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Effects of the COVID-19 pandemic and the war in Ukraine on the local housing rental market in Poland

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Abstract. The COVID-19 pandemic that started in early 2020 and the Russian invasion of Ukraine in February 2022 caused multidimensional shocks to the housing market. Understanding their micro-level impact is crucial to optimizing future responses to similar shocks, designing sustainable urban and socio-economic policies, and investing. Based on the hedonic Spatial Error Model for the local housing rental market in Poland, during the pandemic, the valuation of the leisure-related apartment characteristics (the availability of a balcony and a private garden) increased. As tenants spent more time at home or in their neighbourhood, the proximity of housing to green areas became increasingly important, and the relevance of proximity to university buildings decreased. Then, amidst the war, a reluctance to use gas heating has been noticed. Combined with the observed price premium for the location of apartments in revitalised tenement houses, this means that the modernisation of the historic housing stock is not only ecologically desired, but also is capitalised in the achieved rents. The rent change throughout the pandemic has been estimated at -6.7%, while during the war-related crisis, at +29.7%. Finally, low sensitivity of hedonic rent indices to the detected changes in rent-setting factors has been found.

Keywords: housing market, rental market, revealed preferences, COVID-19 pandemic, war in Ukraine, hedonic models, heating technology, renovation, revitalisation, hedonic rent index.

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1. INTRODUCTION

A developed, long-term housing rental market reduces the volatility of the real estate market and contributes to the overall economic stability (Rubaszek & Rubio, 2020). However, in 2023, only 4.2% of Polish households rented apartments at market prices, much below the EU average of 20.2% (Eurostat,

2024a). The low share of renters may be attributed, among others, to the sale of state-owned apartments following the systemic changes in the last decades of the 20th century (Ronald, 2008). Nevertheless, in Poland, the strong preference for owning instead of renting is still present, which has been documented by Rubaszek & Czerniak (2017) and Bryx et al. (2021). Even though the transition from the "ownership society" (Ronald, 2008) to the "generation rent" (Ronald & Kadi, 2018; Byrne, 2020) may trigger the development of this vital segment of the economy, it has not been the only reason for the recent interest in the housing rental market.

The COVID-19 pandemic spreading globally since early 2020 induced an unprecedented, multidimensional shock to worldwide economies (Iyer & Simkins, 2022; Kholodilin & Rieth, 2023) and can be considered a super-shock, initiating structural changes (Dolnicar & Zare, 2020). It also affected the Polish rental market, which was dominated by young couples, students (Polityka Insight, 2022), and migrants (Narodowy Bank Polski, 2023). First, universities switched to distance learning, and students often decided to terminate the rental agreements in the cities where they studied and return to their family homes (Centrum AMRON, 2020). Secondly, the imposed cross-border traffic restrictions limited the influx of external migrants and suspended international tourism. Thus, many apartments rented on a short-term basis were converted to long-term rental purposes, increasing the long-term market supply (Boros et al., 2020; Marona & Tomal, 2020). Moreover, introducing lockdowns aimed at preventing COVID-19 transmission resulted in GDP declines for Poland estimated at -2% in 2020 (Eurostat, 2024b). To stimulate the demand, the European central banks decreased interest rates (in Poland – from 1.5% in 2020-02 to 0.1% in 2020-05). Hence, the greater availability of mortgages encouraged people to buy apartments instead of renting and to invest in rental apartments.

It may be assumed that in Poland, the effects of the pandemic shock lasted until the first quarter of 2022. First, in March, the COVID-related restrictions reached the lowest level since the beginning of the pandemic (Hale et al., 2021). Secondly, in February, Russia invaded Ukraine, starting a war. The number of refugees fleeing to European countries has equalled 6 million (UNHCR, 2023), while 1 million Ukrainians applied for temporal protection in the neighbouring country – Poland (Office for Foreigners, 2023). In Polish biggest cities, the resulting growth of population ranged from 12% to 53% (Wojdat & Cywiński, 2022), exerting a drastic demand shock to the housing rental market. The prices of energy resources rocketed (Ari et al., 2022), together with the costs of commodities and materials used in the construction sector. The crisis in the energy market prompted national governments to rethink their energy policies (Żuk & Żuk, 2022), as the supply shock quickly translated into general inflationary pressure. Moreover, the European central banks were forced to raise interest rates (in Poland – from 2.25% in 2022-02 to 6.75% in 2022-12), which elevated the perceived risk in housing investments and reduced the creditworthiness of potential buyers of apartments. Hence, it directed the demand from housing sales to the housing rental market.

On a macro scale, based on the theoretical model of DiPasquale & Wheaton (1992), the pandemic should have caused a decrease in rents, while the war-related crisis – rent increase. Similar changes were indicated in the empirical studies of the pandemic (Kuk et al., 2021; Tomal & Marona, 2021; Trojanek et al., 2021) and the war-induced refugee crisis (Gluszak & Trojanek, 2024; Trojanek & Gluszak, 2022). On the other hand, the consequences of recent economic shifts at the micro level have yet to be completely understood and tested. Regarding the pandemic, researchers discussed its several implications for lifestyle and housing preferences (Gallent & Madeddu, 2021; Mouratidis, 2021; Nanda et al., 2021), which was supported by survey studies (Marona & Tomal, 2020, 2023; Noszczyk et al., 2022). However, the quantitative evidence has been limited to date (Tomal & Helbich, 2022; Gamal et al., 2023; Guglielminetti et al., 2021). Concerning the war-related shock, the energy crisis and its implications may have induced a preference switch for some heating types, which has yet to be analysed.

The importance of the rental market, its structural changes triggered by the economic shifts, and the ongoing social transformation constitute a need to understand the new market rules. Moreover, in 2024, infectious diseases and natural resource shortages continue to be listed among the top global risks in both short and long-term perspectives (World Economic Forum, 2024). Thus, knowledge of how the housing market adjusts to economic shocks will allow us to understand its current state better and respond more effectively to similar shocks in the future.

First, the research aims to establish the marginal prices tenants pay for specific micro-level housing features using hedonic methods developed by Rosen (1974) based on Lancaster's (1966) consumer theory. Assuming consumers reveal the utility they attribute to goods through purchasing behaviour (Samuelson, 1948), the obtained marginal prices can be regarded as their revealed preferences. Besides the apartment characteristics included conventionally in hedonic housing models, the marginal prices paid for specific heating types have been estimated, together with the valuation of different scales of renovations of tenement buildings.

In its main part, the study has evaluated the impact of the pandemic- and war-related shocks on the micro-level valuations of rental apartments' characteristics. It was hypothesised that during the pandemic, the valuation of the availability of a balcony/terrace and private garden increased, together with the marginal price paid for the availability of an additional room for remote working or studying. Moreover, the spatial characteristics were considered, hypothesising that the value of proximity to urban green areas increased, and the value of proximity to the university buildings decreased. The attitude towards heating the rented apartment using natural gas was examined for the war-related shock, expecting a growing aversion. Finally, hedonic rent indices (HRI) have been calculated to assess the rent changes in the face of the shocks and to inspect the sensitivity of HRI to the shock-induced variability of rent-setting factors.

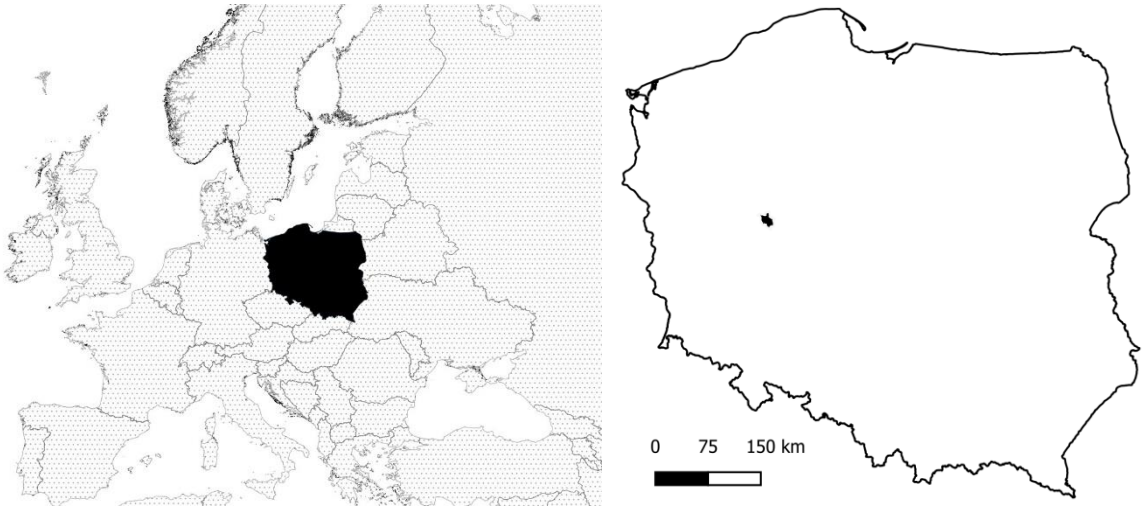

Figure 1. The location of Poland on the map of Europe (left panel). The location of Poznan on the map of Poland (right panel)

Source: own elaboration.

