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The private rental housing market before and during the COVID-19 pandemic: A submarket analysis in Cracow, Poland

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Abstract

How the COVID-19 pandemic has altered the segmentation of residential rental markets is largely unknown. We therefore assessed rental housing submarkets before and during the pandemic in Cracow, Poland. We used geographically and temporally weighted regression to investigate the marginal prices of housing attributes over space–time. The marginal prices were further reduced to a few principal components per time period and spatially clustered to identify housing submarkets. Finally, we applied the adjusted Rand index to evaluate the spatiotemporal stability of the housing submarkets. The results revealed that the pandemic outbreak significantly lowered rents and modified the relevance of some housing characteristics for rental prices. Proximity to the university was no longer among the residential amenities during the pandemic. Similarly, the virus outbreak diminished the effect of a housing unit's proximity to the city center. The market partitioning showed that the number of Cracow's residential rental submarkets increased significantly as a result of the COVID-19 pandemic, as it enhanced the spatial variation in the marginal prices of covariates. Our findings suggest that the emergence of the coronavirus reshaped the residential rental market in three ways: Rents were decreased, the underlying rental price-determining factors changed, and the spatiotemporal submarket structure was altered.

Keywords

Rental housing market, urban housing submarkets, submarket stability, COVID-19 pandemic

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Introduction

The COVID-19 pandemic has become one of the largest humanitarian crises: By the beginning of April 2021, it had caused over 2,800,000 deaths worldwide (Johns Hopkins Coronavirus Resource Center, 2021). The emergence of COVID-19 has also affected many aspects of the urban economy (Nicola et al., 2020). The sales and rental housing markets in cities are no exceptions and have been altered in many countries. For example, the pandemic influenced the activities of housing market professionals (Marona and Tomal, 2020), residential sales and rental prices (Del Giudice et al., 2020), residential architecture (D'Alessandro et al., 2020), housing legislations (Maalsen et al., 2020), and the mortgage market (Nicola et al., 2020).

Much of the existing work is based on the use of hedonic price theory to decompose purchase and rental prices into their utility-bearing characteristics, including a house's structural attributes, neighborhood, and location (Malpezzi, 2002). It was originally assumed that supply and demand are in equilibrium for the housing characteristics. This constraining assumption is, however, relaxed by considering that the housing market is segmented into numerous submarkets (Goodman and Thibodeau, 2007).

Theory suggests a unique pattern of valuing property attributes in response to the interaction between buyers and sellers per submarket (Palm, 1978), resulting in constant marginal prices of the various housing attributes within a submarket. Therefore, houses located in the same submarket are thought to be close substitutes for each other, but poor substitutes for properties located in other submarkets (Grigsby, 1986). Research that adequately addresses the segmentation of housing markets is important for two reasons. First, understanding how housing submarkets operate over space–time increases the accuracy of house and rental price forecasts (Usman et al., 2020), which are the basis of many economic operations such as investments or mortgages. Second, public lawmakers have the ability to shape different housing policies among submarkets (Wu and Sharma, 2012).

Despite speculation concerning the importance of the COVID-19 crises for urban housing markets (Batty, 2020; Goodman and Magder, 2020; Tanrıvermiş, 2020; Tomal and Marona, 2021), we are not aware of any study examining how the outbreak of the pandemic has altered the formation of residential urban submarkets. To fill this research gap, our objective was to analyze changes in the factors that determine the rental prices and the spatiotemporal structure of housing submarkets before and during the COVID-19 pandemic in Cracow, Poland. For that purpose, we developed a data-driven approach that structures the rental market into spatiotemporal submarkets.

We focused on the residential rental market rather than the housing sales market because this market segment has in three respects been more strongly affected by COVID-19 (Kholodilin, 2020). First, as a result of the deteriorating economic situation, many tenants have lost their jobs, which has reduced their ability to pay rent. The latter, in turn, has negatively impacted landlords' revenues. Second, many cities' rental markets rely heavily on specific population groups (e.g., students or business service workers) who continue their work remotely. Third, many countries (including Poland) have closed their borders to restrict tourism. As a result, much of the supply of short-term rentals has been shifted to the long-term rental market. All of these developments have possibly contributed to profound rent declines. These impacts apply to the Cracow rental housing market, which rendered this city an ideal case study.

Literature review

COVID-19 pandemic and the house and rental prices

To date, there is little knowledge on how COVID-19 has affected house prices or rents. Del Giudice et al. (2020) were among the first to investigate the issue and they reported a moderate price decline

in the Italian housing market of 4.16% in the short term (March–June 2020) and 6.49% in the medium term (March 2020–January 2021) due to the pandemic outbreak. A similar analysis for the Irish residential sales market by Allen-Coghlan and McQuinn (2021) revealed that house prices decreased from March 2020 onward. Their study also showed that the drop in sales prices was likely due to a decline in household disposable income and reduced mortgage market activity. Tanrıvermiş (2020) also highlighted the latter aspect: He found a significant decline in residential property transactions in Turkey that were financed by mortgage credit.

