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Modifiable Areal Unit Problem: the issue of determining the relationship between microparameters and a macroparameter

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Abstract

Research background: One of the issues considered by economists such as Tinbergen (1939), Klein (1946), May, (1946), Theil (1965), Pawłowski (1969), Bołt *et al*. (1985) was to determine the mechanism of transition between the results of microeconomics and the theory of macroeconomics. As part of this research, Pawłowski (1969) raised the problem of establishing the relationship between microparameters and a macroparameter. In the presented article, Pawłowski's problem was expanded to include spatial economic research, where micro-dependencies and spatial macro-dependencies were analysed.
Purpose of the article: The purpose of the article is to establish the relationship between the microparameters set for SGM agricultural macroregions and the macroparameter referring to the whole area of Poland, where the parameters describe the economic dependencies regarding the impact of the size of farms in established region on their technical equipment. In the study, the economic relationships analysed in the case of individual SGM agricultural macroregions were defined as spatial micro-dependencies, and in the case of the entire area of Poland as spatial macro-dependencies.
Methods: The methodological part of the article describes the concepts of Modifiable Areal Unit Problem, causal homogeneity of spatial data, homogeneous system of sets of areal units, area and sub-areas of conclusions. The concepts of micro-dependencies and spatial macro-dependencies are presented. Basic equations allowing to determine the evaluation of the spatial macroparameter as a linear combination of spatial microparameters were also presented.

Findings & Value added: In the first stage of the study, spatial micro-dependencies were identified for subsequent SGM agricultural macroregions. In the second stage of the study, the relationship between spatial microparameters for single macroregions and the spatial macroparameter for Poland was determined. Establishing the relationship allowed to determine the macroparameter estimate for the whole area of Poland.

Introduction

The article focuses on the problem of determining the relationships that occur between microeconomic and macroeconomic dependencies within the framework of spatial economic research. The problem of establishing the relationship between microparameters and macroparameter was raised by Pawłowski when analysing time series (see Pawłowski, 1969). In the article, this problem was considered in the context of identifying economic dependencies based on spatial data analysis. In this case, solving the problem boils down to establishing economic dependencies at different levels of aggregation, and then attempting to assess the relationship between them.

In the case of spatial economic research on the issue of micro-dependencies and macro-dependencies, it is necessary to select appropriate sets of areal units and perform the process of spatial data aggregation. This means that research of this type fits into the subject of the Modifiable Areal Unit Problem (MAUP, see Anselin, 1989; Tobler, 1989; Haining, 2005; Suchecka (Ed.), 2014; Pietrzak, 2014a, 2014b, 2014c; Pietrzak, 2017; Pietrzak, 2018a, 2018b; Pietrzak & Ziemkiewicz, 2017). Within the MAUP, the following two issues are considered separately: the Aggregation Problem and the Scale Problem, both in the context of the possibility of receiving different research results (see Openshaw & Taylor, 1979; Openshaw, 1984; Suchecka (Ed.), 2014; Pietrzak, 2018b). Therefore, it is necessary to take into account the research methodology, where it is assumed that both the Aggregation Problem and the Scale Problem may occur, which should ensure the correctness of the procedure for determining the relationship between spatial microparameters and a spatial macroparameter (see Pietrzak, 2018b).

The research objective of the article is to identify the economic dependencies regarding the impact of the size of farms in a selected region on the level of their technical infrastructure, and then to establish the relationship between the microparameters for SGM agricultural macroregions and a macroparameter for the whole of Poland. The determined economic dependencies for individual SGM agricultural macroregions were defined as spatial micro-dependencies. Spatial macro-dependencies was identified for the entire territory of Poland. The implementation of the objective allowed to determine the macroparameter estimate for the area of Poland on the basis of a combination of a linear estimate of microparameters related to individual macroregions.

The spatial economic study was carried out in two stages. In the first stage, the spatial autocorrelation properties of selected processes were examined and the parameters of four spatial econometric models describing the economic dependencies adopted in the study were estimated. Further model specifications were referred to SGM agricultural macroregions. The results obtained allowed performing the initial identification of spatial dependencies for subsequent macroregions. In the second stage of the study, the relationship between the spatial microparameters and the spatial macroparameter was established, where the microparameter estimates for individual SGM agricultural macroregions were used. The implementation of the second stage of the study allowed determining the relationships between economic micro-dependencies and the economic macro-dependencies for selected spatial processes, which is an extension of Pawłowski's problem by spatial aspects.