The hypotheses have been tested with the use of non-spatial (Ordinary Least Squares) and spatial hedonic models (Spatial Error Model) on the local market of Poznan – the fifth most populated Polish city, located in central Poland (its location has been presented in Figure 1). It serves not only as an academic destination but also is considered a business centre, attracting internal and external migrants. As a result, the rental market in Poznan is one of the most developed in Poland and constitutes a well-suited study area. Lastly, it was selected because of the author's knowledge of this market and the availability of data necessary to test the stated research hypotheses.

The research contributes to Rosen's (1974) hedonic price theory and adds to the literature on rent-setting factors, assessing the relationship between certain apartment characteristics and rents. In this regard, it extends the research of Hebdzyński (2024), who estimated the value of building renovations, and Sieger & Weber (2023) and Hahn et al. (2018), who described the impact of the type of apartment heating on rents. Then, it complements Tomal & Helbich's (2022) study of rent-setting factors' variability during the pandemic by testing hypotheses derived from qualitative studies – mainly Marona & Tomal (2020, 2023) and Nanda et al. (2021). As a result, it broadens the understanding of the adjustment process of consumer preferences to the pandemic and war-related shocks, which is important not only for investment purposes but also has implications for designing sustainable urban and socio-economic policies. In the case of hedonic rent indices, the study adds to Hill & Trojanek (2022), who compared different approaches to estimation and Hebdzyński (2024), who studied the sensitivity of HRI to the composition of variables included in hedonic models. The issue should be particularly important for public and private entities interested in tracking changes in rent levels using hedonic indices, which is the method recommended for this purpose by international institutions (European Commission, Eurostat, Organisation for Economic Co-operation and Development & World Bank, 2013).

The rest of the paper follows a structure: Section 2 reviews the literature on the topics covered by the study. Section 3 describes the data used and the chosen methodological approach to modelling. Section 4 outlines the empirical results and discusses the findings. Lastly, Section 5 concludes the manuscript, indicating its limitations and the field for further research.

2. LITERATURE REVIEW

2.1. Micro-level rent-setting factors

The existing literature on rent-setting factors concerns mostly the Chinese market, which is rapidly developing because of the increasing "floating population" – workers migrating temporarily within the country (Cui et al., 2018; Li et al., 2019; Liu et al., 2022; Zhan et al., 2023). A different strand of research has been devoted to establishing the impact of energy efficiency on rents in Germany (Cajias et al., 2019; Hahn et al., 2018; Kholodilin et al., 2017; Sieger & Weber, 2023). Other notable studies analysed the market of Switzerland (Baranzini & Ramirez, 2005; Crespo & Grêt-Regamey, 2013; Löchl & Axhausen, 2010), Greece (Efthymiou & Antoniou, 2013), the United Kingdom (McCord et al., 2014), the United States (Sirmans et al., 1989) and the Netherlands (Tomal & Helbich, 2023).

Among the Central and Eastern Europe countries, the research targeted to the best of our knowledge only the Polish market, focusing primarily on the rent-setting factors (Hebdzyński, 2024; Tomal, 2020; Tomal & Helbich, 2022, 2023) or on hedonic rent indices (Gluszak & Trojanek, 2024; Hebdzyński, 2024; Trojanek et al., 2021; Trojanek & Gluszak, 2022). Besides ordinary least squares (OLS), often used as a baseline approach in the hedonic analysis, authors employed a wide spectrum of methods to account for the Polish market specificity. Thus, their results will be discussed and used as a reference point. Gluszak & Trojanek (2024) constructed the micro-level hedonic models as a base to track the regional impact of the war-related migration on rents in five Polish biggest cities, utilizing a quasi-experimental variant of the difference-in-differences (DD) method. Hebdzyński (2024), based on the example of Poznan and Trojanek & Gluszak (2022), on the example of Warsaw and Krakow, treated the micro-level rent determinants as static in space, allowing them to differ across quality-related or price-related market segments using quantile regression (QR). Trojanek et al. (2021) added the spatial considerations on the geographically varying changes of rents in Warsaw amidst the early months of the pandemic and applied multiscale geographically weighted regression (MGWR). On the other hand, Tomal (2020) showed spatial autocorrelation of residuals

in the OLS models for Krakow and explored rent determinants using spatial autoregressive model (SAR) and spatial autoregressive geographically weighted regression (GWR-SAR). Then, Tomal & Helbich (2022), in the study of Krakow, used geographically and temporally weighted regression (GTWR), which accounts for spatiotemporal non-stationarity of data. Finally, Tomal & Helbich (2023) used spatial autoregressive geographically weighted quantile regression (GWQR-SAR), allowing the model estimates for Warsaw to vary across space and the conditional distribution of rent levels.

The apartment characteristics that influence rents are often divided into structural and locational. As for the variables conventionally included in the hedonic models, it has been proven that floor area has a positive impact on rents, as does the number of rooms, although the latter did not always show statistical significance. Then, depending on the approach taken, the type of the building in which the apartment is located, its age or construction technology have proven to influence rents significantly. Tomal (2020) warned that when multiple approaches are used at once, the collinearity of explanatory variables might be present. Every additional floor of the building has proven to decrease rents, while the higher location of the apartment in the building and the presence of a lift are priced positively (Tomal, 2020; Tomal & Helbich, 2023). Furthermore, the additional spaces were analysed. Hebdzyński (2024) proved that the presence of the designated parking space, balcony and private garden (in some model configurations) individually increase rents in Poznan, but when analysed together, the features have proven to be of little or no significance in Krakow (Tomal, 2020; Tomal & Helbich, 2022). As for the apartment equipment, Hebdzyński (2024) showed that full furnishing may noticeably increase rent. Lastly, apartment quality has proven to be a significant determinant of rents, regardless of the form of its inclusion, which was in detail studied by Hebdzyński (2024).

Regarding locational characteristics, the distance from the building in which the apartment is located to the city centre was most often included in models, showing a negative influence on rents. However, in Krakow, in the model rich in variables reflecting distance to public amenities, this variable showed collinearity problems. At the same time, the distances to the nearest park, university, school or water reservoir have proven to affect rents negatively (Tomal, 2020). In Poznan (Hebdzyński, 2024), the distance to urban green areas has been found to decrease rents, while the distance to the lake has been insignificant. Finally, for Warsaw, based on Tomal & Helbich (2023), the distance to the university and to the nearest public transport stop showed statistical significance for the highest share of analysed observations, revealing their negative relation with rents.

There are also structural variables, rarely analysed at the micro level, which have been targeted in this research to improve understanding of both the current state of the market and the impact of recent economic shocks. The location of the apartments in the renovated tenement buildings in Poznan has proven to increase rents by 4% compared to blocks of flats and non-renovated tenements (Hebdzyński, 2024). However, to the best of our knowledge, the impact of the scale of renovation on rent has not been yet studied for the rental market. In 2021, 14.7% of all apartments in Poznan were located in buildings constructed before 1945 (GUS, 2024). Similar to the downtown area of Wroclaw (Poland) studied by Marcinkowska et al. (2015), most of Poznan's tenement houses were built using similar construction solutions from the second half of the 19th century until World War II, following the Industrial Revolution. Although their maintenance was careful before the war, in the post-war times of socialism, the necessary repairs were not provided, and the buildings have often deteriorated. Nevertheless, the increased demand for apartments in tenements has been noticed since the political transformation in Poland, which started in 1989 (Marcinkowska et al., 2015). Most recently, renovations of tenement houses have been taking place, and some of them are being revitalized. In the context of individual buildings in Poland, revitalisation should be perceived as a change or adaptation of the historical building to meet requirements similar to those imposed on newly constructed ones (Terlikowski, 2013). Although Bieda & Maniak (2024) did not find a

clear effect of the revitalisation of an entire district in Krakow on apartment prices, it may be hypothesised that the relation is stronger on the level of individual buildings and depends on the scale of the renovation.

Secondly, the study has targeted the pricing of apartment heating types, which is connected with upgrading the existing stock of tenements across Poland. Originally, these buildings were heated with coal furnaces, but later, in cities, they have often been changed to gas-fuelled heating systems. Based on our analytical dataset (described in Section 3), they might be regarded as a dominant type of heating in rented apartments located in tenements in Poznan. Yet, the dataset shows that most apartments in revitalised tenements in Poznan have been connected to the district heating system. To date, studies of the rental markets have been mostly devoted to the more general issue of energy efficiency. Kholodilin et al. (2017) found that in Germany, it is capitalised in rents, but the value of future energy cost savings is larger than tenants' willingness to pay for better efficiency. Similarly, Cajias et al. (2019) found the rent premium for energy efficiency in the analysis of 403 local markets in Germany; however, it was not confirmed for metropolitan housing markets. Lastly, März et al. (2022) showed that although tenants pay a price premium for energy efficiency, it is small compared with other property features.

Hahn et al. (2018) divided heating systems into "brown", "standard", and "green" ones, where district heating was perceived as "green", apartments connected to central heating and heated with gas were treated as "standard", and those heated with coal or oil – "brown". The advantages of district heating were discussed by Mazhar et al. (2018), who considered it, among others, energy-efficient (thus cheaper), safer, environmentally friendly and space-efficient (as they require no bulky water boiler). Hahn et al. (2018) estimated the premium for using "green" technologies in Germany. They showed that it can be considered similar to the brown technology discount, equalling +/- 2.4% compared to the "standard" technologies. In the same model, the Authors also accounted for the energy performance of the apartments, which was the approach followed and extended by Sieger & Weber (2023), who estimated the marginal prices paid for particular heating types in the German market in years 2014-2020. District and central heating systems proved to be 0.4% - 0.8% more expensive, while electric heating – 3.7% - 5.5% cheaper than gas heating.

