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The impact of changes in dwelling characteristics and housing preferences on house price indices

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Abstract

Hedonic house price indices adjust the average sales prices for the change in the quality of the property sold over time. This paper proposes a framework to disentangle the contribution of each individual dwelling characteristic to this quality change. We apply our framework to a unique dataset for Belgium for the period 2011Q3-2021Q2 in which we combine the universe of residential real estate transactions with the datasets of the energy performance certificates of the regional energy authorities. We find that the price of an identical dwelling has increased by 7 % less over the past decade compared to the average price of the houses sold and this is largely the result of the improved energy performance over the past decade. Moreover, taking into account the energy efficiency in house price indices will only become more important as it will need to improve substantially more to reach the European climate goal of having an energy efficient building stock by 2050. Turning to the recent period, we show that the strong price increases observed in the first year of the COVID-19 pandemic are not due to changes in the quality of the property sold as the average dwelling characteristics remained broadly stable. Furthermore, despite the slightly increased price discount of terraced houses and small garden and dwelling sizes, price growth continued to be slightly higher in cities compared to their rural urban fringe and the commuter belt.

Keywords: House price index, hedonic regression, quality adjustment, housing market, COVID-19 pandemic, energy efficiency

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Non-technical summary

House price developments have a major impact on housing affordability, wealth of households, economic activity and financial stability. It is therefore important to have reliable house price indices available in order to detect trends, turning points and bubbles. However, house price indices have been identified as a key data gap because the wide methodological differences between existing house price indices often result in varying price developments, which hamper both within-country and cross-country comparisons.

The key difference between house price indices is the extent to which they control for changes over time in the characteristics of the dwellings sold. Indices of the average or median prices do not make any quality adjustments at all and are therefore strongly affected by these changes in the composition of the properties sold. For example, if many large houses are sold in a certain quarter, this will artificially raise the average house price for that quarter. Conversely, hedonic price indices perform a quality adjustment by taking into account a wide range of housing and location characteristics with the aim of measuring the price change of an identical dwelling. Using hedonic regression estimates for the price premia of these different characteristics, they estimate the quality of the sold dwellings as the value of their dwelling characteristics. The hedonic price index can then be obtained by subtracting the change in the quality of the sold dwellings over time from the average price index.

This paper proposes a framework to disentangle the contribution of each individual dwelling characteristic to the change in quality of the sold houses. We show this contribution to be equal to the change in the average of the dwelling characteristic over time multiplied by the estimated regression coefficient of the characteristic. As a result, the contribution to the quality change is only large for a dwelling characteristic that has an important price impact and for which the average level changes substantially over time. Our framework not only makes it possible to understand why the hedonic house price index differs from the average price index, but more generally also sheds light on the differences between house price indices that correct for a different set of dwelling characteristics.

Our framework is applied to the analysis of the Belgian house price developments between 2011Q3 and 2021Q2. We use a unique dataset in which the universe of residential real estate transactions from FPS Finance was merged to the datasets of the energy performance certificates of the regional energy authorities. Our data includes all existing houses and apartments sold in Belgium but does not include new-build homes.

A first finding is that our hedonic house and apartment price indices are less volatile than the existing indices, thanks to their correction for changes over time in the characteristics of the dwellings sold. Therefore, they are more reliable to measure the price change of an identical dwelling and to detect trends and turning points in real time. We also show that part of the volatility of the existing indices is caused by seasonality patterns in the dwelling characteristics, in which the average garden and house size and the share of detached houses are higher for houses sold in the spring and summer months.

Second, we find a strong improvement in the energy quality of the sold houses in Belgium over the past decade, which largely explains why the cumulative average price growth over this period was higher compared to the quality adjusted hedonic price growth. Looking ahead, the energy quality of both houses and apartments will need to improve a lot more in the coming decades in order to reach the European climate goal of having an energy efficient building stock with an average EPC score of 100 kWh/m² by 2050. Moreover, this renovation wave could be accelerated due to the war in Ukraine and the subsequent objective of a rapid reduction in Europe's dependence on fossil fuel sources. This implies that taking into account the improvements in energy quality for the construction of house price indices will only become more important in the future.

Turning to the recent period, we find that changes in quality of the property sold did not have a substantial impact on average price growth in the first COVID year, as the average characteristics of the sold houses remained broadly stable. However, we did find a moderate change in the estimated price premia for several size-related dwelling characteristics, in particular those related to detached dwelling and to a lesser extent dwelling surface and garden size. Finally, our results for the first COVID year do not show a reversal of the urban spatial house price patterns of the past two decades.

Price growth continued to be higher in cities compared to the surrounding more rural areas and it also continued to be higher in cities with a large share of young college educated households. However, the final impact of COVID-19 and of the structural increase in teleworking remains to be seen, given that household relocation decisions could take time and are not easily made in the midst of the pandemic.

Finally, the wide cross-sectional differences in average house prices between municipalities are to a large extent the result of differences in the municipality location value. The latter is strongly positively correlated with the share of highly-educated young adults, which most likely reflects their higher income, wealth and parental financial assistance. In addition, there are also strong differences between municipalities in the quality of the property sold. For instance, the average quality of houses is typically lower in cities compared to other municipalities as cities consist to a larger extent of small, old and terraced houses with a small garden.

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1. Introduction

House price developments have a major impact on housing affordability, wealth of households, economic activity and financial stability. It is therefore important to have reliable house price indices available in order to detect trends, turning points and bubbles. However, house price indices have been identified as a key data gap because the wide methodological differences between existing house price indices often result in varying price developments, which hamper both within-country and cross-country comparisons (Silver, 2014).

The key difference between house price indices is the extent to which they control for changes over time in the characteristics of the dwellings sold.[1] First, indices of the average or median prices do not make any quality adjustments at all and are therefore strongly affected by these changes in the composition of the properties sold. For example, if many large houses are sold in a certain quarter, this will artificially raise the average house price for that quarter. Second, mix-adjustment price indices perform a basic quality adjustment by correcting for compositional changes of certain sub-groups, but they ignore quality differences over time within these sub-groups. An example is the NBB mix-adjustment house price index, which uses apartments, ordinary houses and detached houses at the district level as sub-groups (Warisse, 2017). Finally, hedonic price indices perform a more advanced quality adjustment by taking into account a wide range of housing and location characteristics with the aim of measuring the price change of an identical dwelling. Using hedonic regression estimates for the price premia of these different characteristics, they estimate the quality of the dwellings sold as the value of their dwelling characteristics. The hedonic price index can then be obtained by subtracting the change over time in this estimated quality of the dwellings sold from the average price index. We will refer to this quality change of the dwellings sold as the “quality composition effect”.

While the total quality change of the dwellings sold is a well-known concept and corresponds to the negative sign of what Eurostat (2013) labels as the “hedonic quality-adjustment”, we are the first to disentangle it into the contributions of the individual dwelling characteristics. We show this contribution to be equal to the change in the average of the dwelling characteristic over time multiplied by the estimated regression coefficient of the characteristic. As a result, the contribution to the quality change is only large for a dwelling characteristic that has an important price impact and for which the average level changes substantially over time. Our framework not only makes it possible to understand why the hedonic house price index differs from the average price index, but more generally also sheds light on the differences between house price indices that correct for a different set of dwelling characteristics.

We elaborate our framework for the geometric imputation Fisher hedonic price index and we use a model with yearly changing coefficients, which has the advantage that it takes into account the changes in housing preferences over time. Note however that our framework can also be applied to the frequently used time dummy hedonic price index with constant coefficients. We first derive the framework for the hedonic index of the full sample at the yearly frequency and then provide extensions for the analysis at the quarterly frequency and at the municipality subsample level. For the latter, we also propose a second decomposition in which we decompose the municipality hedonic index as the product of the price index of a reference dwelling and the impact of changing housing preferences. For instance, an increase in the price premium of detached houses compared to terraced houses would increase the price index of rural municipalities compared to that of city municipalities, given that the former has a larger share of detached dwellings. Technically, this second decomposition is possible thanks to our hedonic regression model setup, which only includes regression splines and dummy variables for which the reference category corresponds to a well selected typical reference dwelling.

[1] The difficulty of measuring house price developments is that indicators of house prices are based on the prices of the dwellings sold in a certain period and that the characteristics of these houses differ over time. The large heterogeneity of individual houses and the fact that price of a dwelling is only infrequently observed at the time of sale makes it not possible to apply the matched-model method, in which the price of the same product with the same characteristics is recorded over time and which is the main model used to construct consumer price indices.

Our framework is applied to the analysis of the house price developments between 2011Q3 and 2021Q2 for Belgium, its three Regions as well as its municipalities. We use a unique dataset in which the universe of residential real estate transactions from FPS Finance was merged to the datasets of the energy performance certificates of the regional energy authorities. Our data includes all existing houses and apartments sold in Belgium but does not include new-build homes. In addition to the analysis of the structural patterns over the previous decade, we put a special focus on the recent COVID-19 period, which had impacted housing markets and consumer preferences due to the stay-at-home lockdowns and the strong increase in teleworking, the latter being long-lasting. As the official date of the house sale as recorded by the notaries takes place about 3 months after the signing of the first binding contract, our sample until 2021 Q2 allows to analyse the first full year of the pandemic in Belgium.

A first finding is that our hedonic house and apartment price indices are less volatile than the existing indices, thanks to their correction for changes over time in the characteristics of the dwellings sold. Therefore, they are more reliable to measure the price change of an identical dwelling and to detect trends and turning points. We also show that part of the volatility of the existing indices is caused by seasonality patterns in the dwelling characteristics, in which the average garden and house size and the share of detached houses are higher for houses sold in the spring and summer months.

A second finding is that the price of an identical house has increased by 7 % less over the past decade compared to the average prices of the houses sold in the Flemish and Walloon Regions (and 5 % less for the Brussels-Capital Region). This divergence is the result of the gradually higher quality of the houses sold over the past decade, where quality should be broadly interpreted as the value of the dwelling characteristics of the dwellings sold.

The improvement in quality of the sold houses over the past decade is mainly driven by an improved energy performance and to a lesser extent also due to an increase in the average dwelling and garden size of the houses sold. The average energy performance EPC score of the houses sold has improved substantially over the past decade in the Walloon and Flemish Regions, by respectively 90 kWh/m² and 70 kWh/m², and to a lesser extent also in the Brussels-Capital Region (a reduction of 30 kWh/m²). But, in absolute terms, it is currently still slightly higher in the Walloon Region (425 kWh/m²) than the Flemish Region (410 kWh/m²) and the Brussels-Capital Region (393 kWh/m²). Finally, while the average EPC score of apartments (about 250 kWh/m²) is lower than that of houses thanks to their building structure, it has improved only by 30 kWh/m² over the last ten years. Looking ahead, the energy quality of both houses and apartments will need to improve a lot more in the coming decades in order to reach the European climate goal of having an energy efficient building stock with an average EPC score of 100 kWh/m² by 2050. Moreover, this renovation wave could be accelerated due to the war in Ukraine and the subsequent objective of a rapid reduction in Europe's dependence on fossil fuel sources. This implies that taking into account the improvements in energy quality for the construction of house price indices will only become more important in the future.

Turning to the recent period, house prices rose very strongly in the first year of COVID-19 and this increase was not driven by changes in the quality of the houses sold. The share of detached dwellings, the average garden size and the average dwelling surface of both apartments and houses have remained broadly unchanged compared to the property sold just prior to the pandemic, which likely is the result of the inelastic supply of dwellings in Belgium (Caldera and Johansson, 2013). As a result, the price growth of our hedonic index was about equal to that of the average price index. The year-on-year price growth of houses in 2021Q2 was higher in the Flemish Region (+9 %) than the Brussels and Walloon Regions (+7 %), despite the abolition of the mortgage interest deduction scheme ("housing bonus") in the Flemish Region in January 2020. The price growth was also strong for apartments in the three Regions, but slightly lower compared to houses, which suggests a slight shift in demand from apartments to houses.

The COVID-19 lockdowns and the strong and structural increase in working from home seem to have had an impact (albeit only slight) on size-related housing preferences. The estimated price premium of a detached dwelling rose in the first year of the pandemic, but only in the Flemish Region (+2 percentage points in 2021 compared to 2019) and in the Brussels-Capital Region (+7 percentage points), the latter nevertheless not being statistically significant due to the tiny sample of detached dwellings. There was also a limited increase of about 1 percentage point in the price differential between large and small garden and dwelling sizes, but these changes are not statistically significant. As cities mainly consist of small and terraced houses with a small garden, these price premium changes have had a modest negative effect of up to 2 percentage points on the difference in average house prices between cities and rural areas. Given the above discussed inelastic supply of houses, especially in the short run, we interpret these changes in the price premia to reflect changes in housing preferences.

However, we do not find any evidence for a reversal of the urban house price patterns of the past two decades, in which price growth in cities had outpaced that of the more rural areas. House price growth in the first year of COVID-19 continued to be slightly higher in most cities compared to the surrounding rural-urban fringe and commuter belt, even after taking into account the slightly increased price discount of small and terraced houses and small gardens since COVID-19. Nor do we find any reversal of the inter-urban price patterns. Price growth in the different cities has continued to be strongly correlated with the share of highly educated young adults. Housing demand in the first year of the pandemic is believed to have risen for many of these highly-educated people thanks to higher disposable income, an accumulation of forced savings, the low interest rate environment and extra parental financial assistance. Prices have also risen more in the coastal municipalities as well as in municipalities with a large proportion of holiday houses, which most likely reflects higher demand for second properties. All in all, the final impact of COVID-19 and the structural expansion of remote working remains to be seen, given that household relocation decisions take time and are not easily made in the midst of a pandemic.

Finally, the wide cross-sectional differences in average house prices between municipalities are to a large extent the result of differences in the municipality location value. The latter is strongly positively correlated with the share of highly-educated young adults, which most likely reflects their higher income, wealth and parental financial assistance. In addition, there are also strong differences between municipalities in the quality of the property sold. For instance, the average quality of houses is typically lower in cities compared to other municipalities as cities consist to a larger extent of small, old and terraced houses with a small garden.

Our paper is arranged as follows. Section 2 sets out the methodology and Section 3 discusses the data. Section 4 then analyses the impact of changes in the dwelling characteristics on the house price indices for the three Belgian Regions. Section 5 looks at a more granular level and investigates if and to which extent COVID-19 has altered urban house price patterns. Finally, Section 6 concludes our findings.

2. Methodology

We use a linear hedonic regression model with yearly changing coefficients in which the continuous variables are modelled as piecewise linear functions (linear splines). We present our model in Section 2.1. Section 2.2 then elaborates our framework to decompose the impact of changes in dwelling characteristics and housing preferences on house price indices.

2.1. The hedonic regression model

We use the standard log-linear hedonic regression model of Eurostat (2013) with changing coefficients

$$\log(p_{it}) = \delta_t + \sum_{k=1}^{K} \beta_t^k x_{it}^k + \varepsilon_{it} \quad for\ i = 1, \dots, N_t\ and\ t = 0, \dots, T, \quad (1)$$

where $\log(p_{it})$ is the logarithmic transformation of the price at which dwelling *i* was sold in year *t*, x_{it}^k is the level of characteristic *k* of this dwelling, δ_t is the time fixed effect of year *t*, ε_{it} is assumed to be an independently and normally distributed error term with mean zero and constant variance, *K* is the number of characteristics, N_t is the number of observations in year *t* and *T+1* is the number of years. Finally, the coefficients β_t^k are allowed to differ across the different years. The model (1) is estimated using ordinary least squared for each year separately and estimated coefficients are denoted by a “hat” symbol.

The vector of dwelling characteristics x_{it}^k in our model (1) only consists of dummy variables for the categorical dwelling characteristics (such as the dwelling type and municipality) and linear basis functions for the continuous variables (such as dwelling surface and energy performance EPC score). In particular, for each continuous variable v_{it}^{v}, the following S^v linear basis functions are generated

$$\varphi_{sit}^{v}(v_{it}^{v}) = \begin{cases} 0 \; if \; v_{it}^{v} < c_{s-1}^{v} \\ (v_{it}^{v} - c_{s-1}^{v})/(c_{s}^{v} - c_{s-1}^{v}) \; if \; c_{s-1}^{v} \leq v_{it}^{v} < c_{s}^{v} \\ (c_{s+1}^{v} - v_{it}^{v})/(c_{s}^{v} - c_{s+1}^{v}) \; if \; c_{s}^{v} \leq v_{it}^{v} < c_{s+1}^{v} \\ 0 \; if \; v_{it}^{v} > c_{s+1}^{v} \end{cases} \quad \text{for s in 1,…,S}^{v},$$

where $\varphi_{sit}^{v}(v_{it}^{v})$ is a continuous variable between 0 and 1 and where c_{s}^{v} are the pre-specified knots.[2] For instance, a dwelling with energy efficiency EPC score of 200 kWh/m² will have a value of 0.5 for the basis functions corresponding to the knots 150 kWh/m² and 250 kWh/m² and a value of zero for the basis functions of the remaining knots. In model (1), the regression coefficient is normalised to zero for the reference dummy category for the categorical variables and for the reference basis function for the continuous variables.

Our model setup has several advantages. First, by modelling the continuous dwelling characteristics as piecewise linear functions, we take into account the non-linear relationships between the dwelling characteristics and the selling prices, which have previously been reported (see Bao and Wan (2004) for another application of spline smoothing in estimating hedonic house price models). For example, modelling the non-linear relationship is important for the price impact of the energy performance (Evangelista et al., 2020). Second, by choosing the reference dummy categorical variables and the reference basis functions equal to those of a well selected typical reference dwelling, exp(δ_t) could be interpreted as the hedonic price index of our reference dwelling, which can be obtained by the characteristics prices approach (see Equation (5.8) of Eurostat, 2013), as the level of each characteristic x_{it}^{k} of this reference dwelling equals zero (see also Section 2.2).[3] Third, the coefficients β_t^k in the semilogarithmic model can be interpreted as the price premium at time *t* compared to the reference dummy category or reference basis function by applying the transformation exp(β_t^k)-1 (Halvorsen and Palmquis, 1980). Finally, allowing for time variation in the coefficients β_t^k is important as the coefficients of the dwelling characteristics and dwelling locations are affected by changes in housing preferences over time, including changes in the relative attractiveness of the different municipalities and changes in preferences for certain house types and dwelling characteristics. Examples are the increasing awareness for the importance of energy performance over the past decade and the changes in housing markets and housing preferences since COVID-19. Given the above discussed inelastic supply of houses, especially in the short run, we interpret these changes in the price premia to reflect changes in housing preferences.