In contrast, Qian et al. (2021) assessed pandemic-related changes in property prices in the Chinese housing market. Using the difference-in-difference approach, a price decline of 2.47% was estimated but only in those communities where COVID-19 cases were confirmed. Such a price decline in China's housing sales market was also recognized by Cheung et al. (2021). Specifically, using Wuhan city data, prices decreased by 5% between January 2019 and July 2020. However, the opposite was concluded for the Chinese Yangtze River Delta region (Yang and Zhou, 2021). Explanations put forth include that families desire to stay together during the epidemic.

In the U.S. context, Zhai and Peng (2021) explored changes in housing market indicators between October 2019 and June 2020 and concluded that housing prices continued to rise in most counties, on average by 10%, and a decline was noticeable in only a few central areas. That the pandemic has had a relatively minor influence on U.S. sales prices was echoed in a study on the Houston, Santa Clara, Honolulu, Irvine, and Des Moines areas (Wang, 2021). In Honolulu, there was a significant price decrease of 6.69%, which was supposedly due to stronger associations of the local economy with the service sector than in other cities.

Only a few studies have examined the pandemic's impact on residential rents. Among them, Tomal and Marona (2021) found that the first wave of the pandemic led to a 6–7% price decline in the residential rental market in Cracow, Poland; the second wave led to an extra 6.25% decrease, which makes a return to pre-pandemic rent levels rather unlikely until the second half of 2022. Similar conclusions were reached by Trojanek et al. (2021), who estimated that housing rents in Warsaw fell by 7.7% between March and December 2020. Finally, the analysis conducted by Kuk et al. (2021) showed that in the period immediately after the coronavirus outbreak—namely, from mid-March to early June 2020—apartment rental prices in the U.S. dropped by several percent.

When taken together, our literature review implies that, first, the residential rental market has been more affected by the COVID-19 pandemic than the housing sales market, and second, studies to date have focused solely on determining the percentage decrease or increase in prices due to COVID-19. We are not aware of any study assessing whether and, if so, to what extent the relevance of rental price-determining factors has changed and what the consequences are for the stability of urban housing submarkets.

Approaches to segment housing markets

Numerous methods have been proposed for housing submarket identification. Ad hoc approaches adopt pre-defined boundaries to separate submarkets. Examples include delineations based on zip codes (Jones et al., 2003), land use zonings (Levkovich et al., 2018), street segments (Xiao et al., 2016), local government boundaries (Bangura and Lee, 2020), and socioeconomic characteristics (Tu, 1997). However, such approaches are problematic because the underlying processes between buyers and sellers that generate housing submarkets, including consumer housing preferences, are often poorly aligned with pre-defined boundaries and thus the results are likely susceptible to scale and zoning effects (Helbich et al., 2021; Lee et al., 2016). Therefore, it is likely that, as demonstrated elsewhere (e.g., Helbich et al., 2013), ad hoc approaches yield submarkets that contain dissimilar and non-substitutional residential properties.

To address the limitations of pre-specified submarket boundaries, data-driven approaches have been introduced. Applied approaches are based on, for example, principal component analysis (Bourassa et al., 1999), crisp (Tomal, 2021) and fuzzy clustering (Helbich, 2015; Hwang and Thill, 2009), neural networks (Kauko et al., 2002), and classification regression trees (Fan et al., 2006). Principal component analysis (PCA) is initially used as a data pre-processing step to reduce the dimensionality of the data serving as input for clustering algorithms (Bates, 2006). An optimal number of clusters is usually obtained by fitting hedonic models, including the clusters as fixed effects (Bischoff and Maennig, 2011) or random effects (Leishman, 2009). The partition resulting in the hedonic regression's best goodness-of-fit usually serves as appropriate housing market segmentation (Belasco et al., 2012).

Most of these non-spatial submarket partitions result in crisp submarkets, which are not without critique. First of all, researchers have argued that submarkets do not change abruptly from one submarket into another, but rather undergo a continuous transition (Páez et al., 2011). To circumvent this shortcoming, Helbich et al. (2013) proposed a soft-market segmentation based on a hedonic price function obtained through mixed geographically weighted regression (GWR) (Brunsdon et al., 1999), which allows marginal prices to continuously change their influence on house prices across space. Due to the pronounced volatility of continuously changing marginal prices, Helbich et al. (2013) further clustered the GWR surfaces by means of the SKATER (Spatial' K'luster Analysis by Tree Edge Removal) regionalization algorithm (AssunÇão, et al., 2006). In contrast to aspatial algorithms, SKATER results in spatially contiguous residential submarkets. This is in line with housing market segmentation theory, according to which the substitutability of housing units is closely related to a given location (Wu and Sharma, 2012). However, a striking limitation of SKATER is the use of contiguity constraints in a static way; that is, the contiguity matrix is not updated during clustering. In other words, SKATER ignores the possibility that observations that are not initially spatial neighbors may become so as a result of being assigned to clusters that are next to each other in space (Guo, 2008). Moreover, SKATER faces the so-called chaining problem, resulting in suboptimal clusters. Building upon Helbich et al. (2013), Wu et al. (2018) suggested using geographically weighted PCA in combination with a density-based spatial clustering algorithm that incorporates the spatial contiguity of submarkets and the similarity of housing attributes.

