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Spatial Autocorrelation of Communes' Income Potential in Selected Metropolitan Areas

Abstract: A commune's own income potential, indicative of financial self-sufficiency, underpins the ability of its government to foster local growth. Accurate recognition of the potential levels necessary for improvement of development policies requires that, apart from considering communes' own potential, neighbouring communes' potential should be taken into account, especially if the neighbours are large urban centres of substantial demographic and economic capacity. This article aims to examine spatial autocorrelation of income potential of metropolitan communes of Warsaw, Poznań, Wrocław, and Cracow metro areas in 2014. The study draws on data published by the Central Statistical Office in the Local Data Bank and uses the R programme packages, such as *spdep*, *maptools*, and *shapefiles* for calculations.

Keywords: spatial autocorrelation, local and global Moran I , metropolitan areas, own income potential

JEL: H72, C49

1. Introduction

Communes' own revenues per capita are one of the main indices to consider in assessing financial self-sufficiency of local governments (Surówka, 2013). Their high levels are suggestive of high communes' own income potential that can translate, if stable, into long term capacity of local governments to finance their various tasks and projects (Lubińska et al., 2007: 77); conversely, inadequate income potential can easily hinder development of local communities.

Certain communes stand out in terms of their very high levels of income potential, and these are communes with county rights of the largest cities in Poland. They are granted rights to levy both commune- and county-specific taxes to support their various social and infrastructural functions and discharge numerous obligations. The quality of that execution predetermines the quality of everyday living in the cities and influences the region's social and economic growth, including the growth and potential of neighbouring communes. Spatial considerations are then vital when examining income potential, especially that of communes within the sphere of influence of large urban centres. That influence can be stronger or weaker for different centres and the extent of the sphere can be wider or more narrow. Whatever its strength and range, a situation when one spatial unit, such as a commune, exerts an influence over its neighbours is known in the literature as spatial autocorrelation (Anselin, 1988; Getis, 2007; Kopczewska, 2006).

The article aims to identify the spatial effects of communes' own income potential in four selected provinces and their respective metropolitan areas. Four provinces with demographically the most extensive metro areas were selected: Mazovia with the Warsaw Metro Area, Lesser Poland with the Cracow Metro Area, Lower Silesia with the Wrocław Metro Area, and Greater Poland with the Poznań Metro Area.

2. Sources and Methods

The study relied on 2014 data drawn from the *Local Data Bank* published by the Central Statistical Office (CSO). The four selected metropolitan areas[1] were the largest in Poland, both in terms of area and demographic potential:

[1] The choice was limited by data availability on metropolitan area membership related to the studied communes. Identification of the membership followed the CSO documents: *Statystyczne Vademecum Samorządowca – portret obszaru metropolitalnego* (http://stat.gov.pl/statystyka-regionalna/statystyczne-vademecum-samorzadowca/) for Warsaw, Poznań, Cracow, and Wrocław; Statistical Office paper – *Studium spójności funkcjonalnej we Wrocławskim Obszarze Funkcjonalnym* (2015) for the Wrocław Metro Area.

1) *Warsaw Metro Area* (WarMA) of 71 communes and 1 city with county rights,
2) *Cracow Metro Area* (CraMA) of 51 communes and 1 city with county rights,
3) *Wrocław Metro Area* (WroMA) of 27 communes and 1 city with county rights,
4) *Poznań Metro Area* (PozMA) of 21 communes and 1 city with county rights.

The study proceeded in two stages. First, basic methods of descriptive statistics were used to analyse the communes' own income potential proxied by their own revenues per capita, as suggested by Lubińska et al. (2007: 77–78). Then, during the second stage, spatial relationships were explored through Moran's I global and local statistics.

Spatial autocorrelation, revealed through the use of Moran's statistics, is defined as a correlation between the values of the variable of interest for different spatial units. Two types of spatial autocorrelation are considered in the literature (Kossowski et al., 2013): spatial dependence (if values of Moran's statistics are positive) and spatial heterogeneity (if negative), the first concept being underpinned by the First Law of Geography (Tobler, 1970: 234–240): "everything is related to everything else, but near things are more related than distant things".