2.2. Framework to decompose the impact of changes in dwelling characteristics and housing preferences on house price indices

This section first presents the decomposition of Eurostat (2013) of the geometric mean index as the product of the hedonic price index and a quality composition effect. We then elaborate our framework to further disentangle the quality composition effect into the contributions of the individual dwelling characteristics. Finally, we also assess the impact of changes in housing preferences on the price index at the municipality level. While the general framework is first derived for the full sample at the annual frequency, Sections 2.2.1 and 2.2.2 shows the straightforward adaptations for the analysis at the quarterly frequency and at the municipality subsample.

[2] The term in Equation (1) related to the continuous variable v_{it}^{v} can thus be written as $f^{v}(v_{it}^{v}) = \sum_{s=1}^{S} \gamma_t^s \varphi_{sit}^{v}(v_{it}^{v})$, where the coefficients γ_t^s are part of the coefficient vector. Note that we set $\varphi_{it}^{1} = 1$ if $v_{it}^{v} \leq c_{1}^{v}$ (the smallest knot) and $\varphi_{it}^{S} = 1$ if $v_{it}^{v} \geq c_{S}^{v}$ (the largest knot). Also note that for the very big garden sizes and very big living surfaces, which have values larger than c_{S}^{v}, we add an additional logarithmic term of the garden size and living surface, as the spline modelling is less suitable because of the few number of observations and the wide dispersion of the big garden and living surface sizes.

[3] Note that this interpretation would not have been possible if we would for instance have included the dwelling surface as a continuous variable in the model: exp(δ_t) then would measure the price index of a dwelling with a surface of zero square meters, which is meaningless.

We can write the geometric mean price index as

$$\frac{\prod_{i=1}^{N_t} p_{it}{}^{1/N_t}}{\prod_{i=1}^{N_0} p_{i0}{}^{1/N_0}} = I_t e^{\sum_{k=1}^{K} \hat{\beta}_{0t}^{k}(\bar{x}_t^k - \bar{x}_0^k)}, \quad (2)$$

where

$$I_t = e^{(\hat{\delta}_t - \hat{\delta}_0)} e^{\sum_{k=1}^{K}[\bar{x}_{0t}^{k}(\hat{\beta}_t^k - \hat{\beta}_0^k)]}, \quad (3)$$

where $\hat{\beta}_{0t}^{k} = (\hat{\beta}_0^k + \hat{\beta}_t^k)/2$, $\bar{x}_{0t}^{k} = (\bar{x}_0^k + \bar{x}_t^k)/2$ and $\bar{x}_t^k$ corresponds to the sample mean of the characteristic *k* in year *t.* These formulas correspond to Equations (5.21) and (5.22) of Eurostat (2013) and a proof is given in Appendix A. It can be shown that I_t is a geometric imputation Fisher price index, which is one of the advocated hedonic methods (Eurostat, 2013; Hill et al., 2018). It should be noted that Equations (2) and (3) are also applicable to the frequently used time dummy hedonic price index with constant coefficients (see Equation (5.7) of Eurostat, 2013).

First, Equation (2) shows that we can decompose the average price index as the product of the hedonic index and the factor $e^{\sum_{k=1}^{K} \hat{\beta}_{0t}^{k}(\bar{x}_t^k - \bar{x}_0^k)}$, which corresponds to the negative sign of what Eurostat (2013) labels as the "hedonic quality adjustment factor. In this paper, we label this latter factor (subtracted by 1) as the "quality composition effect", which corresponds to the relative percentage difference between the (geometric) average price index and the hedonic index. One of the contributions of our paper is that we further decompose this quality composition effect as the product of the contributions of each individual characteristic *k* as

$$e^{\sum_{k=1}^{K} \hat{\beta}_{0t}^{k}(\bar{x}_t^k - \bar{x}_0^k)} - 1 = \prod_{k=1}^{K}\left[1 + \left(e^{\hat{\beta}_{0t}^{k}\left(\bar{x}_t^k - \bar{x}_0^k\right)} - 1\right)\right] - 1. \quad (4)$$

We interpret $e^{\hat{\beta}_{0t}^{k}(\bar{x}_t^k - \bar{x}_0^k)} - 1$ as the part of the quality composition effect that is due to changes in the dwelling characteristic *k* over time. It is expressed in percentage points and can for small values be approximated by $\hat{\beta}_{0t}^{k}\left(\bar{x}_t^k - \bar{x}_0^k\right)$.[4] This shows that the contribution of each characteristic *k* to the quality composition effect is approximately equal to the product of on the one hand the estimated coefficient $\hat{\beta}_{0t}^{k}$ (i.e. the estimated implicit price of the characteristic *k*) and on the other hand the difference of the sample mean of the characteristic *k* in year *t* and year *0*. Note that this contribution of characteristic *k* to the quality composition effect is only dependent on the mean and coefficient of the characteristic *k* and is not affected by the other characteristics or coefficients of the model, which greatly facilitates its interpretation and practical use. In particular, this result implies that an important house price determinant, for which the implicit price is large, has a zero contribution to the quality composition effect if the average level of the characteristic does not change over time. Also characteristics for which the average level differs over time but that have a zero coefficient do not have any impact on the quality composition effect. Conversely, the contribution to the quality composition effect is large for a dwelling characteristic that has an important price impact and for which the average level changes substantially over time.

The contributions to the quality composition effect of the different characteristics are additive as they can be added to measure the combined contribution of a group of characteristics. Hence, the total contribution of a continuous variable, which we model using piecewise linear functions, can be obtained as the sum of the contributions of the different basis functions of that continuous variable.

Second, Equation (3) yields an additional decomposition of the hedonic price index in two factors. The first factor $e^{(\hat{\delta}_t - \hat{\delta}_0)}$ corresponds to the hedonic price index of our reference dwelling (see Section 2.1). The second factor $e^{\sum_{k=1}^{K}[\bar{x}_{0t}^{k}(\hat{\beta}_t^k - \hat{\beta}_0^k)]}$ reflects the impact of changes in the coefficients over time on the overall house price index. The formula shows that the

[4] Using the linear approximation of the exponential function and assuming that that $\hat{\beta}_{0t}^{k}(\bar{x}_{kt} - \bar{x}_{k0})$ is close to zero, Equation (2) can be approximated as

$$\frac{\prod_{i=1}^{N_t} p_{it}{}^{1/N_t}}{\prod_{i=1}^{N_0} p_{i0}{}^{1/N_0}} \approx I_t \prod_{k=1}^{K}[1 + \hat{\beta}_{0t}^{k}\left(\bar{x}_t^k - \bar{x}_0^k\right)].$$

impact of a changed coefficient *k* is proportional to the average level of the dwelling characteristic $\bar{x}_{0t}^{k}$. Therefore, this effect is especially important in the context of the analysis of the municipality indices, given their large differences in the average level of the characteristics of the dwellings sold (see Sections *2.2.2* and *5.3*). For instance, an increase in the price premium of detached houses compared to terraced houses would increase the price index of rural municipalities more compared to that of city municipalities, given that the former has a larger share of detached dwellings.

Finally, while Equations (2), (3) and (4) were derived for the analysis of the full sample at the annual frequency, it can be shown that they can be easily adapted for several subsamples. The requirement is that the average of the residuals of these subsamples equals zero at each time period. Sections *2.2.1* and *2.2.2* show that the decomposition can be straightforwardly adapted respectively for the analysis of the full sample at the quarterly frequency and for the analysis at the municipality or urban region level at the annual frequency.

2.2.1. Subsample A: Hedonic price index at the quarterly frequency

In this analysis, we assume that the final three dwelling characteristics x_{it}^{K-2}, x_{it}^{K-1} and x_{it}^{K} are the quarter dummy variables q_{it}^{d} for respectively the second, third and fourth quarter (the first quarter being the reference quarter). While the model (1) is still defined and estimated at the yearly frequency, it can now also be rewritten at the quarterly frequency as

$$\log\left(p_{iq}\right) = \delta_t + \sum_{d=1}^{3} Q_t^d q_{iq}^d + \sum_{k=0}^{K-3} \beta_t^k x_{iq}^k + \varepsilon_{iq} \quad for\ i = 1, \dots, N_q\ and\ q = 0, \dots, Q, \quad \text{(1 bis)}$$

where *t* is the year corresponding to the quarter *q, Q* is the number of quarters and N_q is the number of observations in quarter *q*. The variables q_{iq}^{d} and x_{iq}^{k} and ε_{iq} are the level of respectively the quarter dummy, the dwelling characteristic and the error term of dwelling *i* in quarter *q.* The year-fixed effect δ_t, the coefficients β_t^k and the quarter-fixed effects Q_t^d are allowed to differ across the different years, but we assume constant coefficients between the different quarters of a given year. Finally, as q_{iq}^{d} is a quarter dummy and Q_t^d is the value of the quarter coefficient of quarter *d* in year *t*, the first two terms of Equation (1 bis) can be interpreted as the year-quarter fixed effect α_q at the quarterly frequency, where $\alpha_q = \delta_t + \sum_{d=1}^{3} I[d = q] Q_t^d$ with indicator function *I*.

As the inclusion of the quarter-dummies ensures that sum of the residuals equals zero for each quarter, it can be easily shown that the following very slightly modified versions of Equations (2) - (4) hold:

$$\frac{\prod_{i=1}^{N_q} {p_{iq}}^{1/N_q}}{\prod_{i=1}^{N_0} {p_{i0}}^{1/N_0}} = I_q e^{\sum_{k=1}^{K-3} \hat{\beta}_{0t}^{k} (\bar{x}_q^k - \bar{x}_0^k)} \quad \text{(2 bis)}$$

$$I_q = e^{(\hat{\alpha}_q - \hat{\alpha}_0)} e^{\sum_{k=1}^{K-3} [\bar{x}_{0q}^{k} (\hat{\beta}_t^k - \hat{\beta}_0^k)]} \quad \text{(3 bis)}$$

$$e^{\sum_{k=1}^{K-3} \hat{\beta}_{0t}^{k} (\bar{x}_q^k - \bar{x}_0^k)} - 1 = \prod_{k=1}^{K-3} \left[1 + \left(e^{\hat{\beta}_{0t}^{k} (\bar{x}_q^k - \bar{x}_0^k)} - 1\right)\right] - 1. \quad \text{(4 bis)}$$

2.2.2. Subsample B: Hedonic price index for a subset of municipalities at the yearly frequency

We now derive the hedonic price index for the subsample of a subset of municipalities, with the analysis of one municipality as a special case. We assume without loss of generality that the model has quarter dummy variables and that the *M* last characteristics correspond to the municipality dummies m_t^m. The inclusion of these municipality fixed effects implies that the yearly average of the residuals of each municipality equals zero. Hence, also the yearly average of the residuals is zero for a subset of several municipalities.

It can be easily shown than the following slightly modified versions of Equations (2) - (3) hold for the subsample *S* of one or more municipalities

$$\frac{\prod_{i=1}^{N_t^S} {p_{it}}^{1/N_t^S}}{\prod_{i=1}^{N_0^S} {p_{i0}}^{1/N_0^S}} = I_t^{S,uncorrected} e^{\sum_{k=1}^{K} \hat{\beta}_{0t}^{k} ({\bar{x}_t^k}^S - {\bar{x}_0^k}^S)} \quad \text{(2 tris)}$$

$$I_t^{S,uncorrected} = e^{(\hat{\delta}_t - \hat{\delta}_0)} e^{\sum_{m=1}^{M}[\bar{m}_{0t}^{m\,S}(\hat{\mu}_t^m - \hat{\mu}_0^m)]} e^{\sum_{k=1}^{K-M}[\bar{x}_{0t}^{k\,S}(\hat{\beta}_t^k - \hat{\beta}_0^k)]}, \quad \text{(3 tris uncorrected)}$$

where N_t^S is the number of transactions of the subsample *S* and where $\bar{m}_{0t}^{m\,S}$ and $\hat{\mu}_t^m$ are respectively the average share of municipality *m* in the subsample and the coefficient of municipality *m*. We interpret the factor $e^{(\hat{\delta}_t - \hat{\delta}_0)} e^{\sum_{m=1}^{M}[\bar{m}_{0t}^{k}(\hat{M}_t^k - \hat{M}_0^k)]}$ in Equation (3 tris uncorrected) as the price growth of the reference dwelling of the municipality. The factor $e^{\sum_{k=1}^{K}[\bar{x}_{0t}^{k\,S}(\hat{\beta}_t^k - \hat{\beta}_0^k)]}$ is the impact of changes in the coefficients over time on the house price index. However, the latter factor is partly driven by differences in the distribution of the transactions over the quarters within the year. For instance, the strong increase in the second quarter dummy coefficient in 2021 does have a larger impact on the index for municipalities that happened to have a large share of transactions in this second quarter. As we do not consider the quarter dummies as true dwelling characteristics, we reweight the impact of changes in the quarter dummy coefficients in Equation (3 tris uncorrected) as

$$I_t^S = I_t^{S,uncorrected} e^{\sum_{d=1}^{3}[0.25(\hat{Q}_t^d - \hat{Q}_0^d)} / e^{\sum_{d=1}^{3}[\bar{q}_{0t}^d(\hat{Q}_t^d - \hat{Q}_0^d)}, \quad \text{(3 tris)}$$

where $\bar{q}_{0t}^d$ is the average value of the quarter dummy and $\hat{Q}_t^d$ is the estimated quarter fixed effect of quarter *d* in year *t*.

Finally, our framework also allows to decompose the relative differences of the geometric average prices of the subsample *S* to the average prices of a reference municipality at a given year *t* as

$$\frac{\prod_{i=1}^{N_t^S} p_{it}^{1/N_t^S}}{\prod_{i=1}^{N_t^{REF}} p_{it}^{1/N_t^{REF}}} = e^{\sum_{m=1}^{M}[\bar{m}_t^{m\,S}\hat{\mu}_t^m] - \hat{\mu}_t^{REF}} e^{\sum_{k=1}^{K-M}[\hat{\beta}_t^k \bar{x}_t^{k\,S} - \hat{\beta}_t^k \bar{x}_t^{k\,REF}]}, \quad (5)$$

where the first factor represents the price difference (in percentage points) due to differences in the value of the location, while the second factor corresponds to the price differences due to quality differences of the sold houses (where quality should be broadly interpreted as the value of the dwelling characteristics of these sold houses).

3. Data

We use a unique dataset in which the universe of residential real estate transactions was merged with datasets from the energy performance certificates (EPC) granted by the regional energy authorities. Our data include all existing houses and apartments sold in Belgium between 2011Q3 and 2021Q2.

The database from the FPS Finance's General Administration of Patrimonial Documentation (GAPD) includes all sales transactions of existing dwellings in Belgium. Newly-built homes are not included. The database contains information on the sales price, the date of the notarial deed, the transaction type (e.g. private sale, public sale or inheritance), the nature according to the deed, a unique identifier of the lot ("capakey") and a series of dwelling characteristics.

We include the most important price determining dwelling characteristics. For our model for houses, we include the dwelling type, the dwelling surface, the age of the building, the number of years since the latest officially recorded renovation[5] and the garden size, which we computed as the difference between the plot size and the built surface. In addition, we also include the municipality of the house to capture the location value, but intra-municipality differences in the mobility and amenities are not taken into account due to the unavailability of standardised indicators for the three Regions. For our apartment model, we also included the number of rooms, the presence of multiple bathrooms, the number of garages and the separate storage area. Due to the limited number of apartment sales in many municipalities, we used urban region (see Section 5.1) instead of municipality dummies as location variables for the apartment model, except for the Brussels-Capital Region and the coastal municipalities.

As the transaction dataset does not include indicators on the energy quality of the house, we augmented the dataset with the energy performance certificate (EPC) datasets from the 3 regional energy agencies (VEKA, SPW Wallonie and Brussels Environment).[6] They are a result of EU Directive 2002/91/EC on the energy performance of buildings. Each

[5] Note that the officially recorded renovations only capture reported physical changes that require a building permit. Moreover, policies governing these building permits have changed over time.

[6] Note that the energy performance data of recent dwellings (homes built after 2006) and older ones are stored in separate databases.

dwelling that is built, sold or rented with some form of publicity needs to have an EPC certificate. The EPC score is an overall indicator of the energy efficiency of the house sold and measures the yearly theoretical primary energy consumption for heating and domestic hot water per square meter of floor space (measured in kWh/m² per year). This score depends on the one hand on the wall, roof and floor insulation, the windows, solar panels and the installations for heating and hot water, and on the other hand on the dwelling characteristics such as the property type and dwelling surface. A lower EPC score corresponds to a more energy-efficient dwelling. The Flemish Region started implementing EPC certificates earlier (in 2009) than the Walloon and Brussels-Capital Regions (in 2011).

For houses, we match the transaction dataset with the most recent EPC score prior to the date of sale, where the matching was done using the capakey information on the precise location. While this procedure yields an exact match for the vast majority of the sold houses, there is no exact match possible between the transaction dataset and the EPC dataset at the apartment unit level. The problem is that due to the lack of an official box number in Belgium, the identification of an apartment unit within an apartment building differs between the databases. We therefore assume that the EPC score of a sold apartment unit corresponds to the most recent EPC score prior to the date of sale attributed to an apartment unit in the apartment block. But this often leads to an imperfect match in which the sold dwelling is linked to the EPC score of another apartment unit in the same building. Given the substantial variation in EPC scores within one apartment block depending on the position of the flat within the building, this leads to a measurement error and so an underestimation of the size of the energy efficiency price premia. As an additional analysis, we use the average of the available EPC scores of all apartment units in the building prior to the date of sale, which can be a proxy for the global energy efficiency of the apartment block. But the inclusion of old and possibly outdated EPC scores in the average implies that recent energy renovations are only partially taken into account.

