpo et al. (2009) estimator is available in this software through the *rifreg* command and the Firpo (2007) estimator is implemented following the approach by Frölich and Melly (2010).

3. Data

The dataset used in this paper provides information on the prices and characteristics of more than 256 thousand residential property transactions that were carried out in Portugal from 2009 to 2013.

The dataset was built through the combination of transfer and property tax records with those obtained from the supervisory body of the EPC label in Portugal. The data is the same that was used in Evangelista et al. (2020) for the derivation of OLS and CQR results. A detailed description of the data matching process of these three sources of information is available from the supplemental appendix to this paper.

Table 1 provides the descriptive statistics for some key attributes of the properties and for the nine levels of the EPC energy efficiency scale. Following Evangelista et al. (2020), regions are defined by dividing Portugal into seven territorial units. These follow the official nomenclature, with two exceptions. Given its market transaction relevance, the Porto metropolitan area was isolated from the North region. Conversely, the Azores and Madeira islands were grouped together into a single category due to the low number of transactions in these regions. Table's 1 data is described having in mind the separation between apartments and houses and between new and existing dwellings. However, since this paper extends the analysis of the impact of energy efficiency to the whole spectrum of the price distribution, the dwelling attributes are summarised at the 0.1th, 0.5th and 0.9th price quantiles as well as for all observations. For the nine levels of the EPC energy scale, the proportion of each energy label along each transaction value tertile group is also presented.

Table 1 about here

Table 1 reveals that more than 50% of the transactions refer to existing apartments, followed by new apartments (23.2%), existing houses (13.0%) and new houses (5.3%). Average and median transaction prices are 119,888 € and 96,200 €, respectively. Unsurprisingly, houses display higher average and median prices relative to apartments and new accounts for higher average and median prices than existing. Interestingly, the greater heterogeneity in houses is revealed when the 0.1th and 0.9th price quantiles are compared with those of apartments. While at the 0.1th price quantile the average price for houses is smaller than for apartments, the opposite happens at the 0.9th price quantile, thus suggesting the existence of a wider amplitude of values for the latter dwelling type. As expected, new properties have larger average gross and dependent floor areas and exhibit a higher average for the number of bedrooms than existing properties.

The highest number of transactions is found for 2009 and 2010, which account respectively for 23.5% and 28.5% of all transactions available in the dataset. The following years have a lower number of transactions, reflecting the period of time in which the Portuguese residential property market was depressed. Moreover, the urban region of Lisbon, followed by the Porto metropolitan area, account for the highest number of transactions (36.3% and 20.6%, respectively). On the other extreme, the Alentejo region and the Azores and Madeira islands together represent less than 5%

of all transactions. A notorious feature of the Lisbon region is the fact that it accounts for more than 50% (30%) of the transactions of the most expensive apartments (houses) at the 0.9th price quantile. Conversely, the Porto metropolitan area and the Centre region, concentrate the highest percentages of transactions at the lowest quantiles of the price distribution.

Figure 1 provides another view of the frequency of the EPC ratings along the quantiles of the price distribution. This figure highlights four points. Firstly, the proportion of most efficient labels increases as the price quantile increases. An example of this is the fact that most efficient ratings (A^+, A, B and B^-) correspond to less than 20% of the properties at the 0.1th price quantile. However, these same ratings account for around 40% and 60% of the most expensive houses and apartments, respectively. This is an expected outcome, which suggests the existence of a positive relationship between efficiency levels and property prices.

Figure 1 about here

Secondly, the energy efficiency rating for apartments is generally higher than for houses. While for apartments the most common rating is C, followed by B, for houses the most frequent label is D, followed by C. This difference may be a reflection of physical and engineering differences between the two dwelling types. For instance, as houses are usually bigger than apartments, it is technically more difficult to ensure high energy efficiency standards in houses than in apartments. Thirdly, the figure shows that new properties exhibit a higher energy efficiency performance than existing properties. This difference is more pronounced than the one found for apartments and houses. The adoption throughout time of building codes with better energy saving requirements could help explaining this outcome.

Finally, the figure reveals that the percentage of transacted dwellings is rather low at both extremes of the EPC scale. In fact, when grouped together, the A^+ and A ratings account for only 4.8% of the transactions. Similarly, the F and G ratings only represent 2.6% of all observations. This situation has conditioned the interpretation of quantile regression results when using a disaggregated energy efficiency scale and restricted the reading of energy efficiency partial effect results to those located at the centre of the EPC scale (i.e. B, B^-, C, D ratings).