2.2. Micro-level impact of economic shocks

Marona & Tomal (2020, 2023) discussed the structural changes in preferences for apartment characteristics from the pandemic's beginning. The studies conducted in two phases of the pandemic in Krakow found that, respectively, 80% and 65% of surveyed real estate agents signalled the change in their clients' attitudes. Moreover, the Authors argued that it is highly likely that the changes will last longer than the pandemic and will become permanent. Among them, the increased demand of tenants for apartments with access to balconies or private gardens was indicated, highlighting the change in the ways of spending free time. It was confirmed in the survey study in Italy (Guglielminetti et al., 2021), where increased interest in apartments with private gardens was found.

On the other hand, Nanda et al. (2021) argued that as homes had to adapt to new roles – providing space for efficient work from home, the demand for an additional, separate room has increased. Mouratidis (2021) added considerations on the increased need for having larger, high-quality apartments that allow for comfortable leisure and enable to perform work-related tasks efficiently. It was also highlighted by agents surveyed by Marona & Tomal (2020). Moreover, Nanda et al. (2021), Gallent & Madeddu (2021), and Liu & Su (2021) argued that changes in working patterns reduced the importance of access to city centres, where business premises were traditionally located, which Tomal & Helbich (2022) empirically confirmed for the first phases of the pandemic. Gamal et al. (2023) and Tomal & Helbich (2022) found the decline in demand for apartments in dense, multi-unit buildings and linked it to the need to internalise the risk of the infection.

Similarly, Guglielminetti et al. (2021) showed that the stay-at-home orders in Italy may have increased demand for less congested areas.

Regarding other locational characteristics of apartments for rent, Tomal & Helbich (2022) found that the distance from the university buildings was gradually losing importance because of the introduction of online studies. Nanda et al. (2021) and Mouratidis (2021) discussed the recreational needs that can be satisfied by access to urban green areas, where the risk of infection was relatively lower. It was supported by the survey study of Krakow by Noszczyk et al. (2022), who added that during the pandemic, visits to green areas had a key role in citizens' mental health. Lastly, Broitman (2023) showed the growing willingness to live near urban green areas but warned that the increased prices of such located housing might result in the displacement of low-income residents and "ecological gentrification".

Concerning the preferences for heating types, we have found no study that linked them with economic shocks. However, one may see two reasons for the hypothesised increased aversion to gas heating after the beginning of the war in Ukraine. Firstly, one can name the rapid rise of natural gas prices. Ari et al. (2022) estimated that in 2022, the drastic change in the prices of fossil fuels contributed to the increase in the cost of living of European households by 7%, and the effect could persist until 2026. In Poland, the offered rents most often constitute only a fee for the property owner, not including any costs related to the use of the apartment, such as administrative fees and heating, electricity, or gas bills. On the other hand, as of 2021, around 80% of the natural gas consumed in Poland was imported (GUS, 2023), of which 56% was from Eastern Europe and Central Asia, mainly from the aggressor country – Russia (IGSMiE PAN, 2022). However, some gas supply contracts were terminated because of the tensions between Poland and Russia in the first months of the war in Ukraine (Balawender, 2022). As a result, tenants might have been concerned not only about the increase in gas costs that they would have to cover but also about possible shortages of this fuel.

Secondly, based on the pre-war survey, Rosak-Szyrocka & Żywiołek (2022) argued that Poles are generally little aware of the environmental damage caused by irresponsible energy consumption and of ways to save energy. After the outbreak of the war, Żuk & Żuk (2022) argued that countries could either strive to ensure the energy security or accelerate the energy transition. However, in the European Commission's (2023) study on climate change conducted more than a year from the beginning of the war, 43% of the surveyed Poles admitted that due to the war-induced energy crisis, the use of renewable energy sources should be increased, energy efficiency elevated and the transition to a green economy accelerated. Even if the share was below the EU average of 58%, it may be reflected in citizens' perceptions of heating types.

2.3. Macro-level impact of economic shocks

To study changes in rent level, one can use the theoretical model of DiPasquale & Wheaton (1992). In the four-quadrant analysis in which the real estate market is divided into the market for space and assets, the rent represents the former. It is situated at the core of the long-run analysis of the economic adjustment processes to economic shocks. In the model, the demand for space is assumed to come from tenants and owners who occupy their properties. Then, it relies on the current rent level and exogenous economic factors like number of households or their income. On the contrary, supply is linked with the market for assets, as it depends on real estate asset prices and construction costs. Although the model's framework focuses on individual economic shifts, the net effect of multiple simultaneous changes should reflect the combination of individual impacts.

Within the framework, the events accompanying the pandemic (described in Section 1) – the return of students to their family homes, the suspension of temporary labour migration, and the slowdown of economic activity may be perceived as factors that decrease the demand for space, pushing rents down.

Similarly, the interest rate reduction should contribute to a long-run rent decline. Finally, converting some short-term rental apartments to long-term rental purposes would constitute an exogenous shift in the housing supply, driving rents down. Therefore, rent reductions should be expected during the pandemic. It would be in line with the empirical studies for the early months of the pandemic – Trojanek et al. (2021) for Warsaw, Kuk et al. (2021) for the United States and Tomal & Marona (2021) for Krakow. Concerning the war-related economic shock, the influx of refugees drastically increased the number of households reporting demand for space. Moreover, because of the change in interest rates, an elevated number of Polish households showed interest in apartment rental, as they could not afford to take out mortgages. Thus, the demand pressure directed rents toward higher levels. From the supply side, the negative shift in the construction schedule of new apartments because of the rising costs of materials and energy resources also resulted in upward pressure on rents. Altogether, the observed demand and supply changes indicate that amidst the war in Ukraine, we should have experienced a rise in rent levels in Poland. The expected rent changes align with those indicated in the empirical study by Trojanek & Gluszak (2022) and Gluszak & Trojanek (2024) for Polish biggest cities in the first months of the war in Ukraine. Similar changes were reported by Balkan et al. (2018) regarding the impact of Syrian refugees on the Turkish rental market and Alhawarin et al. (2021), drawing on the experiences of Syrian migration to Jordan.

3. MATERIALS AND METHODS

3.1. Data

The research utilized a dataset of listings of apartments for long-term rental, located in multi-family buildings in Poznan. The listings were gathered quarterly, between 10th and 20th day of March, June, September and December, from 2019-06 to 2022-12, from two leading Polish apartment listing websites – Otodom.pl and Gratka.pl. The data were cleaned of duplicate observations – if the listing of the same apartment reappeared in adjacent periods (within 6 months range), only the last observation has been retained. This way, the listed rent would be as close as possible to the final, transacted rent. The data gaps were filled by exploring the descriptions and photos of listings. It allowed obtaining information on multiple apartment characteristics, which are often not signalled through the structured listings' forms, among others on building renovation, apartment furnishing, and availability of a balcony or a private garden. Then, based on expert market knowledge, the apartments with extreme rent or floor area were excluded, as well as those deemed unrepresentative, e.g., multi-storey apartments and those with gardens bigger than 75 m^2. It was assumed that the tenement buildings were built in Poznan until the 1960s and the newest buildings declared as tenements should be rather treated as blocks or apartment buildings (buildings designed to the highest standards and constructed from the best quality materials). Nevertheless, the average year of construction of the tenements included in the dataset was 1919. Regarding the heating type, the information provided in the listings was supplemented with expert knowledge, assuming that within the market of Poznan, the apartments located in high-quality apartment buildings and in the newest blocks are connected to the district heating system. Moreover, full textual descriptions of apartments were processed using the Wordscores algorithm (Hebdzyński, 2023, 2024; Laver et al., 2003) to obtain the proxy of apartment's quality.

The location of the listed apartments was rarely precisely indicated, thus the information that it is e.g., located "opposite to the XYZ restaurant" or "on a corner of" two streets was used. The observations were categorised into classes, according to the precision of information: up to 500, 250, 125 or 0 meters (the last value was assigned to the exact locations). The ones with lower precision were excluded from the dataset. As a result, the average precision of the location in the full dataset, which consisted of 7,768 observations, equalled 212 meters. Finally, in the study of the variability of rent-setting factors induced by the pandemic

(which has targeted changes in marginal prices of locational factors), only the observations with the precision of up to 250 meters were used, which aimed at increasing the reliability of the results. Then, the average precision equalled up to 123 meters.

