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A STUDY OF METRO'S INFLUENCE ON THE PRIMARY HOUSING MARKET IN WARSAW, POLAND

Abstract: Residential real estate prices vary significantly, being susceptible to numerous components. One of the most contributing factors is thought to be the proximity of an underground train (metro) station. Classically, the relationship between housing prices and distance to a metro station is measured by a hedonic model. This paper presents a new method to study such a relationship, and it is a new composite index – Metro Station Proximity Effect Estimator (MSPEE), which allows looking at differences between not only metro stations but also the city districts. The MSPEE index was calculated as a mean of a set of sub-indicators, assembled as variables determining the final value of the composite indicator. Through the MSPEE index as well as more traditional methods, the paper suggests and illustrates a generally strong negative correlation between the proximity of Metro and apartment prices. Moreover, the study lists and describes exceptions to the trend around Warsaw.

Key words: metro, housing prices, Metro Station Proximity Effect Estimator

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INTRODUCTION

Housing is one of the most important human needs; it provides physical and psychological security and is the basis for personal and professional development. It is also a rather specific good from the point of view of economics and the demand-supply relationship. First, it is an immobile good with high durability, but at the same time, it requires much money for its creation. Housing prices show great diversity and dynamics due to many factors. These can be divided into economic (raw material prices, construction costs, economic crises) and those related to the apartment itself, its location and surroundings. The influence of various factors on housing prices is a topic of interest for economists and economic geographers, among others. The latter group pays particular attention to the attributes of the space in which individual residential developments are located. Apart from the features of the apartment itself (finishing standard, size, furnishing), an important factor regulating the price of apartments will be the attractiveness of the space adjacent to a given development, and this depends on whether that space is provided with adequate infrastructure to satisfy the various needs of residents. These include green areas with an aesthetic and recreational function, shops and other services, educational institutions, and offices. Another key determinant of housing price is transportation accessibility. This accessibility can be understood through the possibility of free movement in terms of individual transport, but above all through the presence of convenient connections by public transport. The metro may be considered the most convenient means of transportation due to the speed of connection and travel convenience.

The important role played by the distance (proximity) of a metro station in shaping prices in the residential market is visible in two ways – in the sales offers of flats and advertising materials presenting the most important advantages of a given residential investment, including the proximity of a metro station. On the other hand, the relationship between housing prices and the presence or distance from a metro station has been the subject of research for several decades. Such research was undertaken as early as the 1970s by Damm, Lerman, Lerner-Lam, and Young, who identified the impact of a future subway line in Washington, D.C., on residential real estate prices even before the line opened (Damm, Lerman, Lerner-Lam, Young 1980).

The hedonic price model is most commonly used in this type of research (*e.g.*, Bae, Jun, and Parth 2003). What makes the study different is the timing of the survey in relation to the opening of the metro line and the type of data used. One study looks at changes in residential property prices before or during the opening of the metro area (Agostin, Palmucci 2008; Bae, Jun, Parth 2003). Lin and Hwang studied residential property prices before and after the opening of the subway line (Lin, Hwang 2004). Another group comprises studies that focus on residential property prices after the metro area has already opened (Bowes, Ihlanfeldt 2001; Efthymiou, Antoniou 2013). The second feature differentiating the research is the type of data used – some researchers use offer prices, while others use transaction prices of apartments (Torzewski 2016).

The urban rapid transport system exerts a considerable influence on the pattern of housing prices (Aytekin and Özdemir 2010). Studies that focus on analysing the impact of the metro's presence on residential property prices show unequivocally that these prices decrease with increasing distance from the metro (Agostin, Palmucci 2008; Gatzlaff, Smith 1993; Martinez, Viegas 2009; Sun, Wang 2015; Zhang, Jiang 2014). Empirical studies (Yiu and Wong 2005) show that improvements in transport infrastructure trigger an increase in housing prices. The correlation between the new transportation infrastructure and a rise in housing prices starts to be significant even before the completion of the construction. Following a study of Hong Kong, Yiu and Wong (2005) suggest that the proximity of transportation influences the investors' pricing decisions. Hewitt and Hewitt (2012) studied the effect of the proximity to urban rail transport (URT) stations in Ottawa. They found that: (i) URT has a macro-level positive effect on housing prices, and (ii) there are also other significant determinants of housing prices, often specific to certain locations, such as the distance from the Central Business

District (CBD), green infrastructure and other types of infrastructure affecting affluence and place desirability.

Furthermore, a recently conducted meta-analysis of twenty-three studies (Mohammad et al., 2013) found a varying, albeit almost invariably positive impact of rail projects on land and property values (mean 8% and median 5.4% increase). Therefore, it is highly apparent that rapid transport systems exert a substantial effect on the residential property prices in their vicinity.

Changes in housing prices depending on the presence and distance from the metro in different cities vary, which is a result of the fact that, as a rule, many factors influence the price of housing, not only the one related to transportation. The identified increase in housing prices is up to, for example, 8% for Santiago (Agostini, Palmucci 2008). In addition to indicating the percentage change in prices, studies also report the distance from the subway station at which such a change occurs – Zhang and Jiang (2014) demonstrated that housing prices generally change within 500 meters but observed a maximum distance of up to 2 km. Bae et al. (2003) in Seoul or Lin and Hwang (2004) in Taipei also found a relationship between residential property prices and the metro area, but these studies differ in the methods used and how the results are interpreted. In the first case, the presence of a metro has been shown to have a stronger effect on property price growth before the opening of the metro line, which is considered the so-called anticipatory effect (Torzewski 2016). It proves a stronger increase in apartment prices in locations with no metro before, thus emphasising the "novelty" effect. That shows that it is not the construction of another metro line that increases prices considerably but the appearance of the first metro line in a certain area. In the second case, the change in housing prices in the period after the metro line opening is proved, but it depends on the station's location.

There are few similar surveys of apartment prices in Poland because Warsaw is the only city with a metro system. Among similar studies performed in Poland, there is a spatial analysis of the factors mentioned by Hewitt and Hewitt (2012), which was performed in Warsaw by Widłak et al. (2015). Among conclusions, they provide an example of Wawer, a district located on the right Vistula bank, far from CBD, in which the long distance from the city centre and Metro stations causes a decrease in housing prices. They also underline compliance of their results with the monocentric city model. Trojanek and Gluszak (2017), meanwhile, used a set of apartment transactions for the years 2008–2015 in Warsaw. The hedonic method was used for data analysis, which follows the usual academia's practice. This study shows that the new Metro line (M2) in Warsaw influenced prices even before being built. Moreover, the work of Gadziński and Radzimski (2015), who interviewed inhabitants of Poznań, showed that 20 per cent of the citizens would be likely to pay more for a property nearer to the rapid transport system. Torzewski (2016), in his study for Warsaw, indicated that the price per square meter of an apartment decreases by 172 PLN as the distance from the metro increases by 1 km. In contrast, Basil (2009) indicates a 15% increase in housing prices, but only up to a distance of 1 km from the metro.

However, due to the spatial factors unique to each city and the high dynamics of changes in housing prices, a detailed analysis of the current effect of Metro on the primary market real estate is needed. In the past, most researchers aimed at finding a direct effect of proximity to rail transport on prices; however, no one performed a study involving accessibility of railway or Metro stations (*e.g.*, walking time needed to reach the station), considering different spatial factors and involving novel means of analysing the data.

The study was conducted in Warsaw, the capital, and the largest city of Poland, populated by c. 1,800,000 inhabitants (Ciesielska *et al.* 2019). It constitutes Poland's biggest primary property market (Markowski 2019; Urząd Statystyczny w Warszawie 2019), with the highest transaction prices per square metre of housing in the primary market (Szpunar and Jakubik 2019). Warsaw Metro, an underground rapid transport system, consists of two lines (M1 and M2) serves 0.66 million passengers daily (37% of the city population) during the week and nearly 190 million passengers yearly (Metro Warszawskie 2018), excluding the negative effects of the current COVID-19 pandemic (ZTM 2021).

As so many people rely on Metro for their daily commute and other travel, its effect on numerous aspects of city life is undisputed.