For communes' income potential proxied by their own revenues p.c., spatial autocorrelation was first analysed globally, i.e. using Moran's I global statistic (Moran, 1950; Kopczewska, 2006):

$$I = \frac{N}{S_0} \cdot \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{N}(x_i - \bar{x})^2}, \tag{1}$$

where w_{ij} denoted the spatial weight between the i-th and the j-th communes (and an element of spatial weights matrix $\mathbf{W}$)[2], x_i was the value of the variable of interest in the i-th commune, the mean of the variable over all communes, and N – their number.

Moran's I global statistic was calculated separately for all communes of the four provinces where metropolitan areas were located: Mazovia, Lower Silesia, Lesser Po-

[2] The neighbourhood structure was determined by the criterion of common border. First, a binary matrix was defined that held a 1 if and only if the corresponding communes shared a common border. Then, the matrix was row standardised to 1 to yield the spatial weights matrix W. The choice of this matrix follows the lines of earlier results of Getis and Alstadt (2004); it is easily interpretable and highly popular in social and economic applications (cf. Kozera, Głowicka-Wołoszyn, 2016; Kopczewska, 2006; Janc, 2006).

land, and Greater Poland, respectively. Additionally, the statistic was computed for member communes of the metropolitan areas only. Moran's I usually varies between –1 and +1, and its positive values signal clustering spatial dependence effects of neighbouring communes with similar values, while the negative ones suggest checkerboard patterns of spatial heterogeneity. Close to zero values of the statistic indicate no spatial effects for the variable of interest (Müller-Frączek, Pietrzak, 2008). The global statistic shows the strength and direction of spatial autocorrelation, but it is by definition global: covering all communes and averaging all local effects in the studied area. To study local effects in the neighbourhood of a particular commune, Moran's I statistic is needed. It identifies local clusters of high or low values, as well as outliers, which in the spatial analysis parlance denotes objects (communes) with values radically different than those of their neighbours (Anselin, 1995; Kopczewska, 2006):

$$I_i = \frac{(x_i - \bar{x})\sum_{j=1}^{N} w_{ij}(x_j - \bar{x})}{\sum_{i=1}^{N}(x_i - \bar{x})^2 / N}, \tag{2}$$

where the symbols bear the same meaning as in Equation (1).

Table 1. Relationship between communes and their neighbours

In the neighbourhood	In the commune	
	Low values	**High values**
High values	**HL** (negative autocorrelation)	**HH** (positive autocorrelation)
Low values	**LL** (positive autocorrelation)	**LH** (negative autocorrelation)

Source: own elaboration based on Kopczewska (2006)

To visualise global and local Moran's I statistics, a scatterplot is often used with the variable of interest plotted on the horizontal axis and the spatial lag, the averaged values of the neighbourhood, on the vertical axis (Table 1). The plot is centred at the means to yield the division into four quadrants: HH, LH, LL, HL. The first letter denotes relatively high or low values of the variable, and the second – of the lag. The HH and LL quadrants hold communes displaying local effects of spatial dependency, while the LH and HL ones of heterogeneity. The first type will produce clusters of communes with similar values: high in the HH quadrant and low in the LL quadrant. The second holds outliers: high valued communes surrounded by low valued neighbours in the HL quadrant, and their opposites in the LH quadrant. The calculations and plots were done using the R programme packages, such as *spdep*, *maptools*, and *shapefiles*.