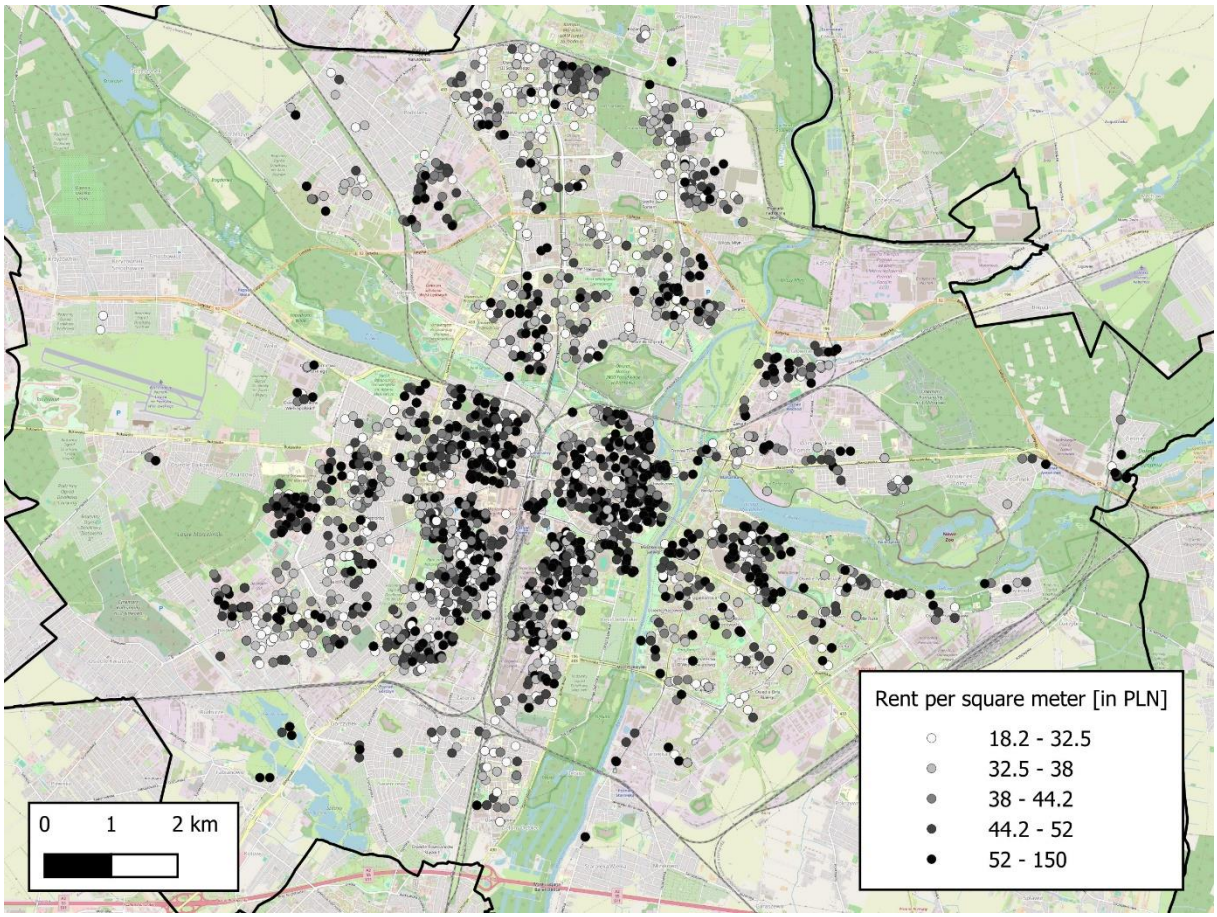

Figure 2. Spatial distribution of rent per square meter on the map of Poznan
Source: own elaboration based on OpenStreetMap

The listings have been used instead of transactions because of the impossibility of obtaining transactional data of the required quality, which is a frequent problem in European countries. In Poland, a high share of rental transactions is concluded without the intermediary of a real estate broker and there is no obligation to report them for purposes other than tax. Moreover, the data gathered by public institutions in the law-regulated process are not publicly available. That is why alternative data sources are often used, among which online listings are the most popular. Although they cannot be regarded as fully representative (Beręsewicz, 2015; Nasreen & Ruming, 2022) and they should be considered only a proxy of market transactions, they are superior regarding the availability of information on housing characteristics, which was utilised fully in this study. It has also been proven that listings-based hedonic indices of rents are highly correlated with transactional ones (Micallef, 2022) and may be considered accurate and leading indicators of transaction prices (Anenberg & Laufer, 2017).

3.2. Theory and calculation

The statistics of variables and tests discussed in this Section have been included in Appendix A.

To test the research hypotheses, the hedonic models were constructed using a logarithm of rent as a dependent variable and the variables presented in Table 1 as explanatory variables. The time-dummy method (Widłak & Tomczyk, 2010) was selected to construct HRI. The structure of the baseline hedonic model may be specified as:

$$lnR_i = \beta_0 + \sum_{j=1}^{J} \beta_j C_{i,j} + \sum_{k=2}^{K} \gamma_k D_{i,k} + u_i \quad (1)$$

where R_i is a rent for an i-th apartment, $C_{i,j}$ represents a value of j-th characteristic of an i-th apartment, β_j reflects the estimated marginal price of j-th characteristic, $D_{i,k}$ is a time dummy indicating whether an i-th apartment was listed in k-th period, γ_k is the estimated parameter reflecting change in rents in k-th period (compared to the base period) and u_i represents model's error.

Table 1

The variables used

Variable	Description
LN_RENT	dependent variable – natural logarithm of rent for the apartment [in PLN]
AREA	floor area of the apartment
ROOMS	number of rooms in the apartment
BLOCK	1 – for apartments located in blocks of flats, 0 – otherwise (base variable)
APART	1 – for apartments located in high-quality apartment buildings, 0 – otherwise
TENE_RENO	1 – for apartments located in renovated, non-revitalised tenements, 0 – otherwise
TENE_REVI	1 – for apartments located in revitalised tenements, 0 – otherwise
TENE_N_RENO	1 – for apartments located in non-renovated tenements, 0 – otherwise
QUALITY	soft quality of apartment obtained through processing of the listing description with the use of Wordscores algorithm, as in Hebdzyński (2023, 2024)
FURN	1 – for furnished apartments, 0 – otherwise
BALCONY	1 – for apartments with a balcony/terrace, 0 – otherwise
PARKING	1 – for apartments with access to the designated parking space, 0 – otherwise
GARDEN	1 – for apartments with access to the private garden (up to 75 m^2), 0 – otherwise
DIST_CC	the distance of the apartment to the city centre [in km]
DIST_GREEN	the distance of the apartment to the closest urban green area [in km]
DIST_TRAM	the distance of the apartment to the closest tram station [in km]
DIST_UNI	the distance of the apartment to the closest university building [in km]
HEAT_DISTR *	1 – for apartments connected to the district heating, 0 – otherwise (base variable)
HEAT_GAS *	1 – for apartments heated by an individual gas furnace, 0 – otherwise
PRE-SHOCK	1 – for observations from the pre-shock period (2019-06 – 2020-03), 0 – otherwise
PAND	1 – for observations from the pandemic period (2020-06 – 2021-12), 0 – otherwise
WAR	1 – for observations from the war period (2022-03 – 2022-12), 0 – otherwise

* The information on heating type has been available for 5,672 out of 7,768 initially selected observations. *Source*: own elaboration.

First, an OLS model was estimated and outliers were excluded based on Cook's distance (Cook, 1977) using the threshold of $4/N$. Then, the restricted model (MOD_0) was tested. Based on the Author's knowledge of the market, the spatial similarity of rents was hypothesised. Thus, Moran's I test was performed, and positive spatial autocorrelation of the model's residuals was proven, pointing to residuals' clustering. However, Cliff & Ord (1970) argued that Moran's I test may give false positive results due to non-linear relationships between the variables or because of the omission of crucial regressors. Thus,

multiple alternative model structures were tested in search of significant explanatory variables or their transformations (squares or logarithms). In this context, the results of RESET test of the model's specification (Ramsey, 1969) and AIC information criterion were considered in order to find the best model. The collinearity of the variables was checked using the VIF test to include only the non-collinear ones. Finally, the spatial distribution of the model's residuals was analysed visually.

As a result, no omitted variable suspected to influence the spatial distribution of residuals was found. Moreover, transforming explanatory variables to logarithmic forms did not lead to achieving better model results in terms of the RESET test and AIC. Therefore, the decision to use spatial methods was made. Due to the heteroscedasticity of residuals detected in the OLS model, its final version has been constructed using a heteroscedasticity-consistent variance estimator (White, 1980).

In the next step, the Lagrange Multiplier test statistics were calculated and proven statistically significant in all test variants. Therefore, it was decided that the MOD_1 model would be constructed in two variants – spatial error model (SEM) and spatial lag model (SLM), and the final decision regarding the estimation method and the way of constructing the weighting matrix would be made based on the AIC criterion. A matrix of spatial weights for neighbours in the proximity of 250 meters was selected as a starting one because it was the minimum value that exceeded the average precision of the location of the analysed apartments. Of all tested model variants, the SEM model, which used the matrix of proximity at a distance of 250 meters, proved to be the best. Hence, it was selected as a final approach to construct models. The main assumption of SEM is that in addition to modelling the parameters presented in Equation 2, the error term is also modelled, and:

$$u = \lambda W u + e \text{ , while } e \sim N(0, \sigma^2 I_n) \text{ ,} \tag{2}$$

where λ is a parameter of autocorrelation, W is a matrix of spatial weights for neighbours in the proximity of 250 meters, Wu is a spatially lagged error of the model, and e is an independent error.

To capture the rent-setting factors' variability, the models with interaction variables and restricted to specific time periods were constructed. The observations from the PRE-SHOCK period (pre-pandemic) were considered the control group, and the observations from the PAND or WAR period constituted the treatment group. Finally, the following models were prepared:

- MOD_0 – a baseline, non-spatial model, not accounting for changes in rent-setting factors,
- MOD_1 – a spatial model, not accounting for changes in rent-setting factors, based on full time range; MOD_2 – an analogous model, but restricted to observations with a known heating type (district or gas heating),
- MOD_3 – a spatial model based on the dataset restricted to the PRE-SHOCK (base period) and PAND periods, including interactions of PAND with: BALCONY, GARDEN, ROOMS, DIST_GREEN and DIST_UNI (the initially selected interaction of PAND and DIST_CC showed problem with collinearity, hence it was excluded from considerations); MOD_3_BASE – an analogous model with no interaction variables,
- MOD_4 – a spatial model based on the dataset restricted to the PRE-SHOCK (base period) and WAR periods, and observations with a known heating type (district or gas heating), including interaction of WAR with HEAT_GAS; MOD_4_BASE – an analogous model with no interaction variables.

