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A DECOMPOSITION APPROACH FOR ASSESSING LAND LEVERAGE AND DEPRECIATION RATE ON THE REAL ESTATE MARKET – EVIDENCE FROM WARSAW POLAND

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ABSTRACT

Most property valuation research concerns entire properties consisting of land and structures. However, different features of land and capital as factors of production determine different patterns shaping their value and their different impact on the total price of real estate. In this article the hedonic decomposition model, which controls for differences in housing quality, is applied to decompose the price of an apartment into the land and structure components. The depreciation rate of housing was calculated and taken into account to properly isolate the dynamics of land over time. This allowed us to compare the house price index with the dynamics of land and structure. The empirical analysis was carried out on the data for the city of Warsaw.

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1. Introduction

The housing stock is undoubtedly one of the main components of a city's wealth and the wealth of households. As economic development grows, the importance of real estate markets as building capital and land that is involved in the production of goods and services, increases. Most of the related research concerns entire properties consisting of land and structures combined. However, there are a number of differences between land and capital and its dynamics. Understanding those differences is a very important topic in urban research.

In the urban context, we usually deal with land already built-up with real estate. A characteristic feature of land prices and income from it, i.e. land rent, in relation to the prices of other factors of production, is that, in fully developed urban areas, the price is not directly observable. While the construction technologies and production costs are relatively homogeneous at any given time, land is characterized by an inelastic supply and specific features, including location and neighborhood effects (Malpezzi, 1996). Despite the lengthy construction process, buildings can be restored, so an existing building can be replaced with a new structure at a given cost. The expenses related to the implementation of such a project are mainly due to the productivity of the construction industry and the prices of certain materials. The value of land fluctuates with the economic and financial cycles; it tends to go upward in the long term, while capital depreciates. In the long term, as the economy grows, the capital resources increase, while the supply of land remains constant. As a consequence, the dynamics of land prices and building capital are different. Therefore, it is necessary to decompose the price of the property over the value of the structure and the land (Diewert & Shimizu, 2016).

Contrary to structures, land in urban areas does not depreciate. Aging, and more precisely the depreciation (house value decreases) may pose a risk on financial institutions management, as approx. 21% of GDP are housing loans in Poland, while this share is

much higher in Europe[1]. According to accounting rules, depreciation is usually "calculated by allocating the costs of past expenditures on fixed assets over subsequent accounting periods"[2]. These are very rough estimates of the depreciation value for accounting purposes. Indeed, the value of depreciation is widely regarded as a concept that is difficult to observe in real life, especially when prices in the economy fluctuate. When nominal property price rises, those increases may mask any asset depreciation value. But in fact, the change in the value of the property consists of the change in property prices and the depreciation of the building, which should be distinguished as the decline in the price of the asset due to aging (Hulten & Wykoff, 1981). Instead of relying on the depreciation estimates made by accountants, actual depreciation rate of housing can be observed and measured empirically by a decomposition hedonic model, taking into account the heterogeneity of housing.

If the relative value of land and structures were constant in space and time, it would be of little importance to distinguish between the two components. However, as proved in the literature (Stewart, 2021; Diewert & Shimizu, 2016; Bostic et. al, 2007; Davis & Palumbo, 2008) this is not true. According to a study of 14 advanced economies, about 80% of the rise in house prices between 1950 and 2012 can be explained by rising land prices, with the rest attributed to rising construction costs (Turner, 2017). Also, housing price dynamics is likely to be largely driven by real land price cycles (Davis & Palumbo, 2008).

The decomposition of property value into land value and structure value can help explain many of the important phenomena observed in the housing market, particularly those related to price volatility over time and space. The failure to include this in the analysis of economic wealth and in national accounting[3] is a serious conceptual error. It makes it difficult or impossible to understand many pressing social and economic problems, including excessively rising real estate prices, increasing inequalities and problems with housing availability. It is also of key importance from the perspective of many important contemporary topics covered in economic and urban studies, such as land finance, real estate price dynamics, urban infrastructure management, gentrification and many others.

In this article it is assumed that changes in structure value over time depend on the construction cost index and depreciation rate, while land value depends on its own dynamics. The economic depreciation is defined as "the decline in asset price due to aging" (Hulten & Wykoff, 1981). As the estimation of the economic rates of depreciation of housing capital is complicated by the fact that housing is a heterogeneous commodity, which makes direct comparisons between housing difficult, the hedonic approach is used. The hedonic decomposition model, which decomposes apartment price into the land and structure component, was applied to study the dynamics of housing price components and calculate the depreciation rate. The land leverage is expressed as the ratio of the value of the land to the total value of the property (see Bourassa et al., 2009). In the model, a lot of geospatial variables were included, such as distances to various amenities.

2. Literature review - methods of decomposing housing into land and structure

The hedonic approach has been used extensively in real estate research (Sirmans et al., 2005) to study the effect of individual attributes on housing prices and calculate its dynamics. The hedonic price model is based on the theory of consumer behavior created by Lancester in 1966. The hedonic hypothesis stated that heterogeneous goods are aggregates composed of certain attributes. Economic choices depend on these sets of characteristics which give some utility. The Lancaster theory was further developed by Rosen in 1974, who created a model of the functioning of heterogeneous goods markets. The most rapid development of hedonic models in the residential real estate markets took place in the 1990s and the beginning of the XXI century. Recently, the most common practical applications of hedonic modeling have been the calculation of property valuations and

[1] Calculated on the basis of GUS (2021) and NBP (2021).

[2] The same definition is assumed by the OECD glossary of statistical terms (2021), the Glossary of the System of National Accounts 1993 (2021) and the UN classifications registry (2021).

[3] In many advanced economies, land values and capital gains from rising property prices are not properly measured and accounted for in national accounts (Eurostat & OECD, 2015). Also in Poland, land is not included in separate asset classes in national accounts, although in some countries (e.g. Australia, Canada, France and Japan) pilot studies have been conducted. According to assumptions of these researches, the value of built-up real estate is divided into the value of land, which increases over time, and the value of buildings, which depreciates.

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price indices (Xu et al., 2018; Lopez & Yoshida, 2022).

Observed on the market are aggregated house prices, which depend on the dynamics of the structure (building) and land values and additionally change due to attribute differences, both qualitatively and quantitatively. Most of the hedonic models take into account differences in housing quality and calculate average house price inflation, but cannot control for the different dynamics of the land and the structure. Due to the fact that structures and land have different characteristics and dynamics, some studies use hedonic decomposition models to decompose price volatility taking into account housing features and different dynamics of both housing components (Bostic et al., 2007). In this approach, the value of the structure fluctuates in line with the depreciation-adjusted construction cost index, while land has a its own dynamics, significantly affected by the limited supply of land.