While the majority of studies on housing submarkets stress the spatial dimension, their spatiotemporal stability remains largely disregarded. Among the few scholars who did not disregard it, Leishman (2009) and Kopczewska and Ćwiakowski (2021) split the housing markets in Glasgow (UK) and Warsaw (Poland) into time periods and examined each period independently. However, this approach ignores the temporal dependencies of house prices, likely leading to inaccurate spatiotemporal housing segments. Consequently, Soltani et al. (2021) used geographically and temporally weighted regression (GTWR) to account for the spatiotemporal heterogeneity of house prices and their characteristics before clustering the principal components (PCs) with SKATER. Nevertheless, the work by Soltani et al. (2021) is constrained by the restrictive and unrealistic assumption that the spatial structure of submarkets remains stable over time. Taken together, spatiotemporal methodologies are clearly underdeveloped, either ignoring temporal dependencies or grounding on unrealistic assumptions of temporally invariant spatial structures of submarkets.

Materials and methods

Study area and data

The collected data represents the rental market in Cracow between the first quarter of 2020 and the first quarter of 2021. Information on rental listings was obtained from otodom.pl by means of web scraping. Data were collected for the following dates: 14 February 2020; 14 May 2020; 14 August

2020; 14 November 2020; and 14 February 2021. The data thus covered the period before[1] and during the pandemic, which allowed us to assess the consequences of the COVID-19 outbreak on Cracow's residential rental market. Note that seasonal variations are not at play in the private residential rental market in Cracow (Tomal and Marona, 2021). We initially collected data on 24,691 monthly housing rentals. We removed duplicates and records with missing information. In total, our data set comprized 14,612 rental listings from the city of Cracow.

Figure 1 shows the spatial distribution of these listings. Residential rentals are concentrated in Cracow's urban center, while dwellings are mostly absent from the eastern part due to the dominance of agricultural and industrial land. In addition to the rental offer price, each listing included information on seven structural characteristics (e.g., apartment size), three locational variables (e.g., distance to the city center), and 11 neighborhood characteristics (e.g., distance to the nearest school). A description per variable along with descriptive statistics is provided in Supplementary Table S1. Following Kim (2013), those variables where the skewness exceeded |2| were logarithmically transformed.

Methods

Our procedure for modeling submarkets consists of four steps (technical details for each step are provided in Supplementary Sections S1–S4 of the Supplementary Materials). First, GTWR developed by Huang et al. (2010) was applied to uncover the variability of the hedonic regression parameters over space–time. GTWR is a locally weighted regression used to model associations between a response variable and covariates across space and over time. To calibrate the GTWR model for a given observation, only a spatiotemporal subset of data is considered. Observations that are closer to the regression point in space and time have a stronger influence. To model the space–time decay, we used the Gaussian kernel as a spatiotemporal weighting function with an adaptive bandwidth optimized by means of cross-validation. Furthermore, because GTWR is computationally