The previous research targeting Warsaw concentrated only on finding a correlation between prices and proximity to Metro, and studies involving accessibility of stations and suggesting new means of analysing the available data are missing from the available literature. This research aims to develop a new composite index – Metro Station Proximity Effect Estimator (MSPEE), which allows looking at differences between each Metro station and between the city districts. The MSPEE index was calculated as the mean of a set of sub-indicators, which were created as variables determining the final value of the composite indicator (see Methods).

METHODS

Published data acquisition

The study is based on an only publicly available record of residential transaction prices in Warsaw – a choropleth map of average transaction prices in the primary market per square metre in the residential flats for the year 2018 published by Miasto Stołeczne Warszawa – RCiWN in 2019, henceforth referred to as "RCiWN map (2019)". The residential property prices are aggregated in base units – squares with a side's length equal to 200 m, as shown in Figure 2.

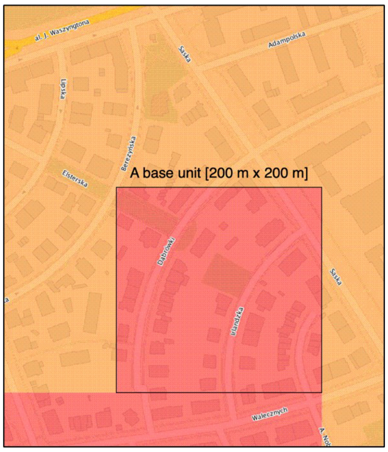

Fig. 1. An example of a base unit on RCiWN map (2019)
Source: RCiWN map (2019)

In the RCiWN map (2019) legend, the price range was divided into six intervals, which are colour-coded, as demonstrated in Table 1. For calculations, the mid-range value of each price range shown in Table 1 was used. However, this approach prevents determining the mid-range value of the highest category, as there is no upper limit for the most expensive apartments provided in the source. Baxted et al. (2015) reported that prices of high-end apartments in Warsaw range from PLN 18,000.00 per square metre. Considering that transactions of above PLN 10,000.00 per square metre are only ten per cent of the overall number of transactions (Szpunar and Jakubik 2019), we decided not to inflate the average price artificially and to set the middle value of the highest category (no. 6) at PLN 18,000.00 per square metre.

For a proper analysis of the influence of metro lines on housing prices, it is vital to realise that in Warsaw, there is a clear Peak Land Value Intersection (PLVI), corresponding to CBD, and three sec-

Table 1. Colour coding of base units in RCiWN Map (2019)

Category number	Assigned colour	Price range per 1 m²
1		up to PLN 5,000.00
2		PLN 5,000.00 – PLN 7,000.00
3		PLN 7,000.00 – PLN 9,000.00
4		PLN 9,000.00 – PLN 11,000.00
5		PLN 11,000.00 – PLN 15,000.00
6		more than PLN 15,000.00

Source: RCiWN map (2019)

ondary areas of high prices, which can be called Secondary Land Value Peaks (SLVP) – see Figure 2. The locations of PLVI and SLVPs are based on information from the RCiWN map (2019) – see Figure 3.

PRIMARY DATA AND DATA PROCESSING

A set of isopleths (circles) concentric in each Metro station was drawn with the use of two determinants of the radius. First, the probability of people willing to reach the station walking. Durand et al.'s (2015) found that with every 1.6 km, the willingness of people to reach further transit infrastructure (*e.g.*, a station or a bus stop) decreased by 12%. We concluded that the maximum radius should be set at 1.5 km so that all isopleths would fall into 88% per cent level of people's willingness to reach a Metro station. The decision was motivated by the will to maximally limit the impact of other possible factors on our study's results. Second, human average walking speed was used to establish two additional isopleths: respectively at ⅓ and ⅔ of the outer isopleth's radius. Knoblauch et al. (1996) concluded that an average person walks 82.5 m in one minute. Therefore, the three isopleths used have the following radiuses: 0.5 km (6 min. of walk), 1 km (12 min. of walk), and 1.5 km (18 min. of walk). The isopleths overlaid on the RCiWN map (2019) are shown in Figures 3 and 4.

The study includes the stations that operated as of 31st December 2018. Those built later were excluded as the latest complete dataset concerning primary market housing prices at the time of authoring this paper covered the year 2018.

The following procedure was used to process the data published in RCiWN for particular Metro stations. Initially, all base units on the choropleth map between the outer isopleth ($r = 1.5$ km) and the middle isopleth ($r = 1.0$ km) were counted with reference to their colour (only those base units which had at least 50% of their area inside the area bound by the isopleths). The following formulas were used for calculation of the mean price of apartments in the area bound by the two said isopleths:

1) the total number of base units recorded:

$$n_{base\ units} = n_1 + n_2 + n_3 + n_4 + n_5 + n_6, \tag{1}$$

where:
$n_{base\ units}$ – the total number of base units,
n_x – the number of base units corresponding to category x (see Table 1);

2) the total price:

$$p_{total} = n_1 \times p_1 + n_2 \times p_2 + n_3 \times p_3 + n_4 \times p_4 + n_5 \times p_5 + n_6 \times p_6, \tag{2}$$

where:

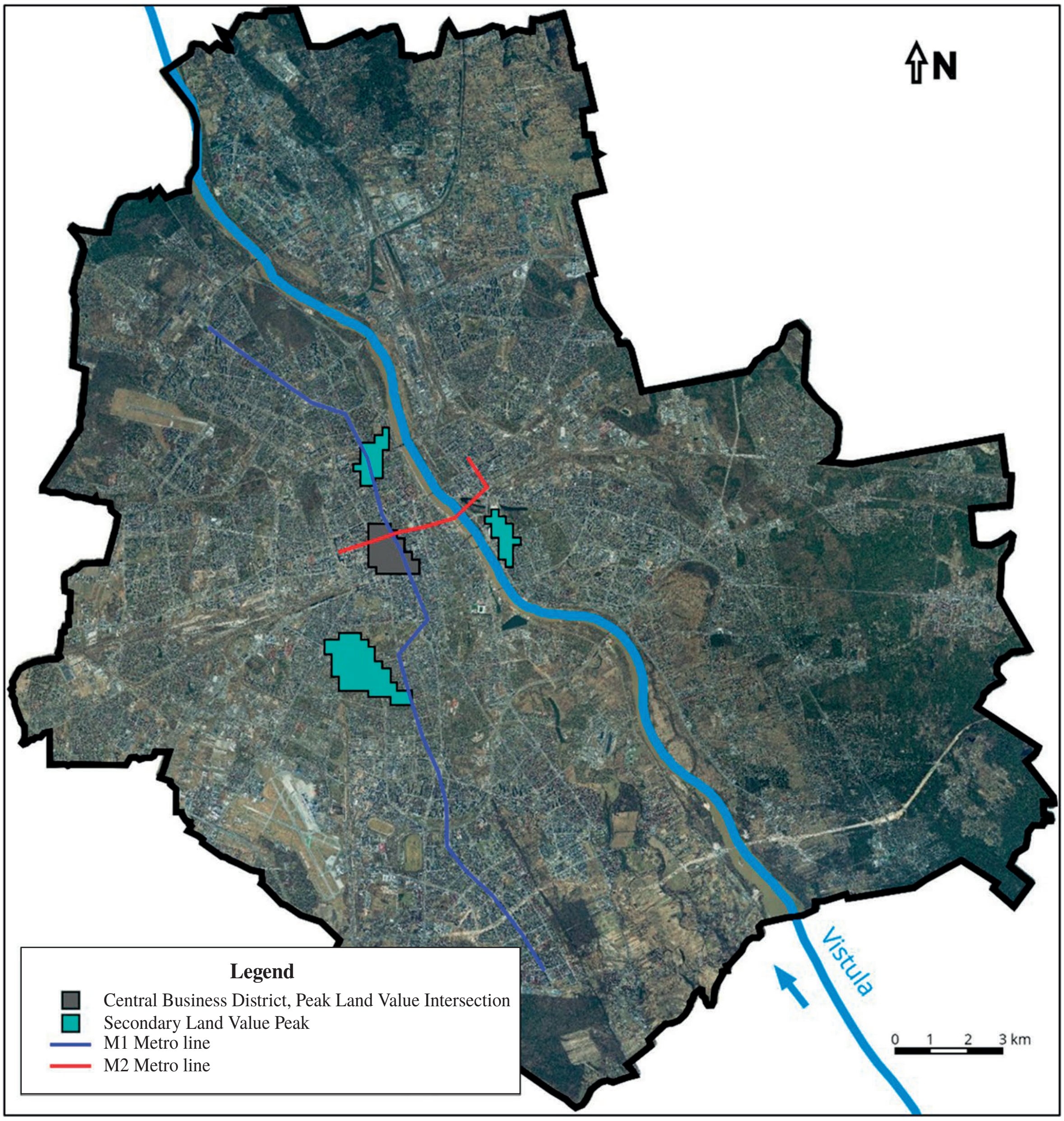

Fig. **2**. Photoplan of Warsaw with CBD, SLVPs and Metro lines shown
Source: author's elaboration based on Office of Surveying and Cadastre, 2018a and RCiWN map (2019)

