Differentiating the value of land from that of real estate to better understand the impacts of NNLT on housing affordability

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Abstract

In recent decades, housing affordability challenges have intensified in Belgium and Europe due to rising prices. Structural factors driving these increases include high demand and insufficient supply responsiveness, compounded by escalating land values. While construction costs are often cited by industry experts as a primary driver of price hikes, research indicates that the increase of land values plays a more significant role. This discrepancy underscores the need to objectively assess the impact of land dynamics on housing values, particularly since the implementation of the No Net Land Take Policy (NNLT) and the resulting scarcity of land are likely to exacerbate these trends.

To accurately assess the impact of land on housing price dynamics and develop innovative public policies such as land value capture, understanding the role of land in housing values is crucial. This requires, among other things, a detailed mapping of land values, enabling us to establish the respective shares of land and real estate values in the increase in housing prices. Countries like Germany, Sweden, and Taiwan have leveraged differentiated land taxation systems based on such insights. However, adapting these evaluation systems in Belgium would be very challenging because may be expensive and it requires the implication of local real estate experts. In this context, we are exploring the capabilities of geographically weighted regressions at multiple scales (MGWR) to derive these insights using existing data. Initial findings show promise in modeling spatially varying relationships affecting housing and land prices. However, the application of MGWR requires substantial computational resources.

Key points

- The main causes of rising housing prices are rising property values, rising demand and inelastic supply.
- Without adequate public policy, the NNLT policy risks to drive up housing prices.
- Most tools that promotes affordable housing require knowledge of property values.
- MGWRs have good housing price modeling capabilities, but represent a major technical challenge.

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Introduction

The *No Net Land Take* (NNLT) objective promulgated by the European Commission (2011) raises many political and operational issues. While each country is responsible for its local implementation, with names such as "Zero Net Artificialization" (ZAN) or "Stop-Béton", one question is present everywhere: what will be the potential impact of NNLT on real estate markets, in a context where access to housing is a growing concern, and underprivileged populations are already facing increasing difficulties in accessing decent housing? (OECD, 2021).

The implementation of NNLT will in fact reduce the opportunities for residential development on greenfield sites, and is likely to impact the supply of housing. Without appropriate public policy support, this could lead to a surge in property prices, particularly in contexts where housing demand is growing.

In order to clarify this issue, the first part of this article is dedicated to identifying the suspected effects of limited land supply on housing markets. To do so, we begin with a brief review of the current housing affordability crisis and the main historical causes of rising property values. In this context, we explore the role of land in the evolution of real estate prices over recent decades. On the basis of these findings, the likely effects of land scarcity on residential property prices are presented, using feedback from countries where land restrictions have been in place for many years. Some ideas for promoting affordable housing are then presented.

The various findings of this first part lead to the conclusion that detailed knowledge of land and property values is needed, which introduces the second part of this article. Some elements of systems for monitoring land and property values abroad are then presented, and serve as an introduction to our decision to use multiscale geographically weighted regressions (GWRM) (Oshan *et al.*, 2019) to carry out our mapping of property and land values. The interest of this method and its technical aspects are then presented, along with our initial results. Finally, we conclude with the advantages, as well as the problems and challenges posed by this method.

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The suspected effects of limiting land supply on housing markets

In order to clarify the likely effects of limiting the supply of land on housing, we first need the current affordability issues.

2.1. The housing crisis

Households are devoting a growing share of their budgets to housing. In Belgium, this share rose on average from 26.2% to 31.8% between 1999 and 2020 (Eurostat, 2024). This implies that a growing proportion of households are facing disproportionately high housing costs, particularly for the lowest incomes, for whom 30% of the budget dedicated to housing represents a much greater financial burden than for higher incomes, as it drastically limits their residual budget for coping with the other necessities of life. The OECD (2021) points out that a growing proportion of the middle class is now facing housing affordability problems.

This general increase in the share of expenditure devoted to housing is a direct result of the overall rise in real estate prices. The results of Knoll *et al* (2017, p. 339) research on long time series from 1970 to 2012 for 14 OECD countries, show that this upward trend in residential property prices began as early as the 1950s. This is also the case in Belgium (Reusens and Warisse, 2018).

To explain this trend in property prices, we distinguish two complementary approaches. The first one analyzes the structural and long-standing reasons for this price growth, and links these movements to those of a series of macroeconomic factors, while the second is based on the idea that a home is the combination of two goods of different natures: on the one hand, land, a non-reproducible natural resource, and on the other hand, the (technically) reproducible built structure.

2.1.1. Structural component of residential property price rises

The upward trend in prices is essentially structural and linked to increasing demand (Reusens and Warisse, 2018). Since the 1950s, demand has in fact risen sharply due to various factors such as population growth, a reduction in household size and post-inflation income growth (Knoll *et al.*, 2017). In recent decades, the financialization of housing and a significant reduction in mortgage rates have also played a major role in boosting demand (Aalbers, 2016, Reusens and Warisse, 2018).