4. Results

This section presents and discusses the energy efficiency partial effects of UQR over the price distribution. OLS and, in some cases, CQR results are also provided as a reference. Three sets of partial effects are analysed. The first one considers different forms of inclusion of the EPC label in the hedonic model. The second details on time and regional effects, by considering the discrete scale EED measurement. Additionally, a third set of results presents a quantile house price index for Portugal.

4.1. Measuring the impact of the EPC label through the use of different scales

Results are shown in Table 2 for the 0.1th, 0.5th and 0.9th price quantiles and in Figures 2 to 4, which provide a wide variety of quantile results, displaying the 0.05th to 0.95th quantiles for both the discrete EED (Figure 2) and AB (Figure 3) scales or, in the case of the 7-level energy efficiency scale, the 0.25th to 0.75th quantiles (Figure 4). In addition to quantile regression, the table and figures also show OLS results and the 95 percent confidence intervals for all of the point estimates.

Table 2 about here

Figure 2 about here

Figure 3 about here

Figure 4 about here

Evangelista et al. (2020) revealed significant but relatively stable CQR results across the price quantiles of the EPC labelling on housing prices (as measured by the binary scale AB). Despite some differences relative to OLS, which are more evident in apartments, the very moderate quantile effects consubstantiated in a modest added value of the CQR approach relative to OLS. CQR results in Figure 2 for the discrete scale EED confirm the stability pattern observed previously. However, the UQR results unveil a more heterogeneous impact of the EPC label. These differences emerge in a scenario were UQR reflects a higher volatility when compared to OLS and CQR, and are explicit not only in terms of magnitude but also in some cases in the direction of the partial effects.

The higher variability of UQR relative to CQR and OLS results, has been observed in previous papers in other areas; see, *inter alia*, Peeters et al. (2017) and Fournier and Koske (2013). This increased variability is acknowledged by the literature, see Firpo et al. (2009), and stems from the nature of UQR. While CQR coefficients reflect a *within-group* impact from changing from less to more energy efficient standards - where in our case *within-group* consists of the set of dwellings with the same values of all covariates (other than energy efficiency), UQR coefficients provide an overall impact change estimate, which reflects, in addition to *within-group* variation, *between-group* variation. In addition, it is worthwhile to note that, as observed in Figures 2 and 3, the width of UQR point estimate confidence intervals is generally larger at lower and upper quantiles of the price distribution and, as it is shown in Figure 4, inflated when the 7-level scale is used, especially for most (least) energy efficient labels at the lowest (highest) quantiles of the price distribution. This should come as no surprise as, it is possible to see in the lower part of Table 1, these refer to situations in which the percentage of transactions by energy efficiency label is low.

Despite the sometimes relatively high degree of dispersion shown in the figures, important quantile effects emerge from UQR results, something that reflects differentiated responses of buyers at different price quantiles to the improvement of energy efficiency property features. Responses to energy efficiency gains are so diverse that apartment and house markets exhibit quantiles with opposite trends as the price quantile increases, the first displaying clear decreasing premiums and the latter a moderate increase in the effects. This difference is naturally exacerbated at the lower price quantiles, where the responsiveness in terms of premium is at the highest level for apartments (especially new) and at the minimum and, in fact, sometimes negative, level for houses. This is apparent both in the discrete *EED* and the *AB* variables of figure 2 and 3, with the latter displaying impacts of a larger magnitude due to the measurement of a global effect of the aggregate *AB* of 4 letters relative to the set of D-G ratings bellow reference.