The value of a structure depends on the construction costs, which change over time, adjusted for the depreciation of the structure with age and quality. A building is a durable good that is used over decades. A part of a building as capital is consumed each year. Assuming housing homogeneity, no inflation and the same level of maintenance and repair expenditure, it would be possible to accurately measure the economic depreciation rate by comparing prices of two or more units of different ages. However, these assumptions are unreal. In order to accurately estimate the effects of aging on values it is necessary to control for housing quality and location differences. Many studies examine economic depreciation of the whole real estate asset, i.e. combined building and land, which occurs when the value declines with age. The hedonic approach provides a simple way to adapt to the quality differences between old and new housing, making it possible to directly estimate economic depreciation.

There have been many theoretical studies on the depreciation of buildings (Chinloy, 1977) and only few that estimate it (Davis & Palumbo, 2008, Bourassa et al. 2011). To estimate the market depreciation rate for housing assets in the hedonic approach age-related variables of the buildings should be included into the hedonic price model (Diewertet al. 2016). A literature review indicates significant variation in estimates of depreciation rates for residential real estate. The variation in the reported results seems to be due to differences in the definition of depreciation employed in the model and data used to estimate depreciation rate, and in some cases the condition of the real estate market examined at the time of study. In most studies cited by Malpezzi et al. (1987) and the current ones (shown in Table 1) estimates of depreciation rates range between half a percent to two and a half percent.

Table 1

Selected research related to the subject of the hedonic decomposition models and depreciation rate assumptions / estimations

Authors	Research period	Methodology and results
Bostic et al. (2007)	Wichita, the capital of Kansas, USA, 1990 – 2004	They introduced the concept of land leverage, which reflects the share of land value in the total property value. Homes with higher land leverage appreciated faster than those with lower land leverage. Moreover, the scale of the price response to market shocks will be positively related to the land leverage. Land in Wichita appreciated faster than structures. In the decomposition model, the geometric depreciation rate amounted to 6.3% was estimated.
Davis & Palumbo (2008)	46 MSA, USA, mid 1980 – 2004	Using the replacement cost method and econometric modeling as well as assuming a depreciation rate of 1.5%, the price indices of land, construction and land leverage were calculated. In the US metropolitan area, land leverage in the single-family home market increased from an average of 32% in 1984 to 51% in 2004, indicating that the value of land will increasingly shape the value of housing.
Nichols et al. (2013)	23 MSA, USA, mid 1990 – 2009	Hedonic regressions with location variables were estimated on a sample of residential and commercial land transactions from the mid-1990s to calculate price indices. Building depreciation was not included in the study. A significant conclusion is that fluctuations in the value of land are much greater than the prices of commercial and residential real estate and the value of structures.
Bourassa et al. (2011)	Switzerland, 1978 – 2008	The hedonic method was used to estimate the prices of real estate, land and land leverage. The models were estimated on a sample of new buildings (up to 20 years old) and on the entire sample. The calculated geometric depreciation rate depended on building conditions and amounted at 2.25% for poor buildings, 1.88% – average, 1.5% – good and 0.5% – very good. It was found that land prices increased more strongly than housing prices and were more volatile.

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Chang and Chen (2011)	6 MSA, USA, 1997 – 2009	The construction and land values were estimated directly using the hedonic model. The estimated depreciation factor in the case of various cities has both positive and negative values, which raises some doubts, as a property should not lose its value with age.
Diewert & Shimizu (2016)	Tokyo, Japan, 2005 – 2015	The hedonic indices of land, structure and whole property were calculated. The paper also derived an estimate for the annual geometric structure depreciation rate for condominiums in Tokyo, which amounted at 3.6%.
Diewert et al. (2016)	Ottawa, Kanada, 1996 – 2009	Hedonic decomposition model was used to extract the component of land value and structure in multi-family housing and to construct indexes of their changes over time. In the decomposition model, the geometric depreciation rate was estimated. The estimated depreciation rate was 2.4%. They found similarities between the Fisher indexes created from their model and other hedonic and stratification methods.

Source: own study (Waszczuk, 2022).

In this article a hedonic decomposition model has been created to decompose housing prices into the land and structure component controlling the differences in the quality of the premises. It has been proved that the dynamics of both components are different. The depreciation rate was calculated to check the impact of age on building value. This is particularly important from the perspective of the Polish as well as Central and Eastern European[4] housing markets, as there are no studies dealing with the issue. In these countries, due to the still poor housing situation of households (Łaszek et al., 2017), the economic depreciation may have a significant impact on many studies at the local level.

3. Research methodology

The research is based on the hedonic approach. In this study, a model of decomposition of apartment prices into the land and structure components was used (Diewert & Shimizu, 2016). For the existing buildings on the secondary housing market, the assumption was made that the value of the property is the sum of discounted production factor costs controlled for individual features of buildings (specific features of apartments) and land characteristics (location and location-specific amenities). As a result, marginal values are estimated as buyers are willing to pay for the particular features of the apartment components. The buyer purchases a certain number of square meters of an apartment with specific property characteristics (e.g. low or high standard, usable area, location etc.). Intuitively, the hedonic method can be presented as the average valuation of each feature of a flat, after comparing premises with a given feature to flats without it, assuming other constant attributes[5].

The decomposition hedonic model is as follows:

$$P_{it} = L_{it} + S_{it} + e_{it} \quad e_{it} \sim N(0, \sigma_e^2 I), \tag{1}$$

where:
P_{it} is the price of the i-th dwelling in time t,
L_{it} is the land value of the i-th real estate at time t,
S_{it} is the value of the i-th building at time t,
e_{it} is a random error.

The dependent variable, which is decomposed into the positive value of the building and land is the price per square meter of the apartment. For each property in the sample, a theoretical value of heterogeneous land and the depreciation-adjusted heterogeneous structure were computed. It was assumed that the buyer of the property would not be willing to pay more for it than the sum of the depreciated cost of building the structure adjusted by the value for the location and the value of the land. The components are described by their hedonic attributes (for land (L): land size, location, etc. and structures (S): building year, usable area, housing standard, etc.).

The structure and land components are specified with a set of attributes, according to the following formula:

$$P_{it} = L(\alpha_t^L, X_{it}^L) + S(\alpha_t^S, X_{it}^S) + e_{it} \; e_{it} \sim N(0, \sigma_e^2 I), \tag{2}$$

where:
α_t^L are the estimates of the parameters of the land attributes (L) at time t,
X_{it}^L are the variables determining the attributes of the land (L) of the i-th property at time t,
α_t^S are estimates of the parameters of the structure attributes (S) at time t,
X_{it}^S are the variables defining the attributes of the structure (S) of the i-th real estate at time t,
e_{it} is a random error.