However, the impact of demand on housing prices depends on the extent to which supply adapts to it (Cavailhes, 2018). In some cases, the construction sector does not respond sufficiently to the increase in demand. In such cases, supply is said to be inelastic, meaning that there is a latency in the construction sector's responsiveness to rising demand. This creates an imbalance between supply and demand, mechanically driving up prices. There are a number of reasons why the construction sector is so unresponsive. It may result from geographical constraints that limit developable land for housing, but also from land-use regulations or land policies unable to limit the retention of landowners (Cavailhes, 2018). Some real estate players also denounce the fact that building permits are being issued less and less quickly or accessible, hampering the responsiveness of the construction sector (Build Europe, 2022).

It should be remembered, however, that while the construction sector's lack of responsiveness partly explains the rise in prices, housing affordability issues are not limited to questions of supply inelasticity alone. Indeed, countries with the highest elasticities are not exempt from major housing affordability problems (Caldera and Johansson, 2013). The unequal distribution of wealth and wider socio-spatial inequalities should also be considered in explaining the housing affordability crisis in Europe.

2.1.2. Housing, a combinatorial good

Another approach to understanding the formation and evolution of housing prices is to consider real estate as the combination of its built structure and the land on which it is. By extension, the price of a house can also be divided between the price of the land and the cost of replacing its structure, i.e. construction costs. This method of analysis is interesting in the context of implementing NNLT, since it implies a scarcity of land resources and raises the question of the impact of land in the evolution of housing prices. Knoll *et al* (2017) and Reusens and Warisse (2018) highlight the use of this method in view of the non-similar trends that house prices follow in relation to construction cost prices (Figure 2). Note that in Belgium, the ABEX index measures changes in the cost of building private homes and dwellings. It is therefore used here as a reference for house construction costs in our analyses.

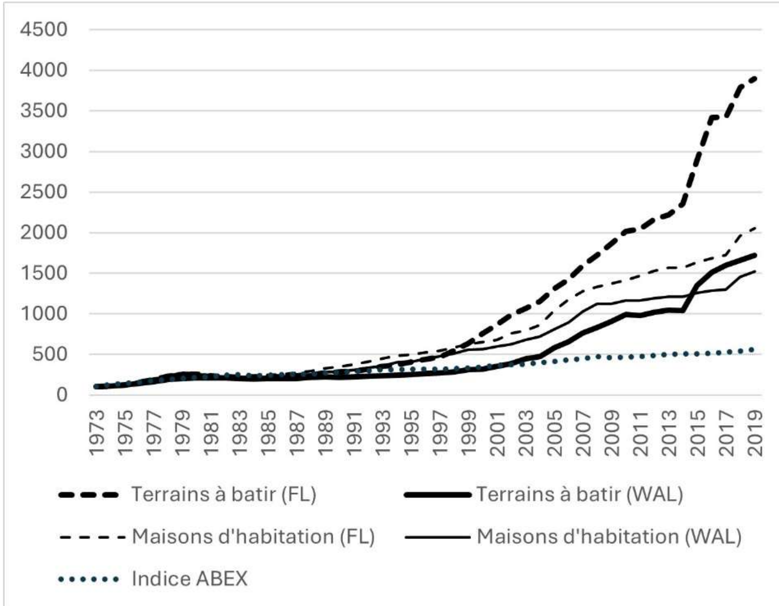

Figure 2: Trend in median land and house prices in Wallonia and Flanders and in construction costs (1973-2019, 1973 = 100) (Sources: StatBel, 2023; FPS Finance)

When questioned on the subject of upward trends in housing prices, stakeholders of the construction sector often highlight changes in construction costs and, in particular, changes in the standards - particularly energy standards - to which they are subject (Bernier *et al.,* 2021; Bavay, 2017). However, Bavay (2017), who specifically studied this issue in France, was unable to confirm this idea that the standards imposed on builders represent a significant explanation for the upward trend in residential property values.

Conversely, Knoll *et al.* (2017, p. 345) show, using long time series for 11 OECD countries, that land has a major impact on rising housing prices. The idea is that the real estate production function can be likened to a Cobb-Douglas-type production function composed of two production factors, land (Z) and residential structures (X), such as:

$$F(Z_t, X_t) = (Z_t)^{\alpha}(X_t)^{1-\alpha}$$

Where α is a constant parameter which value lies between zero and unity[1] .

While breaking down the price of housing into the replacement value of the property and the value of the land with this formula, it appears that around 80% of the increase in real house prices over the second half of the XX^e century in these 11 countries can be explained by an increase in land values (Knoll *et al.,*2017, p. 345). Applying a similar calculation to Belgium between 1973 and 2014, Reusens and Warisse (2018) obtain similar results, with 74% of the share of house price growth attributable to land price growth in Flanders, versus 54% in Wallonia. They also highlight that land price growth is positively correlated with population density, and therefore possibly with land scarcity. This is an important finding in assessing the likely impact of NNLT on housing affordability, and in considering how public policies in favor of affordable housing should be designed.

Replicating this approach for Belgium as a whole for the period 1973-2015 (Figure 3), however, shows great variability in the share of land price growth in house price growth, even if the underlying trend remains the same as that observed by Reusens and Warisse (2018). In

[1] More information on the method can be found in Knoll *et al.* (2017, p. 345) and Reusens and Warisse (2018). In the case of our analysis, an α of 0.6 was used.