3. Income Potential of Communes in Selected Metropolitan Areas

The biggest income potential is shown by the largest urban centres in the country: the metropolises, which combine the functions of communes and cities with county rights. The literature usually reserves the term "metropolis" for large municipalities of at least 500.000 inhabitants, but more often certain functional criteria are stated that include those extending far beyond the city borders (Szmytke, 2013: 37–38; Ładysz, 2009: 47–50). Following these criteria, 12 metropolises can be found in Poland: Białystok, Bydgoszcz, Gdańsk, Katowice, Cracow, Lublin, Łódź, Poznań, Rzeszów, Szczecin, Warsaw, and Wrocław (cf. *Unia Metropolii Polskich*). With the exception of Rzeszów, they can all boast more than 200.000 inhabitants, with Poznań, Wrocław, Łódź, and Cracow exceeding 500.000. By far the largest metropolis is the capital city of Warsaw with 1.700.000 residents (*Local Data Bank*). The socio-economic standing of the metropolises is reflected by their economic power and demographic capacity, as they account for one third of GDP, and one fifth of the total population (*Raport o polskich metropoliach – Poznań*, 2015). There are strong ties between a metropolis and the surrounding metropolitan area. Ładysz (2009: 51) notes that this hinterland frequently takes over some of the city's functions, especially those related to housing, services, and urban facilities. As a result, the economic condition (and consequently the income potential) of a given city's neighbourhood mirrors that of the city itself.

Close examination of a metropolis' (and in fact of any commune's) budgetary stable income items allows to predict its long-term ability to accomplish day-to-day tasks, support projects, and foster regional or local development. The most important element of the study is a commune's own income potential (Lubińska et al., 2007: 77–78) quantified by the sum of revenues from a share of nationally collected personal and corporate income taxes together with locally levied taxes on real estate, transportation, agriculture, forests, and stamp duties – revenues that are the most stable year-to-year.

The study set off with a descriptive summary of communes' own revenues per capita in the four metropolitan areas. Their median level turned out to be over twice that of a median commune in Poland, and in the cases of WarMa, WroMa, and PozMa higher than in the median communes of their respective provinces (Table 2). The initial results bode well for a successful finding of spatial dependency in these areas.

Of the four metro areas, the highest income potential was shown in WarMa, over PLN 3.400 p.c. median value, with some communes far surpassing the median: Warsaw, Lesznowola, Podkowa Leśna, and Nadarzyn with PLN 7.970, PLN 7.960, PLN 6.578, and PLN 6.185 per capita, respectively. This area was also the most diverse of the four with the interquartile range of PLN 1.085 p.c., and the coefficient

of variation of 15.8% (Table 2, Figure 1). The Warsaw Metropolitan Area is the largest in Poland both with respect to the covered area and population. It comprises 71 communes and one city with county rights. The population of over 3 million, over half of all the Mazovia Province, is concentrated in the capital and its density decreases with the distance from that centre, save only alongside the major roads and railways. Demographic trends observed in Poland show movements towards the centre and away from the periphery, so the communes on the fringes of WarMA gradually depopulate. Equally varied is the economic potential of the communes of WarMA: in 2014 out of 77% of companies registered in the province, remarkable 67% were based in the city itself (*Obszar Metropolitalny Warszawy w 2014 roku*, 2015). The disproportionate demographic and economic potentials – unquestionably the primary factors behind the level of communes' own revenues and financial self-sufficiency (Głowicka-Wołoszyn, Wysocki, 2014: 34–44) – bear on imbalance of income potential among the communes of WarMA. The magnitude of the imbalance can be measured by the coefficient of skewness, in this case reaching 0.282, a clear sign of the prevalence of relatively low level communes in the metro area (Table 2).

Table 2. Descriptive statistics of communes' own revenues in selected metro areas in Poland in 2014 (in PLN per capita, including cities with country rights)

Specification	Min	Median	Max	Range	IQR	Coeff. of variation (%)	Skewness*
Poland	456	1.347	47.173	46.718	750	27.9	0.120
Mazovia province	2.528	3.219	7.970	5.442	531	8.3	0.029
Warsaw Metropolitan Area	2.569	3.425	7.970	5.401	1.085	15.8	0.282
Lower Silesia province	2.574	3.284	9.096	6.522	640	9.7	0.206
Wrocław Metropolitan Area	2.767	3.343	6.536	3.769	533	7.9	–0.205
Greater Poland province	2.371	3.158	7.057	4.687	433	6.9	0.005
Poznań Metropolitan Area	2.501	3.282	6.581	4.080	667	10.2	–0.054
Lesser Poland province	2.229	3.116	5.328	3.100	657	10.5	0.104
Cracow Metropolitan Area	2.562	3.110	5.328	2.765	565	9.1	–0.014

* As defined in Wysocki, Lira (2003).