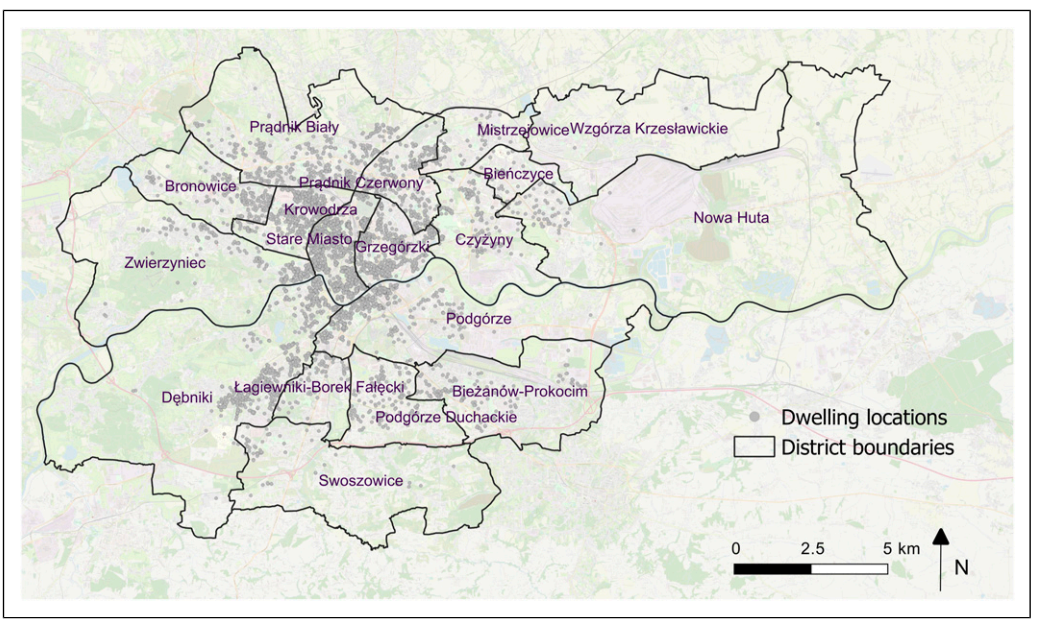

Figure 1. Locations of rental listings (N = 14,612) in Cracow.

demanding, we followed Fotheringham et al. (2015) and randomly selected 50% of the observations per quarter to calibrate the GTWR model.

Second, we used PCA (Bro and Smilde, 2014) to reduce the dimensionality of the obtained GTWR parameter estimates. PCA provides a linear dimensional reduction of the data resulting in a few orthogonal principal components (PCs), reflecting the most inherent variability of the multivariate data. PCA has the advantage of reducing noise and parameter multicollinearity of the GTWR point estimates. Both issues can affect the discriminating power of the segmentation algorithms. An appropriate number PCs were identified through the Kaiser criterion (i.e., PCs with eigenvalues <1 were dropped).

Third, to circumvent limitations of the SKATER algorithm, we used the full-order complete linkage clustering (Full-Order-CLK) method, which is part of the REDCAP (2008) family, to partition the PCs. Following Belasco et al. (2012), the optimal number of clusters was determined by minimizing the Akaike information criterion (AIC) score across hedonic regressions in which the clusters served as fixed effects. The maximum number of clusters was set at 20, as done elsewhere (e.g., Kopczewska and Ćwiakowski, 2021; Watkins, 2001). In cases where the minimum AIC score occurred with 20 clusters, we increased the number of possible clusters and compared the AIC scores. To delineate area-wide submarkets from the location-wise clusters, we determined Voronoi polygons around the locations. Apartments within a Voronoi polygon belong to the same submarket. Steps 2 and 3 were repeated for each time period.

Finally, we employed the adjusted Rand index (ARI) (Hubert and Arabie, 1985) to assess in detail the stability of the submarkets over the time periods. The ARI ranges from -1 to 1, with 1 indicating identical partitions and a value close to 0 indicating a random distribution regardless of the number of clusters.

Results and discussion

Evaluation of the spatiotemporal nonstationarity of housing attributes' marginal prices

None of the covariates resulted in a collinearity problem. The variance inflation factor (VIF) for all explanatory variables was less than 10 (Mason et al., 1989). We therefore used all the covariates shown in Supplementary Table S1 for further analysis. GTWR was estimated to obtain parameter estimates on each rental price-determining apartment characteristics per observation ($N = 7{,}306$). The adjusted R^2 of the model was 0.55, suggesting that rents were fairly well explained compared to other studies that assessed the determinants of rental prices (e.g., Zhang et al., 2019).

Table 1 shows the average values of the standardized parameters (marginal prices) per period (unstandardized parameters are shown in Supplementary Table S2). The results show that for most of the periods, the parameters of the variables had the expected sign. In terms of structural variables, the larger the area of the apartment, the older the building, and the more floors it has, the lower the rent (per square meter), which is line with Cui et al. (2018). In contrast, more rooms in the apartment, the availability of a garage or balcony, and the presence of an elevator in the building increase the rental price, as found in previous studies (e.g., Donovan and Butry, 2011). As in Djurdjevic et al. (2008), the higher the apartment is in the building, the higher the rent.

Concerning the location variables, we observe that proximity to city center and bus/tram/train stop increases the rental price (Su et al., 2021). As in previous studies (e.g., Efthymiou and Antoniou, 2013), apartments located in the vicinity of roads have lower rents, which is likely due to the negative externalities (e.g., noise, air pollution) generated by this type of infrastructure.

In respect to the neighborhood variables, proximity to natural amenities such as a park or reservoir increases the rent. This result is in line with Jun and Kim (2017). Congruent with Huang (2017), being located close to educational facilities (i.e., kindergarten, school, university) increases

Table 1. Results of the standardized parameter estimates based on GTWR.