Flanders and Wallonia, on the other hand, Figure 4 of the share of house price growth attributable to rising land prices (for the period 1973-2019 and according to our use of the Cobb-Douglas function) shows results equivalent to those of Reusens and Warisse (2018). We also observe an upward trend in the share of land in house price growth, somewhat more sustained in Flanders, where land is scarcer and demand is stronger, than in Wallonia. The results for the Brussels-Capital region, on the other hand, are the opposite of those expected, and this can be explained in several ways. Firstly, the use of this Cobb-Douglas function is open to reflection, as varying the parameter α in the equation leads to non-negligible variations in the results obtained, although Reusens and Warisse (2018) state that the results "*remain [...] robust if the value of this parameter is varied within reasonable limits*". Moreover, this use of the Cobb-Douglas function seems to give better results on a macro scale. Finally, it should be noted that Brussels has very few greenfield sites, so the number of transactions on which to base the results is fairly limited.

This analysis therefore has a number of methodological shortcomings that are not insignificant when it comes to gaining a detailed understanding of the role of land in the formation of residential property prices. Furthermore, it only gives the share of residential property price trends attributable to land price trends. Under no circumstances does it give the *share of land in property prices*. This is also the key to a better understanding of the impact of land on housing price trends in the context of the implementation of NNLT.

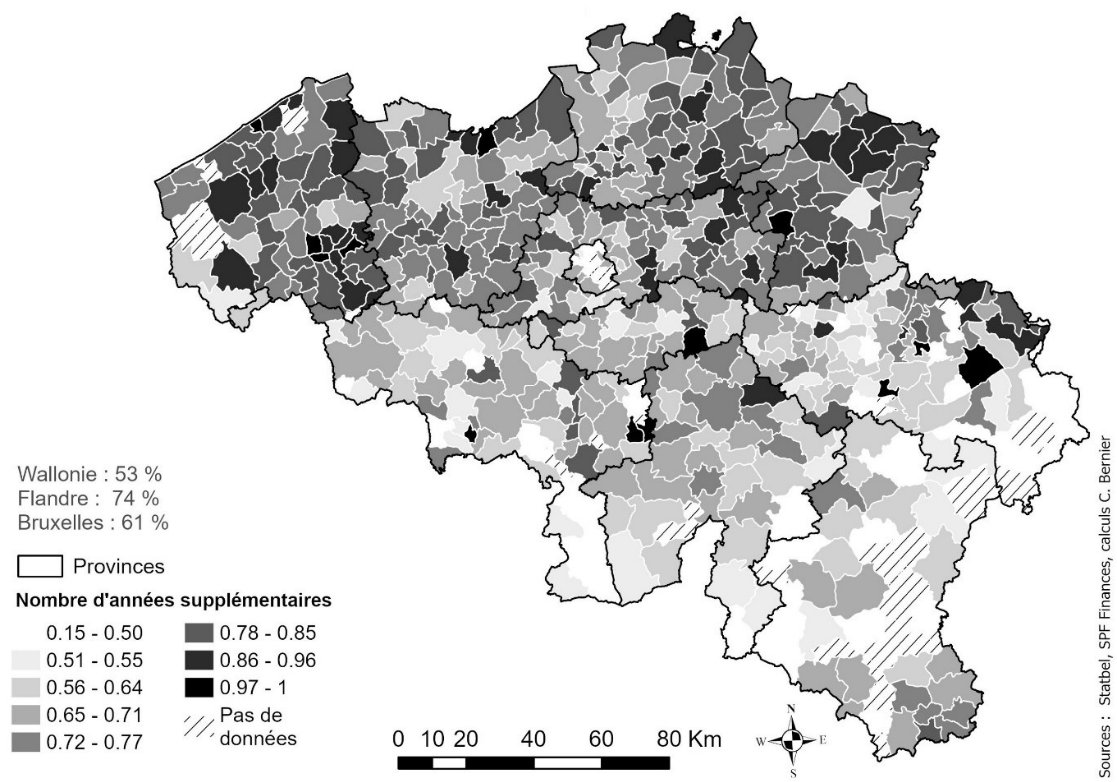

Figure 3: Share of house price growth attributable to rising land prices (1973-2015, Cobb-Douglas function)

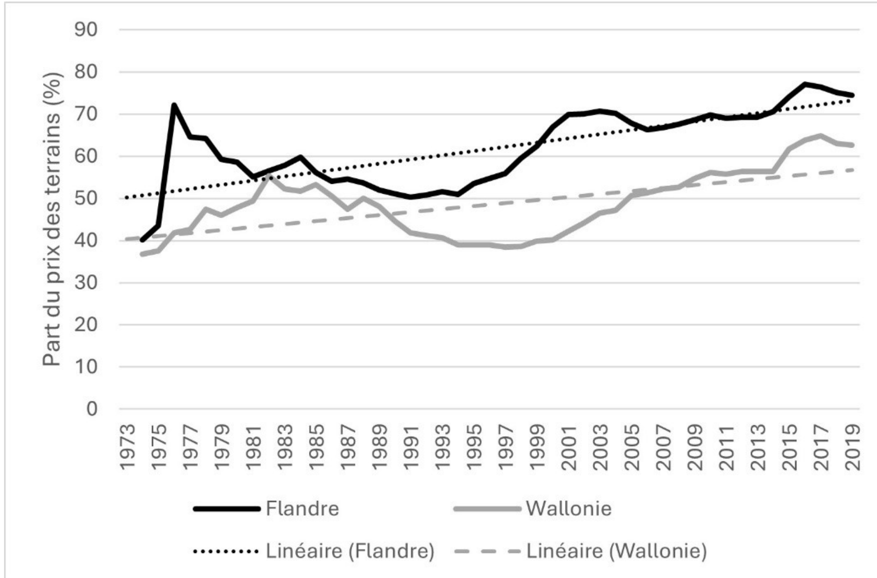

Figure 4: Share of house price growth in Wallonia and Flanders attributable to rising land prices (Cobb-Douglass function, 1973-2019)