Literature review

Over the past fifty years, a systematic development of statistical and spatial econometrics methods in economic research methodology has been observed (see Tobler, 1970; Cliff & Ord, 1973, 1981; Paelinck & Klaassen, 1979; Bivand, 1984; Anselin, 1988; Arbia, 1988, 2006; Zeliaś, 1991; Paelinck, 2000; Haining, 2005; Szulc, 2007; Bivand *et al*., 2008; LeSage & Pace, 2009, Suchecki (Ed.), 2010, 2012; Suchecka (Ed.), 2014; Pietrzak, 2018b). In addition, the availability and advancement of computer software that allows the use of this type of methods is dynamically expanding (Bivand *et al*., 2008), which has led to an increase in the number and quality of spatial economic research (Tobler, 1989; Haining, 2005; LeSage & Pace, 2009; Kiselitsa *et al*., 2018; Raszkowski & Bartniczak, 2018; Shuyan & Fabuš, 2019; Markhaichuk & Zhuckovskaya, 2019). Therefore, there are more scientific works, where the dimension of space is taken into account for the studied economic phenomena. The subject literature presents analyses of the spatial diversity of the phenomena studied (see Balcerzak, 2016a; 2016b; 2017; Nowak, 2018; Semenko *et al*., 2019), the results of the use of taxonomic methods for region analysis (see Smékalová *et al*., 2015; Simionescu, 2016; Reiff *et al*., 2016; Kuc, 2017a; Balcerzak & Pietrzak, 2017; Pietrzak *et al*., 2017; Tvaronavičienė & Razminienė, 2017; Hlaváček & Siviček, 2017; Rollnik-Sadowska & Dąbrowska, 2018; Kljucnikov *et al*., 2018; Rogalska, 2018; Horská *et al*., 2019), the results of the use of spatial statistics methods allowing the identification of spatial dependencies and measurement of spatial autocorrelation (see Furková & Chocholatá, 2017) and the results of the use of spatial econometrics models (see Pietrzak, 2012; Bal-Domańska, 2016; Kuc, 2017b).

It should be emphasized that in the case of economic spatial research, the key problem is the choice of a set of areal units at the selected level of aggregation. The Modifiable Areal Unit Problem is associated with the need to choose a set of areal units (see Anselin, 1989, p. 26; Tobler, 1989, p. 115; Haining, 2005, p. 150; Suchecka (Ed.), 2014, pp. 56–64) , within which separate issues are considered — the Aggregation Problem and the Scale Problem (see Openshaw, 1984, p. 8; Suchecka (Ed.), 2014, pp. 56–57). In both issues, the literature emphasizes the possibility of obtaining various results (see Anselin, 1989, p. 26; Arbia, 1989, pp. 1–4). The issue of obtaining different research outcomes as a result of a change in a set of areal units was referred to in the literature as the Aggregation Problem (Openshaw, 1984, p. 8, Suchecka, 2014 (Ed.), p. 57). In turn, aggregation of spatial data and the related change in the adopted level of aggregation may also lead to different research outcomes, which was described in the literature as the Scale Problem (see Openshaw, 1984, p. 8, Suchecka, 2014, p. 56).

The process of choosing a set of areal units and aggregation of spatial data can be considered much broader in the sense of a bridge that allows the transition between microeconomics and macroeconomics (see Theil, 1965, pp. 1–9). It should be emphasized that different methodological approaches were proposed in the literature regarding the transition from microeconomics to macroeconomics (see Tinbergen, 1939, p. 14; Klein 1946, pp. 93–108; May, 1946, pp. 285–298; Bołt *et al*., 1985, pp. 8–9). The data aggregation procedure should allow the transition from acceptable micro-dependencies within the theory of microeconomics to acceptable macro-dependencies within the theory of macroeconomics. For the problem understood in this way, Pawłowski posed a research problem in the form of determining the relationships that occur between dependencies for lower-order entities, and relationships for higher-order entities. Pawłowski defines this issue as a problem of establishing the relationship between micro-parameters and a macroparameter (see Pawłowski, 1969, p. 235; see also Bołt *et al*., 1985, pp. 33–34). Pawłowski's considerations concerned the analysis of time series and were conducted based on the example of the analysis of the dependencies between the demand for meat *per capita* relative to the average real price of meat (see Pawłowski, 1969, pp. 239–244). It should be emphasized, however, that Pawłowski does not limit the considerations to the approach presented by Theil, where the essence of the problem was to determine the relationship between parameters determining microeconomic relationships and parameters determining macroeconomic relationships (see Theil, 1956). Pawłowski proposes to determine the nature of the parameters based on the relationship between lower and higher order objects. This approach means the possibility of changing the nature of a parameter from a macroparameter into a microparameter due to a change in the level of aggregation (see Pawłowski, 1969, pp. 239–240).