We clean the data in several steps. First, we only include houses with one housing unit and exclude multi-family houses. We also exclude bungalows and inheritance transactions. Second, we removed observations where one of the characteristics is higher than the 99.95th percentile or lower than the 0.05th percentile. Third, we also drop observations in the transaction dataset with missing values of the characteristics. In addition, EPC scores could not be matched with 11 % of the sold houses and about 8 % for apartments in the Flemish and Brussels-Capital Region and to about 27 % for houses and apartments in the Walloon Region. While the exclusion of observations with missing values in general reduces the representativeness of the sample, it could possibly have the opposite effect for dwellings with no EPC score. These partly consist of non-market transactions between family without advertising, for which no EPC certificate is required and the prices of which could deviate from the market value. Finally, we remove observations with studentised residuals outside the interval [-2.2], in line with the Eurostat (2017) best practice to remove outliers.

Since our dataset ranges from 2011Q3 until 2021Q2 and our regressions are performed on a yearly basis, our years are shifted backwards by two quarters. For instance, we will refer to the year 2021 as the sales between 2020Q3 and 2021Q2. This corresponds to the first COVID year, which started in Belgium in mid-March 2020, as the official recording date of the house sale by notaries and land registries typically takes place about three months after exchanging.

4. Impact of changes in the dwelling characteristics on the house price indices of the three Belgian Regions

This section analyses the hedonic price index and the impact of changes in the dwelling characteristics over time on the house price indices of the three Belgian Regions. Section 4.1 first discusses the estimated price premia of the dwelling characteristics, with a focus on the changes in the first COVID year as well as on the energy efficiency price premia. Section 4.2 then analyses the changes over time in the housing characteristics of the dwellings sold and Section 4.3 shows the impact of these changes on average house prices. Finally, Section 4.4 compares our hedonic index to other existing indices and Section 4.5 combines the indices of the Regions to an overall stratified hedonic house price index for Belgium.

4.1. The estimated price premia of the dwelling characteristics

The model (1) is estimated separately for houses and apartments, given that their price determining characteristics differ (e.g. an apartment unit does not have a garden). In this section, the model is also estimated separately for the three Belgian Regions as the estimated coefficients can differ across the Regions due to cultural and economic differences as well as differences in housing policies and housing taxation.

The reference house corresponds to a 50-year-old terraced house with an EPC score of 350 kWh/m², not officially renovated, a dwelling surface of 150 m², a garden of 200 m², located in the main municipality of the Region (Antwerp, Brussels or Liège). The reference apartment is a 50-year-old apartment, not officially renovated, a living surface of 100 m², 4 rooms, 1 bathroom, an EPC score of 250 kWh/m², no garage and no separate storage area.

Appendix B shows the estimated price premia for a selection of dwelling characteristics for each of the three Regions.[7] First, most estimated price premia are broadly similar for the three Regions, but there are some notable differences such as the larger price discount in the Walloon Region for dwellings more than a century old. Second, most price premia have not changed much, which reflects relatively stable housing preferences. The main exceptions are the substantial increase in price premia for energy-efficient houses over the past decade (discussed in detail in Appendix B.5), the slight changes related to dwelling size, garden and dwelling type in the first COVID year (see below) and changes in the location value of the municipalities (see Section 5.3).

The COVID-19 lockdowns and the strong and structural increase in working from home seem to have only slightly impacted size-related housing preferences. Table 4 in Appendix B.4 shows the difference of the estimated price premia for the years 2021 and 2019 of charts 11, 12 and 13 as well as the Z-score of Paternoster *et al*. (1998) to test if the difference is equal to zero. The estimated price premium for a detached dwelling increased in 2021 compared to 2019, but only in the Flemish Region (+2 percentage points in 2021 compared to 2019) and in the Brussels-Capital Region (+7 percentage points), the latter nevertheless not being statistically significant due to the tiny sample of detached dwellings and the corresponding large estimation error. There was also a limited increase in the estimated price discount for several of the small garden and dwelling size categories and a limited increase in the estimated price premia for several of the large garden and dwelling sizes, but these changes are not statistically significant and generally no bigger than 1 percentage point.

4.2. Changes in the average dwelling characteristics over time

Table 1 shows the yearly averages for a selection of dwelling characteristics for the years 2012, 2019 and 2021. We compare 2012 to 2021 to assess the long-term trend and 2019 to 2021 to assess changes in the average variables in the first COVID year. Note that the table does not show all the volatility in the average dwelling characteristics over time and, for instance, does not look at quarterly seasonal patterns, which will be discussed in Section 4.3. Finally, while Table 1 only shows the changes of the average levels of the continuous variables, the regression splines in our model also take into account changes in the distribution of these continuous variables.

We do not see any strong shift in the average dwelling characteristics between 2019 and 2021. In particular, the share of detached houses, average garden size and average dwelling surface of both apartments and houses remained broadly stable. Section 4.3 will in fact confirm that the average price developments in the first COVID year were not affected much by quality composition effects.

But we do observe more substantial differences over the longer horizon. First and foremost, the houses and apartments sold have become more energy-efficient over the past decade. Chart 1 shows the distribution of the energy efficiency EPC scores of the houses and apartments sold as well as their average, by year of sale. The average energy efficiency of the houses sold - and to a lesser extent the apartments too - has improved over the past decade. First, the average EPC score of houses sold has mainly come down in the Walloon and Flemish Regions, by respectively 90 kWh/m² and 70 kWh/m²,

[7] In the interest of space, we do not show the model estimates for the full Belgian sample, which will be used in Section 5.

and to a lesser extent also in the Brussels-Capital Region (a reduction of 30 kWh/m²). But the overall scores are currently still slightly higher in the Walloon Region (425 kWh/m²) than the Flemish Region (410 kWh/m²) and the Brussels-Capital Region (393 kWh/m²). Second, the average EPC score of the apartments sold is lower than for houses thanks to their building structure, but it has declined to a lesser extent, by about 30 kWh/m² in all three Regions, to about 240 kWh/m² in the Flemish Region and to about 260 kWh/m² in the Walloon and Brussels-Capital Regions. The more limited reduction in the EPC score of apartments is most likely due to the co-ownership of apartments and the fact that co-owners and especially residents and landlords have different incentives. This barrier to energy renovation of apartments has recently become smaller thanks to the relaxation of the majority voting rules in 2019. Looking ahead, the energy efficiency of both houses and apartments will need to substantially further improve in the coming three decades to reach an average EPC score of 100 kWh/m² (i.e. energy label A), which is the 2050 target set by the three Belgian Regions for the entire housing stock.[8] This implies that correcting for the improvements in energy quality in the house price index will only become more important in the future.

Table 1 - Average level of a selection of dwelling characteristics[1]

	Flemish Region			Walloon Region			Brussels-Capital Region		
	2012	**2019**	**2021**	**2012**	**2019**	**2021**	**2012**	**2019**	**2021**
Houses									
Energy performance score (kWh/m²)	481	425	410	515	450	425	422	397	393
Terraced (%)	47	43	42	42	40	40	83	82	82
Semi-detached (%)	26	26	27	27	26	26	13	14	14
Detached (%)	27	31	31	32	34	34	4	5	4
Villa (%)	1	1	1	2	2	2	2	3	2
Garden (m²)	429	471	479	522	553	555	143	162	162
Dwelling surface (m²)	159	168	169	157	162	165	172	181	180
Age (years)	64	67	68	85	90	92	81	85	89
Apartments									
Energy performance score (kWh/m²)	267	239	237	290	265	258	298	273	265
Dwelling surface (m²)	87	88	86	83	85	85	88	89	89
Presence of >1 bathroom (%)	3	3	4	2	2	2	4	6	7
Number of garages	0.5	0.3	0.3	0.5	0.5	0.5	0.4	0.4	0.4
Age (years)	35	40	41	40	46	46	53	57	59

Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
[1] Note that our years are shifted backwards by 2 quarters (e.g. our year "2021" corresponds to the first COVID year 2020Q3-2021Q2).

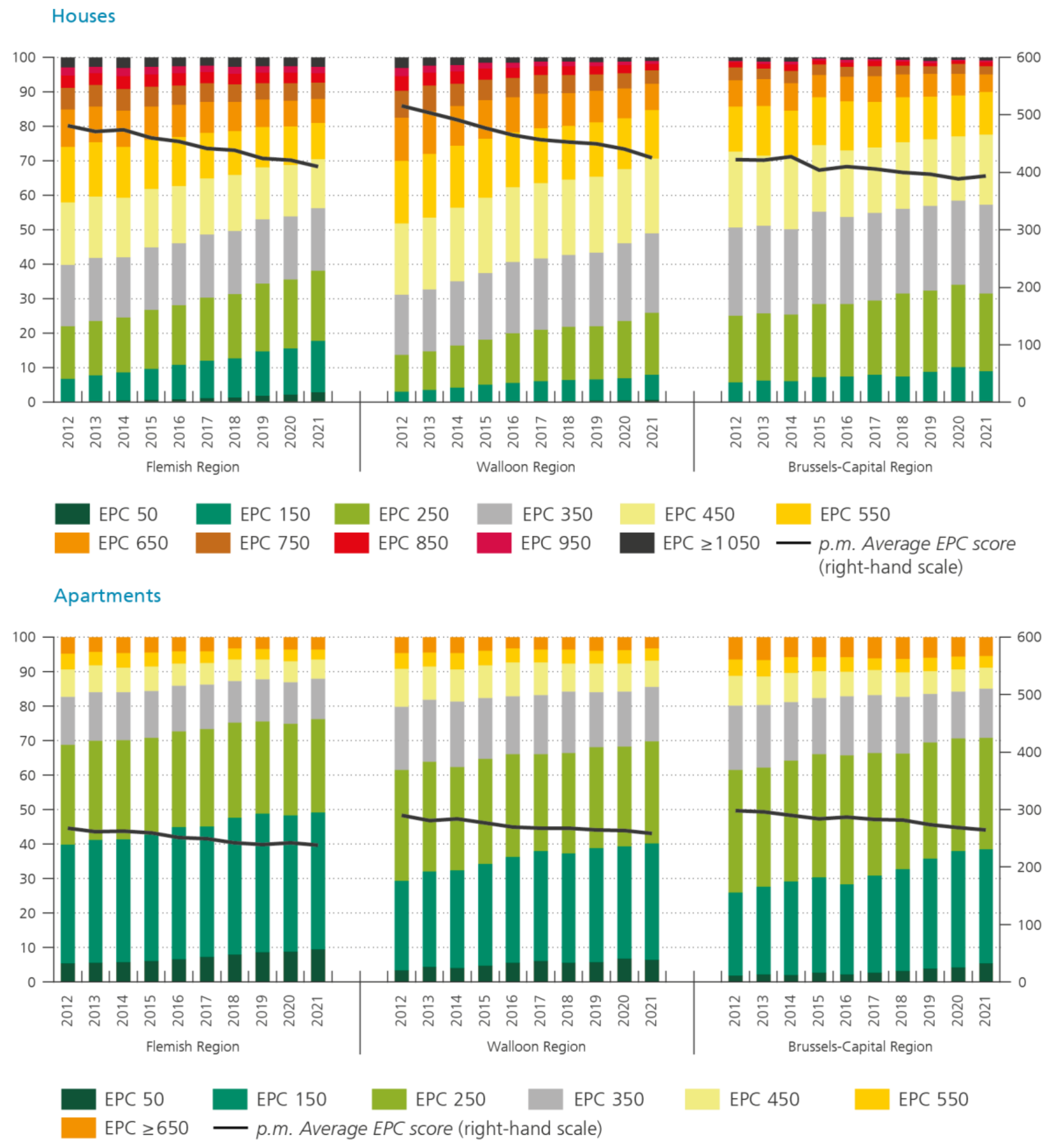
Second, the average dwelling surface of houses sold expanded considerably between 2012 and 2021 by about 5 % in the three Regions. The average garden size has increased substantially as well, in the Flemish and Brussels-Capital Regions even more than 10 % and also the share of detached houses has grown, especially in the Flemish Region, where it rose by 4 percentage points. For apartments, the average number of garages that were sold together with the sale of an apartment has changed, but this most likely reflects the fact that the recording of such joint transactions has changed in the database. Finally, the average age of the sold houses and apartments has gone up by about five years over the past decade.

It should be noted that the dwellings sold are only a small sub-set of the entire housing stock and that the dwelling characteristics of the latter and their change over time can be very different. First, the sale of new builds, for which average dwelling sizes have shrunk, are not included in our dataset of dwellings sold. Second, the sold dwellings are to a large

[8] The EU's Energy Performance of Buildings Directive (EPBD), one of the cornerstones of the European Green Deal, has set a transition to an energy-efficient building stock by 2050 as a goal for the Member States' long-term strategies. All three Regions have a similar objective to move by 2050 towards an energy-efficient housing stock with an average energy label A (i.e. a primary energy consumption of 100 kWh/m² for the Flemish and Brussels-Capital Region and 85.5 kWh/m² for the Walloon Region).

extent sold by the very old generation (due to death or moving into residential care homes and assisted-living apartments), many of which live in large and detached houses (Vastmans, 2020). An increase in the share of houses sold by these old generations over the previous decade could potentially explain the above discussed increase in the average dwelling and garden sizes and share of detached houses. Finally, the average energy performance of the entire housing stock is better than that of our sample of dwellings sold. Energy renovation often follows a property sale (and in such cases is not yet included in the EPC score of the sold dwellings). Moreover, new builds are not included in our dataset of dwellings sold while older dwellings, which generally have a worse EPC score, are over-represented (Vastmans, 2020).

Chart 1 - Distribution of the energy efficiency EPC scores of houses and apartments sold, by year of sale[1]
(in % (left-hand scale); average EPC in kWh/m² (right-hand scale))



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
[1] Note that our years are shifted backwards by two quarters (e.g. our year "2021" corresponds to the period 2020Q3-2021Q2).

4.3. Impact of changes in the dwelling characteristics over time on average prices

Chart 2 (top graph) shows the total quality composition effect of Equation (2 bis), which is the relative percentage difference between the (geometric) average price index and the hedonic index, at the quarterly frequency[9]. Chart 2 (middle graph) then disentangles the contribution of each dwelling characteristic to this total quality composition effect using Equation (4 bis). For visual clarity, we show the yearly averages of our quarterly results. Chart 2 (bottom graph) then shows the seasonal component of the quarterly composition effect, which are obtained by the TRAMO/SEATS method using the JDemetra+ tool for seasonal adjustment. Chart 3 presents the same results for apartments.

First, the quality composition effect of houses has been trending strongly upwards over the past decade and is about 7 percentage points in 2021 for the Flemish and Walloon Regions and about 5 percentage points in the Brussels-Capital Region. This means that quality of the houses sold in 2021 was 5 to 7 % higher in 2021 than in the reference year 2012 (where quality should be broadly interpreted as the value of the dwelling characteristics of these sold houses). In other words, the price of an identical house has risen 5 to 7 % less over the past decade compared to the recorded increase in the average prices of the houses sold (see also Section 4.4).

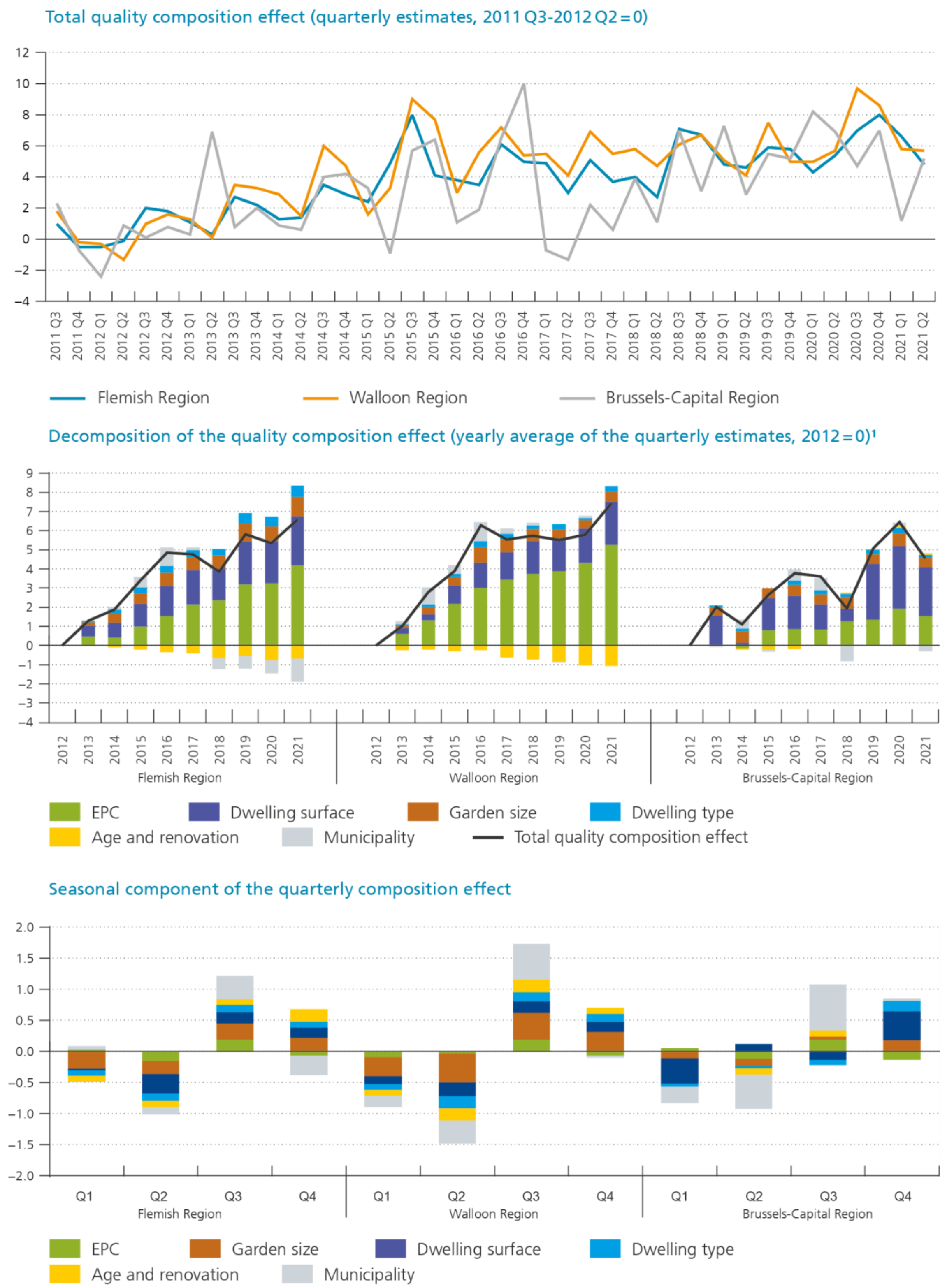
The main driver of the large quality composition effect is the improvement in energy performance, which explains respectively 4, 5 and 2 percentage points of the total quality composition effect in these Regions. This means that hedonic price indices that do not take energy performance into account will overestimate the price growth of an identical house. Another driver behind the increased quality composition is the increase in the dwelling and garden size and share of detached dwellings, which accounts for 4 percentage points of the composition effect in the Flemish Region and 3 percentage points in the Walloon and Brussels-Capital Regions. Conversely, the municipality makes a negative contribution to the quality composition effect in Flanders by about 1.5 percentage points, meaning that the less expensive municipalities have a larger share in the transactions in 2021 compared to 2012. Also, the age and renovation variables contribute negatively to the quality composition effect in the Flemish and Walloon Regions by about 1 percentage point. Finally, note that the sign and magnitude of the contributions of the dwelling characteristics are in line with what could be expected from the change of the average levels of the variables in Table 1 and the magnitude of the price premia in Appendix B. Equation (3) indeed showed that the quality composition effect is only large for a dwelling characteristic that has an important price impact and for which the average level changes substantially over time.