	Mean						Difference in mean parameter values between			
Variable	2020Q1	2020Q2	2020Q3	2020Q4	2021Q1	Significance of spatial nonstationarity[a]	2020Q2 and 2020Q1	2020Q3 and 2020Q1	2020Q4 and 2020Q1	2021Q1 and 2020Q1
Intercept[b]	5.44	5.41	5.51	5.68	5.21	In selected periods	NA	NA	NA	NA
Structural covariates										
(log) Floor area	−0.49	−0.48	−0.58	−0.54	−0.47	Among all periods	0.00	−0.09	−0.06	0.02
Number of rooms	0.26	0.20	0.31	0.32	0.25	In selected periods	−0.06	0.06	0.07	−0.01
Floor level	−0.01	0.07	0.06	0.04	0.05	In selected periods	0.08	0.07	0.05	0.06
Availability of additional space (e.g., garage, basement)	0.07	0.03	0.03	0.03	0.03	In selected periods	−0.05	−0.04	−0.05	−0.05
(log) Age of the building in years	−0.28	−0.31	−0.29	−0.29	−0.28	In selected periods	−0.03	−0.01	0.00	0.01
Number of floors in the building	−0.04	−0.07	−0.09	−0.14	−0.12	In selected periods	−0.03	−0.05	−0.10	−0.08
Availability of elevator in the building	0.18	0.06	0.13	0.22	0.17	In selected periods	−0.11	−0.05	0.05	−0.01
Locational covariates										
Distance to nearest bus stop, tram stop or train stop	−0.06	−0.04	−0.07	−0.06	−0.06	In selected periods	0.03	0.00	0.01	0.01
Distance to city center	−0.52	−0.51	−0.41	−0.36	−0.38	Among all periods	0.00	0.11	0.16	0.13
(log) Distance to nearest primary or secondary road	0.06	0.02	0.00	−0.01	0.03	In selected periods	−0.04	−0.06	−0.07	−0.03
Neighborhood covariates										
(log) Distance to nearest local government building	0.04	0.00	0.03	−0.07	0.00	Among all periods	−0.04	−0.01	−0.11	−0.04
(log) Distance to nearest work center	−0.01	0.06	0.03	0.03	0.05	In selected periods	0.07	0.04	0.04	0.06

(continued)

Table 1. (continued)

Variable	Mean					Significance of spatial nonstationarity[a]	Difference in mean parameter values between			
	2020Q1	2020Q2	2020Q3	2020Q4	2021Q1		2020Q2 and 2020Q1	2020Q3 and 2020Q1	2020Q4 and 2020Q1	2021Q1 and 2020Q1
(log) Distance to nearest kindergarten	−0.03	−0.04	−0.01	−0.05	−0.03	Among all periods	−0.01	0.02	−0.03	−0.01
Distance to nearest school	−0.05	0.01	0.03	−0.05	0.00	In selected periods	0.06	0.08	0.00	0.05
(log) Distance to nearest university	−0.09	−0.07	−0.05	0.00	0.00	In selected periods	0.01	0.04	0.09	0.08
(log) Distance to nearest pharmacy	0.04	0.09	0.02	0.01	−0.03	In selected periods	0.04	−0.02	−0.03	−0.07
Distance to nearest shopping mall	0.01	0.02	0.02	−0.03	−0.07	Among all periods	0.01	0.01	−0.04	−0.08
(log) Distance to nearest supermarket	0.04	0.02	0.04	0.03	0.05	In selected periods	−0.02	0.00	−0.01	0.01
Distance to nearest forest	0.01	−0.02	−0.01	−0.03	0.06	In selected periods	−0.03	−0.02	−0.04	0.05
(log) Distance to nearest park	−0.09	−0.06	−0.09	−0.09	−0.08	In selected periods	0.03	0.00	0.00	0.01
Distance to nearest river or reservoir	−0.15	−0.10	−0.10	−0.24	−0.12	Among all periods	0.04	0.05	−0.10	0.02
N	1149	1250	1790	1483	1634	Sum of absolute values	0.81	0.82	1.09	0.88

[a]The spatial nonstationarity of parameter estimates was assessed based on Fotheringham et al. (2003) by comparing the interquartile value of the GTWR parameter estimates with twice the OLS standard error. A positive difference refers to a significant spatial variation in the parameters. Detailed results concerning the nonstationarity test for each period are given in Supplementary Table S3. The dependent variable is logged rent per square meter. $R^2 = 0.54$, adjusted $R^2 = 0.55$, bandwidth = 731, spatiotemporal ratio (τ) = 4.09. OLS-based $R^2 = 0.43$.
[b]The values of the intercept are not standardized.

rental prices. Supporting the findings of Tomal (2020) and Zambrano-Monserrate and Ruano (2019), we found that the presence of commercial facilities in the vicinity of an apartment lowers the rent. It may also result, as in the case of proximity to a main road, from the pronounced noise level generated by these facilities.

The GTWR estimates also reveal that the floor area of the apartment and its distance to the city center had the strongest effect on rents, which confirms earlier results on the Cracow residential market (Nalepka and Tomal, 2016). The floor, the distance to the work center, and the distance to the closest shopping mall have the least effect on rental prices. However, we found that the relevance of covariates changed over time, which could be explained by the COVID-19 outbreak. Between 2021Q1 and 2020Q1, for example, the effect of the floor level, the number of floors in the building, the availability of an elevator, the distance to the city center, and the distance to the nearest job center, university, government building, and water reservoir changed the most. Empirical findings such as these support our hypothesis that the COVID-19 outbreak has affected the residential rental market in multiple ways.