For the needs of studying the pandemic-related change in rents, the MOD_3 models were used. As the MOD_4 models utilized non-randomly selected observations, no HRI was constructed based on them. Instead, the analysis of the rent changes amidst the war was conducted using the MOD_1 results. Lastly,

the sensitivity of HRI to the changes in rent-setting factors was studied by analysing the differences between HRI derived from the MOD_3 and MOD_3_BASE models.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Models' verification

The results of the discussed statistical tests and plots have been included in Appendix B.

Table 2

The models' results

	MOD_0	**MOD_1**	**MOD_2**	**MOD_3**	**MOD_4**
Variable	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**
AREA	0.0079 ***	0.0080 ***	0.0080 ***	0.0086 ***	0.0083 ***
ROOMS	0.088 ***	0.086 ***	0.092 ***	0.080 ***	0.096 ***
PAND x ROOMS				-0.006	
APART	0.037 ***	0.032 ***	0.023 ***	0.037 ***	0.022 ***
TENE_RENO	0.019 *	0.018 *	0.020	0.037 ***	-0.023
TENE_REVI	0.040 ***	0.039 ***	0.027 **	0.041 ***	0.011
TENE_N_RENO	-0.001	-0.001	-0.001	0.014 *	-0.021
QUALITY	3.009 ***	2.901 ***	2.953 ***	2.858 ***	3.064 ***
FURN	0.045 ***	0.045 ***	0.049 ***	0.042 ***	0.053 ***
BALCONY	0.034 ***	0.033 ***	0.032 ***	0.027 ***	0.012
PAND x BALCONY				0.018 *	
PARKING	0.036 ***	0.034 ***	0.031 ***	0.035 ***	0.029 ***
GARDEN	0.016 **	0.011	0.012	-0.039	0.005
PAND x GARDEN				0.053 *	
DIST_CC	-0.0094 ***	-0.0103 ***	-0.0104 ***	-0.0101 ***	-0.0091 ***
DIST_GREEN	-0.055 ***	-0.058 ***	-0.063 ***	-0.026	-0.068 ***
PAND x DIST_GREEN				-0.049 **	
DIST_TRAM	-0.003	-0.001	-0.007	-0.006	-0.003
DIST_UNI	-0.009 ***	-0.009 ***	-0.006	-0.003	-0.009 *
PAND x DIST_UNI				-0.004	
HEAT_GAS			-0.011		0.012
WAR x HEAT_GAS					-0.040 *
TIME-DUMMIES	YES	YES	YES	YES	YES
CONSTANT	6.390 ***	6.409 ***	6.392 ***	6.394 ***	6.373 ***
METHOD	**OLS**	**SEM**	**SEM**	**SEM**	**SEM**
R^2	**0.828**				
AIC	**-10,173**	**-10,292**	**-7,595**	**-6,012**	**-3,211**
N	**7,391**	**7,391**	**5,381**	**4,342**	**2,344**

Full models' results have been included in Appendix C. *** for p-value < 0.01; ** for p-value < 0.05; * for p-value < 0.1. *Source*: own elaboration.

The results of the constructed models have been presented in Table 2. First, based on R^2 of the MOD_1 model (standard R^2 has equalled 0.828, while adjusted R^2 – 0.827), it should be inferred that the model explains most of the variation of rents, i.e. the major rent-setting factors were accounted for. Compared to the analogous spatial model – MOD_1, the latter should be considered superior as it shows a

lower value of AIC. The visual analysis of the spatial distribution of model residuals did not reveal any clear clustering pattern. However, in Poznan's central districts, the absolute values of residuals seem to be bigger. Thus, the models' residuals were examined using tests of residuals' homoscedasticity (Breusch & Pagan, 1979) and the normality of their distribution (Jarque & Bera, 1980). Firstly, the null hypothesis of homoscedasticity has been rejected in all cases, which may also be caused by autocorrelation of residuals (Kopczewska, 2006). Secondly, most of the models have had problems with heavy tails. Yet, in the models that are based on the restricted dataset (models with interaction variables), the tails of the residual distribution either have been closer to the quantiles of normal distribution (MOD_3) or may be assumed to be normally distributed (MOD_4). Nevertheless, the detected heteroscedasticity may implicate the spatial variability of rent-setting factors. Thus, when interpreting the models' results, the focus should be placed on the changes in rent-setting factors rather than on the analysis of their precise levels.

4.2. Discussion

4.2.1. Micro-level rent determinants and their changes

First, it should be noted that the variables included in hedonic models have shown the expected direction of influence on rents in the MOD_1 model for the full-time range. The apartment area, together with its number of rooms, interior quality and furnishing should be considered the major structural rent-setting factors. Then, the availability of a balcony, designated parking space and private garden has been shown to increase rents. However, the last feature has been insignificant. In line with the expectations, all the analysed locational and distance variables impacted rents negatively – the bigger the distance from the city centre, university buildings or green areas ceteris paribus, the cheaper the apartments in Poznan. A similar direction of influence has been achieved for the proximity to public transport (tram), but, similarly to Krakow (Tomal, 2020), it has shown no significance. Supposedly, it may indicate that the relationship between public transport and rents is more complex and requires more data of greater precision that will allow us to study multiple modes of transport and their both positive and negative externalities.

More attention should be paid to the issue of building types. Based on the MOD_1 and MOD_2 models, the apartments located in revitalised tenements have proven to be 2.7 - 4% more expensive than the ones in blocks ceteris paribus, while the marginal price of the location in a high-quality apartment building has been lower and estimated at 2.4 - 3.3%. Thus, the location in historical buildings that have undergone revitalisation may be considered to provide a price premium. At the same time, the apartments in renovated but non-revitalised tenements also have shown to be more expensive than blocks – by around 2%, and the rents in non-renovated tenements have not statistically differed from the ones in blocks. Thus, although in the case of entire districts, revitalisation proved to be insignificant for price formation in Krakow (Bieda & Maniak, 2024), in Poznan, the performed renovation of the building and its scale have shown to be important factors for determining rents at the level of individual apartments. Importantly, in hedonic models for the full-time range, the heating types have shown no significant impact on individual rents, counter to the previous studies by Hahn et al. (2018) and Sieger & Weber (2023).

Secondly, most hypotheses concerning the changes in rent-setting factors during the pandemic have been confirmed by looking at the MOD_3 and MOD_3_BASE models. As hypothesised, the availability of a balcony or terrace increased rents by 2.8%, which was amplified during the pandemic by an additional 1.8 p.p. Concerning the availability of a small private garden, its impact on rents did not prove to be significant for the pre-pandemic period, however, the weak significance of change during the pandemic has been found. Thus, the overall impact of this variable on rents during the pandemic may be assumed to lie within the range of 1.5-5.4%. It confirms the findings of Marona & Tomal (2020, 2023) and Guglielminetti et al. (2021)

and shows that home-related leisure increased its value for tenants amidst the health crisis and lockdowns. As for the valuation of an additional room for remote working or studying, the hypothesized change discussed by Nanda et al. (2021) has not been proven. It may mean that the increased need for an extra room for work-related purposes could have been balanced by the need for having more spacious rooms for better relaxation and general well-being, as supposed by Guglielminetti et al. (2021) and Mouratidis (2021).

When it comes to locational factors, the impact of proximity to urban green areas on rents was significant in the joint analysis of the pre-pandemic and pandemic periods. Although the variable has been expressed in kilometres, its maximum value has been lower than one kilometre. Thus, it would be more intuitive to analyse the change in rents for 100 m of additional distance. In this regard, the impact should be estimated at -0.5 p.p. for every 100 m. However, when accounting for the pandemic-induced variability, the overall impact may be regarded as -0.23 p.p. (which has proven to be insignificant), while the additional discount during the pandemic has been measured at an additional -0.39 p.p. The noticed change is in line with the survey study by Noszczyk et al. (2022) and confirms the special role assigned to urban green areas during the health-related crisis and lockdowns. Moving to the analysis of the distance from university buildings, in the MOD_1 model conducted on the full-time range, an additional 1 km ceteris paribus has proven to significantly decrease rents by 0.9%. However, in the pandemic period the impact has shown to be not significantly different from 0. It implies that during the pandemic other factors than the proximity to university buildings were taken into account. It confirms the findings by Tomal & Helbich (2022) for Krakow and shows that the students' transition to remote or hybrid education was quickly reflected also in changes in the revealed preferences of tenants.

Finally, the analysis of the MOD_4 model has confirmed the hypothesized growth of the aversion towards gas heating after the outbreak of the war in Ukraine. Although earlier the marginal price of this feature was not statistically different from the value assigned to district heating, the relation changed amidst the war. The negative impact of gas heating on rents in the first four quarters of the war in Ukraine has been estimated at 2.7 - 3.9%. It may be considered a sign of change in the perception of this fuel in the times of the war-related increased volatility of prices of fossil fuels (Ari et al., 2022). Furthermore, it may be a symptom that the acceleration of energy transition discussed by Żuk & Żuk (2022), and studied by the European Commission (2023) is taking place on the micro level in Poland. Thus, it should be taken into account in the valuation of future investment processes, especially those connected with the renovations of the tenement buildings, in which gas heating is often used.

