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ARTICLE

Do 5G cell phone towers decrease house prices? Evidence from Warsaw

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Abstract

This study investigates the impact of telecommunication infrastructure on residential property prices in Poland. This study contributes to the discussion of economic externalities related to new public infrastructure within the urban landscape. We use hedonic regression, matching techniques, and a difference-in-differences estimator to assess the impact of base transceiver stations on apartment prices in Warsaw, the capital of Poland, which covered market data on the sales of residential premises located in Miasteczko Wilanów estate in Warsaw from 2016 to 2021. In the analysed period, 1,825 residential sales were recorded and used for econometric modelling. The results do not confirm the influence of the vicinity of the wireless communication technology infrastructure on residential real estate prices in the studied local market. In particular, we did not observe a detrimental effect of cell phone towers on housing prices. Additionally, we investigate whether residential sale prices in proximity to BTS changed significantly after the introduction of the 5G standard. This particular issue has not been addressed in the economic literature. We found that the sale prices of apartments located in Warsaw were not statistically affected by the introduction of a fifth-generation technology standard for broadband cellular networks. Our research contributes to a better understanding of stigmatisation effects related to telecommunication infrastructure, and in particular, the links between the presence of cell phone towers and residential property values in the neighbourhood. The results may be of interest to all potential agents involved in neighbourhood conflicts arising from investments in cell phone towers and the development of new communication infrastructure in urban landscapes.

Highlights

- The proximity of the base transceiver stations does not significantly affect the transaction prices.
- The introduction of 5G technology did not have a significant effect on residential property prices near cell phone towers.
- These findings contribute to a better understanding of the complex interplay between urban development, community conflicts, and housing prices.

Keywords Housing prices · BTS · Cell phone towers · 5G · Warsaw · Externalities

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1 Introduction

The economic literature has discussed the externalities generated by cell phone towers since the 1990s. The recent development of a new generation of wireless infrastructure has drawn public attention to this problem and has raised both health and socio-economic concerns.

The objectives of the paper are twofold. Firstly, we investigate the impact of cell phone towers on residential property prices in Poland. There is already a substantial body of research that suggests the housing price effects of cell towers are mostly negative but moderate and the effect is weaker when telecommunication antennas blend into urban landscape. Our paper builds on prior research providing new evidence from Central and Eastern Europe, where the impact of cell phone towers on residential property prices has not been investigated before. The attitudes toward new technologies may evolve and are not universal, therefore the results from Poland may differ from those observed in previous studies.

The novelty of the study lies not only in the fact that it is the first study of its kind in this part of Europe but above all in extending the context of the study to include the new 5G technology, which has caused much controversy, conspiracy theories and protests in many cities around the world. The second goal of our research is to investigate whether residential sale prices in proximity to BTS changed significantly after the introduction of the 5G standard. This particular issue has not been addressed in the economic literature. To our best knowledge, it is first study that considers the impact of the introduction of 5G infrastructure on house prices.

Contribution of our research is straightforward. This study fills the gap in the knowledge on the housing market reaction to the introduction of the fifth-generation technology standard for broadband cellular networks. The research has serious policy implications. We contribute to the ongoing debate about the potential negative effects of wireless communication infrastructure on house prices. The results may be of interest to policy makers and other stakeholders investing in telecommunication infrastructure. The major empirical findings may also useful to housing market participants and homeowners concerned about the impact of cell phone towers on property value.

The paper is organized as follows. In Sect. 2 we present the results from the systematic literature review. Based on the literature analysis, we discuss the results from previous studies conducted in the United States, New Zealand, Germany, Australia and Switzerland. In Sect. 3 we introduce the study area, describe the housing transaction dataset and present the econometric methods used in the empirical part of the paper. Section 4 focuses on empirical findings. We present estimation results from a selection of hedonic regression models matching and difference-in-difference estimators used to evaluate the impact of BTS proximity on house prices in Warsaw. We comment on major findings and compare them with existing literature. In the Conclusion section, we present the overview of the results and comment on the novelty of our research.

2 Literature review

2.1 Systematic review methodology

To achieve research goals we identified relevant studies using the main scientific bibliographic databases in the field of economic and social studies - Scopus and Web of Science.

Searches in English-language databases used the following terms to identify the empirical research in question: cellular phone base station, wireless telecommunication tower, cell phone tower, communication tower, and communication antenna. To narrow down the search result in the context of the impact on real estate prices, the following phrase was added to the key: property, house, and real estate prices.

The search algorithm allowed the selection of a preliminary list of studies on base transceiver stations in the context of real estate prices. Only studies published in English were included in this meta-analysis. Not all studies contain empirical results assessing the impact of base station proximity on property prices in the vicinity. Based on this review, only scientific articles relevant to the purpose of the study were included in the next stage. Some indexed studies were inaccessible; therefore, they were excluded from the comparisons (one study). Based on the systematic analysis of the identified articles' bibliography and the analysis of the works citing their results, four items were added that were not indexed in the WoS or Scopus databases but contained results valuable for the analysis objectives. Due to the research subject, in the second step, the search was extended to industry publications unindexed in the main bibliographic databases. This primarily concerns publications related to real estate appraisals. These items were added based on the analysis referred to in other literature articles, but also by including other industry literature databases (e.g. Proquest). As a result of a systematic review, 13 empirical studies were identified that directly assessed the impact of base transceiver stations on real estate prices. All the properties in question were residential (most often single-family houses, but also premises in multifamily buildings).

2.2 Literature review findings

One of the first articles that pointed to the problem of the potential negative impact of wireless towers on property prices was a review article by C. McDonough in the Assessment Journal (McDonough, 2003). The author pointed out that transceiver stations are undesirable in the neighbourhood and therefore adversely affect the value of the nearby real estate. However, the study does not contain specific values and is not based on empirical data. The author compares mobile towers to power lines and suggests that the effect may depend on the type and size of the station (mainly its aesthetic value).

The first empirical study of the impact of cellular phone base stations (CPBS) on neighbouring property prices was carried out in New Zealand (Bond, 2007a). The research covered transactions of the sale of residential properties in the suburbs of Christchurch in 1986–2002. The results show that real estate prices in the base station vicinity drop by about 15% after it is built, although they diminish with the distance from the site and disappear at a distance of approximately 300 m. The results indicated the effect of significant heterogeneity in individual neighbourhoods. This can be explained by their dissimilarity, as well as by media reports on specific cases of neighbourhood conflicts.