An assessment of the sum of the absolute values of the differences in the mean parameter values (SAVMP) between 2020Q2 and 2020Q1 (Table 1), implies that COVID-19 had an immediate impact on the rental market, which echoes previous theoretical and empirical research (e.g., Kholodilin, 2020; Maalsen et al., 2020; Trojanek et al., 2021). SAVMP reaches its maximum value in 2020Q4, suggesting that the marginal prices changed most strongly in 2020Q4 compared to the pre-pandemic period. This may be related to the second COVID-19 wave in Poland and the related much tighter restrictions imposed by the government during the second wave compared to the first. In addition, the SAVMPs across all periods suggest that the changes triggered by the pandemic in the marginal prices in Cracow's rental market are not diminishing. This result confirms Tomal and Marona (2021), who forecasted that residential rents in Cracow will not return to pre-pandemic levels until 2022.

It was not only the relevance of rental price-determining factors that shifted over time; to some extent, so too did the directions of influence on rents. Considering each group of independent variables, the most striking changes concerned distance to the city center, distance to the nearest university, and number of floors in the building (Figure 2). As shown in Figure 2(a), the change of influence of distance to the nearest university covariate was upward and linear, and at the end of period 2021Q1 this regressor was no longer among the residential amenities. We speculate that this is due to the outflow of students from urban areas, including from Cracow, as a consequence of the pandemic (Mok et al., 2021), and therefore proximity to the university was not a locational asset driving up rental prices. A rather similar behavior can be observed for distance to the city center

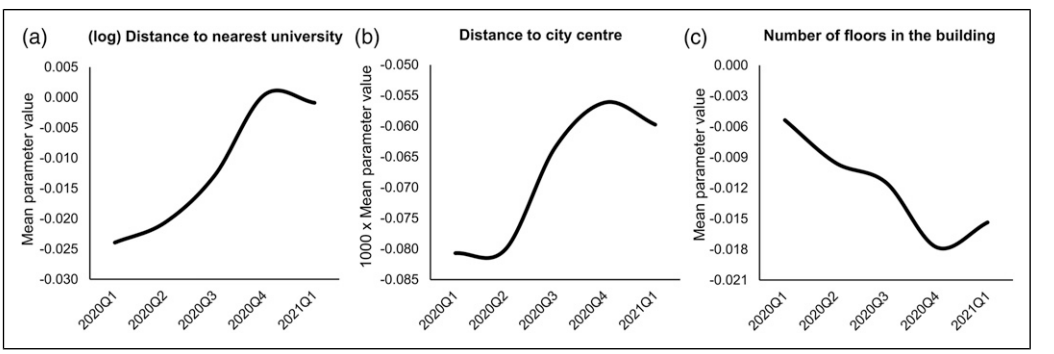

Figure 2. Mean marginal prices of the GTWR over time for (a) the logged distance to nearest university, (b) the distance to city center, and (c) the number of floors in the building.

(Figure 2(b)). In Cracow's city center, there are several facilities whose employees have switched to remote working modes. As a consequence, people who frequently changed their place of work in a given company as well as potential new employees may work remotely and thus reduce the demand for rental apartments close to the city center. In the context of the number of floors in the building variable, the change in marginal prices between periods was also linear but downward (Figure 2(c)). As the pandemic unfolded, the presence of a dwelling in larger apartment blocks began to lower rents considerably, presumably because potential tenants do not want to live in densely populated apartment blocks, putting them at risk for a COVID-19 infection.

Next, we assessed the extent to which the GTWR parameter estimates were spatially nonstationary over time. In general, only 6 of the 21 independent variables showed significant spatial variation in all periods (Table 1). Of similar interest, is that also the number of covariates showing significant spatial nonstationarity changed before and during the pandemic (Supplementary Table S3). In particular, only seven regressors varied across space in 2020Q1, while there were 12–18 in the other periods. This indicates how much of a shock the COVID-19 pandemic was and still is for the rental market. Since the pandemic outbreak increased the number of residential characteristics for which their marginal prices show significant spatial variation, it can be tentatively assumed that this also resulted in an increase in the number of housing submarkets operating in Cracow.

Finally, we assessed the robustness of the GTWR model. As local modeling is sensitive (e.g., the GTWR bandwidth may be inflated) to areas with sparse observations (Mennis, 2006), we re-fitted the GTWR model after excluding those observations (N = 7,285) (Supplementary Figure S1). Moreover, in our sensitivity test we also assessed potentially nonlinear associations between the dependent variable and the covariate describing the floor on which the apartment is located by adding the square of this variable (Xiao et al., 2019). Supplementary Table S4 summarizes the results. There is no indication that either these spatial outliers or non-linearities affected the estimation results given in Table 1. These results suggest that our model covering the entire Cracow rental market is reliable.