4.2.2. Hedonic rent indices and their sensitivity

Based on Figure 3 we may observe the dynamics of HRI in the pre-pandemic and pandemic periods, constructed with the use of estimates from the MOD_3 and MOD_3_BASE models. When comparing the models using the AIC criterion, it can be concluded that the MOD_3 model, which takes into account changes in the rent-setting factors, should be considered superior. Based on it, the mean absolute quarter-quarter dynamics of rents equalled 2.88%, while the mean absolute dynamics' difference – 0.19 p.p. Thus, although the changes in multiple rent-setting factors have been noticed, they have had little influence on the course of HRI in the short-term. This is in line with the study by Hill & Trojanek (2022), who noticed only slight differences between the apartment price indices obtained using the standard time-dummy method and the rolling-time dummy method (which allows for parameter changes in time). Moreover, it is consistent with the results by Hebdzyński (2024) on the little impact on the HRI of minor changes in the composition of hedonic models.

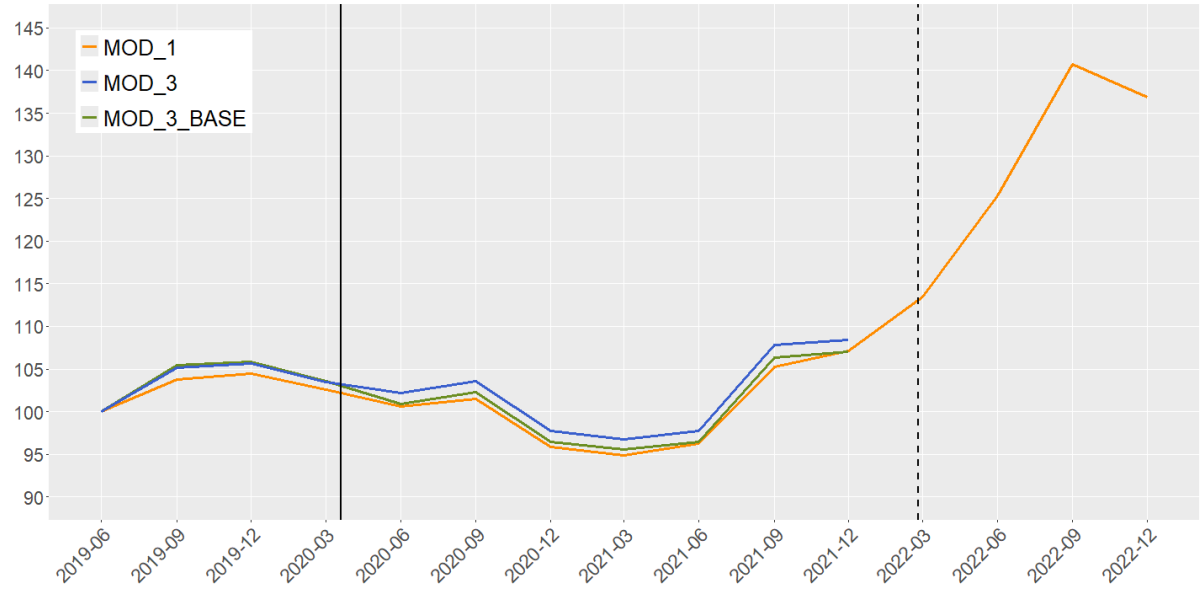

Figure 3. Hedonic rent indices (2019-06 = 100)

The solid vertical line represents the beginning of the pandemic in Poland (first lockdown – 2020-03-20); the dashed vertical line represents the beginning of the war in Ukraine (2022-02-24). *Source:* own elaboration.

Regarding the rent changes indicated by the models, it may be implied that rents in Poznan decreased by 6.7% during the pandemic, while for four quarters after the outbreak of the war the increase equalled 29.7%. The estimated changes in HRI agree with the expectations resulting from the theoretical analysis of both economic shocks at the macro level and with the earlier empirical evidence (Trojanek et al., 2021; Kuk et al., 2021; Tomal & Marona, 2021; Trojanek & Gluszak, 2022; Gluszak & Trojanek, 2024).

5. CONCLUSIONS

The study aimed to establish the factors determining rents at the micro level on the local rental market in Poznan, track their changes in the face of the recent economic shocks, and assess the sensitivity of hedonic rent indices to these changes. In the empirical part of the analysis, the hypotheses derived from the discussion papers and qualitative studies have been tested using spatial hedonic methods. It has been shown that in Poznan, individual apartment features influence rents similarly to other Polish markets, as described in previous research. However, in addition to the characteristics typically included in the hedonic models of housing, the revealed preferences for the types of buildings in which apartments are located have been examined. It has been shown that the pricing of tenements varies depending on whether the building has been renovated and on the scale of the renovation. Importantly, the location of the apartment in the revitalised tenement has been valued the most by tenants among all studied building types. In the next step, the changes in rent-setting factors have been considered. First, the structural characteristics of the apartment (the availability of a balcony or a private garden) were tested to find the increased valuation of leisure-related housing features during the pandemic. Yet, the similar change has not been proven for the marginal price paid for a separate room for remote working or studying. Concerning the valuation of locational characteristics amidst the pandemic, the strength of the impact of the proximity to urban green areas on rents has increased, while the significance of the distance to university buildings diminished. As for the shock caused by the war and the accompanying crisis in the energy market, it has been shown that it could also have had an impact on consumers at the micro level. Although earlier they valued similarly the district

and gas heating, the latter has become a negative factor during the first year of the war in Ukraine. Finally, the hedonic rent indices have been estimated, pointing to the modest decrease in rents during the pandemic and the drastic increase amidst the war-related crisis. The models that allowed for the changes in rent-setting factors have proven to be superior, nevertheless, the impact of the changes on the achieved dynamics of the index has been assessed as small.

It can be expected that changes in preferences for particular housing characteristics reported by consumers since the beginning of COVID-19 will become permanent (Marona & Tomal, 2023). Furthermore, the energy crisis, which has been caused on the one hand by the war in Ukraine and on the other hand by the adjustment of energy policy at the national and international level, also has the potential to change consumers' attitudes. Apart from their reaction to the increased volatility of gas prices on the global markets, which may be of a temporary nature, the perception of the switch towards greener energy might have changed permanently. Even though the housing market has already responded to the described shocks on both the micro and macro levels, infectious diseases, international armed conflicts, and resource shortages continue to be listed among the most important global risks. Therefore, examining the micro-level impact of economic shocks related to health, war and natural resources may help private and public entities to optimize their reaction to future shocks. Moreover, the responsible urban planning decisions aimed at stimulating the development of the housing rental market, which is a crucial economic sector, should incorporate the post-shock preferences of citizens. It would be profitable from both the perspective of satisfaction of the city's residents (because of meeting their housing needs) and from the perspective of economic efficiency of investments. Particularly, providing changes in the heating systems of older, energy-inefficient buildings, is not only desired in a way to reduce the consumption of non-renewable fuels but also proves to be positively priced by tenants. The same applies to the revitalisation of the existing housing stock, which results in the rent premium for the location of the apartment in the historical building.

Although the study utilized the dataset of listings that fully reflects the potential of this data source, it should be noted that the obtained marginal prices have relied on the models built based on listings providers' declarations. Therefore, the results constitute only a proxy of the truly revealed preferences that are possible to be obtained based on transactional data. Furthermore, supposedly also due to the limited size of the Poznan market and the resulting moderate number of observations, in some cases the statistical significance of indicated changes has been relatively weak (p-values < 0.1). Additionally, the study considers only a short-term change of rent determinants, not attempting to answer the question of the durability of the changes. To answer the above weaknesses, it is recommended to repeat the study as soon as transactional data, representing longer time scope and including more observations would become available. On the other hand, the results of the statistical tests point to the possible spatial variability of rent determinants. Thus, studying rent-setting factors in different spatial regimes (e.g. centrally vs. non-centrally located apartments) might reveal more information on the analysed phenomena. However, the primary objective of the study was not to precisely estimate the marginal prices of housing features, but rather to indicate their relative importance and changes over time. Thus, the SEM method, which assumes spatial homogeneity of estimates, was used to facilitate the interpretability of the results. Yet, special care should be taken when making predictions based on the models' results. Finally, we believe that each of the identified micro-level changes may require separate investigation to fully understand its nature, which we recommend as an area of research for future studies.

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APPENDIX A

Table A1

Basic statistics of the variables in the database (N=7,768)

Variable	MIN	AVG	MAX	Count of 1's	VIF
RENT (dependent variable)	700	1,927	6,000		
AREA	15	46.8	150		2.95
ROOMS	1	1.99	4		2.93
BLOCK				5,186	
APART				2,027	1.44
TENE_RENO				196	1.10
TENE_REVI				377	1.22
TENE_N_RENO				686	1.36
QUALITY	-0.014	0.165	0.335		1.52
FURN				6,709	1.04
BALCONY				5,712	1.49
PARKING				1,526	1.07
GARDEN				234	1.03
DIST_CC	0.021	2.969	10.916		2.49
DIST_GREEN	0.001	0.269	0.996		1.13
DIST_TRAM	0.005	0.462	6.478		1.58
DIST_UNI	0.017	1.005	9.141		1.95
HEAT_DISTR				5,238 (out of 5,672)	
HEAT_GAS				434 (out of 5,672)	1.69
PRE-SHOCK				1,666	
PAND				4,601	
WAR				1,501	

VIF values were calculated based on the results of the MOD_0 model. VIF for HEAT_GAS was calculated based on a model analogous to the MOD_0 model but restricted to observations with a known heating type (N=5,672). *Source*: own elaboration.