Both the land and structure components have their

[4] Most of the articles concern the countries of Western Europe or the USA, there is no data for the countries of Central and Eastern Europe.

[5] However, some attributes are not clearly positively or negatively assessed by buyers. Moreover, their valuations may be spatially diversified.

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own time-dummy variable which will be their value dynamics over time. After calculating the theoretical value of the land and relating it to the theoretical value of the property, the soil lever will be obtained.

In this study, the house price decomposition methodology proposed by Diewert and Schimizu (2016) was used. A non-linear econometric model was estimated to decompose the value of the apartment into two components. The Nash (1979) variant of the Marquardt algorithm was used to estimate the nonlinear econometric models described in the empirical results section. This is a gradient-based Newton algorithms optimization method, which minimizes the sum of squared residuals in the nonlinear models. The parameter space, starting with the initial parameters, is searched to find the minimum residuals and the best fit of the model.

4. Empirical results

4.1. Data

The empirical analysis will be presented on the example of Warsaw. Warsaw is the Polish capital and the largest Polish city located in the central part of Poland (Łaszek & Waszczuk, 2021). The method and scope of the analysis was dependent on the availability of statistical data. The data used to estimate the hedonic decomposition models are from the Database of Property Prices (RCN) for the city of Warsaw obtained from the Department of Geodesy and Cadaster of the Warsaw County Office. The database contains information about the prices of properties and their characteristics. The data on the amenities objects, used to calculate distances from housing, came from the Topographic Objects Database (BDOT10K).

For the needs of this study, the data from the above resource were narrowed down based on: 1) property title, 2) type of building, 3) type of transaction. As a result, only apartments with an ownership right were analyzed, whereas other types of property rights (co-ownership, housing co-operatives) were not taken into account. As regards building type, only apartments in multi-family residential buildings were analyzed, and thus detached, terraced and semi-detached houses were eliminated. Due to the intensity of development, the value of land on which multi-family buildings were built is on average higher than the value of land for single-family housing. Estimating hedonic models on single- and multi-family buildings, the value of land in city centers with relatively more skyscrapers could be underestimated, hence it was decided to analyze transaction prices in buildings with more than two floors. Therefore, it is reasonable to use the most homogeneous sample in terms of building density - limited to multi-family housing, and to consider it as relatively homogeneous[6]. In the third category (type of transaction), only private transactions were taken into account[7]. The analyzed time horizon was 1Q2006 to 4Q 2016, i.e. a total of 44 quarters. The timing of the sample results from the relatively low-volatility of the prices. A detailed description of the sample is included in Annex 1. The scope of the attributes of the structure and land was limited by the availability of variables in the acquired transaction database of residential real estate prices.

4.2. Warsaw decomposition model

At the equilibrium point, the structure component depends on the amortized, quality adjusted construction cost. Therefore, it was assumed that the value of the structure changes with the index of construction costs, corrected for the physical characteristics of the building (and apartments) and depreciation[8]. The dependent variable, i.e. the price, has been standardized by the surface, which is equivalent to imposing the unity condition on the surface parameter on the side of the explanatory variables. However, according to the results of the analyses, small and large apartments are characterized by a different price level per square meter, the time-dummy transformed variable was also used as the structure's attributes. The depreciation rate was taken into account together with the year of construction variable, as the structure deteriorates with age. To capture the differences in the valuation of flats located on the lower floors, a variable was added to capture the location on the lower floors. In addition, a variable that indicates whether a given apartment is located in a higher or lower building was included.

[6] It was assumed that, in the case of Polish cities, which are relatively small compared to metropolises such as New York or Los Angeles, spatial relations should be characterized by a relatively constant pattern.

[7] The following types of property were not included in the analysis: property sold by the State Treasury and local governments; property sold in execution proceedings; property sold with a discount.

[8] Because age is correlated with location, the estimated age factor could be biased if the location were not properly accounted for. Usually older flats may be in more or less desirable locations. In Warsaw, the city center is mostly built up with old buildings.

Location is an attribute of land that greatly influences its value. In this empirical study, a lot of variables determining the location, which could be potentially significant in determining the price of the land, were investigated. A very important variable is the distance from the city center. According to the monocentric model, economic, social or cultural activity is concentrated in the city center, which is, in some cases, the Central Business District (Alonso, 1964). The monocentric price gradient[9] should therefore be visible, as there is a certain interchangeable relationship between the costs of commuting to work and housing expenses. The model was supplemented with the dummy variables specifying the decile group in terms of distance from the city center. In fact, the marginal cost of commuting to work tends to be higher in the central area as time costs and negative externalities arise in central areas due to congestion. The form in which the distances from the center was taken into account in the model allows to reflect such dependencies. Thus, the specification of the variable imposes certain limitations. It is assumed that two identical properties located at different points in the same distance from the city center have the same market value according to this specification. The empirical observation and scientific research show that there might be price differences in these two cases. Thus, it is unlikely to fully capture the localization effects, considering only the distance from the COB in the model. An additional variable which was tested in creating the model is the time-dummy district variable, thanks to which the assumption of the same price changes, regardless of the direction, is lifted. Firstly, it shows prestige of the neighborhood and, secondly, it allows for different price levels in different directions from the center. Also additional localization variables were also taken into account, which more accurately reflect local features, e.g. distance from hospitals, green areas, tram and bus stops, metro stations. In the case of residential buildings, certain amenities bring utility to households if they are located in the immediate vicinity. The proposed amenity variables are in line with theoretical knowledge of the factors that play a role in household purchasing decisions. The distances to these objects and quartile groups were calculated, and on their basis dummy variables were created. The first group - properties closest to objects of a given type - was established as the base variable. In land valuation, it is important to capture the effect of building density and possible development opportunities, which is considered a factor that increases the price of plots. For this reason, a variable defining the intensity of development at a distance of 100 meters from the address of the given property was taken into account.

Using the hedonic decomposition models it is necessary to arbitrarily impose a specific functional form of the model[10]. A specific pattern is also assumed for the depreciation rate, therefore the interpretation and influence of this variable on the value of the structure is different. In the case of linear depreciation (M1), the value of the structure fell by the same amount each year, and in the long run, even below zero. Geometric depreciation (M2), on the other hand, is characterized by a constant percentage decrease in the value of the building.