Second, the quality composition effect of houses is volatile, especially at the quarterly frequency. This partly reflects seasonality in the dwelling characteristics, in which the average garden and dwelling size and the share of detached houses are higher in the spring and summer months. Indeed, Chart 2 (bottom graph) shows that the seasonal component of the quality composition effect is about +2 percentage points higher in Q3 and Q4 (reflecting sales in the spring and summer considering the three-month lag before completion) compared to Q1 and Q2 (reflecting sales in autumn and winter).

Third, the quarterly volatility, the cumulative growth and seasonal pattern of the quality composition effect is smaller for apartments (see Chart 3), implying that the value added of the hedonic index over the average price index is smaller compared to houses. This reflects the fact that the average levels of the characteristics of the flats sold are more stable over time compared to those of houses. The standard deviation of the quarterly change of the quality composition effect is about half as large as for houses for the Flemish and Brussels-Capital Regions, but it is comparable for the Walloon Region. The quality composition effect in 2021 is about -2 percentage points in the Flemish Region, about +1 percentage points in the Walloon Region and about +2 percentage points in the Brussels-Capital Region, meaning that the quality of the apartments sold was similar in 2021 and 2012. The estimated contribution of energy efficiency to the composition effect is much smaller compared to houses. This reflects the smaller improvement in the average EPC scores (see Section 4.2) as well as the lower estimated price premia for energy-efficient apartments (see Appendix B.5). However, the fact that the price premia are underestimated implies that we also underestimate the contribution to the quality composition effect. In addition, further improvements in energy quality for apartments will lead to larger quality composition effects in the coming decades.

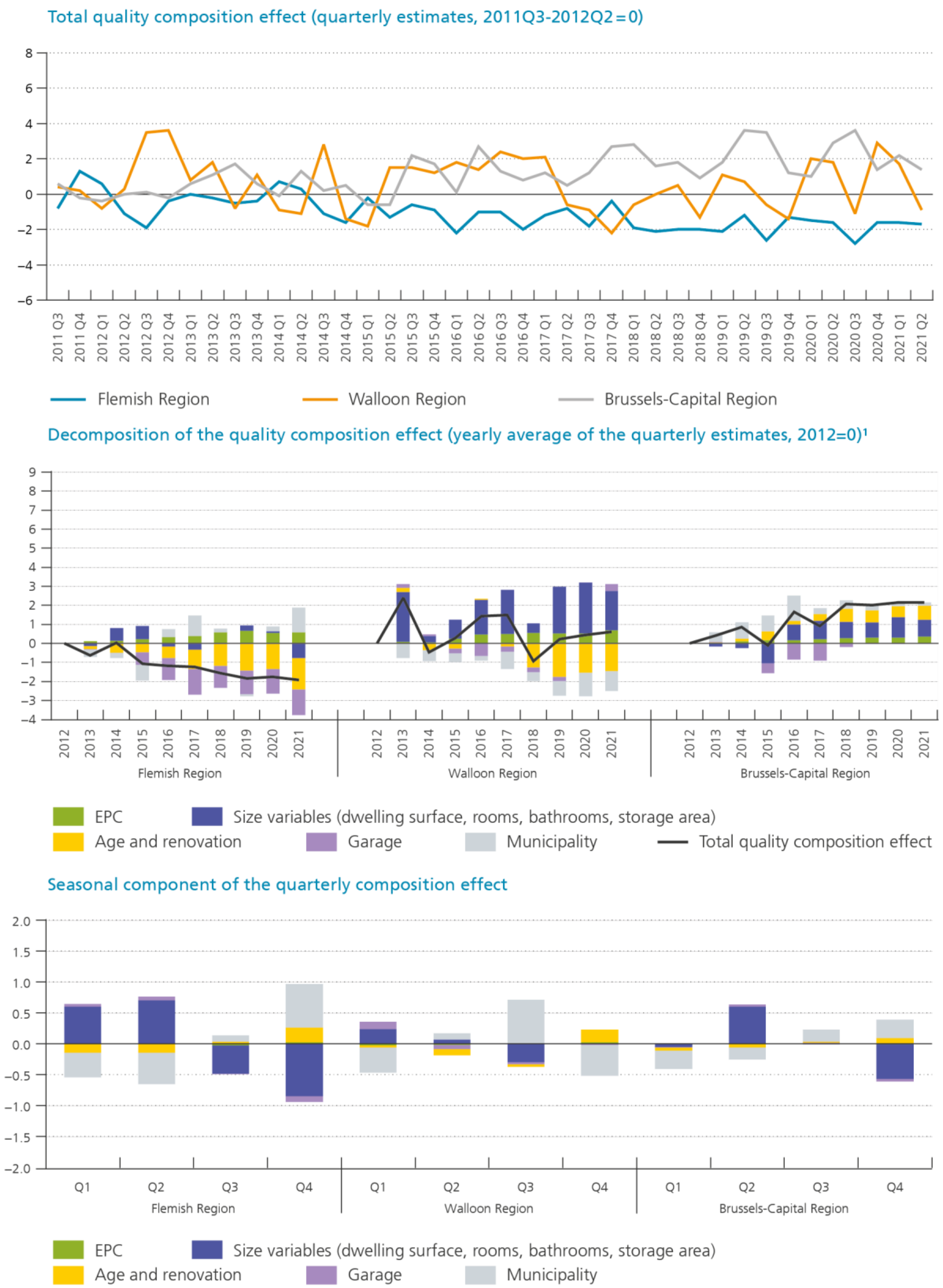
[9] Note that while the quality composition effect is computed using the 2011Q3 as the baseline quarter 0, it is rescaled in the graph such that the average of 2011Q3-2012Q2 equals zero.

Chart 2 - The quality composition effect – houses
(in percentage points)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
[1] Note that our years are shifted backwards by 2 quarters (e.g. our year "2021" corresponds to the first COVID year 2020Q3-2021Q2).

Chart 3 - The quality composition effect – apartments
(in percentage points)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
[1] Note that our years are shifted backwards by 2 quarters (e.g. our year “2021” corresponds to the first COVID year 2020Q3-2021Q2).

Fourth, we find no substantial change in the quality composition effect in the first COVID year, reflecting the findings in Table 1 that the average housing characteristics of the houses and apartments sold remained broadly stable. The quality composition effect of houses in the Brussels-Capital Region and apartments in all three Regions was broadly constant compared to 2019. In the Flemish and Walloon Regions, the quality composition effect of houses actually rose modestly in 2021 compared to 2019, by respectively +0.8 and +1.7 percentage point. However, this increase is mainly driven by improved energy efficiency and to a lesser extent by a larger average dwelling surface, but this is just a continuation of the earlier trend.

Finally, our framework of Equation (2) can be used to assess the impact of the planned energy renovation wave in the coming decades towards an energy-efficient dwelling stock (EPC score of 100 kWh/m² on average), assuming that the price premium stays constant at the estimated value of 2021. To this end, we compare the average price premium for a dwelling stock in which all houses have an EPC score of 100 kWh/m² with that for current property sales. As a result of the improved quality of houses compared to the current situation, the difference between the average price index and the hedonic index would be further increased by about 15 percentage points compared to 2021. This could even be higher if energy renovations are accompanied by improvements in other quality and comfort indicators (which are in this calculation assumed to remain unchanged). As a result, house price indices that do not take improvement in energy performance into account will overestimate the price growth of an identical dwelling. However, the 15-percentage-point bigger wedge between the average price index and hedonic index does not necessarily imply that the average house prices will be 15 % higher as a result of the transformation towards an energy efficient building stock. The evolution of average house prices is affected by the amount that households are able to pay given a fixed percentage of income that goes to housing expenses (Damen et al., 2016). The question to which extent the ability to pay is affected by the investments in energy efficiency is, however, beyond the scope of this paper. For apartments, the increase in the quality composition effect based on our estimates should come to about 3 percentage points, but this is an underestimation as our EPC price premia for apartment units are underestimated (see appendix B.5).

4.4. Comparison of the hedonic price index to other existing indices

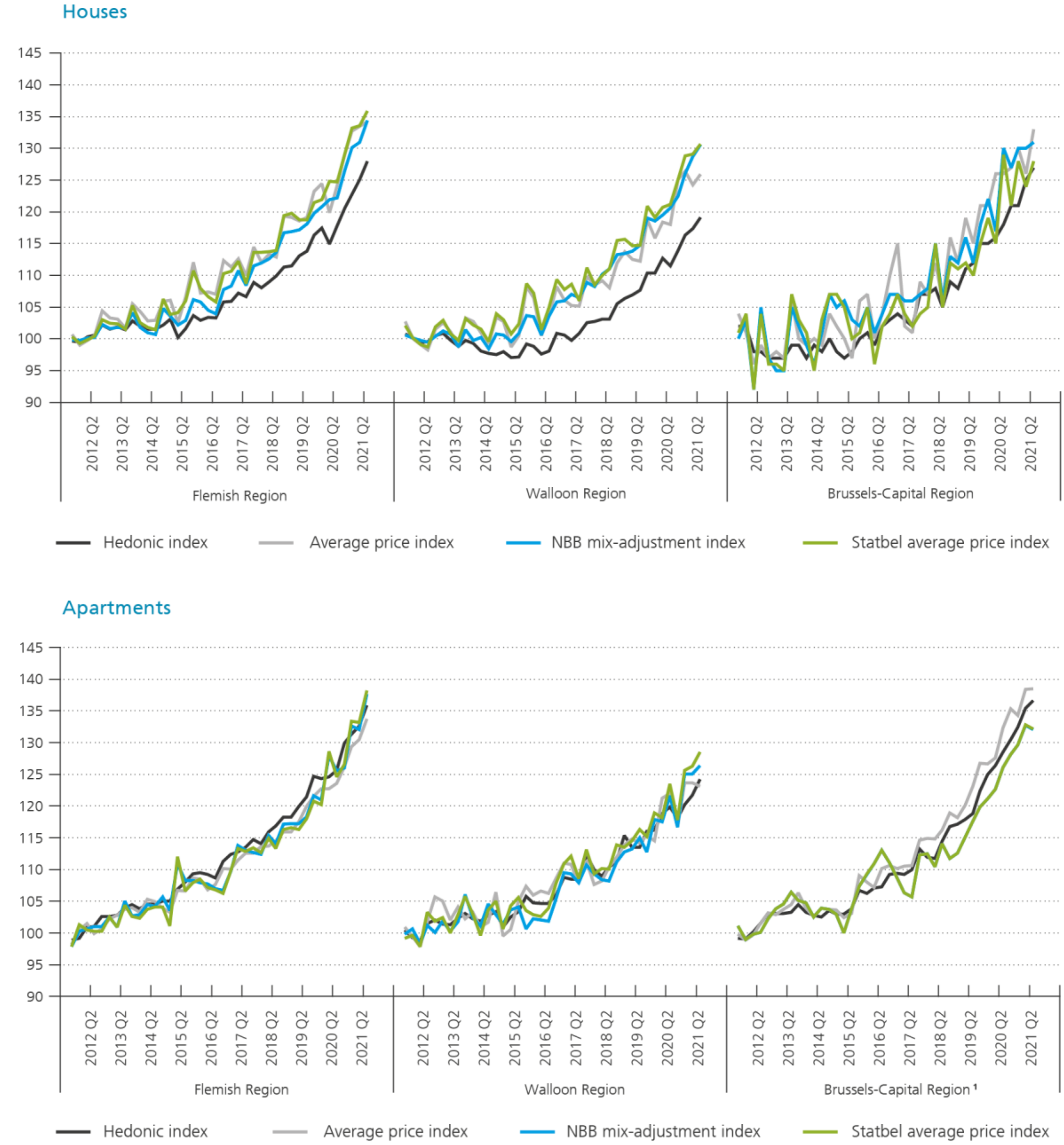
Chart 4 shows different property price indices for houses and apartments in the three Belgian Regions. In particular, the hedonic price index is compared with the (geometric) average price index (Equation (2 bis)), the NBB mix-adjustment index (Warisse, 2017) and the Statbel average price index, which we computed based on (arithmetic) average transaction prices that are available upon request from Statbel.

The first finding is that the cumulative growth of the hedonic index between 2012 and 2021 was substantially lower than that of the other indices for houses, but comparable for apartments. The difference with the geometric average price index is, by construction, fully accounted for by the quality composition effect discussed in Section 4.3, which measures the increase in quality of the houses sold in 2021 compared to 2012. This quality composition effect is large and positive for houses (+7 percentage points for the Flemish and Walloon Regions and +5 percentage points for the Brussels-Capital Region), but small for apartments (-2 percentage points for the Flemish Region, +1 percentage points for the Walloon Region and +2 percentage points for the Brussels-Capital Region).

While the quality composition effect also explains the bulk of the difference between the hedonic index and the Statbel average price and NBB mix-adjustment indices, divergences also arise from varying data samples. In particular, our hedonic index and average price index are calculated on the basis of a sample that differs from the one used to calculate the Statbel average price index and NBB mix-adjustment index. The variation between samples arises from different methods for cleaning the source dataset, for removing outliers and property for which there are no data for one or more dwelling characteristics (see Section 3). Finally, gaps between our average price index and the Statbel average price index also arise because the former is a geometric average and the latter an arithmetic average.

The second finding is that the cumulative price growth over the past decade has been stronger in the Flemish Region (+28 % for houses and +36 % for apartments) and Brussels-Capital Region (+27 % for houses and +37 % for apartments) than in the Walloon Region (+19 % for houses and + 24 % for apartments). It was also substantially higher for apartments than for houses in all three Regions, but this mainly reflects the higher price growth in cities (see Section 5.3), as apartments tend to be located more in built-up areas than rural areas. Turning to the recent period, prices surged in the four quarters of the first COVID year. Despite the scrapping of the housing bonus scheme in the Flemish Region as from January 2020, the year-on-year price growth for houses in 2021Q2 continued to be higher in the Flemish Region (+9 %) than the Brussels and Walloon Regions (+7 %). Price growth was also strong for apartments, but slightly lower than for houses, in particular 8 %, 6 % and 4 % in the Flemish, Brussels-Capital and Walloon Regions respectively. This suggests there was a slight shift in demand from apartments to houses.

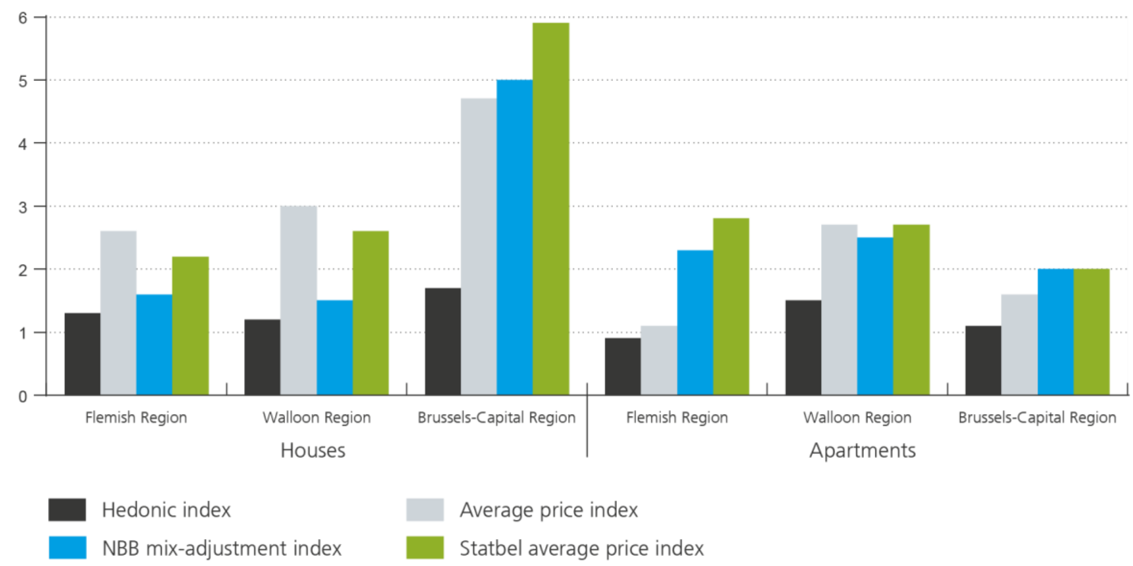
Chart 4 - House price indices in the three Belgian Regions
(index, 2011Q3-2012Q2=100)



Sources: FPS Finance, NBB, VEKA, Brussels Environment, SPW Wallonie, Statbel, own calculations.
¹ Note that the NBB mix-adjustment index equals the Statbel average price index for apartments in Brussels.