One of the first studies on the impact of transceiver stations on house prices was conducted in Florida in the United States (Bond, 2007b). The study included sales of 5,783 single-family homes in Northeast Orange County between 1990 and 2000. The research showed that after a cell phone tower had been erected, transaction prices for houses in its vicinity decreased by approximately 2%, with the effect occurring up to 200 m from the structure. The effect was statistically significant, but remarkably lower than that in previous New Zealand studies. Other studies in the United States used the resale methodology to analyse home transactions in Kentucky (Locke & Blomquist, 2016). The results suggest that the location of the antennas in residential buildings adversely affects the property value, although the impact is moderate. When the antennas were in the vicinity of the property (approximately 300 m), prices dropped by approximately. 1.8%. The authors suggest that the reduction in prices can be prevented by proper placement and shape of towers so that they are not overly visible. Contrary to the research presented earlier, there are results of analyses of over 11.6 million home transactions in California (McLaughlin & Witkowski, 2021), where a quasi-experimental scheme was applied (*difference-in-difference estimator*) to assess the impact of the base station location on real estate prices in near and distant surroundings. Research shows that the presence of a transceiver station has no significant consequences for property prices in its vicinity. The results were consistent and comparable across counties. The authors explain the differences with previous studies (which showed remarkable price reductions) by earlier analyses taking into account the old type of telecommunications towers, often placed in macro-sites. It should be noted that at present, only the abbreviated research report is available. This work has not been published in a peer-reviewed scientific journal.

Another critical empirical study was conducted in New Zealand, based on empirical data from the Auckland area (Filippova & Rehm, 2011). The research covered 55,775 sale transactions of residential real estate in the vicinity of 521 transceiver stations, including 3,168 transactions around base stations located in residential buildings. This study proves the detrimental impact of the base station's immediate vicinity on the prices of the surrounding residential real estate. The transaction prices for houses located within 50 m from the base station were approximately 2% lower than those for comparable properties not located in it (farther than 300 m from the tower). The article highlights that previous research did not consider two important factors influencing how market actors perceive base stations - (i) the base station location, and (ii) the location of the transmitter antenna (e.g. an armed monopole vs. a lamp post). The analysis results show that the base station's impact on house prices is significant only when it is visible and visually unattractive (such as an armed monopole). Interestingly, other research by the same authors conducted in Christchurch(Filippova & Rehm, 2014) did not confirm the negative impact of the immediate vicinity of base stations on housing prices. Moreover, this is true regardless of base station type. The authors explained that the topography and ubiquitous vegetation made the towers invisible and disturbed their view.

Research in Brisbane (Australia) on a sample of 411 home transactions shows that cell towers have a moderately negative impact on neighbouring property values (Rajapaksa et al., 2018). The adverse impact decreases with the distance from the base station, with the effect being especially noticeable up to 200 m from the tower. Contrary to other studies, Rajapaksa et al. (2018) suggest that the impact of base stations on property prices is independent of the tower type (appearance), which shows that buyers pay more attention to health issues than to visual aspects. However, the results of other studies in the United States lead to different conclusions (Affuso et al., 2018). Analysis based on transaction data suggests that cell towers have a moderate yet significant negative impact on house prices in their immediate vicinity. The effect is visibility-dependent and price drops are higher when the base station is high and visible. This finding was also confirmed by another recent study based on US data (Acharya et al., 2022).

Based on the research data from Zurich indicated that the presence of a base station can affect rental rates (Banfi et al., 2008). The results of the hedonic regression model estimation show that the vicinity of the base station (within 200 m) reduced the rental rate by approximately. 1.8% compared with the corresponding property not adjacent to the cell station. Other European studies conducted in Hamburg (Brandt & Maennig, 2012) confirmed the negative impact of base stations on real estate prices in the immediate vicinity (by approximately 5%), but only in the case of exposed towers with several antennas. The authors did not find a negative impact of the proximity of the single antennas and suggested that the antenna grouping strategy should be avoided to prevent conflicts with residents. Nuremberg's research confirms the negative impact of base stations on the offer prices of flats (Mense & Wirth, 2014). Properties in the immediate vicinity of transceiver stations are approximately 4% cheaper than those located further away from the tower. A negative impact was also observed in a recent study from South Africa (Cheruiyot et al., 2024).

In total, the analysed studies on real estate transactions were reviewed for the years 1986–2020, but most of the results are based on data from the 2000s (see Table 1). The studies were published between 2007 and 2021, and 10 out of 13 were published in the last decade. Most articles were published in renowned economic and urban journals. Some of the research was published in international periodicals specialising in real property appraisal (e.g. the Appraisal Journal) and the real property market (e.g. the International Journal of Housing Markets and Analysis). We have also included the results of a previously unpublished report (Witkowski & McLaughlin, 2021).

As can be seen from Table 1, most studies point to a negative, though moderate, impact of the base stations' vicinity on real estate prices. The effect size (the impact of base station proximity on real estate prices) ranges from 0 to -15%. Most studies show that the presence of a base station in a neighbourhood (with various definitions) lowers prices by 2%. Most frequently, research indicates that the effect applies to an area up to 200 m from the tower and then disappears. The visibility and type of an object are essential. Research suggests that highly visible telecommunication masts (conventional cell towers) have a larger negative impact on property prices in the neighbourhood. In the case of structures that blend in with the surroundings (camouflaged cell towers and microsites), the negative impact on the prices of neighbouring apartments is much lower or statistically insignificant. Interestingly, recent research suggests that the impact is now lower than that reported in historical research, which may be explained by a change in perception of technology and differences in the location and design of the transceivers themselves.

The analysis of the literature on the subject shows significant differences among empirical studies. Due to the relatively small number of studies that make it impossible to conduct a meta-analysis, a clear explanation of the role of individual differentiating factors obtained by particular empirical research results was obtained, which identified the main factors that may affect the observed effect size: (i) the geographical/cultural context; (ii) spatial context–city village; (iii) type of the transceiver station; and (iv) the scale of publicising the problem.