Source: own elaboration based on the *Local Data Bank* published by the CSO

The second largest median income potential was in WroMA (PLN 3.343), but in stark contrast to WarMA, without its disparity: the IQR was only PLN 532 and the coefficient of variation 7.9%, the lowest figures of all the four metro areas. It should be noted, however, that WroMA is much smaller than WarMA, having 27 communes and one city with county rights. The provincial capital Wrocław, with PLN 5.588, ranked second to Kobierzyce with its PLN 6.536, which was the winner in the income potential ranking. Skewness of –0.205 indicated the majority of higher level communes.

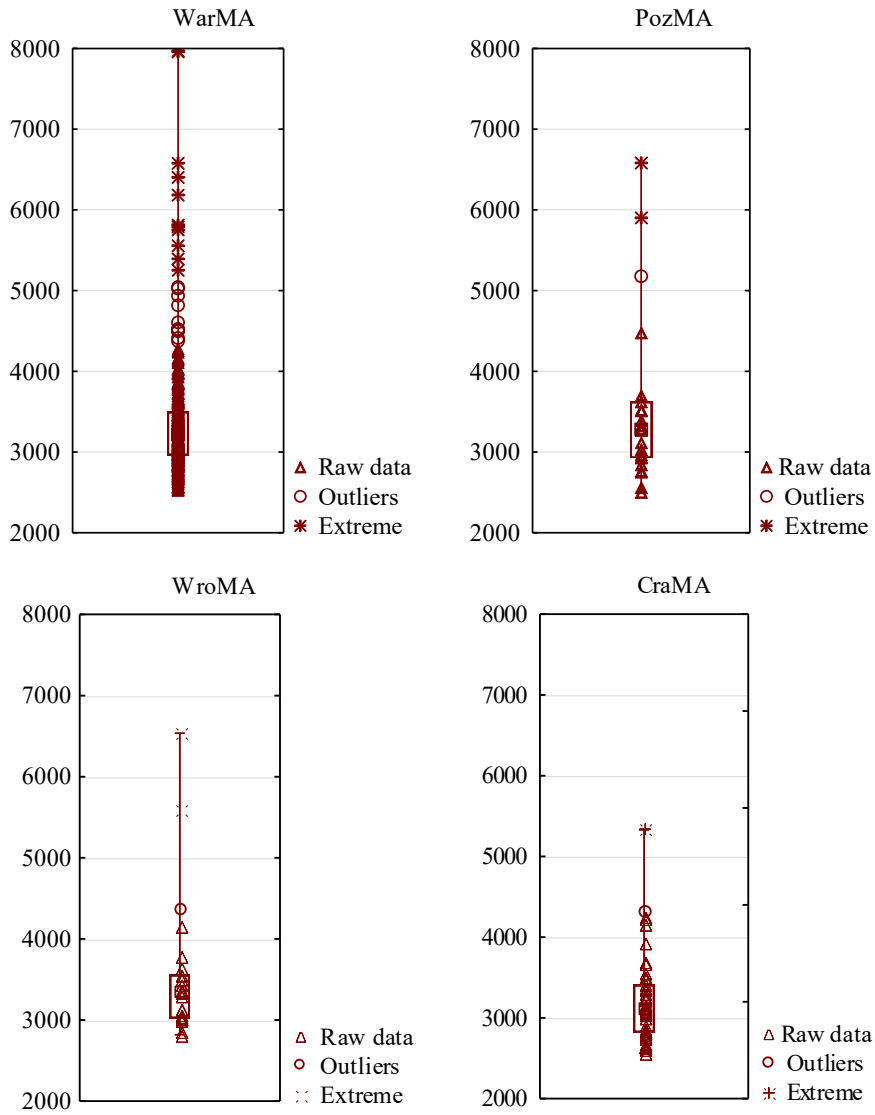


Figure 1. Boxplots of communes' own revenues in selected metro areas in Poland in 2014 (including cities with country rights)

Source: own elaboration based on the *Local Data Bank* published by the CSO

Poznań Metropolitan Area communes, much like WarMA and unlike WroMA, were characterised by high variability of their own income potential, especially with respect to the variability in the whole of the province. At the same time, in PozMA, as in WroMA, the skewness turned out negative, showing prevalence of higher level communes.