Segmentation of Cracow's rental housing market and submarket stability assessment

PCA was then applied to reduce the dimensionality of the parameter point estimates and the correlations between them. The Kaiser criterion suggested 5 PCs per study period except in 2020Q3, when 6 PCs had an eigenvalue above 1 (Supplementary Table S5). The selected PCs per time period explain between 0.85 and 0.92 of the variance in the parameters obtained from GTWR. A similar result in terms of the level of cumulative variance was obtained elsewhere (Bourassa et al., 1999; Helbich et al., 2013).

In order to segment Cracow's rental housing market into submarkets, we applied the full-order-CLK method. The choice of the exact number of clusters was based on minimizing the AIC score of the hedonic regressions in which we included the clusters as fixed effects (Supplementary Table S6). The number of submarkets delimited through Voronoi polygons oscillated over time between 11 and 20. This result for Cracow is in line with that for the Polish capital, Warsaw (Kopczewska and Ćwiakowski, 2021). In the period before the pandemic outbreak, we found only 11 submarkets, which corresponds well with the GTWR estimates indicating only minor spatial heterogeneity in the marginal prices of housing attributes during this period. In contrast, after the outbreak, the number of submarkets increased to 15, 20, 16, and 19 in subsequent quarters. Figure 3(a) and (b) present the submarket segmentation of Cracow. The closer to the city center, the more submarkets were found while their spatial extent decreased. This pattern has also been recognized in other analyses (e.g., Wu and Sharma, 2012; Wu et al., 2018) and is related to the higher density of housing stock in urban centers. Our obtained spatial distribution of submarkets is in line with the general spatial

characteristics of the city of Cracow, whereas the eastern part of the city remains undeveloped for residential housing and includes mainly agricultural and industrial areas (Dale-Johnson and Jan Brzeski, 2001).

Moreover, Figure 3(c) and (d) support the finding that the submarkets are markedly different concerning average residential rental prices. As expected—and in line with Cracow-specific findings (e.g., Tomal, 2020) and those related to other cities (e.g., Crespo and Grêt-Regamey, 2013)—submarkets located in or close to the city center show significantly higher rents than those on the periphery. Such an elevated rent level in Cracow city center is a result of better access to housing amenities (Ziobro, 2018).

When assessing the implications of the COVID-19 pandemic on the rent levels in the submarkets, we observed a decline in average rental prices within the submarkets by several Polish zloty (PLN)[2] per square meter (Figure 3(c) and (d)). These findings are consistent with Tomal and Marona (2021) for Cracow and Trojanek et al. (2021) for Warsaw; however, they contradict those reported by Kadi et al. (2020), who examined short-term rentals for selected Austrian cities. Therefore, our results suggest that the more developed a rental housing market (like in Austria), the greater its resilience to various economic shocks, as proposed by Rubaszek and Rubio (2020).

The decline in rental prices in Poland may be related to the following factors. First, as a result of the COVID-19 pandemic, there has been a negative shock in the labor market, which greatly affects the level of rents in Poland (Tomal and Marona, 2021). In Cracow alone, the unemployment rate increased by 1.3 percentage points between 2020Q1 and 2021Q1 (Cracow Provincial Labor Office, 2021). Second, a likely factor is the influx of short-term rented apartments, mainly from Airbnb (Trojanek et al., 2021), into the long-term rental market, which increases supply in this market and