Table 1 Research on the base transceiver stations' impact on real estate prices

Research	Sample size	Spatial model	Repeat sales model	Quasi-experimental model	Results
(Bond, 2007a)	9 514	No	No	No	The presence of a base station in the neighbourhood* reduces the price by 15%
(Bond, 2007b)	5 783	No	No	No	The presence of a base station in the neighbourhood* reduces the price by 2%
(Banfi et al., 2008)	6 204	No	No	No	The presence of a base station in the neighbourhood* reduces the rent by 1,8%
(Filippova & Rehm, 2011)	55,775	No	No	No	The presence of a base station in the immediate vicinity* reduces the price by 2%
(Brandt & Maennig, 2012)	4,348	Yes	No	No	The presence of a group of antennas in the immediate vicinity** reduces prices by 5,2%. No effect for single antennas.
(Mense & Wirth, 2014)	1,694	Yes	No	Yes	The presence of a base station in the immediate vicinity** reduces the price by 4%
(Filippova & Rehm, 2014)	9,715	No	No	No	The presence of a base station in the neighbourhood * does not affect real estate prices
(Locke & Blomquist, 2016)	141,208	No	Yes	No	The presence of a base station in the neighbourhood* reduces the price by 1,8%
(Rajapaksa et al., 2018)	411	Yes	No	No	The presence of a base station in the neighbourhood* reduces the price by 15%
(Affuso et al., 2018)	23,309	Yes	No	No	The presence of a telecommunications mast in the neighbourhood reduces the price from 2.6 (invisible) to 9.8% (visible)
(Witkowski & McLaughlin, 2021)	11,684,458	Yes	No	Yes	The construction of the base station does not negatively affect real estate prices in the neighbourhood. An increase in real estate prices further away from the station has been noted
(Acharya et al., 2022)	nd.	Yes	No	No	Cell towers decrease house prices by 2%. Camouflage decreases the negative impact of cell towers on house values.
(Cheruiyot et al., 2024)	55,994	No	No	No	Cell towers decrease house prices in the neighbourhood

* immediate vicinity is a distance of up to 100 m from the object, the neighbourhood is a distance of up to 200 m from the object

First, the effect size depends on social and cultural attitudes towards technology (including mobile networks and 5G infrastructure). In some cultural areas, technologies may be more "familiar" so the presence of base stations will not trigger protests. It will also have no significant economic effects, such as a reduction in property prices in the neighbourhood. For the same reason, far-reaching conclusions cannot be drawn from research on the construction of the first cell towers in the late 1990s. Their structure was different from the current base stations, and in the meantime, societies had become partially accustomed to seeing them. For this reason, it is pointless to refer to the results of Western research in specific cases of such facility locations in Poland.

Second, the size of the effect depends on the urbanisation context. In cities, base stations are often invisible and are placed on the roofs of high-rise buildings (e.g. commercial and industrial). Third, in villages, the base stations are placed on towers, which makes them much more visible and exposed because of the topography and lack of obstacles.

Third, the research concerned various base stations - both single and similar to other objects–and very visible devices on high towers. However, these two cases could not be compared. Some of the research cited in the report concerned suburbs, where stations were placed on exposed towers. The negative impact of these properties on the prices of houses in the neighbourhood is usually higher than in similar cases. The research indicated that the effect of exposed stations located on high towers on real estate prices is stronger.

Fourth, the occurrence or absence of a decline in house prices in the vicinity of cell base stations can be explained in many ways. Certainly, one of the factors that must be taken into account is the problem of area stigmatisation, that is, the labelling of a fragment of the city space and its stereotypical perception by market participants. The actual harmfulness of the base station or aesthetics is of secondary importance. What predominates is the promulgation of the issue of cell station location and consolidation of the problem in public awareness. Stigmatisation processes in the context of urban areas have attracted the interest of urban planners, sociologists, and urban economists in recent years (Larsen & Delica, 2019; Wacquant et al., 2014). The effect of the media's role in the stigmatisation of related city areas has been thoroughly discussed in the literature on the subject (Arthurson et al., 2014; Jahiu & Cinnamon, 2021; Martin, 2000). One thread was the decline in real estate prices following the spatial stigma caused by objects generating negative external effects and media (Flynn et al., 2004; McCluskey & Rausser, 2003). Some studies on the impact of mobile antennas on real estate prices have highlighted the issue of media activity. The media message and publicising neighbourly conflicts resulting from the facility location causing adverse external effects may remarkably contribute to the enhancement of the stigmatisation effect on the environment, as well as to a significant drop in real estate prices in its vicinity (Bond, 2007a). In this context, it is worth noting that some empirical studies were inspired by well-identified and extensively discussed cases of building a transceiver network. It is unclear whether the results obtained for such cases are representative of the construction of cell base stations.

3 Methods and data

3.1 Econometric specification

This empirical investigation consisted of two steps. In the first step, we employed a hedonic pricing model to assess the impact of the base transceiver station (BTS) on residential property prices in the neighbourhood. Hedonic regression is a standard and widely used method to investigate the impact of various characteristics (Cellmer et al., 2024) on housing prices (Colwell & Dilmore, 1999). The theoretical framework of the hedonic method was developed by Lancaster (1966) and Rosen (1974). The essence of the hedonic method lies in the assumption that the price of any heterogeneous good (e.g. an apartment in our study) is a function of its attributes (both objective and subjective), which are evaluated by market participants. In this model, the dependent variable is the residential property sale or offer price (P), while the independent variables (X_i) are various property characteristics. In addition, hedonic price models control for time and contractual arrangements (conditions).

Housing is heterogeneous; therefore, a list of characteristics that affect offer or sale prices has often been discussed in the literature. There is a general consensus that housing attributes can be grouped into a certain number of broad categories. Some researchers suggest that the list of these categories may include (Malpezzi, 2002; Nelson & Rabianski, 1988): (1) locational (2) structural, (3) neighbourhood, and (4) environmental attributes. Although there is no consensus on the final selection of a set of attributes, in empirical research similar variables are typically used to control for housing quality (Sirmans et al., 2005, 2006). In our model, the regression equation takes the following general form:

$$lnP = \beta_o + \beta_i X_i + \gamma BTS + \epsilon \tag{1}$$

Where:

lnP - dependent variable (natural logarithm of transaction price).