2.2. The effects of land scarcity on property values

As mentioned in the introduction, the implementation of NNLT will limit the possibility of developing new buildings on greenfield sites, and *de facto* create a certain scarcity of land. NNLT is therefore widely criticized for its potential to increase real estate prices by limiting the supply of housing.

Our review of the literature shows, however, that the issue is far more complex. Indeed, spatial planning research on the relationship between house prices and land supply limitations does not lead to simple conclusions. Our interpretation of this observation is that, as the operation of planning systems varies considerably, the way in which they affect housing markets depends to a large extent on context (Halleux *et al., 2024).*

There is very little literature on the relationship between land supply restrictions and social justice in Europe. Literature on this subject is particularly found in countries where the application of the compact city paradigm has significantly limited the availability of greenfield land for construction purposes. These countries include Norway and the United Kingdom. While these two countries appear to have been successful in combating urban sprawl (Næss *et al*., 2011; Bibby *et al*., 2020a, 2020b), it has to be said that these successes raise questions in terms of housing affordability.

Between the Second World War and the 1980s, Norway developed a strong interventionist housing policy. This policy was based on strict prices regulation, allocations from the National Housing Bank and the construction of a large stock of affordable housing by OBOS, a social housing provider (Sandlie and Gulbrandsen, 2017). From the 1980s onwards, Norway was strongly affected by the neo-liberal turn. This led to the disengagement of public housing policies. Housing prices were deregulated, a large proportion of municipal property was sold to private companies and OBOS adopted a market strategy. Municipal housing stock is now residual (3.3%) and Oslo, in particular, lacks a public housing sector, with a rental market dependent solely on private, for-profit landlords (Nordahl, 2014; Cavicchia, 2021). In Norway, the combination of the compact city model and market liberalization thus seems to be at the root of an accentuation of social and spatial polarization, particularly in Oslo (Andersen and Skrede, 2017; Cavicchia, 2021).

The same combination of limiting land supply and deregulation has been observed in the United Kingdom. In this country, from the 1950s onwards, one of the main objectives of the land-use planning system was to contain urban areas. However, house prices remained relatively stable until the early 1980s, thanks to the construction of a substantial supply of social housing. While reinforcing its policy of combating urban sprawl, the state then reversed its strategy and increasingly relied on the private sector to provide housing. Despite the mitigating effect of the pre-existing supply of affordable social housing, the low land supply combined with a continuing rise in demand, supported by population growth and reduced household size, led to a significant increase in housing prices (Bibby *et al.*, 2020a, 2020b). Reductions in social benefits, combined with deregulation of the private rental sector, then further exacerbated problems of access to housing for low-income populations (Stephens and Stephenson, 2016).

Addison *et al* (2013) have also carried out a comprehensive literature review on the impact on housing affordability of *Smart Growth Policies* in the USA, one facet of which is the introduction of land-use rules that direct growth into specific areas and render others unbuildable (Billard, 2010). This literature review shows that many *Smart Growth Policies* initiatives have led to housing cost inflation, reducing housing affordability for low and moderate incomes.

In the light of the British and Norwegian situations and the American literature review by Addison *et al.* (2013), it becomes clear that the conjunction of a limited land supply and a neoliberal policy disengaged from the issue of affordable housing exacerbates problems of housing affordability and socio-spatial injustice. Overall, the research supports the hypothesis that, without policies specifically focused on access to housing, strong policies to reduce supply lead to an accentuation of problems of housing affordability.

2.3 Some possible solutions

In a liberalized market context, it therefore seems unlikely that the exacerbation of housing access problems caused by the implementation of land restrictions can be adequately addressed if policy instruments to promote affordable housing are underdeveloped. However, the implementation of a policy to limit the artificialization of land remains necessary, particularly for obvious environmental reasons. In order to reconcile the ecological dimension of densification with the social dimension of access to housing, and to avoid the development of serious problems of socio-spatial justice, we need to develop a more active public policy that better addresses the twin issues of inelastic supply and growing socio-economic inequalities. While we do not have any empirical examples combining a policy of limiting land supply on the one hand, and strong public intervention on the other, leading to an improvement in housing affordability, we can nevertheless sketch out some possible operational solutions.

Note that one of the lessons learned by Addison *et al.* (2013, p. 221) is that, despite the challenges, global practices based on more integrated policies could reconcile the seemingly contradictory goals of land sobriety and housing affordability. For them, this requires the "*diligent application of data to study market trends*, *the use of innovative planning practices and more cooperation between governments, as well as between the private and public sectors"*.