Finally, the hedonic price index is much less volatile thanks to the hedonic correction for changes in dwelling characteristics of the houses sold. Chart 5 compares the standard deviation of the quarterly growth rate of our hedonic indices to those of the NBB mix-adjustment index, the average price index and the Statbel average price index. We find that, for all Regions and for both houses and apartment, our hedonic index is about half as volatile as the other indices. The reduction in volatility compared to the NBB mix-adjustment index is however smaller for houses in the Flemish and Walloon Regions, but still amounts to 20 %. The reduced volatility partly reflects the correction for seasonal composition effects (see Section 4.3), but also the standard deviation of year-on-year growth rates is lower, especially for apartments in all three Regions and for houses in Brussels (about 40 % lower compared to the Statbel average price index and NBB mix adjustment index) and to a lesser extent also for houses in Flanders and Wallonia (about 5 % and 9 % lower than the NBB mix-adjustment index and the Statbel average price index respectively).

Chart 5 - Standard deviation of the quarterly growth rate of house price indices (2011Q4-2021Q2)
(in %)



Sources: FPS Finance, NBB, VEKA, Brussels Environment, SPW Wallonie, Statbel, own calculations.

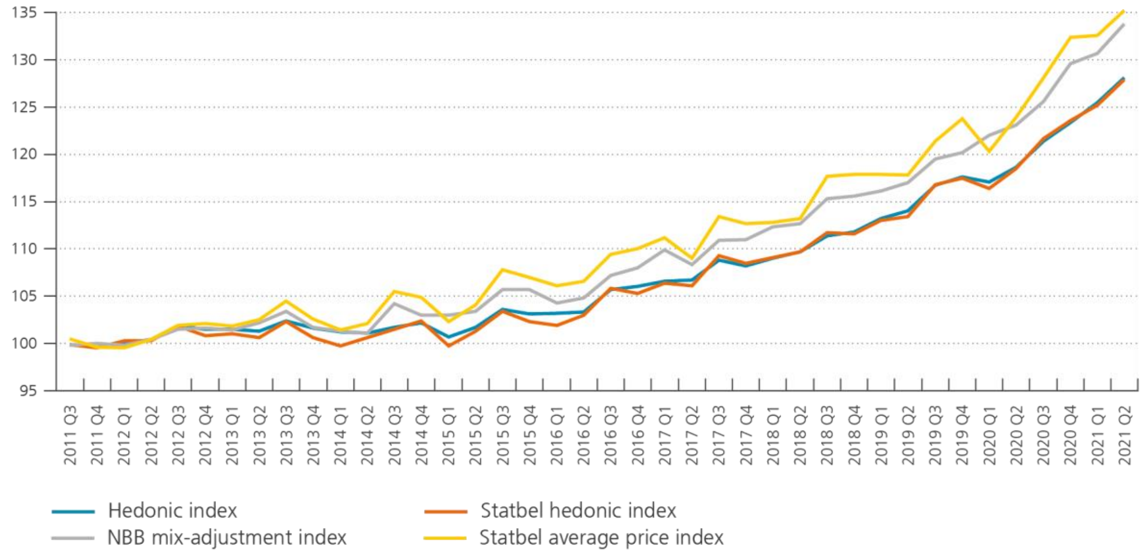
4.5. Belgian stratified hedonic index

Chart 6 shows the Belgian stratified hedonic index, which is computed as the weighted average of the house and apartment indices for the three Regions given in Chart 4. The weights are the sales value share and they are aggregated using a Fisher price index, as recommended by Eurostat (2013). The index is compared with other existing house price indices, in particular the NBB mix-adjustment index, the Statbel hedonic index and the Statbel average price index.

The cumulative growth over the past decade of the hedonic index (+28.1 %) is about 5 percentage points lower than that of the NBB mix-adjustment index (+33.8 %) and Statbel average price index (+35.2 %). This is as expected, given that the price rise in the hedonic index for houses is much lower (see Section 4.4).

We also find that the cumulative growth of our hedonic index is close to that of the hedonic index developed by Statbel. However, we argue that this is a coincidence and the result of methodological and sample differences that largely offset each other. In particular, as the Statbel hedonic index does not take account of energy efficiency improvements in dwellings, its cumulative price growth should in principle be higher. As the energy performance composition effect will become even much more important in the next few decades, we expect our hedonic index to diverge more in the future.

Chart 6 - Comparison of the stratified hedonic index for Belgium with existing house price indices
(index, 2011Q3-2012Q2=100)



Sources: FPS Finance, NBB, VEKA, Brussels Environment, SPW Wallonie, Statbel, own calculations.

5. The impact of COVID-19 on urban house price patterns

While Section 4 analysed the aggregate price developments for the three Belgian Regions, this section looks at a more granular level into whether and to what extent COVID-19 has altered house price patterns at the municipality and urban region level.

Urban patterns have evolved substantially over time and are the result of changes in the costs and benefits of living in one place rather than another. The widespread use of cars and the construction of motorways since the mid-20th century made it possible for households to move further away from the cities while still being able to commute to their jobs and the city amenities. This led to a strong suburbanisation process in many advanced countries, resulting in higher price growth outside the cities. This pattern was reversed in the 2000s and price growth in the cities has since outpaced that of rural areas. Edlund *et al.* (2016) found that centrality attracted skilled workers and argued that high-income-low-leisure-time households have reinforced the gentrification process. Similar patterns are referred to as “The rise of the creative class” (Florida 2002), “Triumph of the city” (Glaeser 2011), “The new geography of jobs” (Moretti, 2012) and “Super star cities” (Gyourko *et al.* 2013).

A key question is whether COVID-19 and the structural increase in working from home have led to a reversal of these urban patterns. More specifically, we investigate whether demand has shifted from the cities to the surrounding rural-urban fringe and commuter belt (intra-urban patterns) and if the gap between the more expensive and less expensive cities has diminished (inter-urban patterns). Several factors are at play.

By reducing work-related commuting costs, the strong and structural increase in remote working has a positive impact on the relative attractiveness of the more rural and less expensive areas compared to the cities. A longer commuting distance obviously becomes less of a burden when workers commute only two or three days a week instead of five. This effect is expected to be stronger in cities in which a large share of the jobs can be done from home. Ramani and Bloom (2021) indeed find subdued price growth in the high-density US cities, which they attribute to their larger share of jobs than can be done from home. Likewise, as working from home is more likely to be possible for highly-educated workers, we expect this effect to be stronger for cities with a large share of highly-educated inhabitants.

But cities are not only centres of production, but also of consumption. The amenity-based theory of location by income developed by Brueckner et al. (1999) shows that the relative location of different income groups depends on the spatial pattern of amenities in a city, which explains why central Paris is rich and downtown Detroit poor. So, if a city is mostly attractive because of its amenities, the impact of the decline of work-related commuting costs on its housing demand is lower. Couture & Handbury (2020) demonstrate that the persistent urban density of non-tradable service amenities accounted for over 40 % of young college-educated urbanisation from 2000 to 2010 in the US.

Another element that may explain divergent price developments between urban regions is the asymmetric impact the coronavirus crisis has on different households' ability to pay and their housing demand. While it had a negative impact on the income of the self-employed, those on furlough and the lowest-income households, aggregate disposable income continued to rise in Belgium. In addition, the saving rate in 2020 surged and was mostly boosted by the forced saving of high-income groups (Basselier and Minne, 2021). Furthermore, there is anecdotical evidence that young households have received more parental financial assistance for the purchase of their house than in the past. Finally, low interest rates have boosted demand for real estate, especially for wealthy households. As all these positive effects on housing demand are believed to be stronger for the highly-educated households, price pressures are expected to be larger for municipalities with a high share of highly-educated inhabitants.

Changes in consumer preferences for dwelling characteristics play a role too. As the price premium for detached dwellings and the value of garden and dwelling size slightly increased in the first COVID year (see Section 4.1), this will have a negative impact on average house prices in cities, as cities consist to a larger extent of small and terraced houses with a small garden.

Finally, in addition to COVID-19, which is assessed to have the largest effect, the Belgian housing market was also affected by two other factors in 2020. First, the National Bank of Belgium introduced new prudential expectations in January 2020 in which banks and insurance companies are encouraged to be more cautious in granting high-risk mortgage loans, in particular those with a high loan-to-value ratio and those with a combination of high loan-to-value ratio and a high debt-service-to-income or debt-to-income ratio. This measure could possibly have a stronger dampening effect on house prices in municipalities with a high share of such high-risk mortgage loans. Second, the abolishment in January 2020 of the tax deductibility of mortgage loans for new mortgages in the Flemish Region is expected to have a larger downward price impact on the dwelling types and locations frequently bought by new homeowners, as the existing homeowners that buy a new house can still keep the tax deductibility on their existing mortgage.

After a brief description of the municipalities and urban regions in Belgium in Section 5.1, Section 5.2 analyses the cross-sectional differences of the average house prices in 2021 between municipalities, which are broken down by municipality location value and quality of the dwellings sold (where quality should be broadly interpreted as the valuation of dwelling characteristics). Section 5.3 compares the price change in the first COVID year to that of the previous decade. This section focuses solely on the analysis of houses, using the model estimates of Equation (1) for Belgium as a whole.[10]

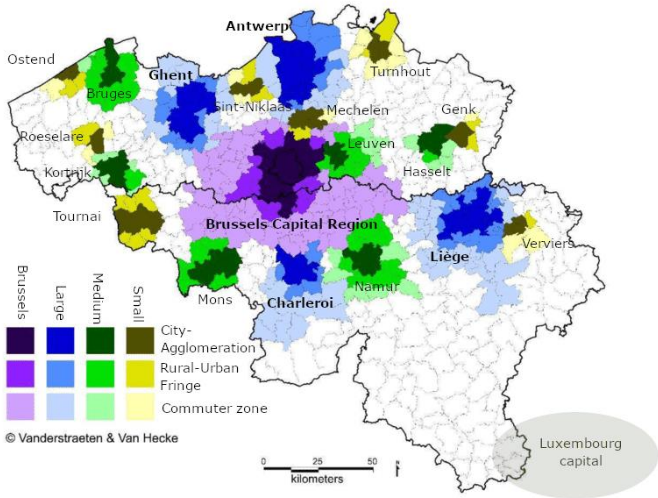
5.1. The Belgian municipalities and urban regions

For the analysis of the house price differences *within* urban regions (intra-urban) and *between* urban regions (inter-urban), we analyse the 581 Belgian municipalities as well as their urban region classification of Vanderstraeten *et al*. (2019), shown in Chart 7. They defined the core of an urban region as the core city (urban level 0) and some agglomeration municipalities (urban level 1), which is a zone of uninterrupted built environment broader than the city borders. The rural-urban fringe

[10] Note that apartments are not analysed in the section because of the data measurement error of their energy quality and because their model does not include location variables at the granular municipality level (see Section 3).

(also called banlieue) (urban level 2) is a zone of more dispersed residential settlements but with a strong focus of the population on the agglomeration. The commuter zone (urban level 3) is the area surrounding the urban region in which many people who work in the city live. Brussels is by far the biggest urban region, spread over the Brussels-Capital Region, the Walloon Region and the Flemish Region. Liège and Charleroi are the two major cities in the Walloon Region. Flanders' central polycentric "metropolitan core area" is the area in the Antwerp, Ghent, Brussels and Leuven quadrangle (Boussauw *et al.* 2018).

Chart 7 - The Belgian urban regions



Source: Vanderstraeten et al. (2017)

We made several small adjustments to the urban classification of the municipalities given in Vanderstraeten *et al*. (2019). First, due to a few recent mergers of municipalities, some urban regions are extended. Second, we also constructed a commuter belt for the municipalities in the south of Belgium close to Luxembourg city (the capital of Luxembourg), as they consist of a high degree of international commuters. Third, we defined municipalities not belonging to any urban region as being the rural region of each province. Finally, we also separately analyse the coastal region and a category of (non-coastal) tourist areas. In particular, we add coastal municipalities that do not belong to the urban regions of Bruges and Ostend to the coastal region and we classify a municipality as touristic if the share of holiday houses in the sales data is higher than 15 %, which is the case for 15 municipalities, mainly situated in the south of Wallonia.

5.2. Cross-sectional breakdown of municipalities' average house prices in 2021

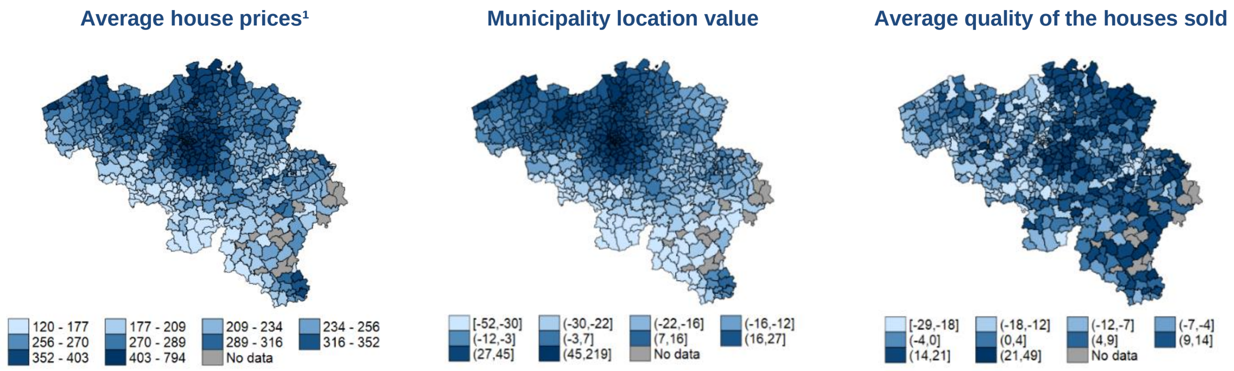
Chart 8 shows the average houses prices of the Belgian municipalities in 2021 and their breakdown into municipality location value and quality of the sold houses. They are obtained using Equation (5) and expressed as a percentage difference relative to the "average municipality", which we define as a municipality with an average municipality value and an average dwelling quality. Table 2 presents these results at the urban region level for the Belgian urban regions. Note that our year "2021" corresponds to the period 2020Q3-2021Q2.

Although Belgium is a relatively small country, we observe big differences in average prices between municipalities (Chart 8, left graph). The bottom 10 % of municipalities have an average house price of less than € 177 000, while this figure is more than € 403 000 for the top 10 %.

These wide price differentials are mainly the result of differences in the municipality location value (Chart 8, middle graph). While the location of the 10th percentile municipality is 30 % cheaper than the average municipality, the location of the 90th

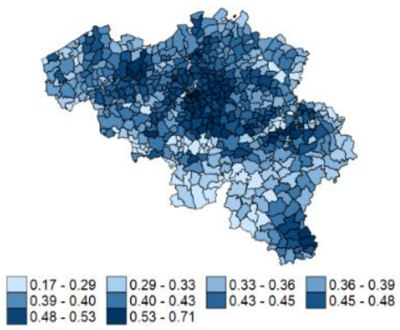
percentile municipality is 45 % more expensive. The municipality location value is strongly correlated with the share of highly-educated young adults in 2011 (see Chart 9) (a correlation of 0.7 for the 100 biggest municipalities), which is most likely driven by their higher income, wealth and parental financial assistance.

Chart 8 - Average house prices of the municipalities in 2021, municipality location value and dwelling quality
(in € thousands (left-hand graph); relative difference from the average municipality, in % (middle and right-hand graph))



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
¹ Note that the arithmetic average price is shown in the left-hand graph and that our year "2021" corresponds to the period 2020Q3-2021Q2.

Chart 9 - Share of highly-educated inhabitants in the 25-35 years age cohort in 2011
(in decimals)



Source: Vastmans and Dreesen (2021).

Also, differences in dwelling characteristics (Chart 8, right-hand graph) explain a large but smaller fraction of the average price differences between municipalities. They reflect differences in the average characteristics of the houses sold, for which detailed graphs are given in Appendix C. While the average quality of the houses sold in the 10th percentile municipality are 18 % lower than for the average municipality, it is 21 % higher for the 90th percentile municipality. These quality differences can partly be explained by four historical patterns. First, Belgium was an early industrialised country and one can clearly see two old industrial axes: the line between Liège, Charleroi and Mons, and the line along the Dender river between Geraardsbergen and Aalst. The houses in these municipalities are on average old and small in size. A second historical pattern is the higher quality of houses in the east of Flanders, which is the result of the younger population and younger dwelling stock. The third pattern is the lower quality of houses in cities, as townhouses are on average smaller, older and more likely to be terraced. This lower quality of townhouses explains why average prices in many cities are lower than their surrounding agglomeration, rural-urban fringe and commuter belt, as the lower quality more than offsets the higher location value of the city. Finally, the rural-urban fringe often has higher values for housing characteristics than in the commuter belt. More specifically, there is a strong correlation (0.43) between the municipality location value of the city and the extent to which the quality of housing characteristics is higher in the urban fringe than in the commuter belt. This means that attractive cities also have a rural-urban fringe with high house prices, not only because of their location value, but also because of the high-quality housing characteristics. This implies that affordable housing in those cities is also a spatial challenge, because the more affordable houses are located in their commuter belt, which is further away from the city.