The final form of the decomposition model with linear depreciation is as follows:

$$P_{tn} = \left(\sum_{i=1}^{18} \omega_i D_{tn,i}\right)\left(\sum_{t=1}^{44} \alpha_t Y_{tn,t}\right)\left(\sum_{j=1}^{4} \theta_j CN_{tn,j}\right) *$$

$$\left(\sum_{k=1}^{4} \vartheta_k HS_{tn,k}\right)\left(\sum_{z=1}^{4} \sigma_z GA_{tn,z}\right) *$$

$$\left(\sum_{p=1}^{4} \gamma_p SCH_{tn,p}\right)\left(\sum_{r=1}^{4} \beta_r BS_{tn,r}\right)\left(\sum_{s=1}^{4} \varphi_s H_{tn,s}\right) +$$

$$O_{tn,t}(1 - W\delta)\left(\sum_{m=1}^{4} \rho_m AA_{tn,m}\right)\left(\sum_{o=1}^{4} \partial_o F_{tn,o}\right) *$$

$$\left(\sum_{d=1}^{2} \pi_d WD_{tn,d}\right)$$

where:

- $D_{tn,i}$ – 0-1 district variables (Bemowo and Bielany, Białołęka and Targówek, Mokotów, Ochota and Wola, Praga Południe, Praga Północ, Rembertów, Wesoła and Wawer, Śródmieście, Ursus andWłochy, Ursynów, Wilanów, Żoliborz),ω_i – district parameter,

[9] Especially in the majority of relatively smaller urban centers, such as Polish cities. It was proven by Waszczuk (2022) in her doctoral dissertation.

[10] There can be a lot of complex relationships between the factors influencing the value of the structure and the land, and the total observable effects may be greater than the sum of individual separate actions - synergy effects, smaller - the crowding-out effect, or so mixed together that it is difficult to assess the scale and direction of the impact individual attributes. The authors also notice the phenomenon of the substitution effect between attributes (Brzezicka et al., 2019). The results should therefore be interpreted as an average effect. Using the hedonic decomposition models arbitrarily it is necessary to impose a specific functional form of the model.

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- $Y_{tn,t}$ – time dummy variable for individual quarters (Q3 2006- Q4 2016), α_t – price index parameter,
- $CN_{tn,j}$ – 0-1 variable distance from the center created on the basis of quartile groups,θ_j - parameters of the 0-1 variable distance from the center,
- $HS_{tn,k}$ – 0-1 variable distance from hospitals based on quartile groups,ϑ_j – parameters of the 0-1 variable distance from hospitals,
- $GA_{tn,z}$ - 0-1 variable distance from green areas based on quartile groups,σ_z - parameters of the 0-1 variable distance from green areas,
- $SCH_{tn,p}$ - 0-1 variable distance from schools based on quartile groups,γ_p – parameters of the 0-1 variable distance from schools,
- $BS_{tn,r}$- 0-1 variable distance from stops created on the basis of quartile groups, β_r- parameters of the 0-1 variable distance from stops,
- $H_{tn,s}$ - 0-1 variable defining the building intensity created on the basis of grouping [0,4), [4,6), [6,14), 14 and more, φ_s - parameters of the 0-1 variable building intensity,
- $O_{tn,t}$ – replacement value of 1 sqm. of residential real estate,
- W – building year, δ- depreciation rate,
- $AA_{tn,m}$ – 0-1 variable defining groups in terms of usable areas (0,40), [40,60), [60,80), 80 and more,ρ_m - parameters for the 0-1 variable defining groups in terms of usable area,
- $F_{tn,o}$ - 0-1 variable defining the floor on which the flat is located (intervals: [0-2), [2-6), [6 and more)), ∂_o– parameters of the 0-1 variable determining the location of the apartment on the floor,
- $WD_{tn,d}$ – 0-1 variable for tall buildings with a number of floors greater than 4, π_d, - parameter of the 0-1 variable defining the number of floors of the building.
- In order to estimate the model, the following assumptions were made:
  $\alpha_1 = 1, \theta_1 = 1, \quad \vartheta_1 = 1, \quad \sigma_1 = 1, \quad \gamma_1 = 1, \quad \beta_1 = 1, \varphi_1 = 1, \rho_1 = 1, \partial_1 = 1, \pi_1 = 1.$

To take into account the decreasing decline in property values over time geometric depreciation was also assumed and estimated. The formula is as follows:

$$P_{tn} = \left(\sum_{i=1}^{18} \omega_i D_{tn,i}\right)\left(\sum_{t=1}^{44} \alpha_t Y_{tn,t}\right)\left(\sum_{j=1}^{4} \theta_j CN_{tn,j}\right)\left(\sum_{k=1}^{4} \vartheta_k HS_{tn,k}\right)\left(\sum_{z=1}^{4} \sigma_z GA_{tn,z}\right)$$
$$\left(\sum_{p=1}^{4} \gamma_p SCH_{tn,p}\right)\left(\sum_{r=1}^{4} \beta_r BS_{tn,r}\right)\left(\sum_{s=1}^{4} \varphi_s H_{tn,s}\right) + O_{tn,t}((1-\delta)^W)\left(\sum_{m=1}^{4} \rho_m AA_{tn,m}\right)\left(\sum_{o=1}^{4} \partial_o F_{tn,o}\right)\left(\sum_{d=1}^{2} \pi_d WD_{tn,d}\right) \quad (4)$$

Table 2

Selected research related to the subject of the hedonic decomposition models and depreciation rate assumptions / estimations

	M1S1	M1S2	M2S1	M2S2
R-square	53.3%	49.5%	52.8%	47.6%
Sum of squares	88214	91859	94767	101373
Depreciation rate	0.007	0.009	0.044	0.037

Source: own study.

The model was estimated on two samples. One of them contained all the observations before the turnover on the Warsaw secondary housing market (S1). The second sample was limited to buildings built after 1930 (S2)[11]. The description of both samples (S1 and S2) can be found in Appendix 1 and the results of the estimation by models is presented in Appendix 2.

Tests of statistical significance of estimated coefficients and the intuitive direction of the impact prove that the model is specified correctly. The results show that the models calculated according to the linear capitalization formula have a better R-square. Also, the sample limited to newer dwellings built after 1930 gives better results due to the its greater homogeneity (see Table 2).

The obtained estimates of the linear depreciation rate for the Warsaw residential real estate market were 0.7% for the extended sample and 0.9%. for the sample limited by the year of construction In the case of depreciation calculated geometrically for the Warsaw residential real estate market, the rate for the extended sample was 4.4% and 3.7% for the limited

[11] Similar models were estimated by Waszczuk (2022) in her dissertation thesis. However, those models did not take into account the age-related depreciation, in order to generally capture the impact of the fact that apartments built at different times on housing prices, the author used zero-one variables.