2.3.1. Supply and inelasticity issues

While greater responsiveness in housing supply does not necessarily solve everything (McClure *et al.*, 2017, p. 200), it remains a means of limiting market tensions. This requires a series of diversified actions to exploit multiple potentials. These include the use of brownfield, action on under-occupation and vacancy, etc. It also implies more active land policies to support densification through destruction-reconstruction, plot division (e.g. "*Build in my Backyard*"), etc. This also implies a policy of land production rather than real estate production, as practiced in the Netherlands, for example, and which enables the servicing of plots of land that the public authorities wish to see developed as a priority. However, such a land production policy requires financial resources, access to land and *sophisticated land engineering* (Van der Krabben and Harvey, 2013).

2.3.2. Price and inequality issues

In terms of inequalities and socio-economic disparities, we would rather mobilize tools to finance affordable housing. The financing of such instruments could be facilitated by land value capture techniques (OECD/Lincoln Institute of Land Policy, PKU-Lincoln Institute Center, 2018; Halleux *et al.,* 2022) aimed at taking advantage of the structural rise in land prices, mentioned above, or the rise in land values attributable to planning decisions or public investment in a defined area, in order to finance affordable housing elsewhere in the territory. One of the main instruments for capturing land value is inclusionary zoning, and this practice is often recognized as highly effective for producing affordable housing as well as for spatially distributing population groups and avoiding excessive segregation phenomena (McClure *et al*., 2017, p. 190; Debrunner and Hartmann, 2020; Cavicchia, 2021).

Implementing new property taxation policies is another way of mobilizing financial resources. Property tax is one of the most commonly used fiscal instruments for raising public revenue to finance social housing. But the use of an innovative form of property taxation can also guide the development and construction of plots. We refer here to the *split rate*, put forward in an OECD report (2018, p. 149) to reform property taxation. In most countries, property taxes are levied on the basis of an assessment of the value of an entire property. With the *split rate*, the idea is to apply a different tax rate, on the one hand, to the land and, on the other, to the built structure that lays it. The aim is to set higher tax rates on the value of land than on the value of buildings in certain areas of interest, and thus create an incentive to use land more intensively. This could, for example, stimulate the redevelopment of urban brownfield or the development of greenfield plots.

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The need for a better understanding of real estate values

What many of the possible measures to promote affordable housing have in common is the difficulty of implementing them without knowing the value of land. For example, how can we recover land value gain or introduce new forms of taxation based on the price of land if we are unable to track its value over time and space, *whether the plots are built on or not*?

Furthermore, if land is indeed what drives up property prices, it's essential to know its value. This is particularly the case if we wish to monitor the effective impact of a proactive policy to limit artificialization, such as NNLT.

3.1. The need for a better understanding of property values

In order to imagine how such a monitoring of land and real estate values could be carried out in perspective of NNLT, we looked at what is being done elsewhere in the world. We also sought to understand how these data are used.

3.1.1 Experience feedback

There are a few examples of land and property valuation systems in use around the world. In many cases, areas with sufficiently comparable parcels are defined. The prices assessed for these areas are called *standard land values* (SLV). Examples include Germany (Voß and Bannert, 2018), Sweden (Kalbro and Norell, 2018) and Taiwan (Chao, 2018).

Germany has had a system for assessing land and property values since the 1960s. Since 2009 and the amendment of the Building Code (BauGB), the implementation of the indication of SLV (*Bodenrichtwerte*) throughout the country and the provision of this information have become mandatory (Hendricks, 2017; Voß and Bannert, 2018).

The "need for market transparency" is at the root of the SLV system in Germany. This is considered fundamental to reliable and sustainable markets (Voß, 2011). Without transparency, perfect competition is not possible and the market is unbalanced. The real estate sector is known to be rather opaque (Halleux, 2005). This is particularly the case if scarcity dominates market conditions: the seller is then often in an advantageous bargaining position. A less opaque market, with better knowledge of prices, should help maintain a fairer balance between buyer and seller. It was with this primary objective in mind, and to avoid land speculation once the system of strict state price controls came to an end, that the Germans enshrined this tool in their constitution over 50 years ago (Voß and Bannert, 2018). This knowledge is also essential for negotiating with developers when implementing inclusionary zoning or for better intervening in markets via a public land production policy.

But the existence of these SLV has also offered the opportunity to change the taxation, regulatory and tax systems in Germany (Hendricks, 2017; Voß and Bannert, 2018). It enables them, for example, to design a new tax base that takes land value into account, with ongoing reflections on integrating the *split rate* concept, or even taxation that no longer includes built value at all. These taxes are also seen as a means of feeding the public budget and generating incentive effects in terms of development (Löhr, 2018). A similar monitoring system has also enabled Sweden and Taiwan to devise a *split rate* system on their territories (Gerber *et al.*, 2018).

SLV are also important for the budgetary control of German municipalities. By law, they are obliged not to sell building land below the market value represented by the SLV. These values therefore have a direct link to local land policy (Hendricks, 2017; Voß and Bannert, 2018).

3.1.2. How applicable are these systems to Belgium?

While the German, Swedish and Taiwanese models are inspiring, they raise the question of their applicability in Belgium. The main pitfall we have identified is the cost of setting up a similar system, mainly due to the way SLV are evaluated.