4. Spatial Effects of Communes' Own Income Potential in Selected Provinces and Metro Areas

An analysis of spatial effects can help to draw a broader picture of communes' own income potential than traditional quantitative methods. Identification of strength and character of spatial autocorrelation was facilitated by using Moran's I global statistic, a concise measure of similarity between spatial units. In all the four selected provinces, the values of the statistic were positive and statistically significant (Table 3), which translates into unambiguous spatial dependency and formation of clusters of communes with similar revenues per capita. The highest value of Moran's I global statistic, of 0.63, was observed in the Mazovia Province, while in the other provinces the values were close to half this figure. One could then venture to declare the existence of strong spatial dependency in the first case, and moderate one in the others.

Table 3. Moran's I global statistics of communes' own income potential

Provinces	Moran's I global statistic	p-value	Metropolitan areas	Moran's I global statistic	p-value
Mazovia	0.63	0.000	Warsaw	0.44	0.000
Lower Silesia	0.31	0.000	Wrocław	0.11	0.092
Greater Poland	0.25	0.000	Poznań	–0.08	0.589
Lesser Poland	0.33	0.000	Cracow	0.22	0.003

Source: own elaboration based on the *Local Data Bank* published by the CSO

Moran's I global statistic was also calculated for selected metropolitan areas. Their values were positive, except for PozMA, but smaller than the corresponding values for the provinces. This means that within the metro areas (much smaller than the provinces), their core centres do not form such prominent clusters, and in the case of Poznań there are no clusters at all. This is because in metro areas revenues are usually much higher than in the rest of the province, and with a much higher base the spatial effects may or may not be visible. Also, strong spatial ties between a metropolis and its neighbours may transcend the artificial borders of a metropolitan area. Hence, to study spatial autocorrelation in such areas, one should go far beyond their boundaries and consider whole provinces. Or as Tobler famously stated in his second law: "The phenomenon external to an area of interest affects what goes on inside".

The problem with Moran's I global statistic is that it only offers a global estimate, averaged over the whole studied area. Inside or close to metropolitan areas, communes are usually tied more strongly than such a global measure would suggest. For a more informative picture, one needs to apply a finer measure: Mo-

ran's I local statistics. Figure 2 depicts Moran scatterplots for the selected provinces, while Figure 3 – maps of the provinces with quadrant membership of their communes. Communes with significant Moran's I local statistics have their names written out on the plots of Figure 4.