X_i - independent variables (structural, locational and neighbourhood attributes of residential properties, as well as time and contract related controls).

BTS - a variable describing the exposure of a given residential property to a base transceiver station.

β_o - constant.

β_i- coefficients expressing the impact of the housing attributes on the sale price.

γ - coefficient expressing the impact of the proximity of a cell base station on real estate prices.

ε – error term.

Hedonic pricing models may have different functional forms including linear, semi-log, or more flexible Box-Cox (Cropper et al., 1988; Malpezzi, 2002). In this study, we adopt a semi-log functional form that has been widely used in previous research. Apart from being able to directly compare our results with those of previous studies, our choice has additional advantages. The estimated regression coefficients offer plausible economic interpretations, where unit changes in independent variables translate to percentage changes in prices (Sopranzetti, 2015). Additionally, the literature suggests that log-linear hedonic models are relatively robust to potential misspecification (omitted variable bias) and help reduce heteroscedasticity (Malpezzi, 2002).

To ensure a more robust estimation of the causal effects of cell phone towers on residential property prices, we apply the Coarsened Exact Matching (CEM) algorithm (Iacus et al., 2011). Matching estimators are widely applied in empirical housing research (Robinson & Sanderford, 2016) and allow us to reduce the imbalance in covariates between the residential properties in proximity to BTS (potentially affected by the presence of the mobile communication infrastructure, treated group) to relatively similar apartments that were not directly affected by the presence of BTS (control group). To match observations, we used the procedure developed by Blackwell et al. (2009).

In the second step, we addressed the controversies related to the launch of a new generation of wireless technology in a quasi-experimental setting. The reasons for conducting the natural experiment are straightforward. It is true that base transceiver stations have become part of the public infrastructure and are partially blended in urban landscapes. Nonetheless, recent studies show that acceptance of new waves of wireless communication (fifth-generation, 5G) is not universal, and anti-5G campaigns have emerged in many countries, mainly due to health-related anxiety and conspiracy theories (Flaherty et al., 2022), aesthetics (Cramer, 2021; Fu et al., 2022), environmental concerns (Zhang et al., 2023), and economic concerns (Qin, 2022). A recent Polish survey on perceptions and attitudes regarding electromagnetic radiation and new technologies revealed a relatively low acceptance of 5G infrastructure in the neighbourhood (*Postawy Polaków Wobec Pola Elektromagnetycznego Oraz Nowych Technologii*, 2021), especially in rural areas. The introduction of 5G technology and offering it in a certain number of BTS has been widely debated and protested against in Warsaw (kn, 2020; Tomaszkiewicz, 2019). Notably, similar debates were held in various countries throughout the world. Anti-5G protests, as well as acts of sabotage directed against BTS were observed in other European countries: UK (Satariano & Alba, 2020), Netherlands (Sterling, 2020), Switzerland (Newman, 2019). It is unclear whether public debate on 5G infrastructure has any detrimental effect on the willingness to accept BTS in the neighbourhood, especially in affluent communities in metropolitan areas, where wireless stations blend within the landscape.

We applied a quasi-experimental setting to investigate whether the launch of the fifth generation of wireless communication in Warsaw (introduced commercially in May 2020) had a significant impact on residential property prices in proximity to 5G BTS. To ensure robust causal inference from hedonic pricing models, we use a classic difference-in-differences (DiD) estimator, an approach that has gained substantial popularity in recent years (Baum-Snow & Ferreira, 2015). DiD is widely used to assess the impact of environmental changes or new infrastructure within the city landscape on housing prices (Ando et al., 2017; Fink & Stratmann, 2015; Gibbons & Machin, 2005; Trojanek & Gluszak, 2018).

We assess how the housing market responded to the introduction of a new generation of wireless communication standards, using the following cross-sectional DiD setting:

$$lnP = \beta_o + \beta_i X_i + \delta BTS_{5G} + \tau AFT + \phi \left(BTS_{5G} * AFT \right) + \epsilon \tag{2}$$

Where:

lnP - dependent variable (natural logarithm of transaction price).

X_i - independent variables (property attributes – structural and related to location and neighbourhood of the residential property).

BTS_{5G} is a treatment variable that indicates whether an apartment sold within the study period belongs to the treatment or control group. The treatment Group consisted of residential proximity within a 200 m radius from the 5G BTS, while the Control Group consisted of properties located outside the potential impact zone.

AFT is a variable that indicates whether the transaction occurred before or after the treatment - the introduction of 5G technology in Miasteczko Wilanow (May 2020).

τ and δ are regression coefficients that capture the effect of the introduction of 5G technologies treatment.

φ is a coefficient that allows us to assess the causal effect of the introduction of 5G on the sale prices of properties located in proximity to 5G BTS. It captures the average treatment effect in the treated (ATET) model.

Other abbreviations as in Eq. 1.

If negative values of φ were observed, the results would suggest the possible negative stigmatisation of the area around cell phone towers (perceived as a negative externality). If positive changes were observed, we would conclude that people perceive the new communication infrastructure as a positive amenity in the urban landscape, potentially due to an objective increase in Internet bandwidth and capacity in the area.

3.2 Empirical data

The report contains an empirical study assessing the impact of base stations (transceiver stations, BTS) on real estate prices. The study was carried out in a local market, including multi-family housing located in the southern part of Warsaw in the area of the so-called Miasteczko Wilanów. It is one of the largest post-communist urban development and housing projects in Central Europe. The construction of the project began in 2002 and later received the Urban Land Institute Award for Excellence in 2010. Miasteczko Wilanów covers an area of 169 ha and is home to over 25,000 residents. It was designed as a large cohesive settlement structure using the concept of a city within a city. This project offers mixed-use areas with diverse functions. It has an average floor area ratio of 1.4 and a residential density of 11,000 inhabitants per square kilometre. Sociodemographic characteristics included a relatively low crime rate and a high birth rate. We believe that the study area is prototypical of large-scale post-socialist urban development in major Polish cities.

The analysis covered market data on the sales of residential properties located in the study area for the period 2016–2021. During the analysis period, 1,825 residential premises transactions were recorded (1).

The dependent variable is the natural logarithm of the apartment sale price in the PLN. The semi-log specification is widely used in hedonic pricing models for several reasons.