Their valuation systems are largely based on the work of local experts. In Germany, SLV are determined by groups of property valuation experts who work on a very detailed scale, re-evaluating land and property values every year, *even for plots that have already been built on*, mainly on the basis of their knowledge of the market. This approach is therefore very costly in terms of time and workforce.

3.2. Fine mapping of property values in Belgium

3.2.1. Objectives and data

While these methods give good results and seem to bring satisfaction in the way they are used (Gerber *et al.*, 2018), in many countries, the allocation of a large budget for a major project, with returns on investment that are difficult to quantify, is rarely received with enthusiasm by the government. We therefore wanted to explore the possibilities offered by an "automated", "lower-cost" method, developed on the basis of pre-existing data.

The objectives for this property value assessment tool are multiple. We would like to be able to achieve :

- An valuation of land values - for both constructed and undeveloped plots - and their impact on real estate values;
- An assessment of the impact of limiting the supply of land on housing affordability.

To do this, we have access to the register of land and houses sales in Belgium from 2008 to 2019. It includes a range of information on the property sold (size, type, living area, number of rooms, etc.). This sales register can be combined with the geolocalized cadastral register. We also have a range of federal and regional data that can be used to define the living environment (income, employment rate, flood zones, slopes, land supply rate...), as well as a range of open-access data such as the ones provided by OpenStreetMap (road layouts and travel speeds, stations, bus stops...).

3.2.2. Method

To achieve this first "fine mapping of land values", even for already-built plots, and using only pre-existing data, we have chosen to use regression models. A first series of models is carried out only for plots sold in Belgium in 2019 (10,299 plots), and another series of models is carried out for houses sold in Belgium in 2019 (90,436 houses).

The concept for separating the value of the land from that of the built structure for already-built plots is illustrated below (Figure 5) using an OLS equation. The idea is simply to isolate the modelled part of the land price from that of the original price, using variables linked to the value of the building and variables linked to the value of the land. To obtain the most reliable results possible, we therefore need to minimize errors and obtain the most reliable modeling possible of the influence of the different variables on the price.

$$y = \beta_{c1}x_{c1} + \beta_{c2}x_{c2} + \cdots + \beta_{t1}\,x_{t1} + \beta_{t2}x_{t2} + \cdots + \varepsilon$$

Prix d'un bien immobilier — Variables liées à la construction — Variables liées au terrain

$$y = y'_{construction} + y'_{terrain} + \varepsilon$$

$$y'_{terrain} = y - y'_{construction} - \varepsilon$$

Figure 5: Differentiate building and land values using OLS property price modeling

The variables constructed and used to model land value are: plot area, number of jobs accessible per minute of car travel, potential land supply rate, noise, flood risk, proportion of "natural" areas in the surroundings and three socio-economic characterization variables, resulting from a PCA. It should be noted that the potential land supply variable introduced also makes it possible to assess the impact of limiting the supply of land on prices.

The variables used to model the value linked to the built structure are those provided by the sales register and the land registry, i.e. living area, number of open facades, age of the building, number of garages and bathrooms, number of rooms, and the fact of having a commercial first floor. Other variables were explored but discarded as too collinear or inconclusive.

Conventional regression models (or *OLS*) are, however, fraught with errors and approximations when applied to a territory as vast as Belgium. This method assumes that the various variables have the same effect throughout the territory. However, there is considerable heterogeneity in the effect of certain variables on the price of housing, such as the size of the plot or dwelling, for example. Conventional *OLS* models also fail to take into account the greater likelihood of similarity between two nearby entities than between two distant ones.

To overcome this, we turned to *Multiscale Geographically Weighted Regressions* (MGWR). Sachdeva *et al* (2022) demonstrate the great technical capabilities offered by these models in the field of hedonic price modeling. The Python package developed in open access by Oshan *et al.* (2019) is the one used for this research.

MGWR is an extension of the well-known GWR (Formula 1) model, which has the major advantage of allowing regression coefficients β_j to vary spatially, and thus "capture" the spatial heterogeneity of processes. To achieve this, a regression model is calibrated distinctly at each point - or plot - thanks to a "data borrowing" system that weights observations on the basis of their distance from one another.

$$y_i = \sum_{j=0}^{m} \beta_j(u_i, v_i)x_{ij} + \varepsilon_i \quad (1)$$

With

n observations where $i \in \{1, 2, ..., n\}$ located in (u_i, v_i) ;

x_{ij} being the $j^{ème}$ independent variables and $\beta_j(u_i, v_i)x_{ij}$ the $j^{ème}$ coefficient ;

ε_i the error term ;

y_i the dependent variable (in this case price).

This "data borrowing" system is achieved using an estimator of the local coefficients at site *i*, which follows the formula :

$$\widehat{\boldsymbol{\beta}}(i) = [\boldsymbol{X}'\boldsymbol{W}(i)\boldsymbol{X}]^{-1}\boldsymbol{X}'\boldsymbol{W}(i)\boldsymbol{y} \quad (2)$$

With

$\boldsymbol{X}$ a matrix of *n* by *j* independent variables ;

$\boldsymbol{W} = diag[w_1(i), \dots, w_n(i)]$ the *n* by *n* diagonal weight matrix that weights each observation according to its distance from location *i ;*

$\widehat{\boldsymbol{\beta}}(i)$, the vector *j* by 1 of the coefficients and $\boldsymbol{y}$ the vector *j* by 1 of the dependent variable.