Table 2 - Average house prices, location value and dwelling quality of the urban regions in 2021[1]
(relative difference compared to the average municipality, in %)

	Average house prices					Location value					Average quality					p.m. share highly-educated (in %)[2]
	City	Agglo-meration	Rural-urban fringe	Commuter belt	Rural area[3]	City	Agglo-meration	Rural-urban fringe	Commuter belt	Rural area[3]	City	Agglo-meration	Rural-urban fringe	Commuter belt	Rural area[3]	City
Largest cities																
Brussels	69	38	44	-5		91	32	21	-6		-12	5	19	1		50
Ghent	19	31	12	-1	-12	48	20	8	0	-6	-20	9	4	-2	-6	56
Antwerp	8	31	31	8	5	33	28	10	10	-7	-19	2	19	-2	13	39
Liège	-42	-37	-18	-23	-24	-23	-27	-25	-29	-28	-24	-14	10	7	6	41
Charleroi	-55	-47	-34	-36	-43	-43	-39	-34	-39	-37	-21	-12	1	5	-10	22
Smaller cities																
Leuven	40	44	37	1	-9	57	22	11	-11	-18	-11	18	24	13	12	71
Bruges	9		14	26	-4	25		6	21	-5	-13		8	4	1	45
Hasselt	9	6	3	-1	-11	0	-18	-21	-22	-25	9	29	31	27	19	52
Mechelen	5	27	32	13	5	30	20	22	1	-7	-19	6	9	12	13	49
Luxembourg-city				0	-35				-12	-40				13	7	55
Sint-Niklaas	-8		-3	19	-12	7		2	5	-6	-14		-5	14	-6	39
Namur	-8		-2	-27		-11		-24	-29		4		28	3		43
Ostend	-11	-3	-5	-5	-4	4	1	-3	1	-5	-14	-4	-2	-6	1	34
Turnhout	-11	35	27	14	5	-1	-4	-9	-8	-7	-10	41	39	23	13	37
Roeselare	-13		-7	-10	-4	-9		-15	-14	-5	-5		9	5	1	43
Genk	-14		-3	-5	-11	-19		-22	-30	-25	7		25	35	19	27
Kortrijk	-19	-20	-16	-31	-4	-6	-15	-16	-21	-5	-14	-6	0	-12	1	46
Tournai	-33		-37		-43	-26		-33		-37	-8		-6		-10	39
Verviers	-34	-37	-30	-15	-24	-26	-31	-28	-24	-28	-11	-8	-3	12	6	30
Mons	-43	-59	-41		-43	-35	-48	-39		-37	-13	-21	-3		-10	41

Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.

[1] Urban levels that do not exist for a certain urban region are denoted by empty cells. Note also that the year "2021" corresponds to the period 2020Q3-2021Q2.

[2] Share of highly-educated inhabitants in the city's 25-35 year age cohort in 2011 (Vastmans and Dreesen, 2021).

[3] "Rural area" corresponds to the municipalities in the province of the city that do not belong to any urban region.

5.3. Price growth before and during the first COVID year at the urban region level

We estimated the hedonic price index at the municipality and urban region level using Equation (3 tris). Appendix D shows that the hedonic index at the municipality level is much less volatile than the average price index, as the latter is strongly affected by quality composition effects. For the remainder of this section, we focus on the analysis of the urban region hedonic indices and, in particular, their price growth of the first COVID year and of the previous decade.

Table 3 shows the quality-adjusted house price growth for the Belgian urban regions, both the cumulative increase for the period 2012-2021 and the yearly price growth in the first COVID year (i.e. the price growth between the periods 2019Q3-2020Q2 and 2020Q3-2021Q2). This price growth is computed using Equation (3 tris) of Section *2.2.2* for the hedonic index at the urban region level. The first column of the table shows the share of highly educated young adults (aged 25-35 years) of each core city (urban level 0) in 2011.

The sharp rise in house prices in the first COVID year was widespread within Belgium, with yearly price growth ranging between 4 and 8 % in most urban regions. We do not find any evidence of a reversal of the intra-urban house price patterns over the past decade, when price growth in cities had outpaced that of the more rural areas. In particular, over the previous decade as well as the first COVID year, price growth in the cities continued to outpace that of the surrounding rural-urban fringe and commuter belt by about one-fifth on average. For the first COVID year, this corresponds to a 1 percentage point higher price rise.

Table 3 - Hedonic index of the Belgian urban regions: price growth for the periods 2012-2021 and 2020-2021[1] (in %)

	Price growth 2012-2021					Price growth 2020-2021					p.m. share highly-educated (in %)[2]
	City	Agglom-eration	Rural-urban fringe	Commuter belt	Rural area[3]	City	Agglom-eration	Rural-urban fringe	Commuter belt	Rural area[3]	City
Largest cities											
Brussels	24.9	22.5	19.9	21.2		6.5	5.6	5.4	6.2		50
Ghent	41.4	30.8	26.6	25.2	26.7	8.0	6.4	6.0	6.3	7.4	56
Antwerp	32.9	25.1	19.5	23.2	20.6	6.8	7.0	7.0	5.3	6.5	39
Liège	18.3	22.1	18.8	19.3	17.7	6.8	6.5	0.1	4.6	1.3	41
Charleroi	12.5	17.1	16.0	13.0	12.3	4.0	4.4	4.7	4.4	4.7	22
Smaller cities											
Leuven	29.7	23.2	24.0	21.5	16.7	6.5	4.8	6.4	4.4	3.4	71
Bruges	22.9		20.1	19.6	21.3	6.0		4.8	7.2	5.8	45
Hasselt	24.4	20.6	17.1	20.7	17.8	9.6	8.0	3.5	9.5	5.1	52
Mechelen	35.1	31.8	27.7	19.6	20.6	7.0	10.0	9.0	7.5	6.5	49
Luxembourg-city				33.6	19.9				8.1	5.0	55
Sint-Niklaas	28.0		22.5	21.6	26.7	5.9		6.0	5.7	7.4	39
Namur	19.6		18.3	19.4		7.0		5.5	3.7		43
Ostend	20.1	17.8	21.1	18.7	21.3	6.3	5.0	5.7	5.2	5.8	34
Turnhout	14.8	10.2	15.2	16.7	20.6	6.7	12.1	3.4	4.6	6.5	37
Roeselare	21.5		23.3	28.5	21.3	3.6		8.6	7.1	5.8	43
Genk	15.2		24.5	10.3	17.8	5.3		10.7	4.4	5.1	27
Kortrijk	26.2	20.5	23.8	20.0	21.3	5.7	2.7	5.3	5.9	5.8	46
Tournai	11.2		9.1		12.3	4.1		4.9		4.7	39
Verviers	16.5	12.2	11.8	21.7	17.7	7.6	0.7	-1.0	-1.2	1.3	30
Mons	11.6	10.2	13.8		12.3	2.5	2.5	4.3		4.7	41

Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
[1] Note that our years are shifted backwards by two quarters (e.g. our year "2021" corresponds to the period 2020Q3-2021Q2).
[2] Share of highly-educated inhabitants in the city's 25-35 year age cohort in 2011 (Vastmans and Dreesen, 2021).
[3] "Rural area" corresponds to the municipalities in the province of the city that do not belong to any urban region.

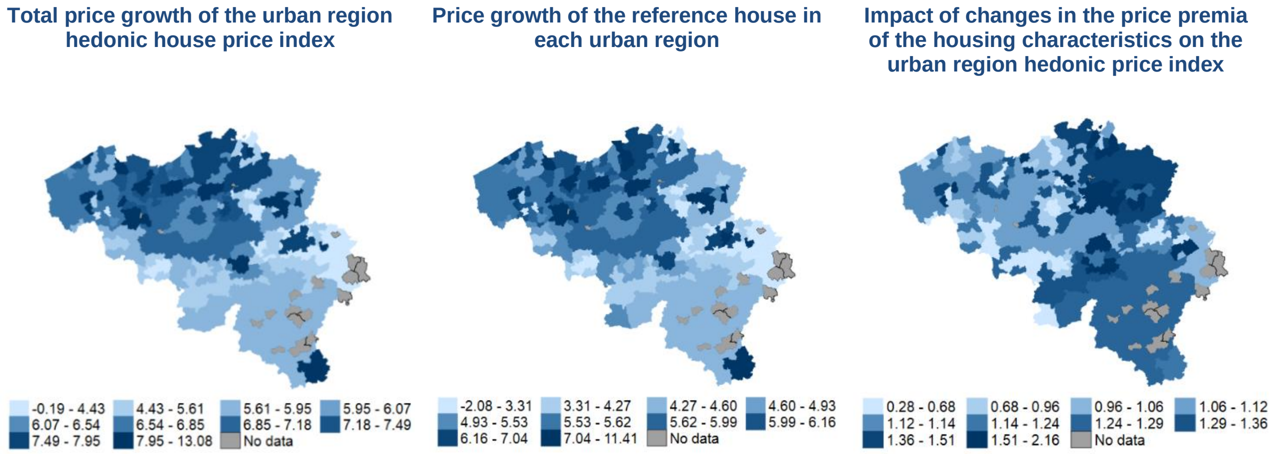
Nor do we find any reversal of the inter-urban price patterns, as the correlation between the pre-COVID price growth (2012-2020) and the price increase in the first COVID year is 0.4 for cities (urban level 0). The price growth in these cities continues to be strongly positively correlated (0.4) with the share of highly-educated young adults. This finding is in line with Vastmans and Dreesen (2021), who argue that the higher demand from young higher-educated buyers is the main explanation for urban price surges of houses in the Flemish Region. In addition, we also find that there is strong positive correlation (0.4) between the growth in the price index and the growth in homeownership in Flemish cities between 2018 and 2021. This suggests that investors are not crowding out households in the cities with the largest price pressures for houses. But this does not mean that investors and the search for yield behaviour have had no price impact. They are certainly part of the residential property demand, but more so in cities than elsewhere, and more for apartments than houses (Vastmans and Dreesen, 2021).[11]

[11] Based on Census 2011 data and some recent trends, Vastmans and Dreesen (2011) found that, even in the large Flemish cities, the share of home-ownership is much higher for houses than for apartments. Ghent has the lowest share of home ownership in houses, namely 71 % in 2011. This clearly illustrates that the market for houses is not dominated by investors in Belgium, even not in cities. Moreover, the share of houses in the private rental market is falling and the share of apartments rising, based on survey evidence in Flanders. Conversely, investors are more active in the market for (new-build) apartments.

Furthermore, house prices rose very strongly (+ 9 %) at the coastal municipalities and in the touristic municipalities, which are mainly the green municipalities in the Walloon Region. This likely reflects the increased demand for second homes in the first COVID-19 year.

Finally, the slightly increased price discount of terraced houses, small houses and houses with a small garden in the first COVID year had a slightly negative impact on the value of the average city house compared to the average house in the other municipalities, as cities consist to a larger extent of small and terraced houses with a small garden. Using Equation (3 tris), Chart 10 breaks down the 2021 price growth of urban region hedonic price index (left-hand graph) into the price growth of the reference house (middle graph) and the impact of changes in the price premia of the housing characteristics (right-hand graph). The reference house of each municipality corresponds to a 50-year-old terraced house with an EPC score of 350 kWh/m², not officially renovated, a dwelling surface of 150 m² and a garden of 200 m² (see also Section 4.1). While we observe that the changes in the price premia in the first COVID year had a larger positive impact on the hedonic index outside cities compared to that of cities (i.e. the lighter spots on the map in the right-hand graph are mostly cities), the difference is limited to no more than 2 percentage points.[12] Still, it implies that the gap between the price growth of the reference dwelling between cities and rural areas is slightly larger than the gap between the total hedonic price growth.

Chart 10 - Breakdown of the 2020-2021 price growth of the urban regions' hedonic house price index into the price growth of the reference house and the impact of changes in the housing preferences (in %)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
[1] Note that our years are shifted backwards by two quarters (e.g. our year "2021" corresponds to the period 2020Q3-2021Q2).

6. Conclusion

This paper proposes a framework to disentangle the contribution of each individual dwelling characteristic to the change in quality of the sold houses. The decomposition that we propose not only makes it possible to understand why the hedonic house price index differs from the average price index, but more generally also sheds light on the differences between house price indices that correct for a different set of dwelling characteristics. We believe that decomposing the price evolution into its different components could help in understanding the impact of methodological differences of different house price indices, which currently hamper both within-country and cross-country comparisons.

[12] Note that one should compare only the difference of the impact of changes in the price premia on the hedonic index between urban regions. In levels, this impact is larger than zero for all urban regions as the price premium of detached houses compared to terraced houses has increased, the reference house is a terraced house, and the share of detached houses is larger than zero even for cities.

We find a strong improvement in the energy quality of the sold houses in Belgium over the past decade, which largely explains why the cumulative average price growth over this period was higher compared to the quality adjusted hedonic price growth. Moreover, taking into account the energy quality in house price indices will only become more important as it will substantially further increase in the coming decades to reach the European climate goal of having an energy efficient building stock.

Turning to the recent period, we find that changes in quality of the property sold did not have a substantial impact on average price growth in the first COVID year, as the average characteristics of the sold houses remained broadly stable. However, we did find a slight change in the estimated price premia for several size-related dwelling characteristics, in particular those related to detached dwelling and to a lesser extent dwelling surface and garden size. Finally, our results for the first COVID year do not show a reversal of the urban spatial house price patterns of the past two decades. Price growth continued to be higher in cities compared to the surrounding more rural areas and it also continued to be higher in cities with a large share of young college educated households. However, the final impact of COVID-19 and of the structural increase in teleworking remains to be seen, given that household relocation decisions could take time and are not easily made in the midst of the pandemic.

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Appendix A: Proof of Equations (2) and (3) of Section 2.2

This appendix shows the proofs of Equations (2) and (3) of Section 2.2.

The geometric mean price index can be written as

$$\frac{\prod_{i=1}^{N_t} p_{it}^{\frac{1}{N_t^m}}}{\prod_{i=1}^{N_0} p_{i0}^{\frac{1}{N_0^m}}}$$

$$= \frac{\prod_{i=1}^{N_t} e^{\left[\hat{\delta}_\mathrm{t}+\sum_{k=1}^{K}\hat{\beta}_t^k x_{it}^k+e_{it}\right]^{\frac{1}{N_t}}}}{\prod_{i=1}^{N_0} e^{\left[\hat{\delta}_0+\sum_{k=1}^{K}\hat{\beta}_0^k x_{i0}^k+e_{i0}\right]^{\frac{1}{N_0}}}}$$

$$= e^{[\hat{\delta}_t-\hat{\delta}_0]+\sum_{k=1}^{K}[\hat{\beta}_t^k\bar{x}_t^k-\hat{\beta}_0^k\bar{x}_0^k]+[\bar{e}_t-\bar{e}_0]}$$

$$= e^{[\hat{\delta}_t-\hat{\delta}_0]+\sum_{k=1}^{K}[\hat{\beta}_t^k\bar{x}_t^k-\hat{\beta}_0^k\bar{x}_0^k]}$$

$$= e^{[\hat{\delta}_t-\hat{\delta}_0]+\sum_{k=1}^{K}[\frac{\hat{\beta}_t^k\bar{x}_\mathrm{t}^k}{2}-\frac{\hat{\beta}_0^k\bar{x}_0^k}{2}+\frac{\hat{\beta}_t^k\bar{x}_\mathrm{t}^k}{2}-\frac{\hat{\beta}_0^k\bar{x}_0^k}{2}]}$$

$$= e^{[\hat{\delta}_t-\hat{\delta}_0]+\sum_{k=1}^{K}[\frac{\hat{\beta}_t^k\bar{x}_\mathrm{t}^k}{2}+\frac{\hat{\beta}_t^k\bar{x}_0^k}{2}-\frac{\hat{\beta}_0^k\bar{x}_0^k}{2}-\frac{\hat{\beta}_0^k\bar{x}_\mathrm{t}^k}{2}+\frac{\hat{\beta}_t^k\bar{x}_\mathrm{t}^k}{2}+\frac{\hat{\beta}_0^k\bar{x}_\mathrm{t}^k}{2}-\frac{\hat{\beta}_t^k\bar{x}_0^k}{2}-\frac{\hat{\beta}_0^k\bar{x}_0^k}{2}]}$$

$$= e^{[\hat{\delta}_t-\hat{\delta}_0]+\sum_{k=1}^{K}\left[\bar{x}_{0\mathrm{t}}^k\left(\hat{\beta}_t^k-\hat{\beta}_0^k\right)\right]+\sum_{k=1}^{K}\left[\hat{\beta}_{0t}^k\left(\bar{x}_t^k-\bar{x}_0^k\right)\right]}$$

$$= I_t e^{\sum_{k=1}^{K}\hat{\beta}_{0t}^k(\bar{x}_t^k-\bar{x}_0^k)},$$

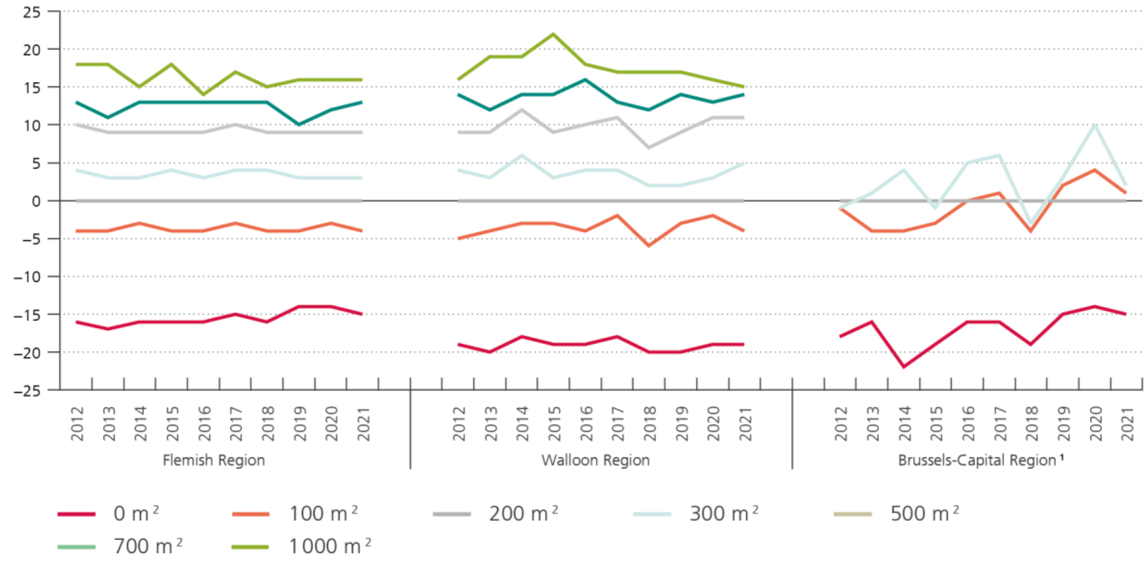
where we use that the average residual in each year $\bar{e}_t$ equals zero because of the inclusion of yearly time fixed effects and where $I_t = e^{(\hat{\delta}_t-\hat{\delta}_0)}e^{\sum_{k=1}^{K}[\bar{x}_{0\mathrm{t}}^k(\hat{\beta}_t^k-\hat{\beta}_0^k)]}$ is the geometric imputation Fisher price index (see Equation (5.21) of Eurostat (2013)).