Table A2

Test statistics for the MOD_0 model

Type of test	Test statistics	p-value of test statistics
Moran	0.0468	< 0.001
RESET	2.7478 (df1=30, df2=7331)	< 0.001
Breusch-Pagan	202.5 (df=29)	< 0.001
Lagrange multiplier (LMERR)	149.59 (df=1)	< 0.001
Lagrange multiplier (LMLAG)	125.89 (df=1)	< 0.001
Lagrange multiplier (RLMERR)	77.53 (df=1)	< 0.001
Lagrange multiplier (RLMLAG)	53.83 (df=1)	< 0.001

Source: own elaboration.

Table A3

Values of AIC achieved in the process of selection of the best spatial variant of the MOD_1 model

Spatial modelling approach	Weighting matrix distance, m	AIC
SEM	250	-10,291.69
SLM	250	-10,282.61
SEM	375	-10,280.86
SLM	375	-10,278.77
SEM	500	-10,276.52
SLM	500	-10,285.16
SEM	600	-10,264.44
SLM	600	-10,271.60

Source: own elaboration.

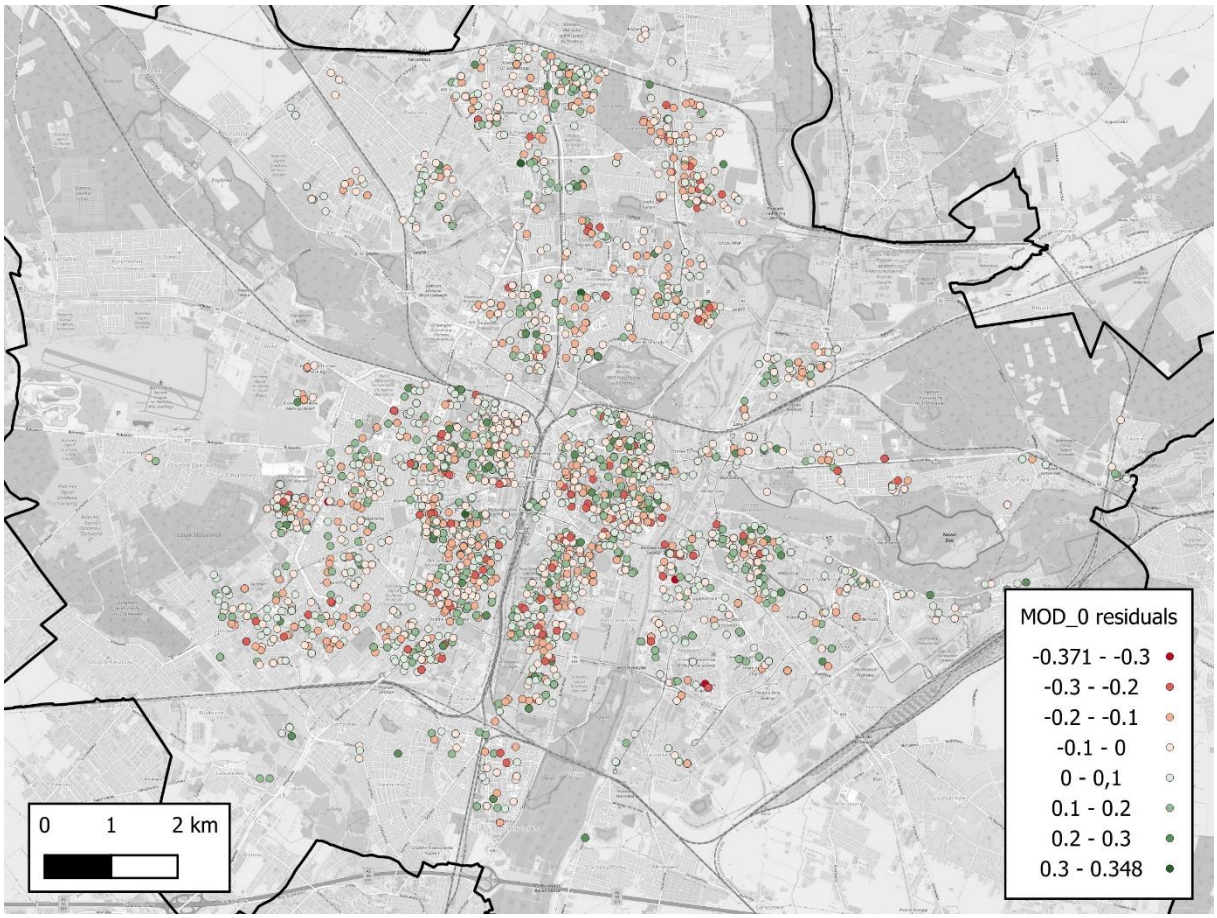

Figure A3. Spatial distribution of the MOD_0 model residuals

Source: own elaboration based on OpenStreetMap.

APPENDIX B

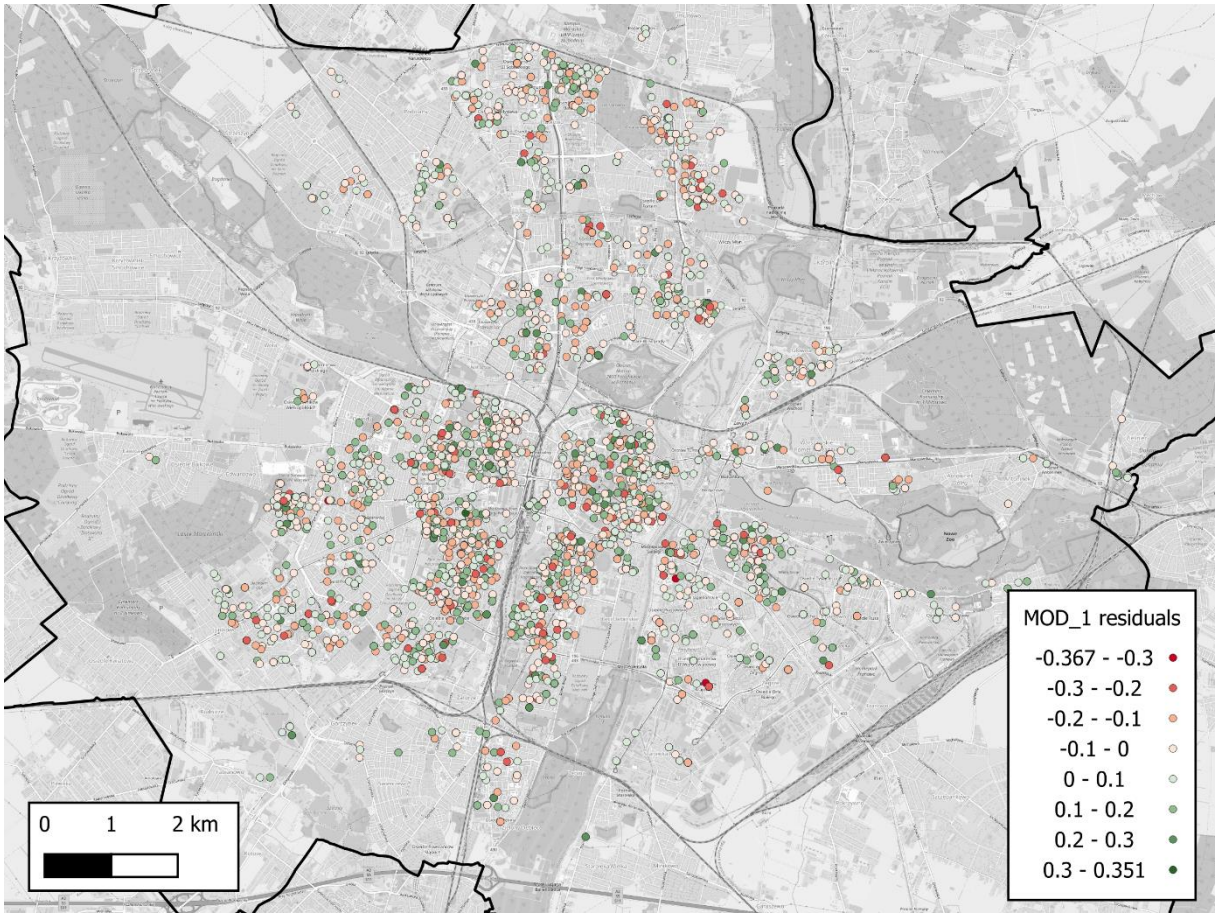

Figure B1. Spatial distribution of the MOD_1 model residuals

Source: own elaboration based on OpenStreetMap.