To investigate the effect of exposure to BTS on residential sale prices in a robust and consistent manner, we use different econometric specifications. Prior research usually assumed that the potential impact of BTS on real estate prices is a function of distance. Generally, the impact diminishes with distance. In the literature, this relationship has been described by the concept of distance decay. In addition, the results of empirical research thus far clearly show that the base station can only affect real estate prices in the close vicinity; for practical reasons, it can be assumed that at a certain threshold distance (for example, 200 m), the influence is no longer relevant. In the empirical section, we use three alternative measures of exposure to BTS:

1) A qualitative (dichotomous) variable BTS_Prox takes the value of 1 in the case of close proximity to BTS and 0 otherwise. For example, a BTS_Prox feature value of 1 is assigned to all properties within a radius of 200 from the BTS. A property located 122 m in a straight line from the base station will have BTS = 1, and one 213 m away will have BTS = 0.
2) The quantitative variable BTS_Num measures the absolute number of BTS located within a 200 m radius from a given apartment. If an apartment is located further than 200 m from the nearest BTS, BTS_Num takes a value of 0.
3) The quantitative variable BTS_Dist is the objective distance in a straight line from BTS. A property located 322 m in a straight line from the base station will have BTS = 0.322, and one 1213 m away will have BTS = 1.213.

Additionally, we controlled for other salient characteristics of the apartments. We used three variables that allowed us to control for neighbourhood and environmental effects – (Bus)

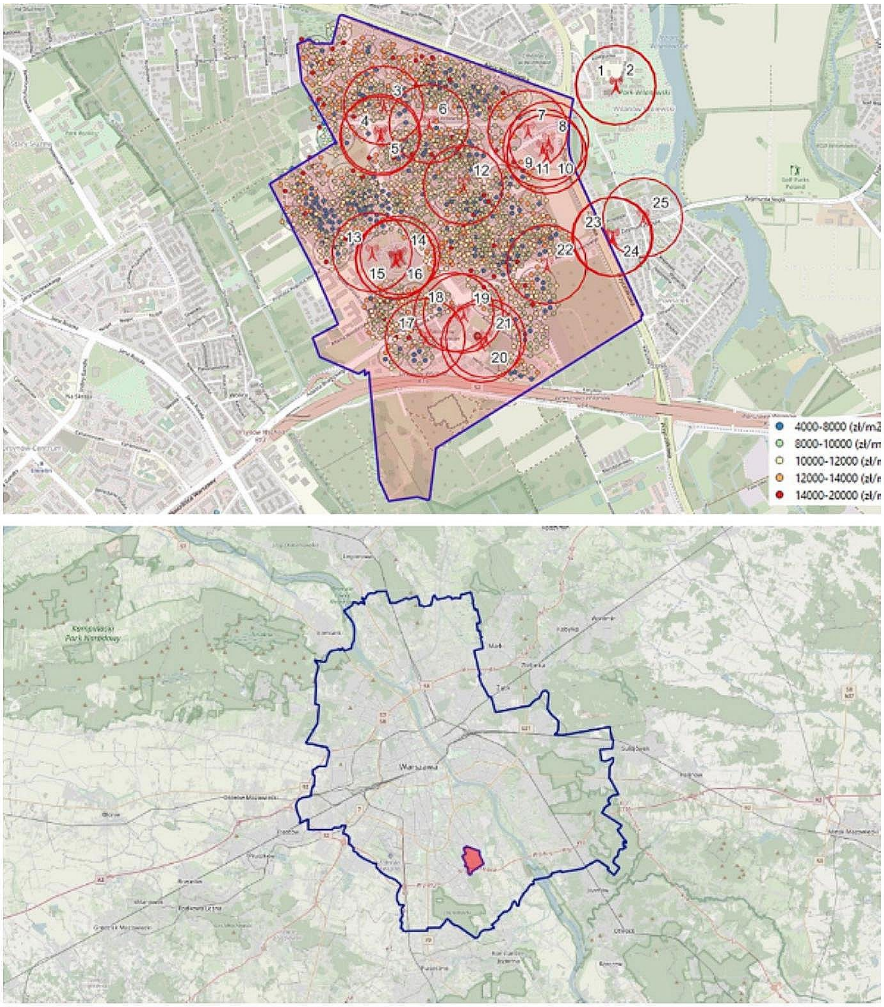

Fig. 1 Study area. The figure presents the location of the study area in Warsaw (upper panel) as well as the detailed location of each sale relative to the existing BTS (lower panel)

the distance to a bus stop (a proxy for accessibility to urban public transport), (School) distance to school (accessibility to educational infrastructure), and (Noise) road noise level–in order to separate quiet neighbourhoods and noisy neighbourhoods. We also controlled for a limited number of structural characteristics of the apartments (area, floor, and rooms). We accounted for the time when transactions occurred (using Time_k dummies) and the contractual arrangements (Trans_C). The selection of the independent variables is presented in the table (Table 2).

The adopted variables are, on the one hand, consistent with those used in other studies – and reflected structural, neighbourhood and location amenities (see Malpezzi, 2002). However, they cover a range of factors that are intuitively seen as factors that affect the sale

Table 2 Descriptive statistics (N=1825)