In the context of economic research, Pawłowski drew attention to the fact that it is customary to use the term 'macroeconomic' in the analysis of higher-order entities, and the term 'microeconomic' when analysing lower-order entities (Pawłowski, 1969, p. 239). Pawłowski also emphasizes that the terms 'macroeconomic' and 'microeconomic' are used only within the framework of object-type aggregation (Pawłowski, 1969, p. 239). This remark is important in the context of spatial data aggregation, since it is an aggregation of the object type, where the geographical criterion is taken as the hierarchical criterion of economic objects. In Pietrzak's work (2018b, pp. 121–141), the Pawłowski's problem was presented for spatial economic research, where analyses are performed on the basis of spatial data. The difference between micro-dependencies and spatial macro-dependencies was determined on the basis of a criterion based on the possibility of changing the nature of the analysed economic dependencies (see Pietrzak, 2018b, pp. 62–70). Similarly to the results obtained by Pawłowski, it was proved in Pietrzak's work (2018b, pp. 60–75) that the estimate of a spatial macroparameter is a linear combination of the estimates of spatial microparameters and properly defined weights.

Research methodology

The key issue in economic spatial research is the choice of a set of areal units, since any analysis based on spatial data requires referring them to a specific set. The choice of the right set of areal units as part of the research problem determines the success of further research. Pietrzak (2018b, pp. 37–48) indicates the necessity of choosing such a set of areal units, where the spatial data referred to it are characterized by causal homogeneity. The concept of causal homogeneity of spatial data is an extension of the concept of causal homogeneity proposed by Zieliński (see Zieliński, 1991, pp. 7–17). Spatial data have this property if they are the result of the same combination of main causes for each of the areas forming a set of areal units (see Pietrzak, 2018b, pp. 37–48). Spatial data that display casual homogeneity should properly reflect the impact of causes within the adopted set of areal units (Tobler, 1989, pp. 115–116). This means that the use of data in the study that display casual homogeneity ensures proper identification of spatial economic dependencies (Tobler, 1989, pp. 115–116; Anselin, 1988, p. 27; Haining, 2005, pp. 150–151).

Spatial economic research can be conducted for different levels of aggregation, which is associated with the need to examine the causal homogeneity of spatial data for each of these levels. Therefore, Pietrzak (2018b, pp. 42–48) proposed the concept of a homogeneous system of sets of areal units. A homogeneous system of sets of areal units has been defined as collection of sets of areal units at different levels of aggregation, where spatial data related to these sets have the property of causal homogeneity. The use of sets of areal units belonging to a homogeneous system of sets of areal units should ensure the correctness of research performed.

Another important element of spatial economic research is determining the area or sub-areas of conclusions (see Pietrzak, 2018b, pp. 42–48), which consists in determining the boundaries of the area in relation to which conclusions will be drawn on the basis of the analysis performed. The boundaries of the area of conclusions should be set in such a way that there are no changes in the properties of the examined spatial process with shifts in space. The selection of the area of conclusions is significant, since the applications related to it are formulated on the basis of the research tools used. Failure to ensure the required properties of the examined spatial process within the adopted area of conclusions causes that the cognitive value of the research tool is reduced.

Pawłowski points to the need to divide the economic dependencies and structural parameters analysed from the macroeconomic and microeconomic perspectives. The regularities regarding higher order entities were defined by him as macro-dependencies, and the corresponding parameters as macroparameters (see Pawłowski, 1969, pp. 239–240). However, micro-dependencies and microparameters were determined in relation to lower-order objects. In the context of economic research, Pawłowski drew attention to the fact that it is customary to use the 'macroeconomic' term when analysing higher-order entities, and the 'microeconomic' term in the case of the analysis of lower-order entities (see Pawłowski, 1969, p. 239).