Appendix B Estimated price premia for a selection of the dwelling characteristics

First, Appendix B.1 and B.2 show the estimated price premia for a selection of dwelling characteristics of the model of houses and apartments and for each of the three Regions.[13] These price premia are obtained by applying the transformation exp($\hat{\beta}_t^k$)-1 of Halvorsen and Palmquis (1980) and which for most coefficients is almost identical to the alternative transformation proposed by Kennedy (1991) and Van Garderen and Shah (2002). The estimation errors of the (untransformed) estimated coefficients $\hat{\beta}_t^k$ are shown in Appendix B.3. Appendix B.4 shows the difference between the 2021 and 2019 price premia estimates for a selection of dwelling characteristics. The standard error of most estimated coefficients amounts to about 1 percentage point, but is larger for apartments in Wallonia, and for houses in Brussels because of their smaller number of observations. Finally, the estimated price premia of energy quality are discussed in detail in Appendix B.5.

B.1 Estimated price premia for the model for houses

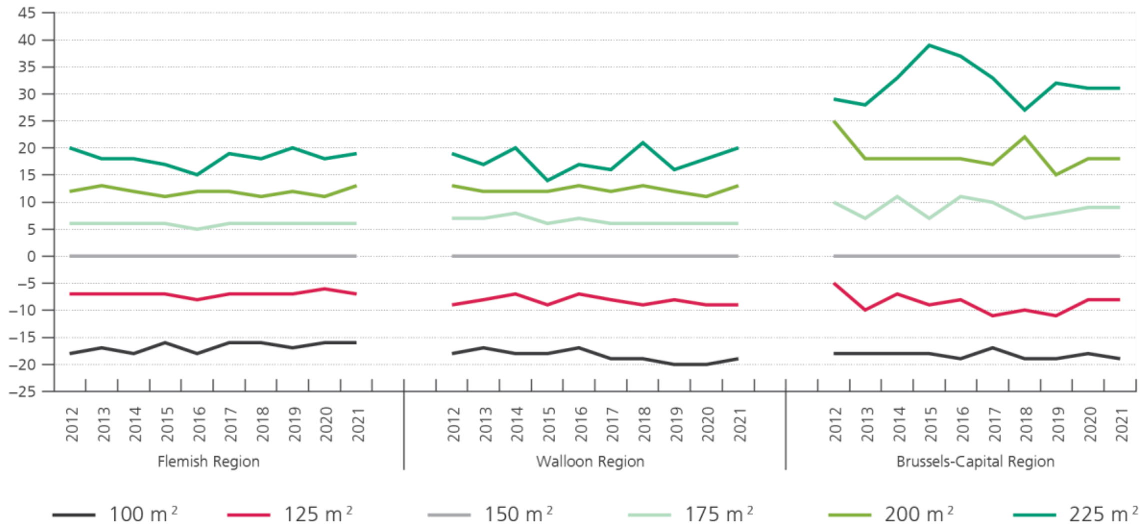
Chart 11 - Estimated price premium of garden size
(in %, price difference to a comparable house with a garden size of 200 m²)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
[1] The price premia for larger garden sizes are not shown for the Brussels-Capital Region, because there were not enough observations.

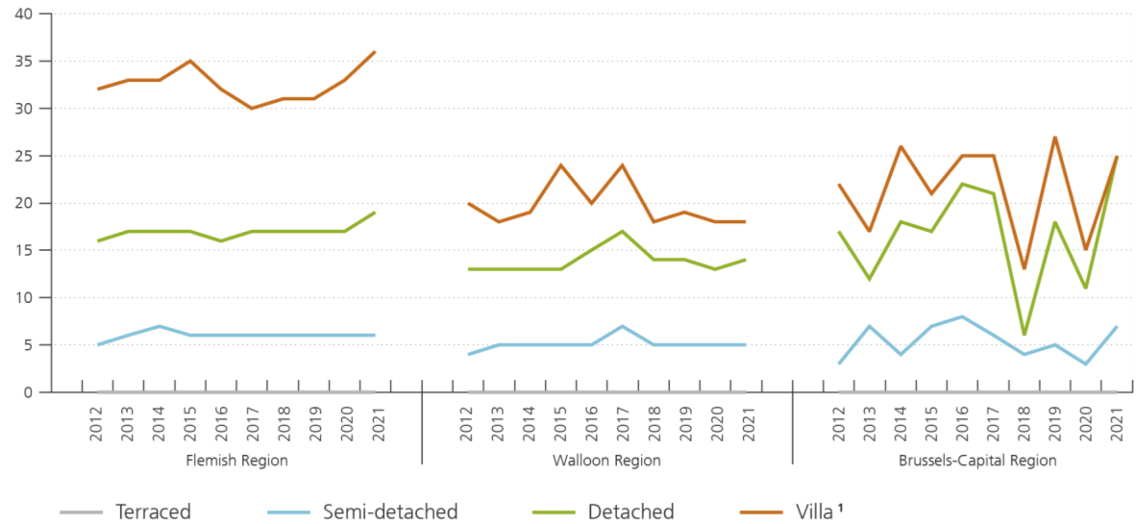
[13] In the interest of space, we do not show the model estimates for the full Belgian sample, which will be used in Section 5. Note also that our years are shifted backwards by 2 quarters (e.g. our year “2021” corresponds to the first COVID year 2020Q3-2021Q2).

Chart 12 - Estimated price premium of dwelling surface
(in %, price difference to a comparable house with a dwelling surface of 150 m²)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.

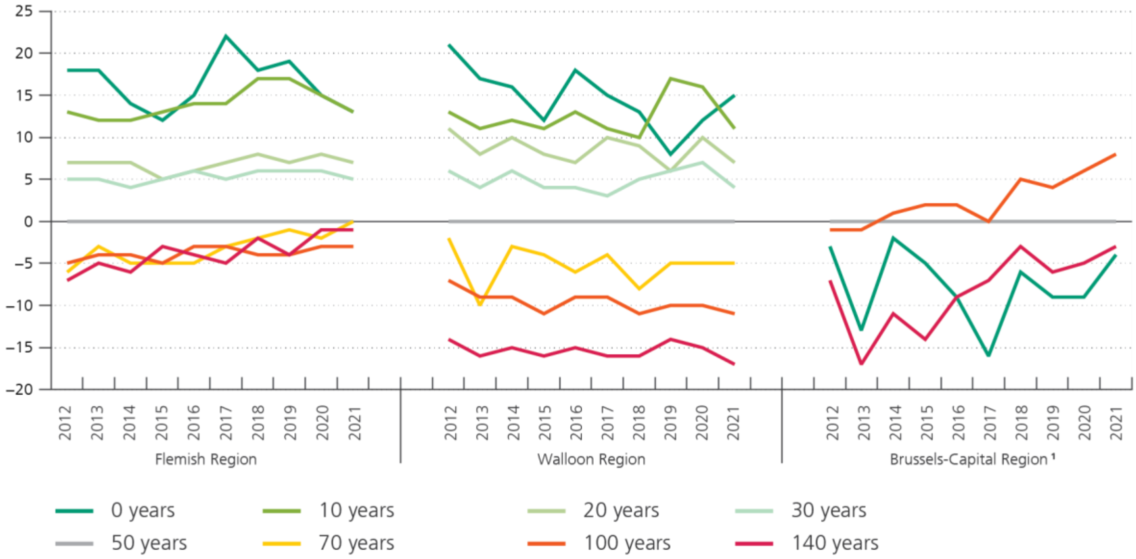
Chart 13 - Estimated price premium of different dwelling types
(in %, compared to a terraced house with otherwise comparable characteristics)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.

[1] The villa classification corresponds to a more premium detached dwelling and its price premium is therefore equal to the sum of the price premia of villa and detached dwelling. While most detached dwellings are also classified as villas in the Brussels-Capital Region, this is only the case for 4 % of all detached houses in the Flemish and Walloon Regions.

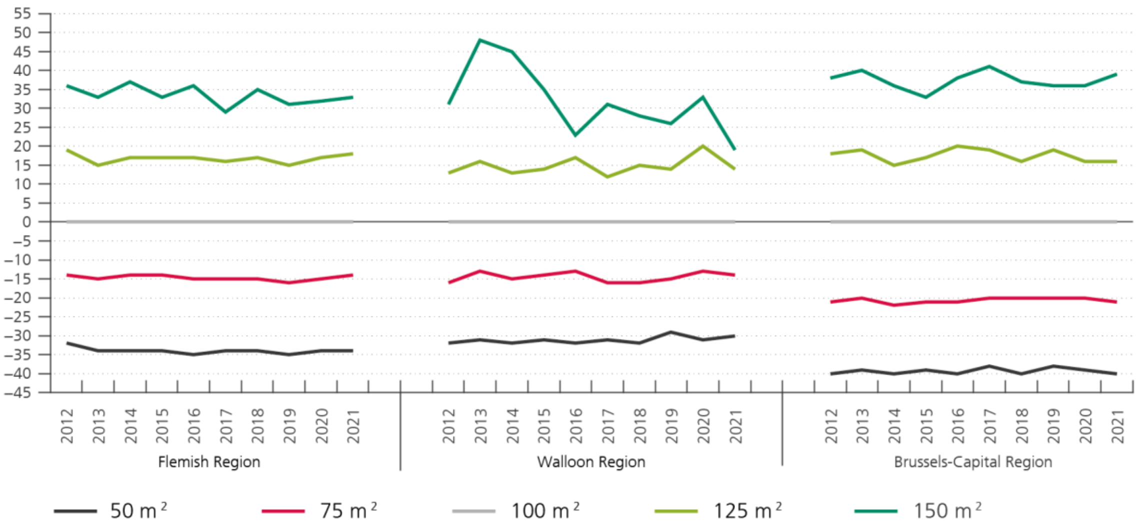
Chart 14 - Estimated price premium of age
(in %, price difference to a comparable house with an age of 50 years)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
¹ For Brussels-Capital Region, several price premia are not estimated due to to small number of young houses in the sample.

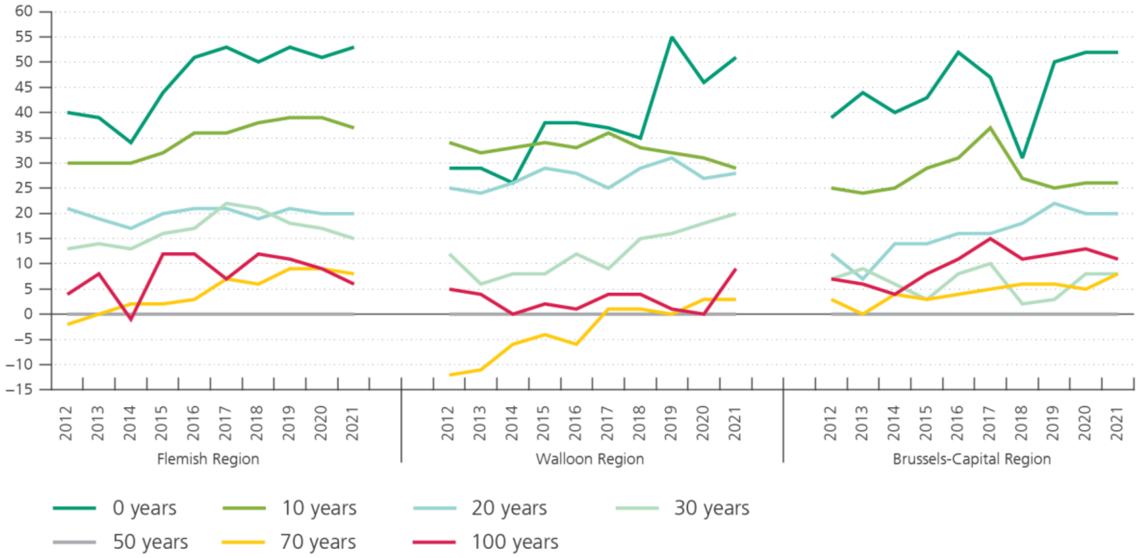
B.2 Estimated price premia for the model for apartments

Chart 15 - Estimated price premium of dwelling surface
(in %, price difference to a comparable apartment with a dwelling surface of 100 m²)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.

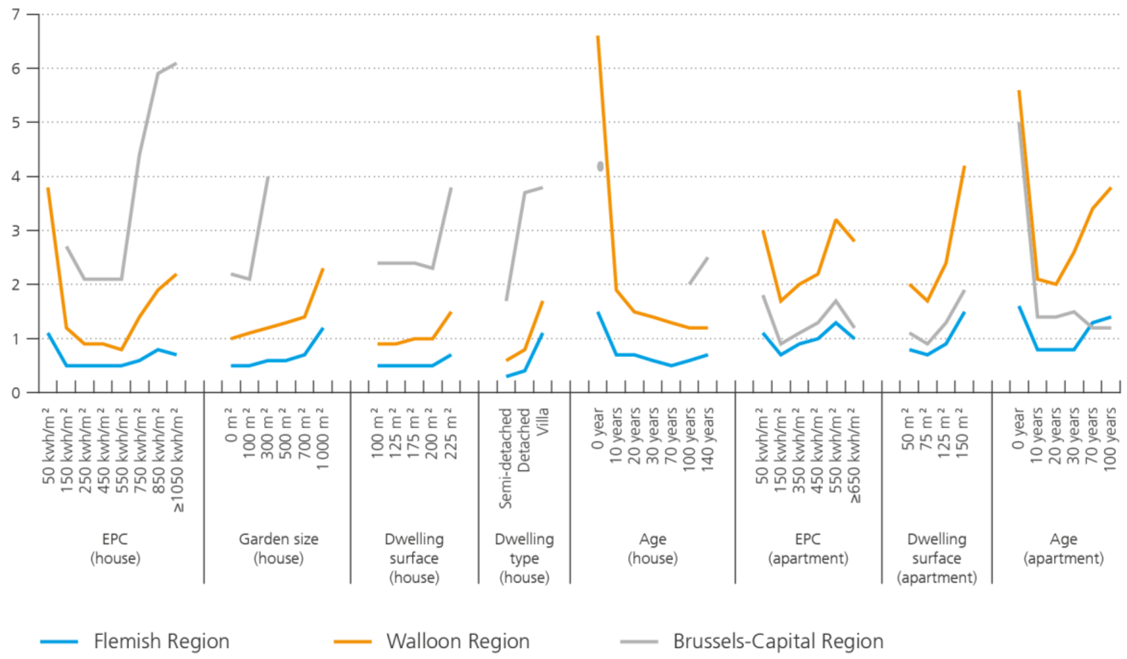
Chart 16 - Estimated price premium of age
(in %, price difference to a comparable apartment with an age of 50 years)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.

B.3 Standard error for a selection of the estimated coefficients in 2021

Chart 17 - Standard error for a selection of estimated (untransformed) coefficients in 2021
(in %)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.

B.4 Comparison of the estimated price premia in 2021 and 2019

Table 4 - Difference of the estimated price premia in 2021 and 2019 and Z-score of the statistical significance test[1]

	Flemish Region		Walloon Region		Brussels-Capital Region		Belgium	
	2021-2019 price premium difference	Z-score	2021-2019 price premium difference	Z-score	2021-2019 price premium difference	z-score	2021-2019 price premium difference	Z-score
A. Dwelling type (reference category is terraced)								
Semi-detached	0.1	0.1	-0.6	-0.8	1.9	0.7	-0.2	-0.4
Detached	2.0	2.9	0.2	0.1	7.2	1.2	1.5	2.5
B. Garden size (reference category is 200 m²)								
0 m²	-1.0	-1.6	1.8	1.5	0.0	0.0	-0.3	-0.5
100 m²	-0.2	-0.4	-1.2	-0.8	-0.9	-0.3	-0.6	-1.0
300 m²	0.7	0.8	2.4	1.3	-0.5	-0.1	0.9	1.2
400 m²	-0.1	-0.1	-3.2	-1.8			-0.9	-1.2
500 m²	0.6	0.6	1.4	0.7			0.6	0.7
600 m²	-0.7	-0.7	3.0	1.4			0.1	0.1
700 m²	2.1	1.9	-0.5	-0.2			1.4	1.3
800 m²	0.1	0.1	3.2	1.3			0.9	0.8
900 m²	0.1	0.1	1.5	0.6			0.9	0.7
1000 m²	0.0	0.0	-1.5	-0.4			-0.5	-0.3
C. Dwelling surface of house (reference category is 150 m²)								
0 m²	-0.9	-0.7	1.1	0.5	-1.0	-0.1	0.1	0.1
100 m²	0.3	0.6	0.5	0.5	-0.3	-0.1	0.4	0.8
125 m²	-0.2	-0.3	-1.2	-1.0	2.7	0.9	-0.4	-0.7
175 m²	0.0	0.0	0.6	0.4	0.9	0.3	0.1	0.2
200 m²	1.0	1.4	0.2	0.1	3.0	0.8	0.8	1.1
225 m²	-0.9	-0.7	4.6	1.8	-0.3	0.0	0.4	0.4

Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.