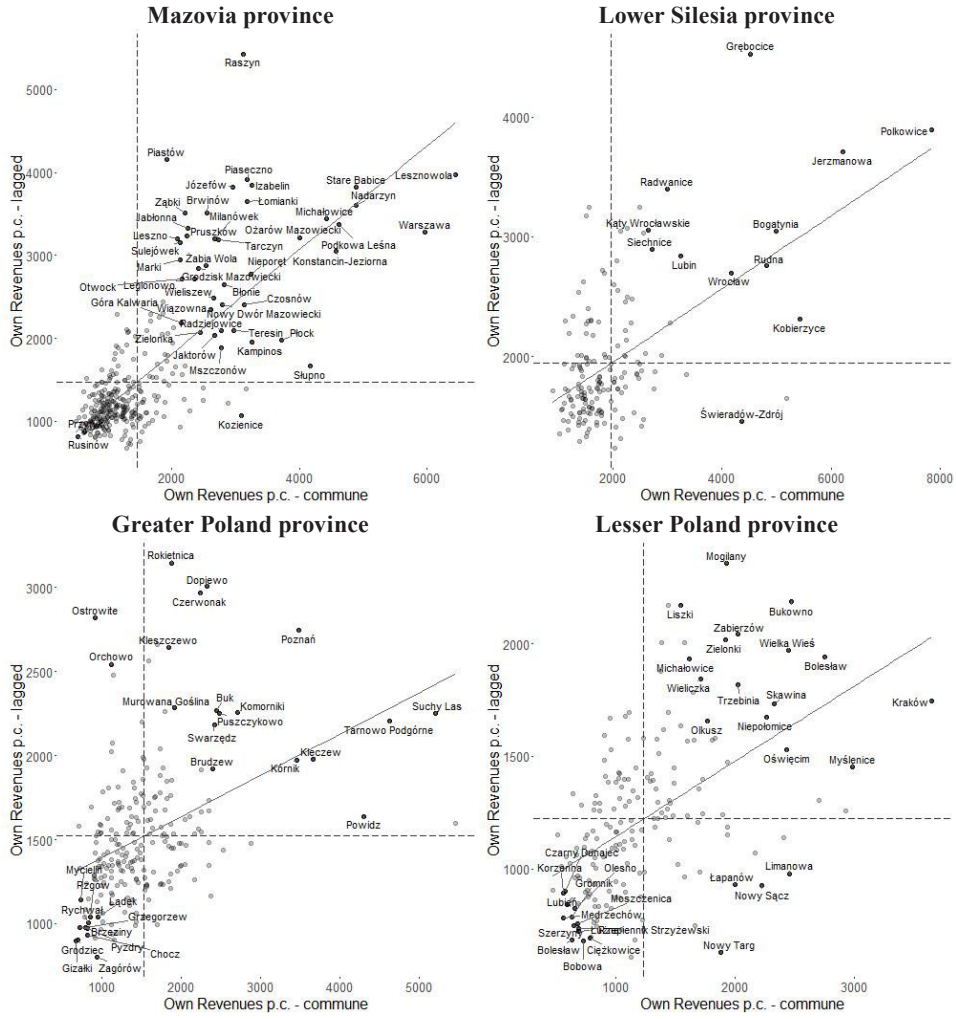
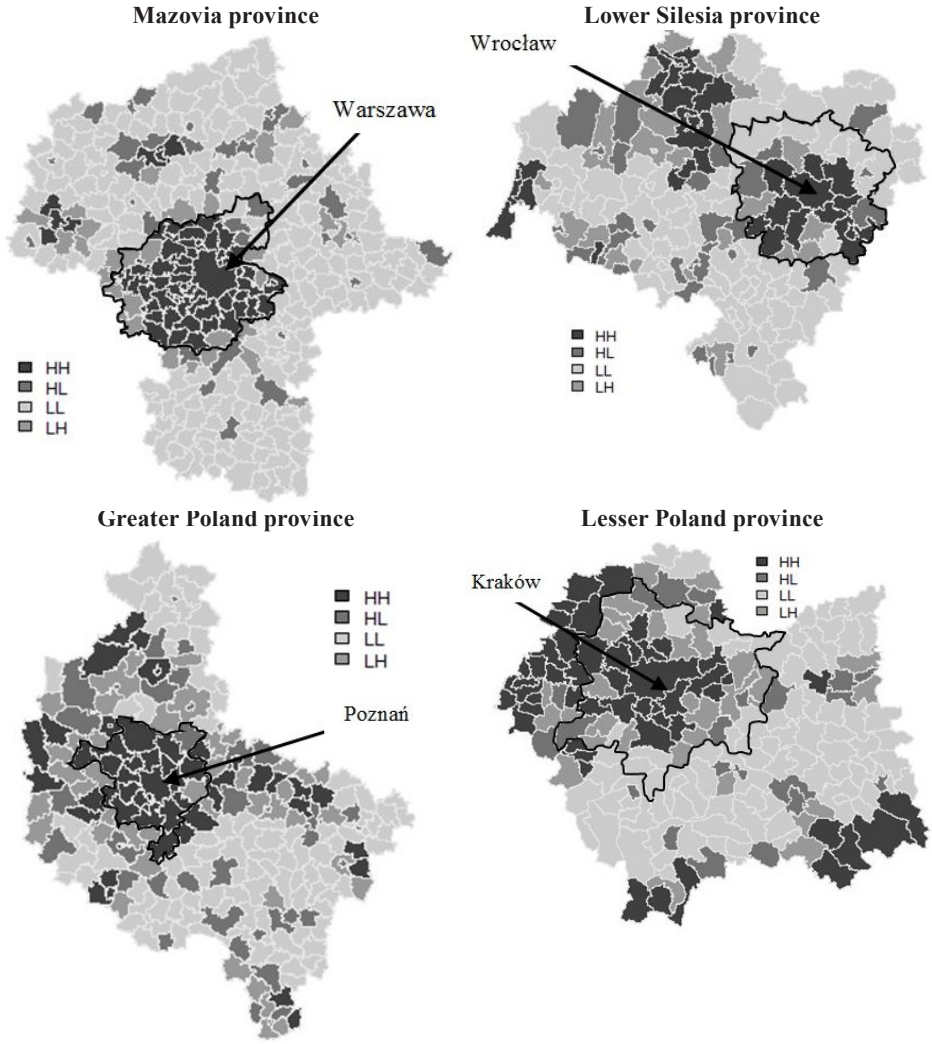