p_{total} – the total price,
n_x – the number of base units corresponding to category x,
p_x – the average primary market residential property price corresponding to category x (see Table 1).

3) the mean price:

$$\overline{p} = \frac{p_{total}}{n_{base\ units}}, \tag{3}$$

where:
$\overline{p}$ – the mean price.

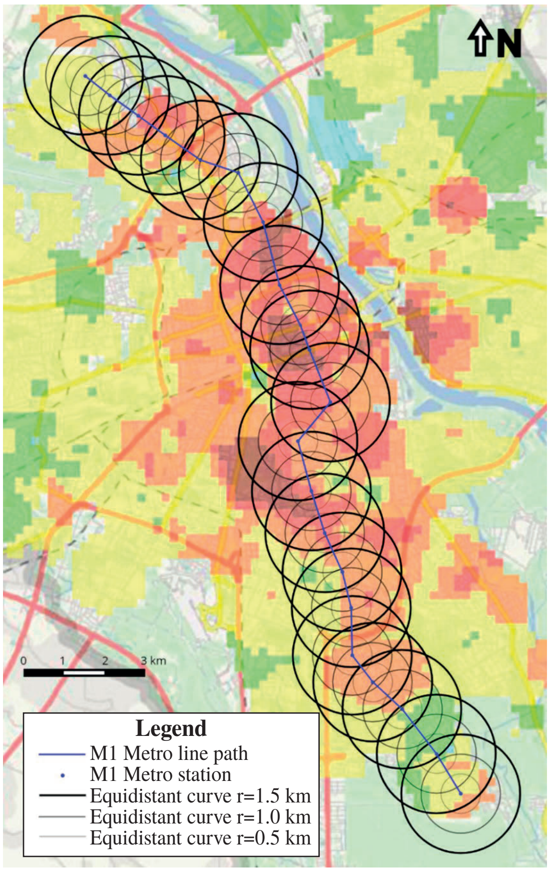

Fig. **3**. M1 line, with monocentric, circular isopleths drawn around each station, on RCiWN map (2019)
Source: author's elaboration based on RCiWN map (2019).

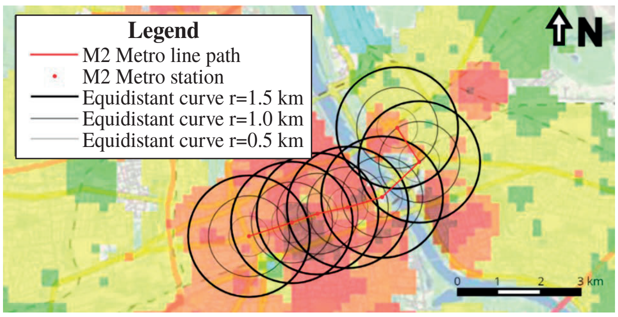

Fig. **4**. M2 line, with monocentric, circular isopleths drawn around each station, on RCiWN map (2019)
Source: author's elaboration based on RCiWN map (2019).

The aforesaid actions were repeated for the $r = 1.0$ km isopleth (area limited by the inner isopleth) as well as for the $r = 0.5$ km isopleth (the innermost area). The above procedure was done separately for each station of both Metro lines.

The method below was then used to assess the perceived impact of Metro presence in particular Warsaw city districts as it aggregates the mean prices for each district with at least one Metro station.

First, the total number of M1 line stations in a city district was recorded. Then, Aggregated Price (AP) was calculated using a formula:

$$AP_x = \bar{p}_1 + \bar{p}_2 + \ldots + \bar{p}_n, \tag{4}$$

where:

AP_x – the aggregated price around every station in a given city district for an area x (bound by an area innermost to the station or two isopleths), where $x = \{0.5 \text{ km}, 1.0 \text{ km}, 1.5\text{km}\}$,

$\bar{p}_n$ – the mean price around station n for an area x in a given city district.

Subsequently, Aggregated Mean Price (AMP) was obtained by dividing the AP_x by the total number of stations in the district.

$$AMP_x = \frac{AP_x}{n_{stations}}, \tag{5}$$

where:

AMP_x – the aggregated mean price around every station in a given city district for an area x, where $x = \{0.5 \text{ km}, 1.0 \text{ km}, 1.5 \text{ km}\}$,

AP_x – defined as above,

$n_{stations}$ – the total number of stations in a given city district.

The above process was repeated for each of the areas x in the city districts as well as for the M2 line.

The MSPEE index

We created a new composite indicator – Metro Station Proximity Effect Estimator (MSPEE) to illustrate each Metro station's potential to influence the primary market housing prices in Warsaw. The MSPEE index is calculated as the weighted arithmetic mean of two sub-indicators – Station Influence Index (SII) and Station Passengers Index (SPI) – which were designed as variables determining the final value of the composite indicator.

The "traditional" method of raw data treatment outlined in the other part of the Methods section is intended to illustrate Metro's general impact on the primary residential property market prices (see AMP). While stemming from the same data, MSPEE, on the other hand (i), allows one to familiarise oneself with how a particular station affects the real estate monetary value nearby (ii) in the context of the real-life significance of the station to the commuters.

Moreover, due to its simplicity – the fact that it is designed to consider only the impact of the metro's proximity to housing prices – and the ease of use MSPEE allows almost anyone interested to analyse the data quicker than with a hedonic model use. Second, as mentioned above, in contrast to the other method, it considers factors external to the real estate market, namely the public transport usage, which reflects the population transport preferences. Then, we imagine our composite indicator as a potential tool for introductory analysis of the future trends in the real estate market due to the development of the metro; especially in the cities such as Warsaw, *i.e.*, having ambitions to expand their rapid transportation systems

Because of the SII's direct connection to the property prices, we decided to strengthen its impact on the MSPEE values while attributing an auxiliary role to the other index. Thus, the following weights (w) were attributed to each sub-index: $w(SII) = 2$ and $w(SPI) = 1$. Consequently, the MSPEE can be obtained through the formula:

$$MSPEE_x = \frac{2 \times SII_x + 1 \times SPI_x}{3}, \tag{6}$$

where:

$MSPEE_x$ – the value of MSPEE for a station x,

SII_x – Station Influence Index for a station x,

SPI_x – the Station Passengers Index for a station x.

Station Influence Index (SII)

The first indicator was invented to assess a station's true potential to influence residential prices in its vicinity. As its design directly expresses this paper's aim – to attempt at measuring the effect of a Metro station proximity on the dwellings' prices – it was given the highest weight in MSPEE calculation.

It is computed as the absolute difference between the price within the area limited by the isopleth nearest to the station x ($\overline{p}_{x_1} : r = 0.5$ km) and the price within the area bound by the outer isopleth ($\overline{p}_{x_3} : r = 1.5$ km) and is expressed according to the formula:

$$SII_x = \frac{\left|\overline{p}_{x_1} - \overline{p}_{x_3}\right|}{\overline{p}_{x_1}} \times 100, \tag{7}$$

where:

SII_x — Station Influence Index for a station x.

The value of the indicator was given a coefficient of 100 to improve the presentation of the data.