Abbreviation	Category	Measurement	Mean	SD	Min	Max
Price	DV	Apartment's transaction price in PLN (Natural logarithm)	717,799.3 (13.39)	341,466.5 (0.41)	215,000 (12.28)	2,900,000 (14.88)
BTS_Prox	IV (N)	Proximity to BTS. 1 if the apartment being sold was located within a 200 m radius from BTS and 0 otherwise	0.48	0.50	0	1
BTS_Dist	IV (N)	Linear distance to the nearest elementary school (in 100 m)	2.13	0.87	0.29	4.98
BTS_Num	IV (N)	Number of BTSs in proximity (within a 200 m radius from the apartment being sold)	0.69	0.92	0	5
BTS_5G	IV (N)	Proximity to 5G BTS. 1 if the apartment being sold was located within a 200 m radius from 5G BTS and 0 otherwise	0.28	0.45	0	1
School	IV (N)	Linear distance to the nearest elementary school (in 100 m)	5.94	2.50	0.59	10.78
Bus	IV (N)	Linear distance to the nearest public transport stop (in 100 m)	2.25	1.18	0.22	5.01
Noise	IV (E)	Road noise measured in interval brackets (less than 55 dB – 1, 55–60 dB 2, 60–65 dB – 3, 65–70 dB – 4)	3.39	0.86	1	4
Area	IV (S)	Apartment's usable area in m^2 (Natural logarithm)	71.13 (4.19)	29.43 (0.38)	26.09 (3.26)	287.94 (5.66)
Rooms	IV (S)	Number of rooms in the apartment	2.91	1.06	1	7
$Floor_i$	IV (S)	Location on floor. Dummy variables that take a value of 1 if the apartment was located at a given floor and 0 otherwise ($Floor_1$ -ground floor, base category omitted in regression models, $Floor_2$ – other floors; $Floor_3$ – first and second floor).	$Floor_1$ (318 obs.), $Floor_2$ (874), $Floor_3$ (633)			
Trans_C	IV (c)	The transaction involves a corporate participant. 1 when either buyer or seller is not a private person (household). 0 otherwise	0.07	0.26	0	1
$Time_k$	IV (t)	Time dummy variables taking a value of 1 if a transaction occurred in a given quarter within the study period (from 2016Q1 to 2021Q2)	2016q1 (40 obs.); 2016q2 (58); 2016q3 (74); 2016q4 (42); 2017q1 (50); 2017q2 (74); 2017q3 (87); 2017q4; (77); 2018q1 (74); 2018q2 (88); 2018q3 (95); 2018q4 (110); 2019q1 (91); 2019q2 (114); 2019q3 (124); 2019q4 (114); 2020q1 (101); 2020q2 (64); 2020q3 (104); 2020q4 (111); 2021q1 (107); 2021q2 (26)			

Note DV=dependent variable; IV=independent variable; N=neighbourhood attribute; S=structural attribute; E=environmental attribute; c=contract-related control variable; t=time-related control variable prices of residential properties. However, we acknowledge the risk that we cannot account for all salient characteristics that may affect housing prices. The unobserved heterogeneity in housing quality is a major problem in hedonic price modelling (Bajari et al., 2012; Francke & Van de Minne, 2021; Osland, 2013), but to our defence, we were restricted by data availability. We did not have access to information on apartment interior design, technical condition, aspect, or view from the window. The housing stock in Miasteczko Wilanow is relatively homogenous in terms of building height, architectural design, building construction technology, overall quality, and age (construction started in 2002). We believe that despite not directly controlling for other neighbourhood quality features, there are no substantial unobserved differences within the study area.

4 Results and discussion

4.1 Hedonic regression and matching estimators

To perform a comprehensive inference, calculations were performed for six models in the two groups (Table 3). The first three (Mod. 1 - Mod. 3) are baseline hedonic regression models based on all transactions within the sample ($N=1825$). The remaining models (Mod. 4 - Mod. 6) use the matching transaction data. We applied the Coarsened Exact Matching (CEM) algorithm(Iacus et al., 2011) to match residential units in proximity to BTS (treated group) to relatively similar apartments that were not directly affected by the presence of BTS (control group). The sample size in these models was small ($N=834$). Within each group, we used different measures of exposure to BTS, as described in detail in the previous section. In particular, we control for the presence of BTS using a binary proximity measure (BTS_Prox), linear distance (BTS_Dist), and number of BTS in proximity to the property (BTS_Num).

We use a log-linear specification; thus, the natural logarithm of the sale price is a dependent variable (Price). Table 3 presents the estimation results.

The R^2 coefficients obtained from the hedonic regression models range from 0.883 for the baseline models (Mod. 1- Mod. 3) to 0.875 for the CEM matching. The models exhibited a relatively good fit with the empirical data. All models show price growth in the subsequent years of the analysis, which we controlled for using quarterly fixed effects time dummies.

Generally, the coefficients estimated for the statistically significant variables have intuitive (logical) signs. Along with expectations, the area is positively linked with sale prices; bigger apartments are more expensive, and others remain equal. The estimated price elasticities (0.88–0.92) have an intuitive economic interpretation that is also consistent with the law of diminishing marginal utility derived from an increase in apartment size. The number of rooms did not have a statistically significant effect on apartment sale prices after controlling for the usable area.

A similar interpretation applies to the $Floor_i$ variables (the story where the apartment was located). There was a significant discount related to the location on the ground floor (baseline category) compared with the other floors. Other floors remained equal, whereas the sale prices were significantly higher in the case of apartments located on the first or second floor ($Floor_3$). Street noise (Noise) did not have a significant impact on property prices within our sample, potentially because it was not seen as a crucial factor differentiating properties.

Table 3 Hedonic regression models. The dependent variable is the natural logarithm of the sales price

Variables	Mod. 1	Mod. 2	Mod. 3	Mod. 4	Mod. 5	Mod. 6
BTS_Prox	0.014*			-0.001		
	(0.007)			(0.008)		
BTS_Dist		0.006			0.008	
		(0.004)			(0.005)	
BTS_Num			0.006			0.003
			(0.004)			(0.005)
Ln Area	0.913***	0.919***	0.912***	0.882***	0.886***	0.880***
	(0.017)	(0.017)	(0.017)	(0.023)	(0.023)	(0.023)
Rooms	0.008	0.006	0.008	0.011	0.010	0.011
	(0.006)	(0.006)	(0.006)	(0.008)	(0.008)	(0.008)
$Floor_2$	0.014	0.015	0.014	-0.007	-0.007	-0.007
	(0.009)	(0.009)	(0.009)	(0.013)	(0.013)	(0.013)
$Floor_3$	0.076***	0.077***	0.076***	0.037**	0.037**	0.037**
	(0.010)	(0.010)	(0.010)	(0.013)	(0.013)	(0.013)
Noise	0.000	-0.001	-0.000	-0.006	-0.006	-0.006
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)
School	-0.006***	-0.005***	-0.006***	-0.006***	-0.006**	-0.006**
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
Bus	0.010***	0.009**	0.011***	0.013***	0.011**	0.013***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
Trans_C	-0.097***	-0.097***	-0.097***	-0.039*	-0.039*	-0.040*
	(0.013)	(0.013)	(0.013)	(0.018)	(0.018)	(0.018)
Constant	9.302***	9.278***	9.307***	9.525***	9.496***	9.525***
	(0.062)	(0.064)	(0.062)	(0.084)	(0.086)	(0.084)
Time fixed-effects (Quarterly)	yes	yes	yes	yes	yes	yes
Matching (CEM)	no	no	no	yes	yes	yes
R-squared	0.883	0.883	0.883	0.875	0.875	0.875
Adj R-squared	0.881	0.881	0.881	0.870	0.870	0.870
AIC	-1935.767	-1933.516	-1933.813	-1153.1	-1155.791	-1153.508
BIC	-1764.977	-1762.727	-1763.024	-1006.586	-1009.277	-1006.995
N	1825	1825	1825	834	834	834