Figure 2. Moran scatterplot for income potential of communes in selected areas.

Source: own elaboration based on the *Local Data Bank* published by the CSO

A close analysis of the plots and maps shows strong concentration of high potential communes around the core city in WarMA. The capital together with 58 neighbouring communes (80% of all WarMA) formed an HH cluster that wove four concentric semicircles around its core towards the south-west but only two due

east. Figure 4 confirmed that most of them had significant Moran's I local statistics. The influence of Warsaw turned out then geographically lopsided, strong and broad towards the centre of the country, while weak and narrow away from it.



* Black border delimits the metro areas.

Figure 3. Moran scatterplot quadrant membership in selected metro areas

Source: own elaboration based on the *Local Data Bank* published by the CSO

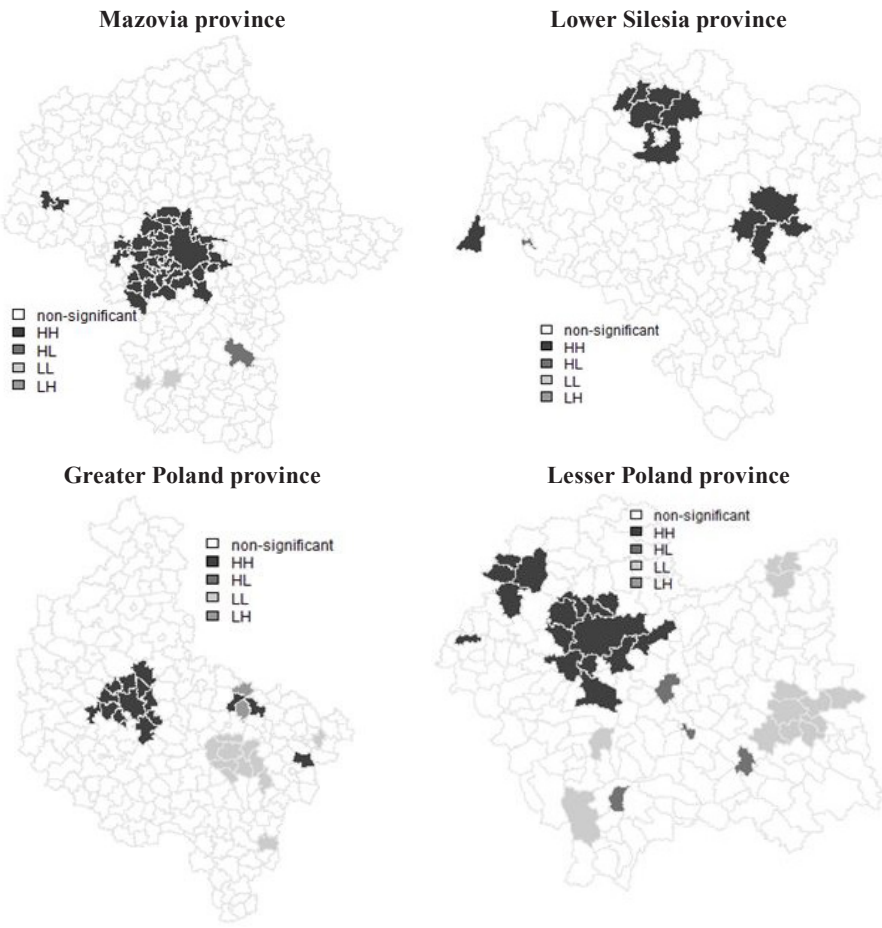


Figure 4. Significance of Moran's I local statistics for communes in selected metro areas