Station Passengers Index (SPI)

The second index reflects the yearly number of passengers travelling through each station. It aims to contextualise the previous indicator's results by assessing a station's significance to the travellers. Through that, it lessens the risk of an erroneous assessment of the station's impact on the real estate.

The data for the calculations was obtained from the Metro Annual Report 2018 (Metro Warszawskie Sp. z o.o. 2018). The index's scale is set as a ranking with a maximum value equal to $max(SII)$, which is the largest number in the set of Station Influence Index values. This interconnection between the MSPEE's sub-indicators ensures obtaining results unbiased by the differences in the sub-indicators ranges. The maximum value is given to the station with the largest yearly number of passengers, whereas each subsequent station is given a value corresponding to its yearly number of passengers. The SII, therefore, is calculated according to the formula:

$$SPI_x = \frac{max(SII)}{N_{stations}} \times v_{rank_x}, \tag{8}$$

where:

SPI_x – the Station Passengers Index for a station x,

$max(SII)$ – the largest number in the set of Station Influence Index values,

$N_{stations}$ – the total number of stations in the city,

v_{rank_x} – the value of station x's rank according to the yearly number of passengers, where: $v_{rank} = \{v \in \mathrm{N}1 \leq v \leq N_{stations}\}$.

RESULTS

Obtained results are presented in Figure 5 (M1 line) and Figure 6 (M2 line), with the mean price ($\overline{p}$) of an average primary market dwelling calculated for areas bound by subsequent isopleths. The city district of each station was recorded as a reference for the following calculations.

The aggregated mean price versus distance from the M1 line stations is shown in Figure 7. One of the first things visible is the general trend for four of five data sets. Disregarding Żoliborz, in all the districts through which the M1 line passes, the price of square metre of new dwellings decreases with the distance from the station increasing. The largest change in the housing prices, almost twice the rate in other districts, is observed in the Śródmieście district.

The case of Żoliborz, a district lying in northern Warsaw, proves, however, that the effect of the presence of Metro on real estate prices is not universal. It is observed that the difference in prices

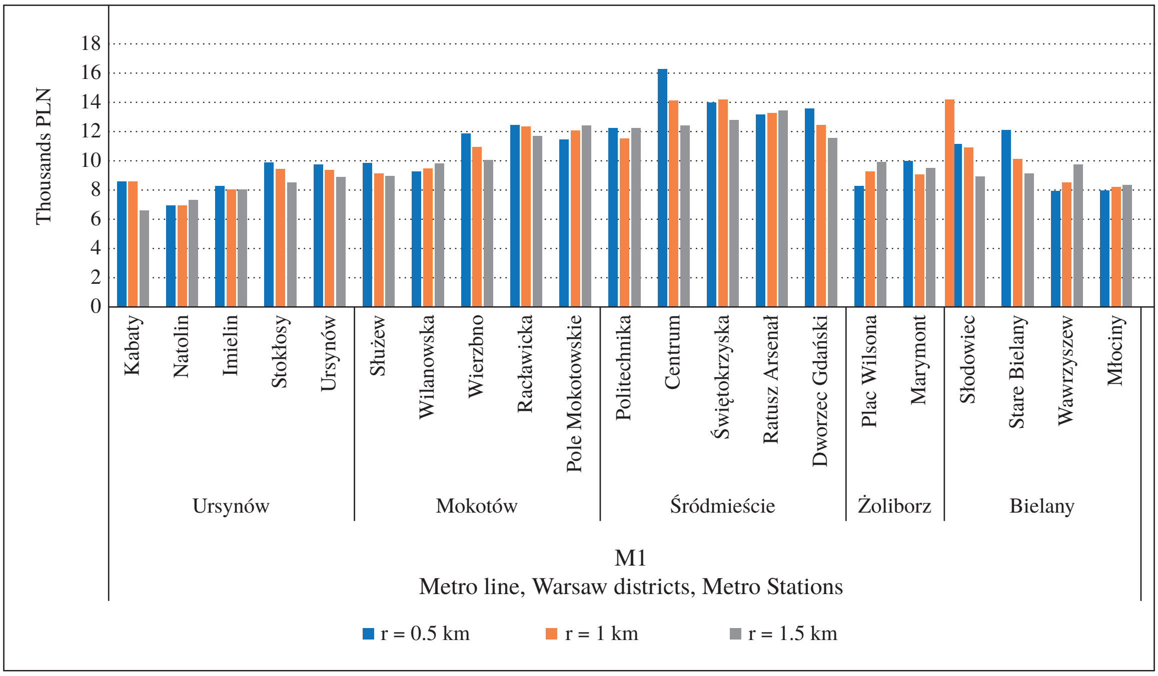

Fig. **5**. Primary market residential property mean price ($\overline{p}$) per 1 m² for M1 line stations
Source: author's own elaboration.

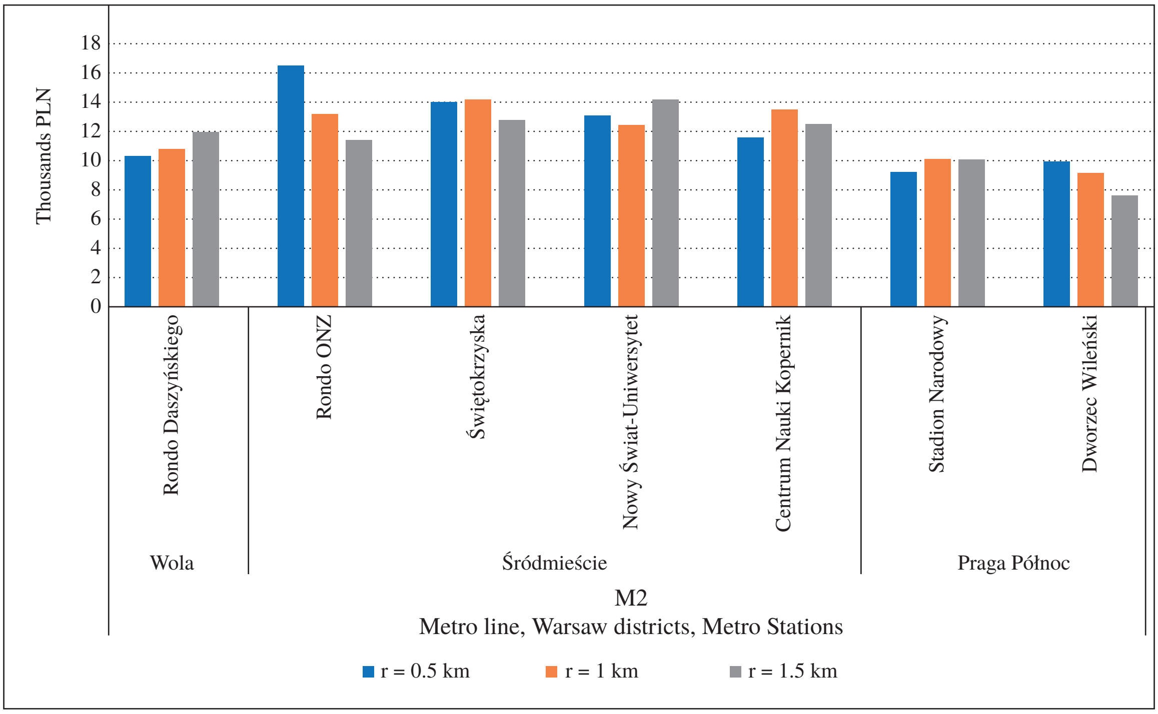

Fig. **6**. Primary market residential property mean price ($\overline{p}$) per 1 m² for M2 line stations
Source: author's own elaboration.