Note Standard errors are in parentheses. Statistical significance * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Distance from the closest school has negative impacts on apartment prices. The result is also intuitive; in general, the farther from the school, the lower the apartment price, and the other stay equal. However, we report that the positive coefficient for the bus variable – the increase in distance from the bus stop–is associated with an increase in apartment prices. This finding is somewhat surprising; however, the marginal increase in accessibility may be due to disturbances caused by the traffic associated with the operation of buses in this particular district. Additionally, in all models, we controlled for parties involved in apartment sales (Trans_C). We observed that transaction prices, where either a buyer or seller was a business organisation, were significantly lower than in the case of scale between private market participants, while others remained equal. One potential explanation is that, on the one hand, companies are less likely to be anchored by unrealistic offer prices compared to private market participants when selling real estate. However, when buying apartments, corporate buyers may be more rational and not guided by emotions. The results were statistically significant for all specifications.

In summary, taking into account the economic interpretation of the results obtained for the control variables, both the coefficients' signs and values are fairly consistent with the knowledge of the particular factors' impact on real estate prices. Generally, it should also be noted that the results obtained for the control variables are consistent and stable for all specifications used, as they are not always statistically significant.

The most relevant estimates were related to the BTS (BTS_Prox, BTS_Dist, and BTS_Num). The signs of the coefficient do not necessarily align with a priori expectations based on results from previous studies and widespread public beliefs. Nonetheless, both of these variables proved to be statistically significant. In the case of proximity to BTS (BTS_Prox, which was used in Mods 1 and 4), the coefficient was positive (0.004), which is counterintuitive. If statistically significant, the results would suggest that apartments located within a 200 m radius from the BTS were generally more expensive. Paradoxically, and more in line with expectations, the coefficient is also positive in the case of distance from BTS (BTS_Dist) (Mod 2 and Mod 5), and the number of BTS within the 200 m radius from the apartment (BTS_Num) variables that were used in alternative specifications. The results are mixed, but due to the lack of statistical significance, they are not conclusive.

4.2 Difference in differences estimator

We used differences-in-differences regression (DID) to assess the causal effect of the introduction of 5G technology in May 2020 and compared the transaction prices of residential properties in proximity to BTS with 5G antennas (treatment group) to the sales prices of comparable housing units not affected by the event (control group). In line with the empirical specifications used in hedonic regression models, we control for the presence of BTS using a binary proximity measure (BTS_Prox), linear distance (BTS_Dist), and the number of BTS in proximity to the property (BTS_Num). The estimation results of the three DiD models (Mod. 7 - Mod. 9) are listed in Table 4.

DiD is reasonably well suited to empirical data. Additionally, we tested the parallel-trend assumption. Based on the test results ($Prob > F = 0.073$), we could not reject the null hypothesis that the linear trends were parallel in the pretreatment period. Additionally, based on the Granger causality test, we note that anticipation of treatment had no effect ($Prob > F = 0.1425$).

We used the Average Treatment Effect on the Treated (ATET) to assess the causal effect. ATET coefficients (ranging from −0.022 to -0.021) were not statistically significant in any specification. We conclude that the introduction of 5G technology did not have a significant effect on residential property prices in the study area. We note that there is no solid support for the claim that sale prices dropped significantly in the vicinity of those BTS that offered 5G signals. This effect is presented graphically in Fig. 2.

Telecommunication infrastructure cannot create in my back yard (NIMBY) opposition of residents living in proximity. Wireless communication infrastructure, similar to other similar developments related to conflicting land uses, may generate neighbourhood conflicts due to the potential stigmatisation of the area or subjective assessment of environmental and health risks by the local community (Bennett & Davies, 2015; Llurdés et al., 2003; Mei et al., 2021). These concerns often manifest as decreases in house values in neighbourhoods.

Table 4 Difference-in-differences regression models. The dependent variable is a natural logarithm of the sale price

Variables	Mod. 7		Mod. 8		Mod. 9	
ATET	-0.021	-0.022		-0.022		-0.021
Treatment (BTS_5G*after)	(0.005)	(0.004)		(0.005)		(0.005)
BTS_Prox	0.026					
	(0.005)					
BTS_Dist			0.010			
			(0.011)			
BTS_Num					0.014	
					(0.012)	
Ln Area	0.919*		0.916*		0.915*	
	(0.019)		(0.015)		(0.020)	
Rooms	0.007		0.007		0.007	
	(0.009)		(0.008)		(0.009)	
$Floor_2$	0.015		0.015		0.014	
	(0.004)		(0.005)		(0.005)	
$Floor_3$	0.077		0.077*		0.077	
	(0.007)		(0.005)		(0.006)	
Noise	-0.001		-0.001		-0.002	
	(0.003)		(0.003)		(0.003)	
School	-0.006*		-0.005		-0.006	
	(0.000)		(0.001)		(0.001)	
Bus	0.012		0.007		0.013	
	(0.006)		(0.006)		(0.005)	
Trans_C	-0.098*		-0.095*		-0.098*	
	(0.006)		(0.003)		(0.005)	
Constant	9.275**		9.278**		9.288**	
	(0.064)		(0.019)		(0.071)	
Time fixed-effects (Quarterly)	yes		yes		yes	
N	1825		1825		1825	

Note ATET estimates are adjusted for covariates, group effects, and time effects. Note: Standard errors are in parenthesis. Statistical significance * $p<0.05$, ** $p<0.01$, *** $p<0.001$

The results indicate that this was not the case for BTS in Miasteczko Wilanów, as we did not find significant evidence that prices were lower in proximity. The lack of an economic impact of BTS on apartment prices requires further comment, as has been observed in many prior studies, especially when neighbourhood conflicts were intense and extensively covered by the media (Bond, 2007a). First, the turbulent introduction of BTS has become a more acceptable part of urban and rural environments. In recent years, more people have used wireless technology and are reluctant to express negative emotional arousal when exposed to the presence of BTS. Many recent studies suggest that the negative impact of BTS is currently smaller than that during the early 2000s and is often not statistically significant (Witkowski & McLaughlin, 2021). Second, the technologies also changed significantly and blended more aesthetically into the city landscape. Currently, BTS are less visible and are often concealed. Other studies have suggested that the potential impact of BTS on house prices in the vicinity is significantly reduced when the disamenity is not directly visible (Affuso et al., 2018).