Thus, the vector of local coefficients for each observation *i* is estimated using the weight matrix ***W***, which involves the use of a Kernel function to calculate the weight w_{ij} of each observation. We opted for a *bisquare* function, as the influence w_{ij} of neighboring observations on point *i* decreases with distance and is zero once the number of neighbors considered is exceeded (Oshan *et al.,* 2019). It therefore drastically reduces computation time in the case of large samples such as ours (90,436 homes sold, for 2019 alone). The calculation of the size of this bandwidth, i.e. the number of neighbors considered for the construction of the weighting matrix ***W***, is done through a trial-and-error system of the algorithm and the improvement of a quality indicator of the model's fit to the data, such as the AIC or AICc (Fotheringham *et al.*, 2017). This calculation is relatively fast in the case of GWR models, as the number of neighbors used to weight the observations is the same for all the independent variables considered in the model.

GWR models can therefore take into account the spatial heterogeneity of processes. They do not, however, take into account *variations in the scale of influence of different variables*. Some variables have an assumed global effect, or at least one that is very similar over the whole territory (and which could therefore be well captured by a classic *OLS*), such as the influence of commuting time, while others have effects on price that vary greatly in space, such as the size of the dwelling. To take this into account, the GWR formula is slightly modified (Figure 6). In this case, the index *bwj* indicates the size of the bandwidth used to calculate β. This means that each variable will have a different bandwidth, and therefore a different number of neighbors considered in the weighting matrix.

GWR

$$y_i = \sum_{j=0}^{m} \beta_j(u_i, v_i)x_{ij} + \varepsilon_i$$

MGWR

$$y_i = \sum_{j=0}^{m} \beta_{bwj}(u_i, v_i)x_{ij} + \varepsilon_i$$

Figure 6: Adding the multi-scale extension to the GWR equation

3.2.3. First results

In order to verify the validity and, above all, the efficiency of MGWR in transcribing the heterogeneous processes affecting prices at various spatial scales in Belgium, we initially used this method solely on land prices for plots of land sold in 2019 in Belgium (10,299 plots). Our initial results show a substantial improvement in hedonic price modeling.

Taking spatial heterogeneity into account leads to a substantial increase in modeling quality, from an R^2 of 0.15 for the OLS to an R^2 of 0.61 for the GWR model. The addition of the Multiscale extension also brings a substantial improvement, with an R^2 of 0.76. The results of the analysis of the spatial autocorrelation of the models residuals also demonstrate a very good ability to capture the different processes and dynamics of the territory using the variables considered for the GWR models, since the use of Moran's Global Index concludes with a random distribution of the residuals. Furthermore, an analysis of the Local Indicators of Spatial Association (LISA) of these same residuals does not reveal any local clusters, unlike the OLS and GWR models.

Figure 7 illustrates how GWRs allow regression coefficients to vary spatially, and how the multiscale extension of these models allows us to capture different scales of influence of processes on prices.