The way energy efficiency is rewarded across the price distribution is clearly different for apartments and houses, not only in terms of quantile shape, but also because the former receives, in general, higher price premiums compared to the latter. This feature had already been observed in the OLS results of Evangelista et al. (2020) where, for example, the premium for *AB* energy efficiency labels was 12.3 percent for new apartments and 5.5 percent for new houses. Despite revealing similar differences for those properties at the central location (the median) of the price distribution (respectively, 11.6 and 5.2 percent), UQR unveils new patterns of responsiveness of apartment and house buyers discussed in the previous paragraph, a behaviour that CQR estimates, given their stability and closeness to the OLS results, do not capture. To detail, note that the high rewards for low priced apartments, especially for new properties where the upgrade reward of 8% by EPC letter (16% due to *AB* classification), contrast with the low or almost inexistent reward at high prices. The potential energy saving disregard at the high end of the price distribution may stem from the fact that good energy efficiency standards are standard for most of the expensive apartments. On the other hand, homebuyers of houses, which are on average less responsive to energy saving features, for price quantiles higher than the 0.4th for the discrete scale and the 0.2th for the AB scale, probably due to an increase in the housing area and the consequent increase of energy costs, tend to respond positively and in a stable manner to energy saving labels. In contrast, for low priced houses, increased energy efficiency by one letter tends to be either mostly penalized with price discounts or irrelevant for existing and new properties, respectively. Buyers in this market segment appear to overweight the costs involved by energy saving devices relative to the potential reduction of the energy bill. This feature was missed by both OLS and CQR results, essentially because the former merely captures the response at the mean and the latter provides results conditional on housing characteristics.

When contrasting existing and new dwellings, it is possible to see that, while the conditional mean effect is slightly higher for new properties, most patterns of quantile partial effects are shared (see Figures 2 and 3). The exception is given by low priced apartments, where new rewards clearly more than existing, denoting that the typology of homebuyers that makes the additional investment for purchasing a new instead of an existing apartment (note that for low priced apartments, for example for the 0.1th quantile, new almost doubles the price effect of existing), is more responsive to energy saving ratings.

Despite the high variability, the analysis of the results of the 7-level scale (Figure 4) suggest some additional conclusions. First, for both OLS and quantile confidence intervals, excessive overlapping is observed for houses, while for apartments the differences in responsiveness are clear. The overlapping in existing houses is more relevant for OLS, while for new houses is more evident in UQR, where variability is at the highest levels. In particular, for new houses an OLS premium of B relative to D of around 6.7% more than doubles that of B^-, while C is not distinguished from D. On the other hand, for existing (new) apartments OLS premiums of 16.4% (12.1%) for B, are followed by 8.9% (4.3%) for B^- and a far less relevant difference for C for both dwelling categories. UQR results reflect the descending global quantile shape of both EED and AB with the apartments price, with the novelty that, at high price quantiles, sometimes discounts are observed. Note that discounts on low priced houses already detected with EED and AB, are also clear in this scale, and increase for the highest labels.

In general, the use of three alternative measurements of the EPC scale produced a rich analysis, as different types of price responses are measured. Two major aspects emerge. Firstly, the AB scale appears as an effective way of examining the robustness of the results of the central EPC measure EED, as the estimated quantile patterns are very similar (despite their different magnitude). Secondly, the 7-level scale based on dummy variables allowed a complementary and more detailed characterization of price response to particular ratings. For the remaining of the paper, the analysis will be focused on the discrete scale EED. On the one hand, the calculation of disaggregated effects by year and region separating EPC ratings is not suitable, given the scarcity of observations and the limitations already identified with this scale. On the other hand, patterns of the AB binary approach mimic those of the discrete measurement EED.

4.2. Time and regional effects of the EPC label

The evolution of energy efficiency partial effects throughout the quantiles of the unconditional price distribution of residential properties for each one of the five years considered in this study is presented in Figure 5. As in the previous section, Figure 5 also presents OLS results and 95 percent confidence intervals.

Figure 5 about here

As the results show, the average energy efficiency partial effects remain relatively stable across time for apartments and houses. This is more evident for houses, where the confidence intervals of the different estimates overlap each other and do not preclude the hypothesis of being the same in all years. However, this relative stability contrasts with the results obtained for the quantile partial effects, where it is possible to see a variety of patterns throughout the years and for the different market segments.

The overall patterns of the previous section for 2009-2013, which display decreasing premiums for EPC upgrading as prices of apartments increase and discounts at low priced houses followed by stable or slightly increasing effects for houses, are not reflected by the yearly behaviour. For apartments, decreasing premiums may be seen in the last two years of the analysis (2012 and 2013). However, in previous years, the responses to the label changed substantially, especially for the low-priced segment where homebuyers of existing (new) properties, in 2009 and 2010, offer a smaller (similar) reward to a EPC rating upgrade than those at central quantiles of the price distribution. This pattern changed in 2011, the year when an important decay in the proportion of transactions was observed; see section 3. In 2011, homebuyers of existing (new) apartments start to provide a similar (larger) reward to that of the median quantiles, which then was amplified in the subsequent years. For houses, in a scenario of increased variability, it is worth to note that discounts or irrelevant responses at low price quantiles reduced throughout the years for new properties. In general, an increasing effect with the price in 2009, is followed by a nonlinear quantile behaviour in 2010 and 2011 and somewhat random and volatile pattern in 2012, 2013, which may be connected to the reduction of transactions in these years.