Source: own elaboration based on the *Local Data Bank* published by the CSO

Although global Moran's I was rather moderate in the Greater Poland province, the ties in and close to PozMA seemed stronger than what the overall measure would suggest. There, Poznań and 19 communes of PozMA (90%) formed an HH cluster, but it did stop at its boundary, embracing a few communes further to the south. Local Moran's I, however, was only significant for the PozMA communes. CraMA and WroMA showed smaller HH central clusters than either WarMA or PozMA. Both were formed by only one ring of communes around their core cities and constituted 19 and 11 communes, or 37% and 40% of their respective metropolitan areas. In Lesser Poland, the metropolitan cluster bordered on another one located to the north-east alongside the border with Silesia. In Lower Silesia, out of 11 communes of the metropolitan cluster, only three had significant local

Moran's I statistics suggesting a rather weak influence of Wrocław in comparison with the other three metro areas. Moreover, within that province, there was another even larger cluster located in the Copper Basin District to the north-west. High income potential of these communes hinges on the presence of natural resources and a high degree of industrialisation.

5. Conclusions

A commune's own income potential attests not only to its financial self-sufficiency, but first and foremost, to the capacity for promotion and sustentation of growth. This long term commitment of any local government demands accurate identification of its own potential: demographic, economic, and financial, which in turn requires employment of adequate methods. Spatial analysis can permit researchers to isolate clusters of communes similar with respect to the studied phenomena, show the strength and extent of influential centres, or pinpoint weaknesses of backward periphery. In-depth enquiry into the spatial effects of income potential in metropolitan areas may represent one of the key elements to better understanding of core-periphery dynamics of economic geography at the local level.

This study, with the help of global and local Moran's I statistics, found high and moderate levels of spatial autocorrelation in income potential among the communes of the four selected metropolitan areas. The elevated levels were observed in the largest metropolitan area around the capital city of Warsaw, whose influence penetrated four rings of high potential communes to the south-west and two rings to the east. The lowest levels were discovered around Wrocław, with only one full ring of high potential communes, and only three of them significantly.

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Autokorelacja przestrzenna potencjału dochodowego gmin w wybranych obszarach metropolitalnych

Streszczenie: Własny potencjał dochodowy gmin stanowi nie tylko o ich poziomie samodzielności finansowej, ale przede wszystkim o zdolności danej JST do kreowania rozwoju lokalnego. W celu ulepszenia prowadzonej polityki rozwoju regionalnego, w identyfikacji poziomu własnego potencjału dochodowego JST należy brać pod uwagę nie tylko wewnętrzny potencjał poszczególnych gmin (m.in.

demograficzny i gospodarczy), ale także uwzględnić ich lokalizację przestrzenną, a zwłaszcza oddziaływanie największych miast – metropolii. Celem artykułu jest ocena zjawiska autokorelacji przestrzennej w zakresie kształtowania się poziomu własnego potencjału dochodowego gmin w wybranych obszarach metropolitalnych – warszawskim, poznańskim, wrocławskim oraz krakowskim w 2014 roku. Badania empiryczne przeprowadzono na podstawie danych pochodzących z Głównego Urzędu Statystycznego (*Bank Danych Lokalnych*). Obliczenia wykonano w programie *R* z wykorzystaniem pakietów *spdep*, *maptools* i *shapefiles*.

Słowa kluczowe: autokorelacja przestrzenna, statystyki lokalna i globalna I Morana, metropolie, obszary metropolitalne, własny potencjał dochodowy

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