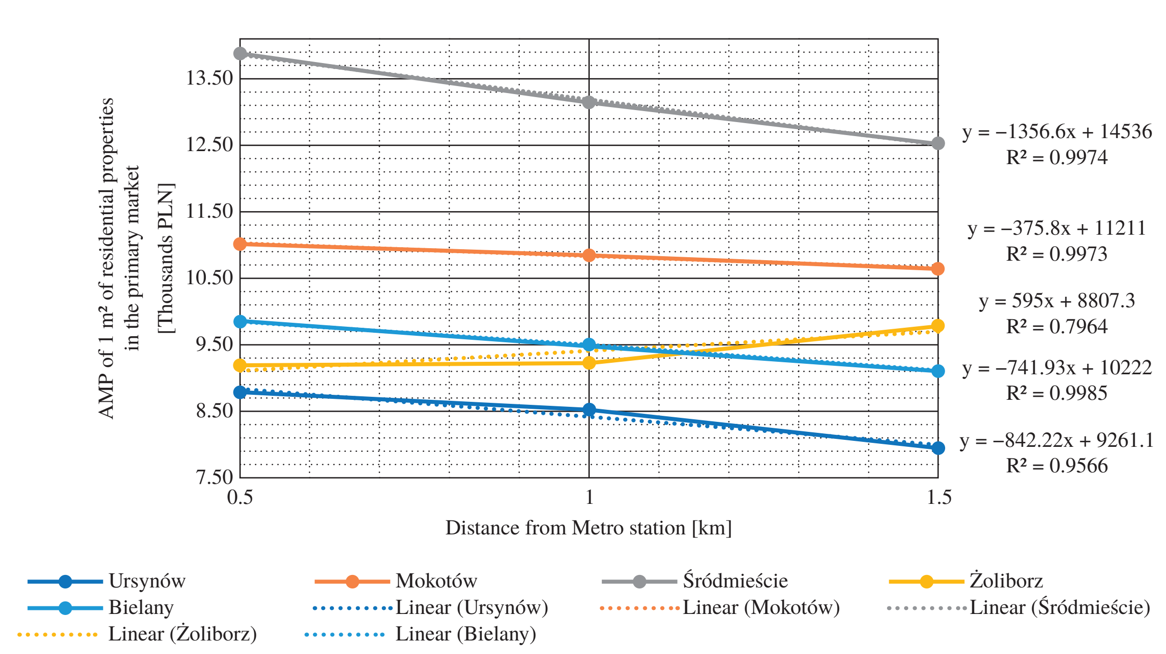

Fig. 7. Aggregated effect of distance from M1 line station on primary market housing prices
Source: author's own elaboration.

between the region bound by the 1 km isopleth and the one bound by the 0.5 km isopleth is almost negligible, yet the higher price is the one being further from the station (difference of PLN 36.93). What is more visible is the sharp rise in the average price in the sector bound by the outer isopleth.

The results are more equivocal for the second Metro line (M2) (Figure 8). Similarly to the M1 line case, one may see that Śródmieście has a visibly negative relationship between the price and the distance from a Metro station. However, the correlation between the prices and a Metro station proximity in Wola and Praga Północ could be read as ambiguous.

MSPEE

The Metro stations were ranked according to the value of the MSPEE index (Table 2), and fluctuations in the two indices versus the stations' ranking are shown in Figure 9. One may see that the value of the MSPEE index is generally between the values of the Station Influence Index and Station Passengers Index. The MSPEE allows to quickly estimate the effect of proximity to a given Metro station on primary market residential properties. It considers both the difference in prices as well as the importance of the station by accounting for the number of passengers.

DISCUSSION

In Żoliborz city district, the opposite pattern of housing prices (increasing with increasing distance from Metro stations) can be observed. It may be explained by the fact that Plac Wilsona Metro station's vicinity was built before the Second World War, and it is primarily composed of prestigious detached or semi-detached houses (Figure 10; for local peak land value intersections, see Figure 2).

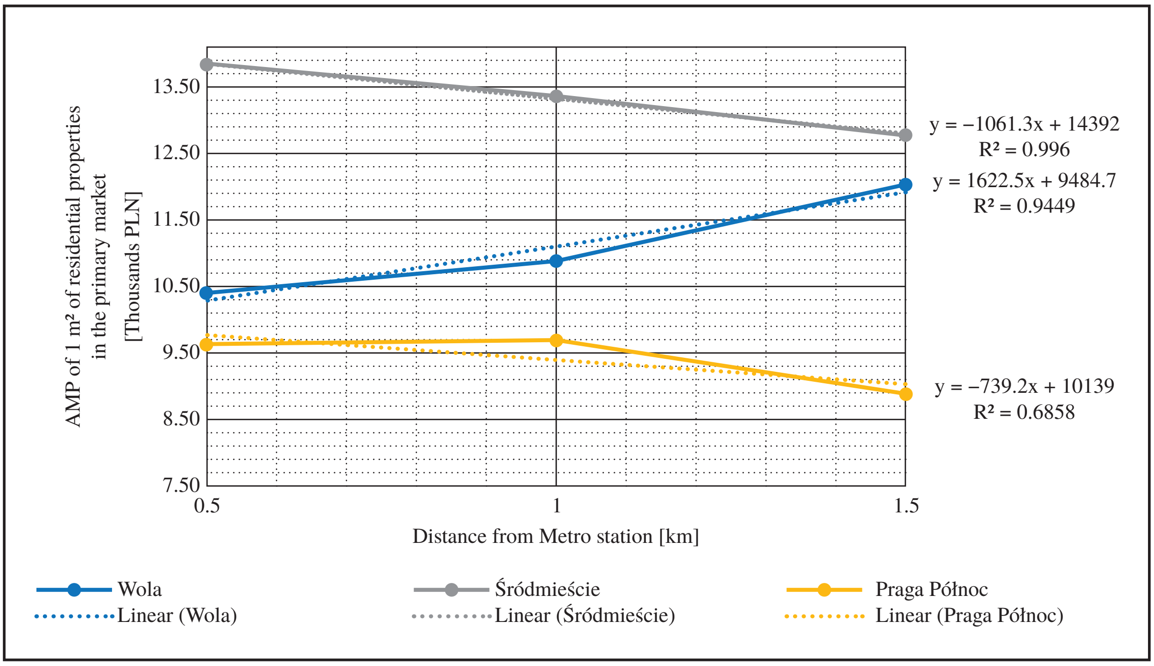

Fig. 8. Aggregated effect of distance from M2 line station on primary market housing prices
Source: author's own elaboration

Therefore, the sale of primary market dwellings in this old part city is severely limited (Miasto Stołeczne Warszawa 2019a). In the case of the second Żoliborz's station – Marymont (a newer part of Żoliborz, built after the war) – the typical pattern is well visible as the price decreases with distance from the Metro station (Figure 5).

The rapid decrease in housing prices in Śródmieście, together with increasing distance from the Metro stations, is the bid-rent theory and the fact that, despite significant urban intensification in this district, the area undergoes dynamic redevelopment with new skyscrapers, including office buildings and luxury apartments houses (Figure 11).

Analysing the data from the statistical side, the correlation coefficient (R^2) in all four non-ambiguous cases is very high. That suggests that the relationship between the average price and the distance from Metro station is almost linear, *i.e.*, that the share of variance of the average price foreseeable from the Metro station proximity is indeed high.

In the case of Wola, the only M2 station there, Rondo Daszyńskiego, lies directly West of the peak land value intersection (with both middle and outer isopleth intersecting it). It means that the outer isopleth sector's average price is heavily influenced by its presence.

On the other hand, the primary market dwellings lying in Praga Północ, on the other hand, are influenced by the vicinity of the secondary land value peak. Stadion Narodowy station is located in the area north of the SLVP, which, similarly to other ambiguous cases described in this paper as well in the literature (Zhang et al. 2016), influences the prices bound by the outer as well as the middle isopleth area.