[1] For the testing of the equality of the price premia, the Z-score of Paternoster et al. (1998) is computed for the statistical test of equality of coefficients estimated on independent samples. This test is computed using the standard errors of the untransformed coefficients of Figure 17. A Z-score larger than 2 in absolute value means that the difference of the price premia in statistically significant at the 95 % confidence level. Finally, note that our years are shifted backwards by 2 quarters (e.g. our year “2021” corresponds to the first COVID year 2020Q3-2021Q2).

B.5 The price premia of energy efficient dwellings

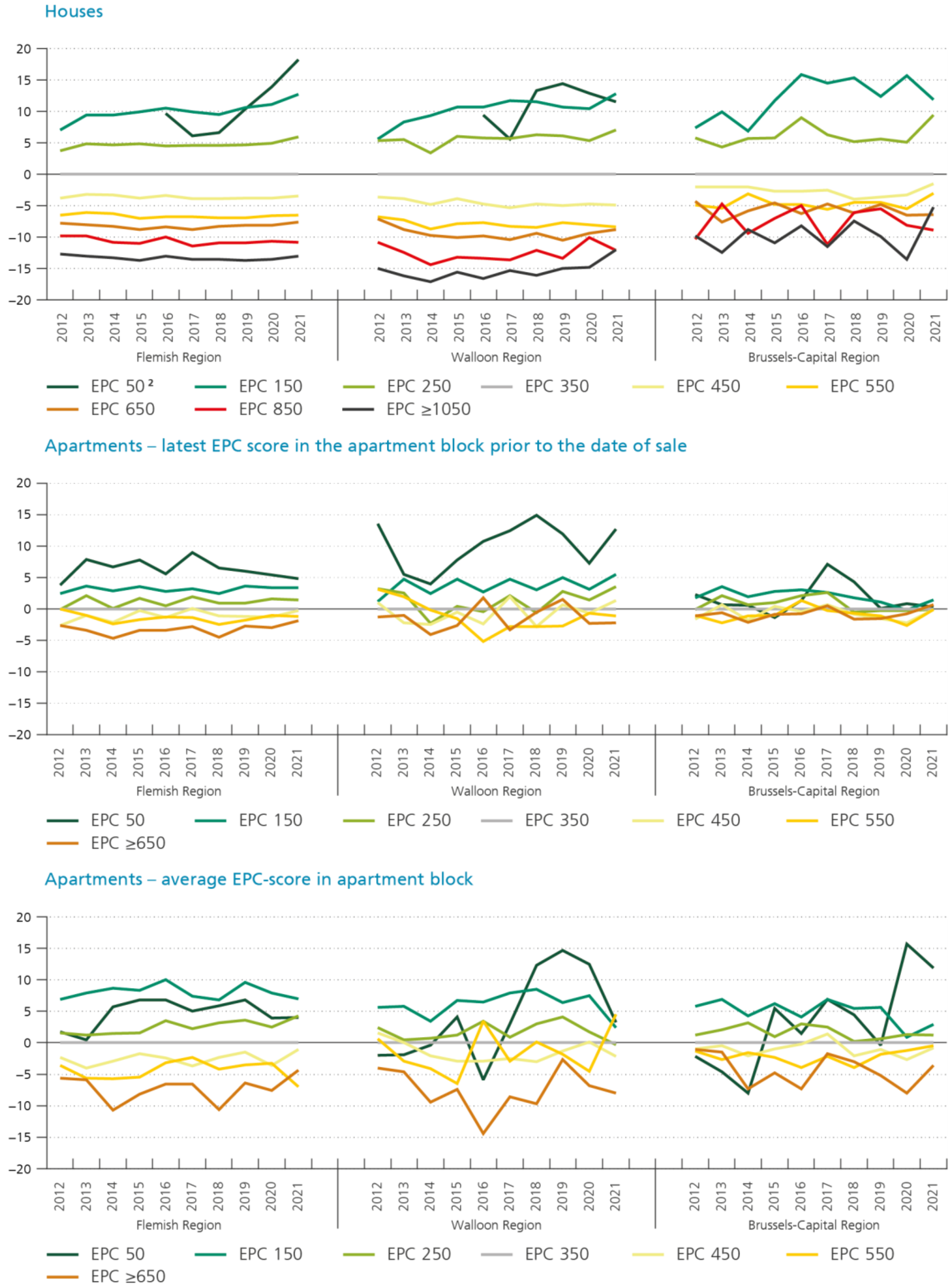
We are the first to estimate the price impact of energy efficiency on house prices in Belgium by combining the transaction dataset from the FPS Finance and the regional energy agencies' EPC datasets. Chart 18 shows the estimated price premium for different energy efficiency values for both houses and apartments. These price premia measure the price difference to a comparable dwelling with an EPC of 350 kWh/m² (corresponding to the midpoint of the Flemish energy label D) but that is similar in terms of the other dwelling characteristics of the model (e.g. the same dwelling size, dwelling type, age and location). In addition, in order to single out the pure price impact of the EPC score, the estimated price premia in Chart 18 are corrected for the impact of quality and comfort characteristics for which no data is available. Without this correction, the magnitude of the estimated price premia for energy efficiency are likely to be substantially overestimated, given that these unobserved quality and comfort characteristics are positively correlated with the energy efficiency. For instance, the uncorrected price premium for energy-efficient dwellings would partly capture the fact that the quality and comfort of energy-efficient homes are typically above average. Based on the difference between the price premia between a model with and without these additional quality and comfort characteristics estimated by Damen (2019), we reckon the additional quality and comfort characteristics account for a third of the estimated price premium for EPC values below 350 kWh/m² and half in the case of EPC values above 350 kWh/m². All in all, the estimated price premia should be interpreted with caution, given that, in addition to estimation error, they could be affected by uncertainty and differences in this correction factor over time and between Regions.

Chart 18 (top graph) shows that the energy efficiency price premia of houses are large and of similar magnitude in the three Regions. Correcting our estimates for the above discussed impact of unobserved quality and comfort variables, they amount to about +17 % (EPC 50), +12 % (EPC 150), +6 % (EPC 250), -4 % (EPC 450), -7 % (EPC 550), -8 % (EPC 650), -9 % (EPC 750), -11 % (EPC 850), -11 % (EPC 950) and -13 % (EPC above 1050) in 2021. These estimated price premiums are slightly larger than the estimates by Damen (2019) for the Flemish Region, which were obtained using realtor data for the period 2009-2017. They are also well within the range of those reported in previous empirical studies (see, for instance, the extensive overview given in Table 1 in Copiello and Donati, 2021), but it should be noted that this range is very wide due to differences in the data availability, methodology, sample period and country of the studies.

The positive price premia of the energy efficient houses with EPC score of 150 kWh/m² have almost doubled compared to 2012, from about 6.5 % in 2012 to about 12 % in 2021, which is also statistically significant. Conversely, the price discounts of the low energy efficient scores have remained broadly constant. This finding of an upward trend in energy efficiency price premiums is in line with Damen (2019), Evangelista *et al*. (2020) and Aroul and Rodiuz (2017). It is the result of the increasing awareness by households of the importance of energy efficiency when purchasing a house, which can reflect the increased transparency by the EPC certificate, an increase in the expected future energy prices and the increased environmental consciousness, including the target to reach energy label A by 2050. Given the findings of Myers *et al*. (2019) that homebuyers are attentive to energy costs, the recent surge in energy prices as well as the recent announcement by the Flemish government on compulsory energy renovation requirements could push up the price premium even further.

Chart 18 (middle and bottom graph) show estimates for the price premia for the energy efficiency of respectively the apartment unit and the entire apartment building, but these should be interpreted with a lot of caution. In contrast to houses, there is no exact match possible between the transaction dataset and the EPC dataset at the apartment unit level due to differences in the identification of an apartment unit within an apartment building (see Section 3). First, Chart 18 (middle graph) assumes that the EPC score of a sold apartment corresponds to the most recent EPC score prior to the date of sale, but the imperfect matching implies that the flats sold are in many cases linked to the EPC score of another apartment unit in the same block. Second, Chart 18 (bottom graph) shows the price premia using the average of the available EPC score of apartment units in the building prior to the date of sale, which can be a rough proxy for the global energy efficiency of the whole block of flats.

Chart 18 - Estimated energy efficiency price premium[1]
(in %, price difference to a comparable dwelling with an EPC score of 350 kWh/m²)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.

[1] The estimated price premia have been roughly corrected for the impact of unobserved quality and comfort characteristics, but should still be interpreted with a lot of caution, especially for apartments (see box 1). Note also that our years are shifted backwards by two quarters (e.g. our year "2021" corresponds to the period 2020Q3-2021Q2).

[2] The price premium of EPC 50 for houses is omitted for the period before 2015 and for Brussels houses as it was based on too few observations.

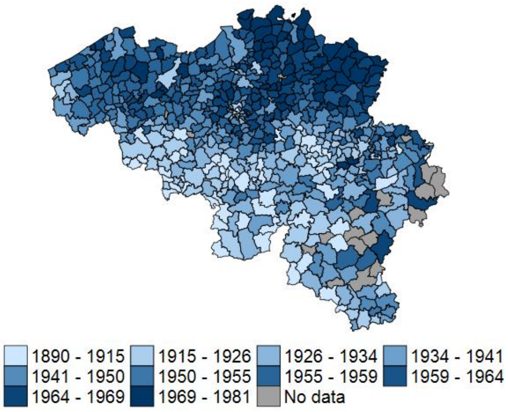
Chart 18 (middle graph) shows that the estimated price premia are much smaller for apartments compared to houses, especially in the Brussels-Capital Region. Also, in contrast to houses, the estimated price premia have not increased over the previous decade. Correcting for the impact of unobserved quality and comfort variables, the estimated price premia of an apartment with an EPC of 150 kWh/m² equals 4 % (Walloon Region), 3 % (Flemish Region) and 2 % (Brussels-Capital Region), while the price discount of a dwelling with an EPC of 550 kWh/m² equals only -1 % in the three Regions. However, the magnitude of our estimated price premia for apartments is very likely underestimated because of measurement error. The reason is that, due to the lack of an exact match of the databases at the apartment unit level, the sold dwelling is in many cases linked to the EPC score of another apartment unit in the same apartment building (see Section 3). Still, the finding of a small price premia for the EPC score of apartment units is in line with the findings of Damen (2019), but Evangelista *et al.* (2020) found the price premia for apartments to be larger than for houses.

Finally, Chart 18 (bottom graph) seems to suggest that the average EPC score of the apartment building has a larger price impact than the EPC score of the individual apartment unit. Apartments with an average EPC score at the building level of 150 kWh/m² are sold at a price premium of about 8 % in the Flemish Region and about 6 % in the Walloon and Brussels-Capital Regions. The price discount of apartments in buildings with an average EPC score of 550 kWh/m² is -4 % in the Flemish Region and -2 % in the Walloon and Brussels-Capital Regions. This could possibly indicate that households anticipate the costs of future energy renovations of the entire apartment building, as all owners have to contribute to the energy renovation of the common parts of the building, including the outer walls, roof and floor. However, the higher importance of the average EPC score of the apartment block can also be the result of the above discussed measurement error and it could in addition be the result of differences in the unobserved quality and comfort variables. In this respect, we welcome the introduction of the EPC score for the common parts of an apartment building, which will make it possible to estimate the price importance of energy efficiency in these common parts more accurately.

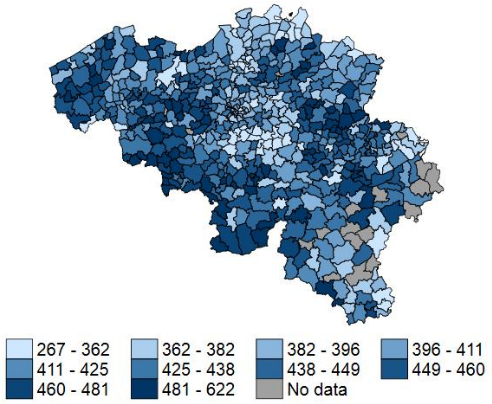
Appendix C Municipality average of the characteristics of the sold houses in 2020Q3-2021Q2

Chart 19 - Municipality average for a selection of dwelling characteristics of the sold houses in 2020Q3-2021Q2

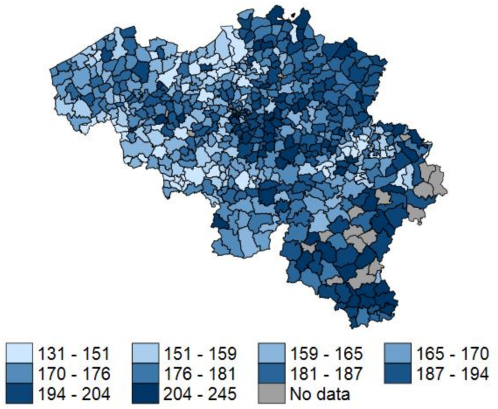
Average building year



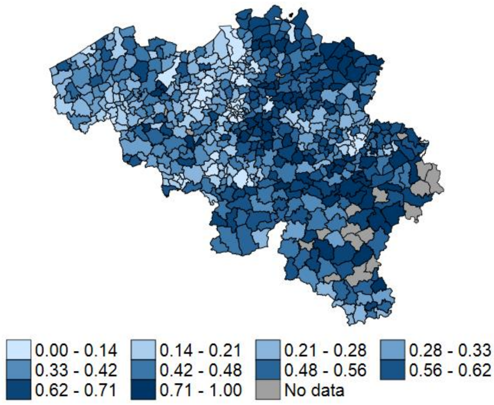
Average energy performance EPC score
(in kWh/m²)



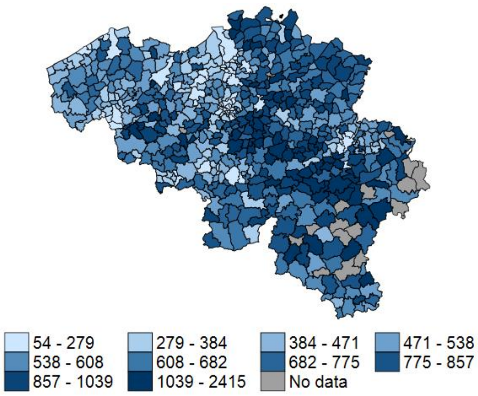
Average dwelling surface
(in m²)



Proportion of detached houses
(in decimals)



Average garden size
(in m²)



Sources: FOD Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.

Appendix D Hedonic house price index at the municipality level

This section shows the results of the estimated hedonic index of the 581 Belgian municipalities, obtained using Equation (3 tris), where we use the model estimates of Equation (1) for Belgium as a whole.

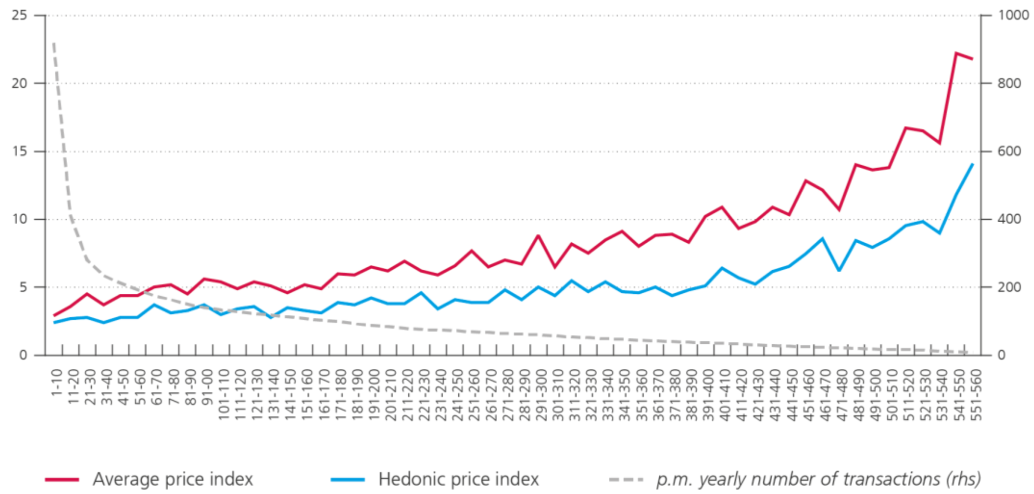
Chart 20 shows the standard deviation of the yearly growth in our municipality index as well as of that of the (arithmetic) average price index. This is believed to be a good indicator of the precision of our hedonic index estimates. While a certain degree of volatility in the growth rates can reflect changing local or aggregate price dynamics, a highly volatile growth rate is very likely to be largely driven by estimation noise.

First, we find a clear negative relationship between the number of transactions and the volatility of the two house price indices. Municipalities with few transactions have a volatile house price index. Conversely, the biggest municipalities have a very low standard deviation from their yearly growth of about 2.9 percentage points, which is only slightly higher than the standard deviation from the yearly growth of the Belgian aggregate house price index discussed in Section 4.5, which equals 2.0 percentage points.

Second, by correcting for the impact of quality composition effects, the hedonic index is substantially less volatile than the average price index. The gain in volatility is larger for municipalities with a smaller number of transactions. While the standard deviation from the yearly growth is only about 20 % lower for the biggest municipalities, it is around 35 % lower for the first half of the municipalities surveyed and about 41 % for the second half. Because of the law of large numbers, quality composition effects are greater when the number of transactions is smaller.

All in all, while being substantially less volatile than the average price index, the hedonic house price index remains volatile, especially for the smallest municipalities. This higher volatility can be the result of unobserved dwelling characteristics, local differences in housing preferences and idiosyncrasies of the transaction process related to, for instance, the bargaining power of the buyer and seller. As these do not reflect fundamental price dynamics, the price index at the municipality level should be interpreted with care, especially for the smallest municipalities.

Chart 20 - Standard deviation of the yearly growth rate of the hedonic and average price index, by municipality number (sorted by the decreasing number of yearly transactions (right-hand scale))[1]
(in percentage points)



Sources: FPS Finance, VEKA, Brussels Environment, SPW Wallonie, own calculations.
[1] The graph shows the average standard deviation of 10 municipalities with a similar number of transactions (for example, "1-10" is the average of the standard deviation for the 10 largest municipalities). We left out about 20 municipalities with too few transactions.

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