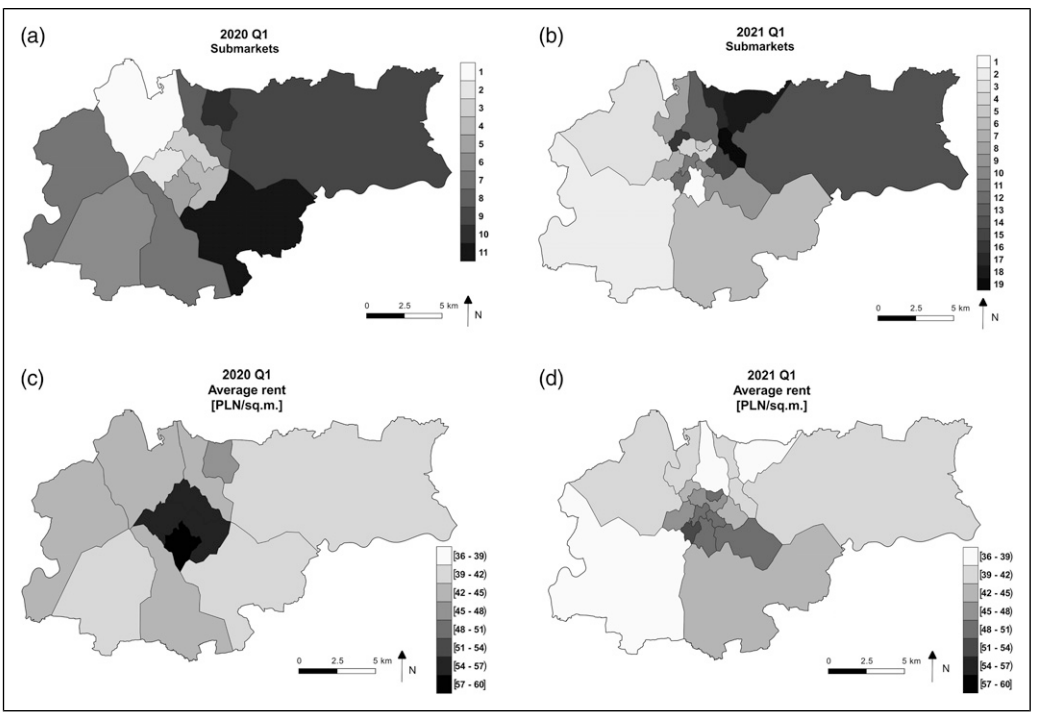

Figure 3. Segmentation of Cracow's rental housing market (a) before the COVID-19 pandemic, and (b) 1 year after as well as average rent level within the submarkets (c) before the COVID-19 pandemic, and (d) 1 year after.

reduces prices. Third, the monetary policy of the state may also play a role: Since 2020Q2, interest rates in Poland have been at a record low level (<1%), which, accompanied by high inflation, increases the scale of investments in residential real estate. A significant part of the latter is assigned for long-term rental, which increases the supply on the residential lease market and at the same time leads to a decrease in rental prices.

The results of our final robustness checks concerning the spatial stability of the identified submarkets over time are summarized in Supplementary Table S7. First, confirming the GTWR estimates, we found that the impact of the COVID-19 pandemic on the stability of Cracow's residential submarkets was immediate, as indicated by the ARI value of 0.74 for the segmentations representing the first and second quarters of 2020. Second, as also suggested by our GTWR results, the impact of the pandemic on the spatial structure of submarkets did not diminish, but remained constant. The ARI values between 2020Q1 and subsequent periods do not converge to 1, but remain around 0.70 (Supplementary Table S7).

Conclusions

Main findings

This study was the first to assess the impacts of the COVID-19 pandemic on the formation of submarkets in the residential rental market in Cracow, Poland. Use of a newly developed data-driven approach to segmenting the market under investigation into submarkets led to the following conclusions. First, the COVID-19 pandemic significantly lowered rents across the entire city of Cracow. Second, the pandemic outbreak modified the relevance of rent-determining factors in the studied market. Among others, the outflow of students from Cracow's residential rental market had a pronounced effect on rental price valuations. In particular, before the pandemic, proximity to the university was a central amenity, while a year after the start of the pandemic, the opposite was the case. In addition, the influence of proximity to the city center on rent levels weakened considerably, which can be linked to the remote working of many employees and the decline in city tourism. Also, after the pandemic outbreak, the presence of a dwelling in a large residential facility began to significantly lower rents. This may be due to the reduced demand for this type of unit caused by potential tenants' fear of living in large concentrations of people, which may increase the COVID-19 infection risk. Third, COVID-19 led to an increase in the number of residential submarkets, especially in the city center. The results also revealed that the pandemic's impact on the market is not abating and that all the identified changes are ongoing, which may be due to the pandemic restrictions that are still in place in Poland.

Study limitations and future research directions

This study had some limitations. First, due to the lack of information on transaction rents, only the supply side of the residential rental market was analyzed. Second, while our hedonic model was adjusted for numerous factors, it did not include, for example, factors describing the building quality; thus, we cannot exclude that the absence of such data affected our results. Third, we assumed that all covariates operate on a similar spatial scale. However, it could be that some may operate on different scales and thus may be better captured through individual covariate-specific bandwidths. Future work examining spatiotemporal submarkets may apply multiscale GTWR (Wu et al., 2019; Zhang et al., 2021).

Implications for practice and policy

Our findings have implications for both practice and policy. For example, they inform landlords who, based on information about changed housing preferences in the wake of the COVID-19 pandemic, can adjust their investment strategy accordingly. In addition, knowledge of currently existing submarkets is central if real estate valuers are to achieve more accurate appraisals. This analysis is also useful for local policymakers, who can conduct better housing policy as well as monitor the market in Cracow more effectively, especially in the context of significant fluctuations in the housing market triggered by the coronavirus pandemic.

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Supplemental Material

Supplemental material for this article is available online.

Notes

1. The first case of COVID-19 was reported in Poland on 4 March 2020.
2. On 14 April 2021 PLN 1 was equal to EUR 0.22. The exact magnitude of the decline in rental prices across the Cracow districts is given in Supplementary Figure S2.

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