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sample (see Figure 1). We have proved Malpezzi et al.'s (1987) observation, made based on their review of the literature that the linear form of the depreciation rate resulted in low estimates, while the declining balance depreciation rate resulted in higher values. According to the geometric formula the initial absolute drops in real estate values are large, then diminish over time. According to the model results, the dwelling is worth 50% of its initial value after 15 years, and after 18 years for the entire sample.

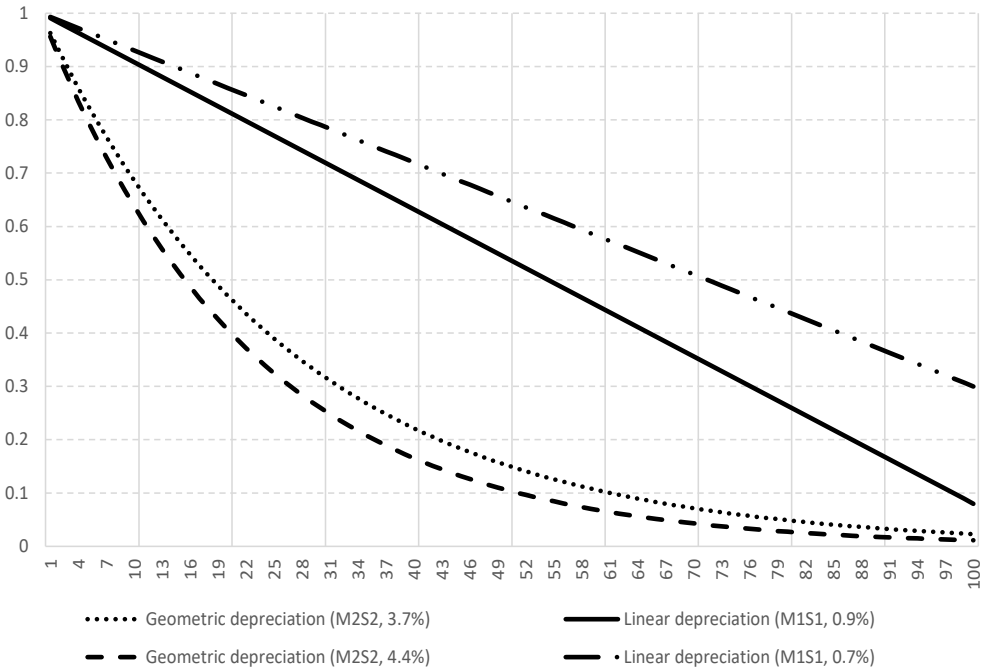


Fig. 1.Change in value over time in accordance with estimated depreciation rates. *Source*:own calculations.

The land leverage shows similar patterns of changes over time (see Figure 2). In the years 2006-2016, the ground leverage in the entire city of Warsaw ranged from approx. 56% to 66%, while in the center of Warsaw this range was 70% - 79%. However, the volatility of these indicators over time is similar. This difference between the value of land leverage in the center and its level achieved for the entire city proves that the land component has a large impact on the value of real estate in the center.

An additional result of the decomposition model is the index of the dynamics of the land value over time, which can be compared with the average dynamics on the real estate market and with the construction price index. According to the M1S1 model, which was characterized by the best results, the land dynamics is much more variable than the construction cost index and the average dynamics of the entire property. In 2006 and 2007, the value of the land was increasing. The decline in the value of land in 2008 and 2009 resulted in a decline in home prices, which was due to the economic slowdown. After 2009, the demand on the real estate market was largely generated thanks to the government's support program Rodzina na Swoim and the possibility of financing real estate with indexed loans. In 2012, as a result of problems faced by the construction industry, there was a slight decline in prices on the real estate market. In the following years, the economy grew rapidly and interest rates fell, which also meant that the value of land began to increase faster than the value of housing. During the growth phases in the real estate market, the dynamics of land value growth is higher. The construction index in Poland, as well as in Warsaw, is relatively stable in the analyzed period.

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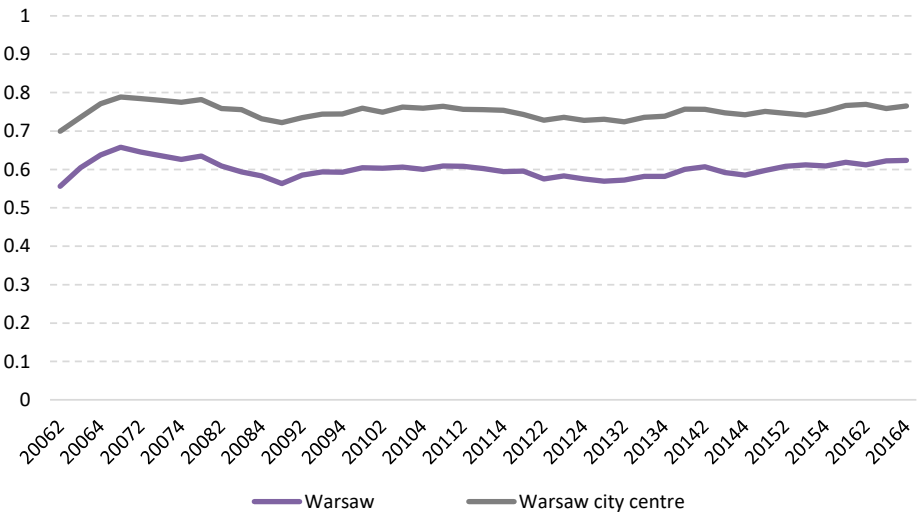


Fig. 2. Median land leverage in Warsaw and its city center (the 1st decimal group of the distance - up to 2,140 m). *Source*: own calculations.

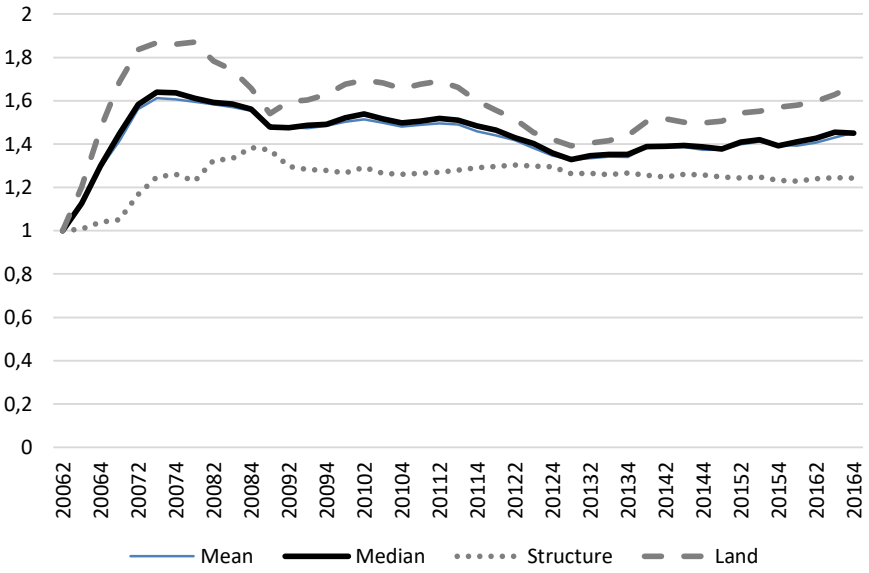


Fig. 3.Dynamics of housing prices and the value of structure and land over time (M1S1).*Source*: own calculations.