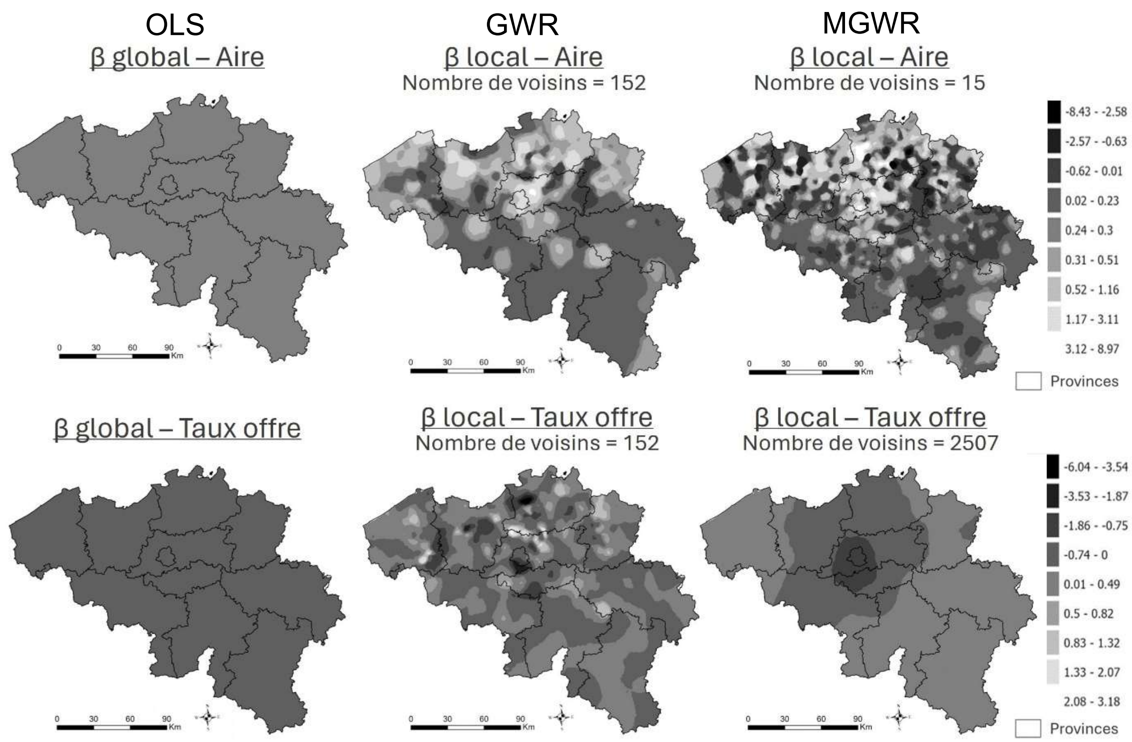

Figure 7: Comparison of equation coefficients (global or local) obtained with the OLS, GWR and MGWR models for the plot area and potential land supply rate variables.

3.2.4. MGWR-related issues

The initial aim of our research was to produce MGWR for houses sold each year for the period 2019-2009, i.e. the period for which we have all the variables selected and cited in the previous point. However, two problems have arisen. The first is the large processing capacity required to run MGWR with 90,436 houses (sold in 2019). This implies considerable computation times for our servers (16 CPUs), i.e. over 30 days of calculations when the algorithm for finding the number of neighbors is run "blind". The second is the large amount of

RAM required. For example, to carry out these models for our 90,436 houses, we need to allocate 1 Tb of RAM to store the weighting matrices.

We are currently working on solving these problems. In the first case, we are trying to reduce the time needed to find the number of neighbors for each variable in the model, using the feature introduced by Oshan *et al.* (2019) in their Python package. This allows us to set the number of neighbors for each variable *a priori* in order to reduce computation time. The authors indicate, however, that this should only be done on the basis of sufficient knowledge of the scale of influence of the processes. In the absence of such knowledge, which is part of our questioning of land and real estate market dynamics, we are currently seeking to verify the *stability of* the number of neighbors found by the algorithm according to the variables introduced into the model, so as to be able to extrapolate them for our future iterations of the models. This idea stems from the findings of Fotheringham *et al.* (2003, p. 101). However, having found no literature concerning the stability of bandwidths found using MGWR, we are carrying out tests. We have now completed 40th iterations of our model, the results of which are presented in section 3.2.3. The results are very encouraging, since bandwidth stability has been determined and extrapolated for the other land sales years, with R^2s of 0.71 for 2018 and 0.70 for 2017 respectively. These performances are superior to those obtained during unsupervised modeling. The in-depth results of this part of the study will be published later.

As for reducing the amount of RAM required, this is still under consideration.

-5-

Conclusion

Over the last few decades, the problems of housing have only increased in Belgium, as elsewhere in Europe. While there are many explanations for this, price remains the cornerstone. The structural causes of rising housing prices are an increase in demand combined with a lack of responsiveness on the supply side. On the other hand, while real estate professionals point to rising construction costs as the main factor behind rising prices, research tends to point to rising land values. These contradictory positions show that it is necessary to objectivize the weight of land in the evolution of real estate values, particularly in the perspective of a restriction in the use of greenfield.

Furthermore, in a context of a liberalized market combined with underdeveloped policies to promote affordable housing, the necessary implementation of NNLT risks to exacerbate existing problems (segregation and spatial injustice, reduced housing affordability…). To counter this, innovative public intervention *will* be required (social, fiscal, land-use planning and production policies, etc.).

What many measures to promote affordable housing have in common is the difficulty of implementing them without knowing the value of land. Such knowledge has, for example, enabled Germany, Sweden and Taiwan to devise a different taxation system on their territories (Gerber *et al.*, 2018). It should be noted that, in addition to scientific interest, such knowledge of land values is also necessary to monitor the effective impact of a voluntarist policy to limit artificialization.

These findings have led us to the conclusion that we need detailed knowledge of land and real estate values, as well as a good overview of the dynamics already present on Belgian territory, in order to answer these two main questions:

- What would be the impact of limiting the supply of land on housing affordability in Belgium?
- What impact does land have on property values in Belgium?

However, since Belgium do not have land value assessment tools as sophisticated as the one in Germany, but do have a certain amount of data on the sale price of land and housing, answering those questions requires, among other things, a detailed modeling of land and real estate values. The aim is to establish the respective shares of each of these values in the increase housing prices and to objectivize, on the basis of the availability of land supply, whether or not a reduction in the supply of land has led to an increase in land values, and whether a further restriction in supply could have the same impact.

To achieve this first fine mapping of land values, even for plots that have already been built on, Multiscale Geographically Weighted Regressions (MGWR) (Oshan *et al*., 2019) are used to model property and residential land prices throughout Belgium, using sales data from 2008 to 2019. With an R^2 of 0.76, our initial results for models of land prices sold in 2019 demonstrate the good abilities of these models to transcribe spatially non-stationary processes affecting prices at various spatial scales, as put forward by Sachdeva *et al.* (2022).

However, while these initial results are encouraging for the future, MGWR require long processing times and substantial RAM. These technical aspects do not make the systematic use of these models easy, and many tests are still needed to conclude their concrete use in a - possible - institutionalized land and property value monitoring system in Belgium.

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