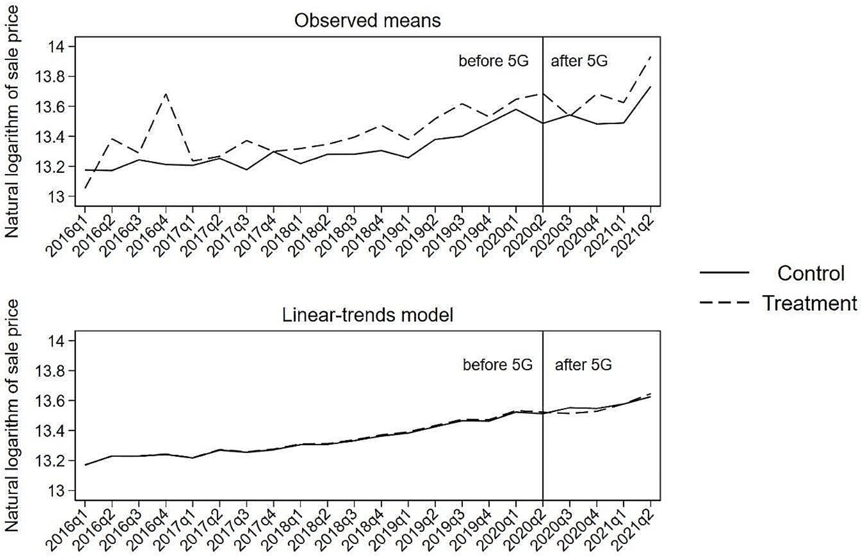

Fig. 2 Causal effect of the introduction of 5G in Miasteczko Wilanów

Our study had some limitations. First, it is unclear whether the results can be generalised to other rural and urban areas in Poland. Most likely, the results would be similar in major cities, where telecommunication infrastructure blends within urban landscapes and the majority of market participants are relatively unaware of their exact location, but different in rural and suburban areas where cell phone towers are less concealed. Extending empirical investigations beyond major cities to less urbanised areas seems to be a promising direction for future research. Second, despite our best efforts, we were unable to control for all relevant housing attributes. Unobserved heterogeneity may lead to biased estimation results, as suggested by econometric literature (Francke & Van de Minne, 2021). We attempted to reduce this risk by employing matching techniques and quasi-experimental settings. Finally, the fact that the proximity of BTS did not affect residential property prices, may be due to asymmetric information between buyers and sellers. Telecommunication infrastructure has blended into the urban landscape thus buyers are often not aware of the presence of BTS (Klaps et al., 2016). As a result, the information about the proximity of BTS may not be revealed in hedonic prices (Pope, 2008). It is worth extending the research to include stated preferences data, particularly in terms of buyers' attitudes towards 5G networks but also awareness that this infrastructure exists in the location where they live.

5 Conclusion

This article engages in a discussion on the perception of telecommunication infrastructure within an urban landscape. This research provides new evidence on how base transceiver stations (BTS) influence housing prices. This study aimed to determine the impact of the

BTS on housing estate prices using housing market data from the capital city of Poland (Warsaw). In the empirical part of this study, we analysed 1,825 housing sales from 2016 to 2021 using hedonic regression models and matching techniques. Additionally, the introduction of commercial 5G technology in Warsaw in May 2020 allowed us to investigate its potential impact on residential property prices near 5G infrastructure. A quasi-experimental difference-in-differences design was adopted.

The hedonic estimation results do not confirm the influence of the vicinity of wireless communication technology infrastructure (BTS stations) on residential real estate prices in the studied local markets. The proximity of the base stations does not significantly affect transaction prices. The research results are fairly consistent with those of the majority of empirical studies in recent years, which indicated a negative impact but also suggested that camouflaged cell towers have relatively weak effects on property prices. To some extent, it is not surprising that we have not observed the negative effect of cell phone towers on house prices in an urban area such as Warsaw, where base transceiver stations are concealed at the top of buildings and market actors are not fully aware of their presence.

On the other hand, contrary to prior research we were able to observe whether the widely discussed introduction of 5G technologies had a significant effect on the prices of residential properties located in the proximity of cell towers. We did not find any causal effect; thus we conclude that there is no empirical evidence of the negative impact of the introduction of 5G technologies on residential property prices near telecommunication infrastructure. These findings are in stark contrast to widespread beliefs and conspiracy theories spread by anti-5G protesters.

This study is pioneering in nature, as the economic literature lacks empirical studies on the impact of BTS on residential property prices in Central and Eastern Europe. In addition to insights into the impact of the proximity of cell phone infrastructure on house prices in cities, this study also sheds light on the influence of implementing 5G technology on property prices. To the best of our knowledge, this is one of the few studies that has tackled this issue using empirical data. These findings contribute to a better understanding of the complex interplays between infrastructure within the urban landscape, community conflicts, and property values.

Author contribution Bartłomiej Marona: Conceptualization, Software, Supervision, Data curation, Writing-Original draft preparation, Michał Głuszak: Visualization, Methodology, Investigation, Software, Radosław Gaca: Software, Validation, Methodology, Writing- Reviewing and Editing, Investigation.

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Data availability All data and materials were collected and compiled in an ethical manner. They do not violate the property of other individuals or institutions.

Declarations

Ethical approval The authors declare that the work was done independently and with the highest ethical standards.

Competing interests All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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