5. Conclusions and policy implications

Studying the evolution of land prices and structures separately makes it easier to understand home price dynamics, which are largely driven by real land price cycles. In this study the depreciation rate of housing was isolated and it was proved that the high volatility of house prices is related to the land component. Land values are more volatile over time than housing prices and structure costs. Also, the location variables in the decomposition model are significant, which confirms the influence of the location on the land value.

To isolate properly the dynamics of the value of the structure over time the depreciation rate of housing buildings was estimated under different assumptions. The obtained estimates of the linear depreciation rate for the Warsaw residential real estate market were 0.7% for the extended sample and 0.9%. for the sample limited by the year of construction In the case of depreciation calculated geometrically for the Warsaw residential real estate market, the rate for the extended sample was 4.4% and 3.7% for the limited sample. Measuring economic depreciation in residential real estate is very important for deepening our understanding of housing market behaviors and for assessing a variety of public policies. Public policies such as rent control and tax incentives for construction could be better evaluated and designed with improved estimates of depreciation. Better estimates of depreciation rates can contribute

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to better targeting of incentives.

According to the results, the value of land nowadays has a significant share in the value of residential real estate. High volatility of housing prices (over 50%) is related to the land component. This share changes over time and space. Housing price increases translate more into an increase in the value of land than in structure. Also a greater share of the land value in relation to the value of the entire property is in central locations. The example of Warsaw is also a good illustration of the spatial variability of the soil lever. In the years 2006-2016, the ground leverage in the whole of Warsaw ranged from approx. 56% to 66%, while in the center of Warsaw, this range was 70% - 79%. However, the volatility of these indicators over time is similar. The results of the research are therefore consistent with the literature - the relative value of land in the city is higher for central areas.

The growth rate of land prices is more volatile than the index of house prices and structure values. The vast majority of these increases in household (housing) wealth and property prices in this range were not due to increases in construction costs, which remained relatively flat, but to increases in land prices. With a relatively constant supply, favorable economic and demographic factors causing increased demand for land, the value of which constitutes a significant part of the value of residential real estate, will contribute to the emergence of tensions on the housing market, which may result in bubbles or even crises when the situation changes rapidly and rapidly way. It is very important to analyze the land and building components separately, as the values of these real estate elements have different dynamics and other factors affect them. This issue should be the subject of further intensified empirical analyses and research. Studying the evolution of land prices and structures separately makes it easier to understand home price dynamics, which are largely driven by real land price cycles. Further research is necessary to understand the factors determining changes in individual components of housing prices, and discussions on this issue should focus mainly on research on the land and building components and taking into account the depreciation that allows the loss of value of the capital good, which is the structure over time.

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Appendix A. Description of the research sample

The geocoded dataset consisted of 70,024 observations from Q1 2006 - Q4 2016. Due to the small number of observations in 2006 Q1 (11 observations), it was decided to reject them.

Sample 1 – full dataset (S1)

Observations were rejected where:

- the price is less than 1,500 PLN / sqm. or more than 15,000 PLN / sq m,
- the area is less than 25 sq m. or greater than 120 sq m.,
- the price per sq m. it is not within 3 standard deviations from the average in a given district.

The final sample 1 amounted at 62,160.

Table A.1.

Summary statistics of Sample 1

Variable	Number of obs.	Mean	Standard deviation	Median	Minimum	Maximum
Apartment floor	62160	3.94	2.60	3.00	0.00	36.00
Distance from the shopping centres	62160	878.37	521.50	790.27	13.81	3604.08
Distance from green areas	62160	544.21	347.20	489.06	5.88	3879.55
Distance from schools	62160	288.21	280.16	200.45	0.00	2108.69
Distance from hospitals	62160	1089.66	901.79	839.39	0.00	4728.38
Distance from bus and tram stops	62160	164.09	105.50	143.53	3.88	991.72
Distance from metro stations	62160	2891.51	2786.51	2007.34	8.73	14585.89
Distance from the city center	62160	6417.57	3611.51	5889.55	301.19	17035.55
Number of floors	62160	6.82	3.33	5.00	1.00	25.00
Price (PLN/sq. m.)	62160	7.57	1.77	7.38	3.00	15.00
Usable area	62160	50.99	17.99	47.60	25.01	119.98

Source: Own calculations based on RCN.

Sample 2 - dataset with apartments built after 1930

Observations were rejected where:

- the price is less than 1,500 PLN / sqm. or more than 15,000 PLN / sq m,
- the area is less than 25 sq m. or greater than 120 sq m.,
- the price per sq m. it is not within 3 standard deviations from the average in a given district,
- the property was built after 1930.

The final dataset 2 amounted at 60,204.

Table A.2.

Summary statistics of Sample 1

Variable	Number of obs.	Mean	Standard deviation	Median	Minimum	Maximum
Apartment floor	60204	3.97	2.62	3.00	0.00	36.00
Distance from the shopping centres	60204	879.34	524.07	786.96	13.81	3604.08
Distance from green areas	60204	544.01	348.65	489.00	5.88	3879.55
Distance from schools	60204	291.32	282.86	201.64	0.00	2108.69
Distance from hospitals	60204	1103.99	908.64	857.87	0.00	4728.38
Distance from bus and tram stops	60204	165.28	106.11	144.88	3.88	991.72
Distance from metro stations	60204	2953.41	2792.05	2117.91	13.99	14585.89
Distance from the city center	60204	6534.83	3586.76	5982.37	301.19	17035.55
Number of floors	60204	6.88	3.36	5.00	1.00	25.00
Price (PLN/sq. m.)	60204	7.54	1.75	7.35	3.00	15.00
Usable area	60204	50.82	17.84	47.50	25.01	119.98

Source: Own calculations based on RCN.

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Appendix B. Model results on various research samples

Table B.1.