The M2 line data set's correlation coefficients have high values both in the case of Śródmieście and Wola, which proves the existence of a linear relationship in both cases. The first of the coefficients sets (Śródmieście) proves the established geographic theory, while the second (Wola) demonstrates the immense influence of the PLVI proximity on dwelling prices. The low value of the correlation coefficient for Praga Północ stems most probably from the discrepancy in the price trends around the district's two stations. The above-mentioned Stadion Narodowy station exhibits a positive relationship

Table 2. MSPEE and its components' values for each Metro station in Warsaw

Metro line	Station	Passengers in 2018 [1 × 10^6]	v_{rank}	Station Passenger Index (SPI)	Station Influence Index (SII)	MSPEE
1	Centrum	20.7	28	30.6	23.5	25.9
2	Rondo ONZ	4.27	8	8.74	30.6	23.3
2	Dworzec Wileński	8.46	21	22.9	22.9	22.9
1	Kabaty	5.58	14	15.3	23.0	20.5
1	Plac Wilsona	5.09	12	13.1	20.0	17.7
1	Wawrzyszew	3.77	6	6.55	22.3	17.1
1	Dworzec Gdański	7.71	20	21.8	14.7	17.1
1	Stare Bielany	2.87	3	3.28	23.9	17.0
1	Wierzbno	6.78	19	20.7	15.0	16.9
2	Rondo Daszyńskiego	6.41	17	18.6	15.6	16.6
1	Świętokrzyska	13.5	27	29.5	8.69	15.6
1	Słodowiec	3.42	5	5.46	20.1	15.2
2	Świętokrzyska	11.6	25	27.3	8.69	14.9
1	Stokłosy	4.89	11	12.0	14.0	13.3
1	Wilanowska	9.67	24	26.2	6.13	12.8
1	Pole Mokotowskie	6.63	18	19.7	8.23	12.0
1	Młociny	9.09	23	25.1	5.08	11.8
1	Służew	5.75	15	16.4	9.04	11.5
1	Politechnika	12.4	26	28.4	0.11	9.54
1	Ratusz Arsenał	8.84	22	24.0	2.03	9.36
2	Nowy Świat-Uniwersytet	4.49	10	10.9	8.33	9.19
1	Ursynów	3.86	7	7.64	9.00	8.55
1	Natolin	5.28	13	14.2	5.06	8.11
1	Imielin	5.76	16	17.5	3.34	8.05
1	Racławicka	4.34	9	9.83	5.75	7.11
2	Stadion Narodowy	2.84	2	2.18	8.78	6.58
2	Centrum Nauki Kopernik	2.47	1	1.09	8.17	5.81
1	Marymont	3.25	4	4.37	4.74	4.62

Note. All numbers are given with accuracy to three significant figures (3 s.f.)
Source: author's own elaboration; raw data from Metro Warszawskie Sp. z o.o., 2018.

between the average price and the distance from a Metro station, while the Dworzec Wileński station's trend is exactly the reverse.

MSPEE

Analysing the trendlines of both MSPEE and its components, it is visible that for stations with the highest value of MSPEE, the difference between the prices of properties in the inner isopleth is significantly higher than those in the outer. Moreover, there is an evident correlation between the Metro station proximity effect on housing prices and the station's influence (SII). That is especially visible in the case of Centrum station (M1). Its position as a leader in terms of the yearly number of passengers is reflected in its overall MSPEE stance.

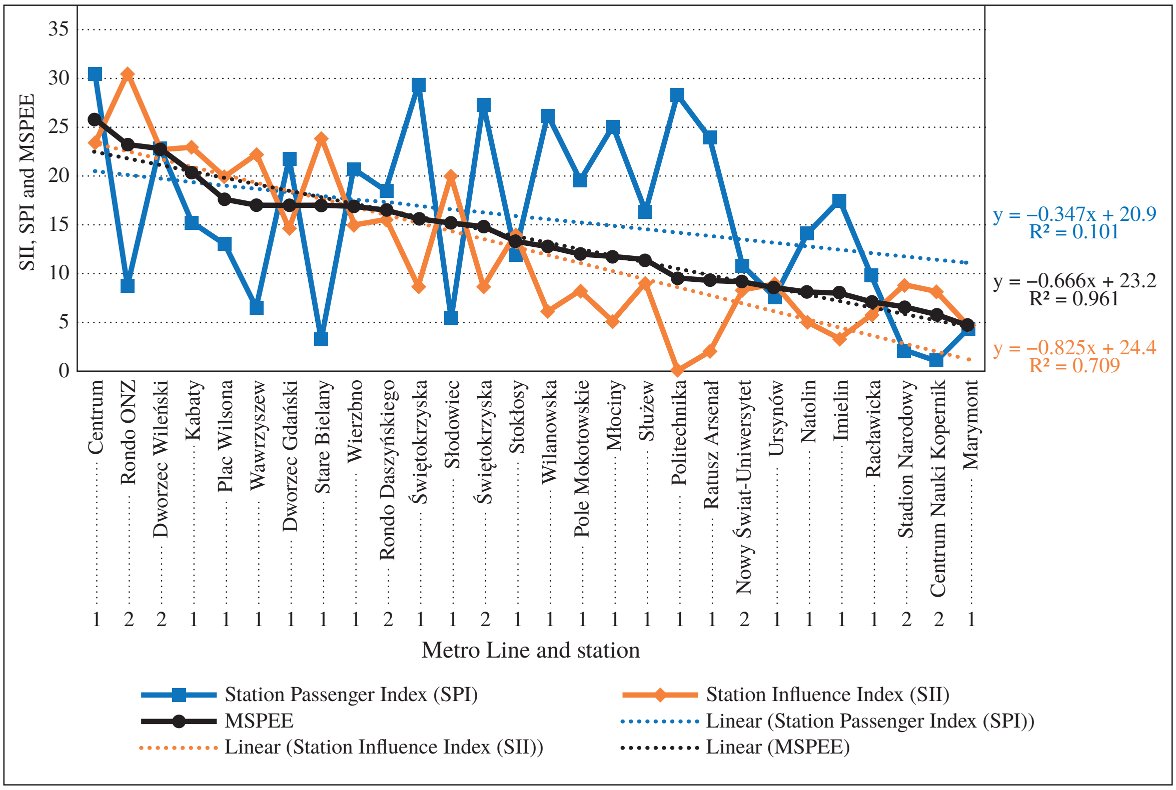

Fig. 9. Metro Station Proximity Effect Estimator (MSPEE) and its two components (3 s.f.)
Source: author's own elaboration.

However, the correlation between the Station Passengers Index and SII is less noticeable. Although both SPI and SII show a clearly negative correlation connected to the MSPEE value reflected in their trendlines, the SPI values may be seen as somewhat ambiguous. That may be seen especially in the case of M1 line stations from Ratusz Arsenał to Stokłosy. Whereas they note a high yearly number of passengers, their influence reflected in SII is low. Moreover, the correlation coefficient for the SPI trendline suggests a slight correlation between the individual values.

CONCLUSIONS

Following the analysis of the research results, one may say that there is generally a strong negative correlation between the apartment prices and distance from a Metro station. With a few exceptions (stations in Wola and Żoliborz), being anomalies to a general trend (caused by proximity to peak land value areas), the prices of one square metre of primary market residential properties built in the year 2018 are decreasing with the distance from a Metro station increasing. Worth underlining is the fact that this pattern is evident in the case of the first Metro line (M1), where four out of five aggregate curves follow it. The results from the M2 line are less suited to the theory established in the literature. Nevertheless, it is most probable that the reason is the proximity to PLVI concerning the western bank of the Vistula and the closeness of SLVP in the case of the eastern bank. It is also possible that due to the relatively brief period of M2 line functioning, its full effect on the housing market may still not be noticeable.