Overall, it can be said that the market price premium responsiveness to energy efficiency improvements has increased over the years. This suggests that for Portugal, some time was required for the market to translate the benefits of a property showing most energy efficient EPC ratings.

This awareness improvement is particularly promising because it occurred in a time span affected by a crisis, which was reflected in our dataset by a reduction of transactions, see also the results on the price indexes of section 4.3. Finally, note that, despite being promising, the scenario clearly asks for policies aimed at increasing the responsiveness of homebuyers of high (low) price apartments (houses).

Figure 6 provides results for each one of the seven regions considered by the hedonic models.

Figure 6 about here

The regional responsiveness to energy efficiency improvements is very heterogeneous. However, results can be summarised in four main points. Firstly, due to the low number of transactions in the Alentejo region and in the Azores and Madeira islands, the OLS and UQR results are particularly volatile and show wide confidence intervals. As such, the results of these regions have not been analysed. Secondly, in the Algarve region, the effects of the EPC label are either statistically irrelevant for houses or, in the case of apartments, much lower than in other regions. A possible explanation for this may rest in the fact that, since the Algarve is a touristic region in which many properties are bought as a secondary or temporary residence, energy efficiency may not be seen as an important attribute. Thirdly, it is possible to see that the Lisbon displays a distinctive behaviour when compared with the rest of the regions. This translates into price discounts at the lower price quantiles and high price premiums for most expensive properties. Although there is no clear-cut explanation for these facts, the attractiveness and the concentration of transactions of most expensive properties in Lisbon (see Table 1), may help explaining, at least for the upper end of the market, why the region exhibits a price pattern different from the rest of the country. Finally, the energy efficiency market responsiveness found for the Porto, North and Centre regions are very similar and close to the one shown in Figure 2. Moreover, when compared with these results, energy efficiency price discounts emerge not only at the lower price quantiles for houses, but also for most expensive apartments in the North and Porto regions and for existing apartments in the Centre region.

4.3. An unconditional quantile price index

This section extends the quantile regression analysis carried out in the previous sections to the investigation of how prices behaved in the Portuguese residential property market across the dwelling sales distribution from 2009 to 2013, a period that was influenced by an economic crisis and dwelling price decreases. More concretely, it is possible to estimate a time dummy quantile hedonic price index by taking the anti-log of the coefficient estimates of the yearly time-dummy variables included in the models for the four market segments presented in this paper; see Hill (2013) for details on the construction of time-dummy price indexes.

Although using quantile regression for the analysis of residential price changes is not a novelty, evidence on this topic is not abundant and, where available, it is derived using the CQR framework (see, for example, Coulson and McMillen, 2007; Zhang and Yi, 2017). While the construction of conditional quantile price indices focuses on the theoretical conditional price distribution of dwellings, the use of the unconditional quantile regression framework allows researchers to evaluate inflation at any point of the price distribution without any conditionality constraint. By using UQR, it is not only be possible to analyse the general evolution of dwelling prices for the different segments of the market (e.g. high, medium and low segments), but also to assess their plausibility against the results for the mean of the prices distribution provided by the official price index for Portugal (INE, 2014).

Figure 7 below displays the estimated yearly price changes for the four markets for Portugal from 2010 to 2013 using the UQR and OLS estimators, obtained from the models of Section 4.1, based on the *EED* measure, that gave rise to Figure 2. The values are expressed as the cumulative price change using 2009 as the base year.

Figure 7 about here

Figure 7 shows OLS and UQR results that picture an overall decay in residential prices in the years considered in this paper. Although more evident for 2011 and 2012, this is also present for 2013, something that is in line with the figures provided by the official house price index for Portugal. In effect, when compared to 2009, the official price index for Portugal shows annual price drops of 4.17%, 10.95%, and 12.63% in 2011, 2012, and 2013, respectively. For 2010, this indicator records a marginal price increase of 0.77%.