Models results

	Nr	Variable	M1S1			M1S2			M2S1			M2S2		
			Parameter	Std. error	t-stat	Parameter	Std. error	t-stat	Parameter	Std. error	t-stat	Parameter	Std. error	t-stat
District	1.	Bemowo and Bielany	5.31	0.08	66.5	5.44	0.08	68.5	6.17	0.06	100.2	6.02	0.06	94.7
	2.	Białołęka and Targówek	3.93	0.07	59.9	4.05	0.07	61.8	5.11	0.05	96.1	4.95	0.06	89.9
	3.	Mokotów	6.00	0.09	70.3	6.13	0.08	72.2	6.75	0.06	105.0	6.60	0.07	99.3
	4.	Ochota and Wola	4.97	0.07	70.9	5.11	0.07	72.6	5.98	0.05	108.7	5.81	0.06	101.7
	5.	Praga Południe	5.16	0.08	66.1	5.35	0.08	68.4	6.08	0.06	100.9	5.94	0.06	95.6
	6.	Praga Północ	4.29	0.07	60.8	4.33	0.07	62.0	5.24	0.05	95.6	5.10	0.06	88.5
	7.	Rembertów, Wesoła and Wawer	3.98	0.07	56.7	4.16	0.07	58.9	5.21	0.06	88.3	5.06	0.06	83.5
	8.	Śródmieście	6.19	0.08	74.4	6.32	0.08	76.4	7.04	0.06	112.2	6.87	0.06	106.0
	9.	Ursus i Włochy	4.76	0.08	58.8	4.89	0.08	61.0	5.89	0.06	91.8	5.70	0.07	87.0
	10.	Ursynów	6.23	0.10	61.8	6.33	0.10	63.9	6.93	0.08	91.7	6.79	0.08	87.5
	11.	Wilanów	5.61	0.10	56.3	5.72	0.10	58.2	6.31	0.08	82.5	6.18	0.08	79.2
	12.	Żoliborz	6.54	0.10	65.8	6.48	0.10	66.8	7.11	0.07	97.4	6.86	0.08	90.9
Land index	13.	Y20063	1.20	0.02	66.2	1.19	0.02	67.9	1.14	0.01	98.9	1.14	0.01	94.3
	14.	Y20064	1.47	0.02	69.9	1.46	0.02	71.7	1.34	0.01	106.0	1.35	0.01	100.9
	15.	Y20071	1.68	0.02	67.7	1.67	0.02	69.6	1.49	0.01	103.7	1.50	0.02	99.0
	16.	Y20072	1.84	0.03	69.9	1.81	0.03	71.7	1.62	0.02	107.4	1.63	0.02	102.1
	17.	Y20073	1.87	0.03	70.8	1.85	0.03	72.5	1.66	0.02	108.3	1.68	0.02	102.9
	18.	Y20074	1.86	0.03	69.3	1.86	0.03	71.1	1.67	0.02	105.5	1.69	0.02	100.6
	19.	Y20081	1.87	0.03	70.5	1.86	0.03	72.3	1.66	0.02	108.2	1.68	0.02	103.0
	20.	Y20082	1.78	0.02	72.5	1.78	0.02	74.5	1.63	0.01	110.4	1.65	0.02	105.3
	21.	Y20083	1.74	0.02	72.2	1.73	0.02	74.3	1.61	0.01	109.8	1.62	0.02	104.9
	22.	Y20084	1.66	0.02	71.6	1.65	0.02	73.8	1.56	0.01	107.7	1.57	0.02	103.1
	23.	Y20091	1.54	0.02	66.9	1.53	0.02	69.0	1.48	0.01	100.3	1.48	0.02	96.1
	24.	Y20092	1.60	0.02	69.1	1.59	0.02	71.1	1.49	0.01	103.6	1.50	0.02	99.1
	25.	Y20093	1.60	0.02	70.4	1.59	0.02	72.5	1.50	0.01	106.3	1.50	0.01	101.7
	26.	Y20094	1.63	0.02	71.2	1.61	0.02	73.1	1.51	0.01	107.4	1.52	0.01	102.5
	27.	Y20101	1.68	0.02	71.6	1.67	0.02	73.8	1.55	0.01	108.7	1.56	0.02	103.8
	28.	Y20102	1.69	0.02	72.1	1.69	0.02	74.2	1.57	0.01	109.5	1.58	0.02	104.5
	29.	Y20103	1.68	0.02	72.5	1.68	0.02	74.7	1.56	0.01	110.5	1.57	0.01	105.6
	30.	Y20104	1.66	0.02	72.4	1.66	0.02	74.7	1.53	0.01	110.1	1.55	0.01	105.3
	31.	Y20111	1.68	0.02	72.5	1.67	0.02	74.6	1.55	0.01	110.3	1.56	0.01	105.3
	32.	Y20112	1.69	0.02	72.4	1.69	0.02	74.6	1.56	0.01	110.3	1.58	0.02	105.3
	33.	Y20113	1.66	0.02	72.8	1.66	0.02	74.8	1.55	0.01	110.6	1.55	0.01	105.5
	34.	Y20114	1.60	0.02	71.1	1.60	0.02	73.2	1.50	0.01	107.3	1.51	0.01	102.6
	35.	Y20121	1.56	0.02	71.5	1.55	0.02	73.5	1.48	0.01	107.7	1.48	0.01	102.8
	36.	Y20122	1.52	0.02	70.2	1.53	0.02	72.6	1.46	0.01	105.7	1.47	0.01	101.4
	37.	Y20123	1.45	0.02	69.7	1.46	0.02	72.0	1.41	0.01	105.1	1.42	0.01	100.6
	38.	Y20124	1.42	0.02	67.7	1.42	0.02	70.0	1.38	0.01	102.1	1.39	0.01	97.8
	39.	Y20131	1.39	0.02	68.3	1.40	0.02	70.5	1.36	0.01	102.9	1.36	0.01	98.6
	40.	Y20132	1.41	0.02	70.2	1.40	0.02	72.3	1.37	0.01	106.0	1.37	0.01	101.3
	41.	Y20133	1.42	0.02	72.0	1.42	0.02	74.2	1.37	0.01	108.6	1.38	0.01	103.8
	42.	Y20134	1.44	0.02	72.2	1.45	0.02	74.5	1.39	0.01	109.0	1.40	0.01	104.3
	43.	Y20141	1.50	0.02	72.0	1.49	0.02	73.8	1.43	0.01	108.4	1.43	0.01	103.2
	44.	Y20142	1.52	0.02	71.7	1.52	0.02	73.7	1.43	0.01	108.1	1.45	0.01	103.2
	45.	Y20143	1.50	0.02	71.8	1.50	0.02	73.8	1.43	0.01	108.3	1.43	0.01	103.4
	46.	Y20144	1.50	0.02	71.1	1.51	0.02	73.4	1.43	0.01	107.3	1.44	0.01	102.7
	47.	Y20151	1.51	0.02	72.2	1.51	0.02	74.3	1.43	0.01	108.9	1.44	0.01	104.1
	48.	Y20152	1.54	0.02	72.8	1.55	0.02	75.0	1.46	0.01	110.0	1.47	0.01	105.2
	49.	Y20153	1.55	0.02	73.2	1.55	0.02	75.3	1.46	0.01	110.8	1.47	0.01	105.7
	50.	Y20154	1.57	0.02	72.9	1.57	0.02	74.9	1.46	0.01	110.4	1.47	0.01	105.3
	51.	Y20161	1.58	0.02	73.1	1.57	0.02	75.1	1.47	0.01	110.8	1.48	0.01	105.6
	52.	Y20162	1.60	0.02	73.4	1.60	0.02	75.5	1.49	0.01	111.4	1.50	0.01	106.2