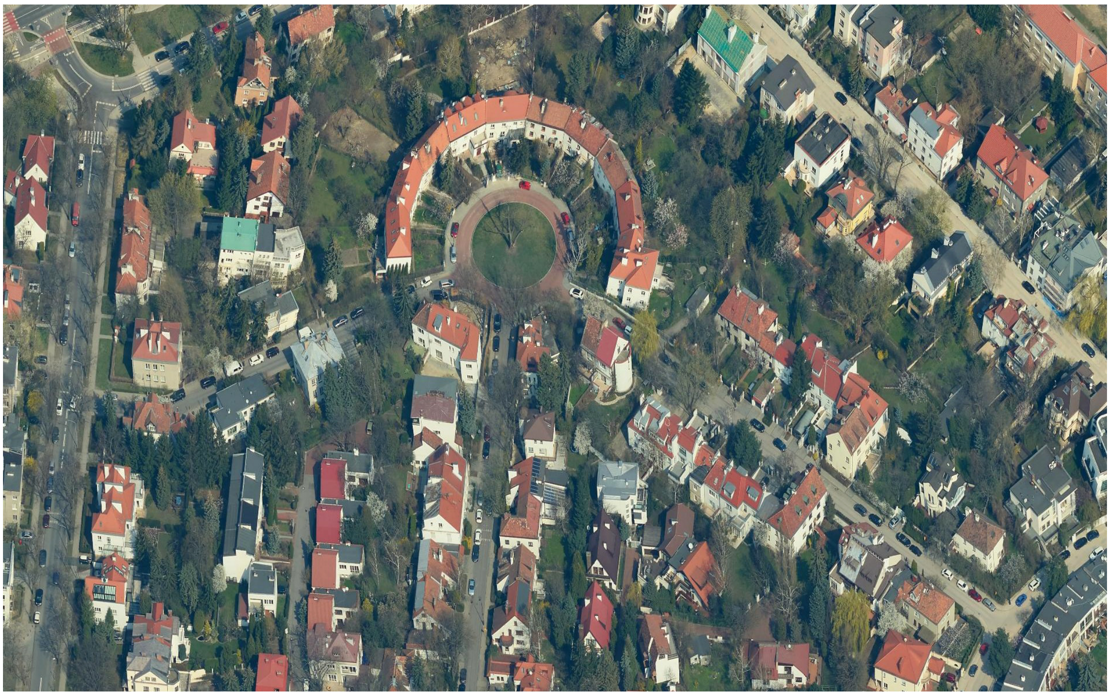

Fig. **10**. Oblique photo plan (north-oriented) of a Żoliborz Oficerski's part
Source: Office of Surveying and Cadastre 2018b.

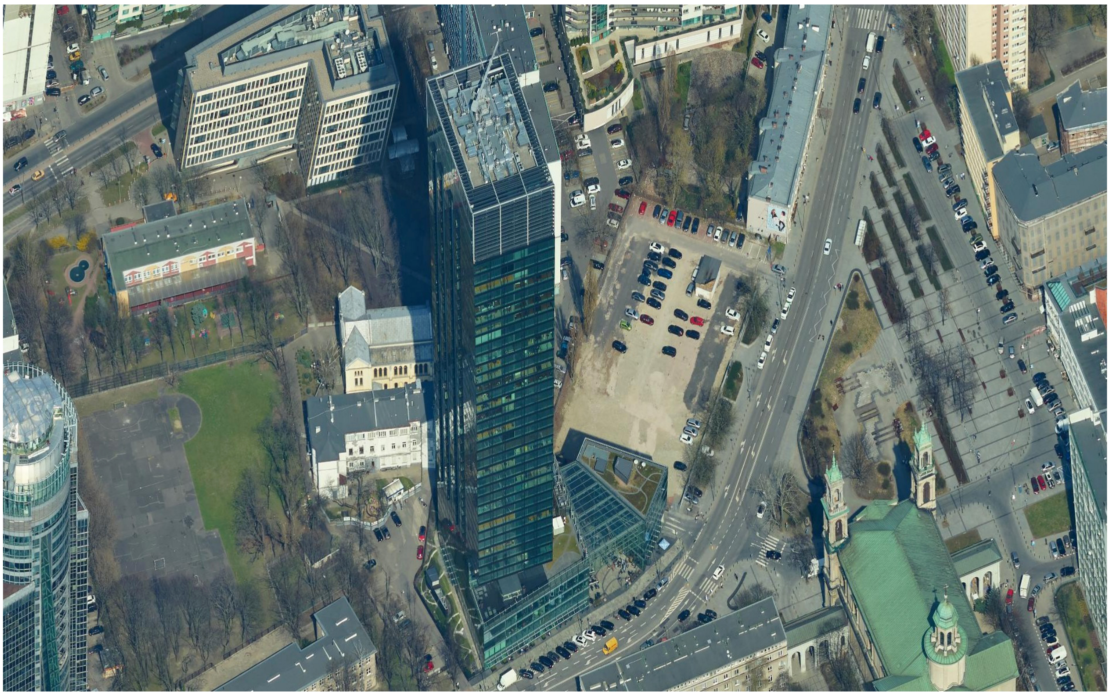

Fig. **11**. Oblique photo plan (north-oriented) of Cosmopolitan Twarda 2/4, a luxury residential skyscraper built in 2014
Source: Office of Surveying and Cadastre 2018c.

Moreover, this research concluded with an attempt to visualise the stations' potential to influence nearby real estate prices. The Metro Station Proximity Effect Estimator (MSPEE) proved to be a simple, albeit useful measure in data analysis and may be used again in different cases as it is not city-specific. In conclusion, the results of this study corroborate the initial hypothesis that there exists a clear negative correlation between the distance from a Metro station and the primary market's residential property price. As mentioned in the introduction, the issue of the relationship between housing prices and distance from the metro has been of interest to many researchers. It may seem an obvious conclusion that such a relationship exists. However, as it is visible in a brief review of the literature, each case differs due to studied-city-specific factors as well as the methods used. Moreover, the research results presented in this article show the possibility of a different approach to the analysis of housing prices. At the same time, with some exceptions, it confirms that this dependence is also visible in a city such as Warsaw.

Analysing the results, one may worry that they have been affected by a mistake or methodology issue. The most probable issues are: first, the chance of a mistake in calculations (*e.g.*, when extracting the data from the RCiWN map (2019)) or the map of average transaction prices for a square metre in the residential flats may not dutifully reflect the reality.

For future research in the field, we could advise using computer software to count the base units more efficiently. Moreover, a more detailed set of data that would not require approximation would be beneficial. For example, the area bound by isopleths could be divided into a constant number of base units in the case of all stations.

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Appendix

This section contains a table (Table A1) with the processed data from RCiWN Map (Miasto Stołeczne Warszawa – RCiWN, 2019). Significant results of the calculations included in the table beneath as well as the methodology behind data processing are stated in the appropriate parts of the main section of this paper. For the purpose of the table below $t_x = n_x \times p_x$, where t_x is the cumulative price of n base units corresponding to category x (see Table 1, the main body of the paper). The respective price (p) used in calculations here is determined according to the Methods section. All prices are given in Polish zloty (PLN).

Table A1. Calculations using data from RCiWN map (2019)

Station	r [km]	n_1	t_1	n_2	t_2	n_3	t_3	n_4	t_4	n_5	t_5	n_6	t_6	$n_{base\ units}$	p_{total}	$\overline{p}$
M1 line																
Kabaty	0.5	0	0	0	0	15	120000	8	80000	0	0	0	0	23	200000	8695.65
	1	0	0	0	0	24	192000	10	100000	0	0	0	0	34	292000	8588.24
	1.5	0	0	17	102000	9	72000	0	0	0	0	0	0	26	174000	6692.31
Natolin	0.5	0	0	12	72000	10	80000	1	10000	0	0	0	0	23	162000	7043.48
	1	0	0	31	186000	24	192000	3	30000	0	0	0	0	58	408000	7034.48
	1.5	0	0	24	144000	30	240000	6	60000	0	0	0	0	60	444000	7400.00
Imielin	0.5	0	0	5	30000	7	56000	9	90000	0	0	0	0	21	176000	8380.95
	1	0	0	20	120000	21	168000	22	220000	0	0	0	0	63	508000	8063.49
	1.5	0	0	26	156000	42	336000	31	310000	0	0	0	0	99	802000	8101.01
Stokłosy	0.5	0	0	0	0	0	0	25	250000	0	0	0	0	25	250000	10000.00
	1	0	0	0	0	17	136000	48	480000	0	0	0	0	65	616000	9476.92
	1.5	0	0	7	42000	56	448000	37	370000	0	0	0	0	100	860000	8600.00
Ursynów	0.5	0	0	0	0	2	16000	21	210000	0	0	0	0	23	226000	9826.09
	1	0	0	0	0	18	144000	48	480000	0	0	0	0	66	624000	9454.55
	1.5	0	0	1	6000	54	432000	47	470000	1	13000	0	0	103	921000	8941.75
Służew	0.5	0	0	0	0	4	32000	15	150000	2	26000	0	0	21	208000	9904.76
	1	0	0	1	6000	27	216000	38	380000	1	13000	0	0	67	615000	9179.10
	1.5	0	0	4	24000	44	352000	53	530000	1	13000	0	0	102	919000	9009.80
Wila-nowska	0.5	0	0	1	6000	5	40000	14	140000	0	0	0	0	20	186000	9300.00
	1	0	0	5	30000	17	136000	35	350000	8	104000	0	0	65	620000	9538.46
	1.5	0	0	2	12000	34	272000	43	430000	21	273000	0	0	100	987000	9870.00
Wierz-bno	0.5	0	0	0	0	1	8000	6	60000	14	182000	0	0	21	250000	11904.76
	1	0	0	1	6000	11	88000	32	320000	14	182000	6	108000	64	704000	11000.00
	1.5	0	0	9	54000	32	256000	34	340000	16	208000	8	144000	99	1002000	10121.21