More importantly, Figure 7 reveals relevant differences in the way prices change across the whole spectrum of the prices distribution, with price falloffs for the most expensive properties generally being increasingly smaller than those for lower price quantiles and less expensive properties. This is particularly evident for apartments from 2011 to 2013, for new houses from 2012 to 2013 and for central price quantiles (0.4th to 0.6th quantiles) of existing houses. In contrast, for apartments in 2010 and for houses in 2010 and 2011, the quantile results are not in line with this pattern, except for the higher quantiles and most expensive existing apartments, where the increasing trend in price premiums is evident.

Overall, the results highlight the importance of carrying out quantile regression analysis to have a broader view of the evolution of residential property prices. In this particular case, they show that the impact of the crisis, which is captured by an overall drop in the mean price of properties, was not homogeneous across the distribution of dwelling prices. While the lower end of the residential property market tends to exhibit price decreases, high-priced properties seemed to be more resistant to the effects of the crisis. Apartments, for instance, illustrate this situation perfectly as the deterioration in prices was very small for the most expensive properties, while the discounts through time were substantial for apartments located at the bottom of the price distribution.

5. Conclusions

This paper provides a comprehensive analysis of the impact of the EPC label on residential property prices in Portugal from 2009 to 2013, a period characterised by the beginning of the legal enforcement of the issuing of energy efficiency certificates for all dwelling transactions and that largely overlaps the years in which the Portuguese housing market was severely depressed.

The impact of the EPC label on dwelling transaction prices at the country level was analysed for the first time using the UQR framework in such a way that allowed its assessment across the price distribution, throughout time, regions, type of property and according to its new or existing status. This flexible analytical setting yielded very important information not only to those interested in unveiling the complex relationship between energy efficiency and transaction prices in the residential market, but also because it provides an illustration on the usefulness of UQR results to policy makers aiming at tailoring policy measures to enhance energy efficiency in Portugal.

The results show that the impact of the EPC label was not uniform across the price distribution and that it clearly displays differences according to the type of property. When analysing the reaction to an energy efficiency improvement it is possible to see that, while for apartments effects decrease from the lowest to the highest price quantiles, the opposite succeeds for houses, with homebuyers covering the cheapest market segments exhibiting clear energy efficiency price discounts. While the existence of price discounts is not revealed by just looking at the mean of the prices distribution, the use of quantile regression analysis provides a clearer view of the full impact of the EPC label. The existence of discounts also emerges for the higher end of the price distribution for apartments for most energy efficient EPC scale levels and for the North region of the country when quantile regression analysis is disaggregated by level and region, respectively.

The results taken from an unconditional quantile price index suggest that the housing market crisis did not affect all market segments uniformly, with properties pertaining to the highest price quantiles being almost unaffected by the strong overall downward price effect during the period in which the market was depressed.

The analysis of UQR results throughout time highlight two interesting aspects associated with the implementation of the EPC certification in Portugal. Low priced apartments, precisely the segment of the market that was most affected by the crisis, seem to increasingly reward energy efficiency throughout time. In fact, in the last two years covered by the dataset (2012 and 2013), a shift of the entire distribution of partial effects towards a better price responsiveness to greater energy efficiency is evident for these properties. For houses, an encouraging feature is the reduction of the estimated price discount as we move towards 2013.

Moreover, the results illustrate how UQR may provide an important background for the design of effective policies in this area. In the particular case of Portugal, in the period under analysis, policies directed to two types of properties may be seen as relevant. On the one hand, interventions are required for high-priced apartments, a segment where potentially high-income buyers are not attentive to energy efficiency features, either because energy bill decreases are not considered relevant or because energy saving features are standard and, as such, an upgrade in them is not seen as appealing. On the other hand, houses, particularly those located at the bottom of the price distribution, appear as another possible focus for intervention. Given the importance of this dwelling category in the Portuguese housing stock [4], this finding provides an extremely important policy message on where informational campaigns or on where a possible design of incentives could focus its attention. Finally, the extension of possible policy interventions to cover the bottom of the residential price distribution of all property types in the Lisbon area, precisely the Portuguese region with the highest degree of urbanisation and with the highest number of transactions, clearly stands out as an area in which effective regional policies could be developed.

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[4] The Portuguese housing stock amounts to 5,859,540 classic residential dwellings (INE, 2012). Of these, 52 percent refer to residential single family (detached, semi-detached and row) houses (author's own calculations based on Census data).

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