	53.	Y20163	1.63	0.02	73.4	1.62	0.02	75.6	1.51	0.01	111.5	1.52	0.01	106.4
	54.	Y20164	1.67	0.02	73.5	1.66	0.02	75.5	1.54	0.01	112.0	1.55	0.01	106.7
Distance from	55.	the city center (2 decile)	0.91	0.00	225.3	0.94	0.00	225.6	0.94	0.00	309.7	0.95	0.00	290.4
	56.	the city center (3 decile)	0.86	0.01	165.5	0.89	0.01	172.2	0.92	0.00	234.3	0.93	0.00	226.3
	57.	the city center (4 decile)	0.79	0.01	153.3	0.81	0.01	162.5	0.87	0.00	222.9	0.87	0.00	218.2
	58.	the city center (5 decile)	0.74	0.01	133.2	0.75	0.01	137.1	0.82	0.00	196.0	0.82	0.00	186.3
	59.	the city center (6 decile)	0.68	0.01	116.5	0.70	0.01	123.5	0.79	0.00	180.2	0.79	0.00	175.3
	60.	the city center (7 decile)	0.67	0.01	110.3	0.68	0.01	114.4	0.78	0.00	171.2	0.78	0.00	162.5
	61.	the city center (8 decile)	0.67	0.01	103.3	0.69	0.01	107.9	0.76	0.00	153.8	0.76	0.01	148.2
	62.	the city center (9 decile)	0.64	0.01	95.3	0.66	0.01	98.9	0.74	0.01	143.0	0.74	0.01	137.8
	63.	the city center (10 decile)	0.68	0.01	100.1	0.69	0.01	104.5	0.78	0.01	145.8	0.77	0.01	140.9
	64.	hospitals (2 quartile)	0.99	0.00	358.9	0.98	0.00	372.0	1.00	0.00	503.6	0.99	0.00	486.9
	65.	hospitals (3 quartile)	0.95	0.00	297.1	0.96	0.00	305.7	0.97	0.00	423.9	0.97	0.00	407.6
	66.	hospitals (4 quartile)	0.99	0.00	224.0	0.98	0.00	230.2	0.98	0.00	327.0	0.98	0.00	314.3
	67.	greenareas (2 quartile)	1.00	0.00	326.6	0.99	0.00	339.3	0.99	0.00	467.2	0.99	0.00	453.3
	68.	greenareas (3 quartile)	0.99	0.00	327.0	0.98	0.00	339.2	0.98	0.00	466.8	0.98	0.00	452.2
	69.	greenareas (4 quartile)	0.98	0.00	322.4	0.97	0.00	334.1	0.97	0.00	458.5	0.97	0.00	444.1
	70.	bus and tram stops (2 quartile)	1.00	0.00	339.2	1.00	0.00	353.3	1.00	0.00	483.0	1.00	0.00	469.0
	71.	bus and tram stops (3 quartile)	1.02	0.00	334.1	1.01	0.00	347.5	1.01	0.00	476.6	1.01	0.00	462.4
	72.	bus and tram stops (4 quartile)	1.03	0.00	304.4	1.02	0.00	315.6	1.01	0.00	441.4	1.01	0.00	427.4
	73.	metrostations (2 quartile)	0.77	0.01	100.3	0.78	0.01	103.9	0.91	0.00	283.0	0.91	0.00	246.9
	74.	metrostations (3 quartile)	0.76	0.01	99.0	0.76	0.01	100.7	0.90	0.00	256.1	0.90	0.00	219.7
	75.	metrostations (4 quartile)	0.73	0.01	81.3	0.72	0.01	82.8	0.86	0.01	158.4	0.86	0.01	145.9
Other land attribute	76.	buildingdensity [4-6)	0.95	0.00	329.3	0.95	0.00	340.8	0.96	0.00	460.3	0.96	0.00	445.8
	77.	buildingdensity [6-14)	0.92	0.00	219.5	0.91	0.00	228.7	0.93	0.00	311.7	0.93	0.00	303.3
	78.	building density more than 1	0.93	0.01	151.2	0.92	0.01	159.1	0.91	0.00	222.3	0.91	0.00	218.6
Structureattributes	79.	usableareagroup 2 <40,60)	0.90	0.00	217.5	0.89	0.00	205.3	0.77	0.01	106.2	0.79	0.01	112.4
	80.	usableareagroup 3 <60,80)	0.88	0.01	168.7	0.85	0.01	157.4	0.70	0.01	82.0	0.72	0.01	87.2
	81.	usable area group 4 more than 80	0.97	0.01	149.2	0.92	0.01	140.3	0.76	0.01	74.1	0.78	0.01	80.7
	82.	apartmentfloor gr. 2 [4-6)	1.01	0.00	244.9	1.02	0.00	239.3	1.06	0.01	111.0	1.06	0.01	124.8
	83.	apartmentfloor gr. 3 [6-14)	1.00	0.00	204.6	1.01	0.00	203.3	1.06	0.01	98.2	1.05	0.01	109.9
	84.	apartment floor gr. 4 more than 14	1.08	0.02	49.3	1.09	0.02	49.6	1.22	0.04	28.0	1.20	0.04	30.6
	85.	building height (more than 4 floors)	0.35	0.02	20.8	0.37	0.02	22.2	0.06	0.01	5.9	0.09	0.01	7.9
	86.	depreciation	0.01	0.00	58.0	0.01	0.00	61.4	0.04	0.00	40.3	0.04	0.00	36.6

Source: Own calculations based on RCN.

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