Table B1

Test statistics for spatial models

Type of test	Tested model	Test statistics	p-value of test statistics
Breusch-Pagan	MOD_1	221.4 (df=29)	< 0.001
Breusch-Pagan	MOD_2	147.1 (df=30)	< 0.001
Breusch-Pagan	MOD_3	164.2 (df=30)	< 0.001
Breusch-Pagan	MOD_4	59.6 (df=24)	< 0.001
Jarque-Bera	MOD_1	38.4 (df=2)	< 0.001
Jarque-Bera	MOD_2	21.7 (df=2)	< 0.001
Jarque-Bera	MOD_3	16.6 (df=2)	< 0.001
Jarque-Bera	MOD_4	2.1 (df=2)	0.349

Source: own elaboration.

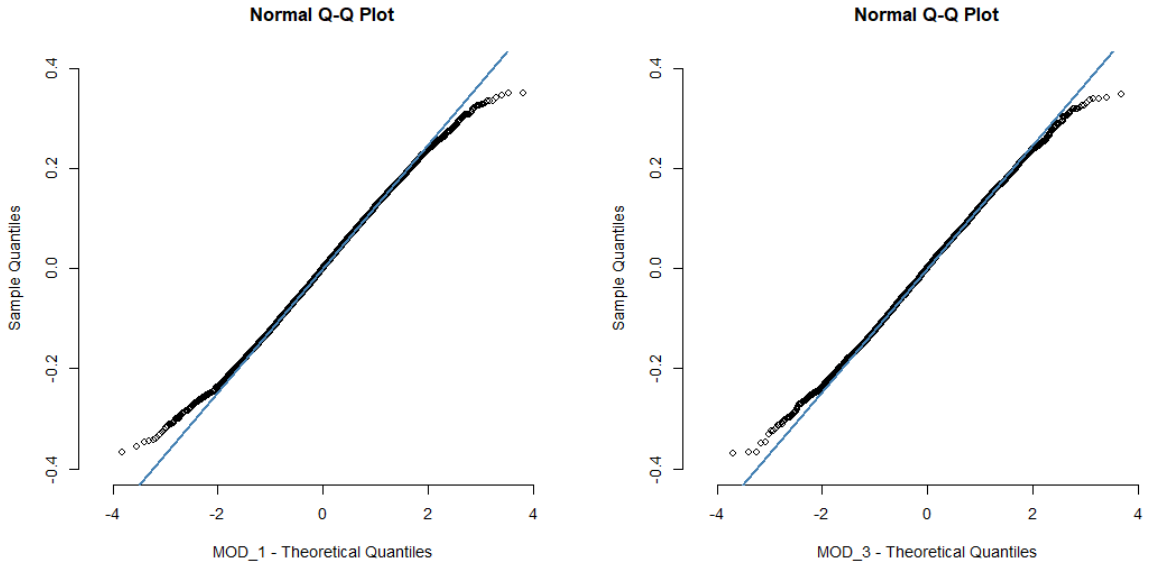

Figure B2. Distribution of selected models' residual versus quantiles of normal distribution

Source: own elaboration.

APPENDIX C

Table C1

Full results of models

	MOD_0	MOD_1	MOD_2	MOD_3	MOD_3_BASE	MOD_4	MOD_4_BASE
Variable	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**
AREA	0.0079 (0.000)	0.0080 (0.000)	0.0080 (0.000)	0.0086 (0.000)	0.0086 (0.000)	0.0083 (0.000)	0.0083 (0.000)
ROOMS	0.088 (0.000)	0.086 (0.000)	0.092 (0.000)	0.080 (0.000)	0.076 (0.000)	0.096 (0.000)	0.096 (0.000)
PAND x ROOMS				-0.006 (0.359)			
APART	0.037 (0.000)	0.032 (0.000)	0.023 (0.000)	0.037 (0.000)	0.037 (0.000)	0.022 (0.000)	0.022 (0.000)
TENE_RENO	0.019 (0.021)	0.018 (0.067)	0.020 (0.162)	0.037 (0.004)	0.038 (0.004)	-0.023 (0.424)	-0.325 (0.246)
TENE_REVI	0.040 (0.000)	0.039 (0.000)	0.027 (0.011)	0.041 (0.000)	0.042 (0.000)	0.011 (0.489)	0.012 (0.446)
TENE_N_RENO	-0.001 (0.823)	-0.001 (0.787)	-0.001 (0.890)	0.014 (0.077)	0.014 (0.080)	-0.021 (0.184)	-0.021 (0.184)
QUALITY	3.009 (0.000)	2.901 (0.000)	2.953 (0.000)	2.858 (0.000)	2.858 (0.000)	3.064 (0.000)	3.049 (0.000)
FURN	0.045 (0.000)	0.045 (0.000)	0.049 (0.000)	0.042 (0.000)	0.041 (0.000)	0.053 (0.000)	0.052 (0.000)
BALCONY	0.034 (0.000)	0.033 (0.000)	0.032 (0.000)	0.027 (0.003)	0.041 (0.000)	0.012 (0.126)	0.012 (0.000)
PAND x BALCONY				0.018 (0.082)			
PARKING	0.036 (0.000)	0.034 (0.000)	0.031 (0.000)	0.035 (0.000)	0.035 (0.000)	0.029 (0.000)	0.029 (0.000)
GARDEN	0.016 (0.020)	0.011 (0.202)	0.012 (0.189)	-0.039 (0.168)	0.005 (0.647)	0.005 (0.715)	0.005 (0.721)
PAND x GARDEN				0.053 (0.089)			
DIST_CC	-0.0094 (0.000)	-0.0103 (0.000)	-0.0104 (0.000)	-0.0101 (0.000)	-0.0101 (0.000)	-0.0091 (0.002)	-0.0092 (0.000)
DIST_GREEN	-0.055 (0.000)	-0.058 (0.000)	-0.063 (0.000)	-0.026 (0.227)	-0.064 (0.000)	-0.068 (0.000)	-0.068 (0.000)
PAND x DIST_GREEN				-0.049 (0.028)			
DIST_TRAM	-0.003 (0.440)	-0.001 (0.863)	-0.007 (0.226)	-0.006 (0.413)	-0.006 (0.424)	-0.003 (0.666)	-0.003 (0.695)
DIST_UNI	-0.009 (0.000)	-0.009 (0.009)	-0.006 (0.121)	-0.003 (0.633)	-0.006 (0.156)	-0.009 (0.061)	-0.009 (0.058)
PAND x DIST_UNI				-0.004 (0.409)			
HEAT_GAS			-0.011 (0.187)			0.013 (0.487)	-0.010 (0.461)
WAR x HEAT_GAS						-0.399 (0.058)	
TD_201909	0.035 (0.000)	0.037 (0.002)	0.041 (0.004)	0.050 (0.000)	0.053 (0.000)	0.041 (0.004)	0.041 (0.004)
TD_201912	0.043 (0.000)	0.044 (0.000)	0.041 (0.000)	0.055 (0.000)	0.056 (0.000)	0.041 (0.000)	0.041 (0.000)
TD_202003	0.025 (0.001)	0.025 (0.001)	0.022 (0.018)	0.034 (0.000)	0.035 (0.000)	0.016 (0.102)	0.015 (0.112)
TD_202006	0.007 (0.318)	0.006 (0.439)	0.008 (0.349)	0.022 (0.177)	0.009 (0.288)		
TD_202009	0.015 (0.045)	0.015 (0.047)	0.018 (0.051)	0.035 (0.030)	0.023 (0.011)		
TD_202012	-0.042 (0.000)	-0.042 (0.000)	-0.033 (0.000)	-0.023 (0.154)	-0.036 (0.000)		
TD_202103	-0.052 (0.000)	-0.053 (0.000)	-0.052 (0.000)	-0.033 (0.044)	-0.046 (0.000)		
TD_202106	-0.039 (0.000)	-0.038 (0.000)	-0.030 (0.001)	-0.023 (0.158)	-0.036 (0.000)		
TD_202109	0.052 (0.000)	0.051 (0.000)	0.054 (0.000)	0.075 (0.000)	0.062 (0.000)		
TD_202112	0.069 (0.000)	0.069 (0.000)	0.064 (0.000)	0.081 (0.000)	0.068 (0.000)		
TD_202203	0.126 (0.000)	0.126 (0.000)	0.130 (0.000)			0.133 (0.000)	0.131 (0.000)
TD_202206	0.228 (0.000)	0.225 (0.000)	0.222 (0.000)			0.223 (0.000)	0.221 (0.000)
TD_202209	0.342 (0.000)	0.342 (0.000)	0.338 (0.000)			0.335 (0.000)	0.332 (0.000)
TD_202212	0.314 (0.000)	0.314 (0.000)	0.315 (0.000)			0.321 (0.000)	0.318 (0.000)
CONSTANT	6.390 (0.000)	6.409 (0.000)	6.392 (0.000)	6.394 (0.000)	6.405 (0.000)	6.373 (0.000)	6.378 (0.000)
Method	**OLS**	**SEM**	**SEM**	**SEM**	**SEM**	**SEM**	**SEM**
R^2	**0.828**						
AIC	**-10,172.8**	**-10,292.0**	**-7,595.1**	**-6,012.4**	**-6,010.5**	**-3,211.8**	**-3,210.2**
AIC of an OLS equivalent		**-10,172.8**	**-7,488.2**	**-5,942.0**	**-5,940.7**	**-3,194.1**	**-3,192.9**
N	**7,391**	**7,391**	**5,381**	**4,342**	**4,342**	**2,344**	**2,344**

P-values have been included in parentheses ("0.000" indicates p-values lower than 0.0005).
Source: own elaboration.