Station	r [km]	n_1	t_1	n_2	t_2	n_3	t_3	n_4	t_4	n_5	t_5	n_6	t_6	$n_{base\ units}$	p_{total}	$\overline{p}$
M1 line																
Racławicka	0.5	0	0		0	2	16000	7	70000	8	104000	4	72000	21	262000	12476.19
	1	0	0	2	12000	9	72000	17	170000	23	299000	14	252000	65	805000	12384.62
	1.5	0	0	2	12000	7	56000	55	550000	28	364000	16	288000	108	1270000	11759.26
Pole Mokotowskie	0.5	0	0	0	0	0	0	11	110000	11	143000	0	0	22	253000	11500.00
	1	0	0	0	0	3	24000	23	230000	30	390000	6	108000	62	752000	12129.03
	1.5	0	0	2	12000	14	112000	36	360000	34	442000	26	468000	112	1394000	12446.43
Politechnika	0.5	0	0	0	0	0	0	5	50000	16	208000	0	0	21	258000	12285.71
	1	0	0	0	0	0	0	29	290000	28	364000	1	18000	58	672000	11586.21
	1.5	0	0	0	0	2	16000	40	400000	50	650000	11	198000	103	1264000	12271.84
Centrum	0.5	0	0	0	0	0	0	0	0	7	91000	13	234000	20	325000	16250.00
	1	0	0	0	0	2	16000	8	80000	28	364000	20	360000	58	820000	14137.93
	1.5	0	0	2	12000	4	32000	24	240000	58	754000	10	180000	98	1218000	12428.57
Świętokrzyska	0.5	0	0	0	0	1	8000	5	50000	5	65000	8	144000	19	267000	14052.63
	1	0	0	0	0	1	8000	10	100000	29	377000	22	396000	62	881000	14209.68
	1.5	0	0	0	0	2	16000	20	200000	56	728000	11	198000	89	1142000	12831.46
Ratusz Arsenał	0.5	0	0	0	0	0	0	2	20000	16	208000	2	36000	20	264000	13200.00
	1	0	0	0	0	1	8000	13	130000	32	416000	12	216000	58	770000	13275.86
	1.5	0	0	0	0	0	0	19	190000	53	689000	20	360000	92	1239000	13467.39
Dworzec Gdański	0.5	0	0	0	0	0	0	6	60000	8	104000	6	108000	20	272000	13600.00
	1	0	0	0	0	11	88000	9	90000	11	143000	12	216000	43	537000	12488.37
	1.5	0	0	0	0	9	72000	24	240000	28	364000	5	90000	66	766000	11606.06
Plac Wilsona	0.5	0	0	0	0	10	80000	2	20000	0	0	0	0	12	100000	8333.33
	1	0	0	0	0	12	96000	18	180000	1	13000	0	0	31	289000	9322.58
	1.5	0	0	1	6000	13	104000	33	330000	10	130000	0	0	57	570000	10000.00
Marymont	0.5	0	0	0	0	4	32000	13	130000	3	39000	0	0	20	201000	10050.00
	1	0	0	4	24000	16	128000	31	310000	1	13000	0	0	52	475000	9134.62
	1.5	0	0	4	24000	23	184000	38	380000	10	130000	0	0	75	718000	9573.33
Słodowiec	0.5	0	0	0	0	0	0	13	130000	9	117000	0	0	22	247000	11227.27
	1	0	0	0	0	6	48000	18	180000	17	221000	0	0	41	449000	10951.22
	1.5	0	0	6	36000	25	200000	41	410000	0	0	0	0	72	646000	8972.22
Stare Bielany	0.5	0	0	0	0	0	0	4	40000	10	130000	0	0	14	170000	12142.86
	1	0	0	0	0	13	104000	20	200000	11	143000	0	0	44	447000	10159.09
	1.5	0	0	0	0	30	240000	34	340000	3	39000	0	0	67	619000	9238.81
Wawrzyszew	0.5	0	0	0	0	15	120000	0	0	0	0	0	0	15	120000	8000.00
	1	0	0	0	0	26	208000	5	50000	2	26000	0	0	33	284000	8606.06
	1.5	0	0	0	0	28	224000	23	230000	14	182000	0	0	65	636000	9784.62
Młociny	0.5	0	0	0	0	21	168000	0	0	0	0	0	0	21	168000	8000.00
	1	0	0	0	0	32	256000	5	50000	0	0	0	0	37	306000	8270.27
	1.5	0	0	3	18000	41	328000	15	150000	0	0	0	0	59	496000	8406.78

Station	r [km]	n_1	t_1	n_2	t_2	n_3	t_3	n_4	t_4	n_5	t_5	n_6	t_6	$n_{base\ units}$	p_{total}	$\overline{p}$
M2 line																
Rondo Daszyńskiego	0.5	0	0		0	0	0	19	190000	3	39000	0	0	22	229000	10409.09
	1	1	2500	2	12000	3	24000	38	380000	15	195000	4	72000	63	685500	10880.95
	1.5	0	0	3	18000	4	32000	47	470000	23	299000	18	324000	95	1143000	12031.58
Rondo ONZ	0.5	0	0		0	0	0	0	0	6	78000	15	270000	21	348000	16571.43
	1	0	0		0	2	16000	17	170000	23	299000	15	270000	57	755000	13245.61
	1.5	1	2500	5	30000	2	16000	43	430000	42	546000	7	126000	100	1150500	11505.00
Świętokrzyska	0.5	0	0	0	0	1	8000	5	50000	5	65000	8	144000	19	267000	14052.63
	1	0	0	0	0	1	8000	10	100000	29	377000	22	396000	62	881000	14209.68
	1.5	0	0	0	0	2	16000	20	200000	56	728000	11	198000	89	1142000	12831.46
Nowy Świat-Uniwersytet	0.5	0	0	0	0		0	4	40000	14	182000	3	54000	21	276000	13142.86
	1	0	0	0	0	4	32000	11	110000	31	403000	5	90000	51	635000	12450.98
	1.5	0	0	0	0	3	24000	12	120000	35	455000	30	540000	80	1139000	14237.50
Centrum Nauki Kopernik	0.5	0	0	0	0	3	24000	3	30000	2	26000	2	36000	10	116000	11600.00
	1	0	0	0	0	1	8000	5	50000	21	273000	8	144000	35	475000	13571.43
	1.5	0	0	0	0	3	24000	21	210000	40	520000	9	162000	73	916000	12547.95
Stadion Narodowy	0.5	0	0	0	0	6	48000	5	50000	1	13000		0	12	111000	9250.00
	1	0	0	1	6000	18	144000	14	140000	8	104000	3	54000	44	448000	10181.82
	1.5	0	0	3	18000	40	320000	18	180000	11	143000	8	144000	80	805000	10062.50
Dworzec Wileński	0.5	0	0	0	0	6	48000	11	110000	4	52000	0	0	21	210000	10000.00
	1	0	0	0	0	29	232000	10	100000	7	91000	0	0	46	423000	9195.65
	1.5	0	0	11	66000	41	328000	3	30000	0	0	0	0	55	424000	7709.09

Source: author’s elaboration based on data from RCiWN map (2019)