Pietrzak (2018b, pp. 62–75) made a distinction between spatial macro-dependencies and micro-dependencies, where a criterion based on the possibility of changing the nature of the economic dependencies was used. A change in the nature of the dependencies between processes is understood as a significant change in their strength or a change in the functional form of the dependencies examined at the transition between established areal units. Therefore, spatial micro-dependencies were defined as dependencies occurring between the processes analysed, which have a permanent character for all areal units forming the area of conclusions. Spatial macro-dependencies, in turn, were defined as dependencies in which their character changes within the adopted area of conclusions (see Pietrzak, 2018b, pp. 62–65). In the case of determining spatial micro-dependencies, it is possible to set the boundaries of the area of conclusions in such a way that the spatial dependencies between the analysed processes are of a permanent nature for all areal units forming this area. In this situation, the identified micro-dependencies can be generalized for the whole area of conclusions.

Spatial autocorrelation property of the processes analysed is identified in most spatial economic research. Then, in such cases, the specification of a spatial autoregression model should be adopted for the analysis of economic dependencies (see Arbia, 2006, p. 110; Suchecki (Ed.), 2010, pp. 241–254, Pietrzak, 2013, pp. 131–133), whose form was recorded by means of the following equation:

$$\mathbf{Y} = \beta_0 + \rho\mathbf{WY} + \beta_1\mathbf{X} + \boldsymbol{\varepsilon}, \tag{1}$$

where $\mathbf{Y}$, $\mathbf{X}$ are the vectors of spatial process values, β_0, β_1 are structural parameters, ρ is a spatial autoregression parameter, $\mathbf{W}$ is a neighbourhood matrix, where matrix elements reflect the existing spatial structure for *n* areal units (see Pietrzak, 2010a, 2010b; Bivand *et al.*, 2008), $\boldsymbol{\varepsilon}$ is white spatial noise.

In the case of the spatial autoregression model, it should be noted that the significant impact of the spatial lag of the explained process Y enforces a different interpretation of regression parameters than in the case of the linear regression model. Appropriate transformation of the spatial autoregression model allows deriving an $\mathbf{S}(\mathbf{W})$ matrix with the n^2 number of elements (see Pietrzak, 2013, pp. 131–133):

$$\mathbf{Y} = \frac{\beta_0}{1-\rho} + \mathbf{S}(\mathbf{W})\mathbf{X} + \boldsymbol{\varepsilon}, \tag{2}$$

$$\mathbf{S}(\mathbf{W}) = (\mathbf{I} - \rho\mathbf{W})^{-1}\beta_1, \tag{3}$$

where $\mathbf{I}$ is a unit matrix and $\mathbf{S}(\mathbf{W})$ is a matrix of detailed interpretation of the regression parameter, and the other symbols as in the case of equation (1). Individual elements of the $S(W)_{ij}$ matrix illustrate the strength of interaction from the explanatory process X. The selected element $S(W)_{ij}$ is interpreted as the average impact of the change in the explanatory process

X, which occurred in the region i, on the value of the process explained Y in region j.

Therefore, when determining the relationship between spatial microparameters and the spatial macroparameter, the specification of the spatial autoregression model should be adopted and the resulting consequences taken into account. A detailed derivation of the equation for the spatial macroparameter as a linear combination of microparameters was described in Pietrzak (2018b, pp. 121–141). In the methodological part, however, the basic steps and equations will be presented to determine this relationship, where four sub-areas of conclusions[1] comprising the whole of Poland (the macroparameter) were adopted. The adopted sub-areas of conclusions correspond to four microparameters and the macroparameter was referenced for the area of Poland. By means of equations (4-8), specifications of SAR spatial autoregression models for subsequent agricultural macroregions R1, R2, R3, R4 and the whole of Poland $R0$:

$$\mathbf{Y}_{R1}^{\text{NUTS4}} = \beta_{0,1}^{\text{NUTS4}} + q_{1,1}\mathbf{W}_{R1}\mathbf{Y}_{R1}^{\text{NUTS4}} + \beta_{1,1}^{\text{NUTS4}}\mathbf{X}_{R1}^{\text{NUTS4}} + \boldsymbol{\varepsilon}_{R1}, \quad (4)$$

$$\mathbf{Y}_{R2}^{\text{NUTS4}} = \beta_{0,2}^{\text{NUTS4}} + q_{1,2}\mathbf{W}_{R2}\mathbf{Y}_{R2}^{\text{NUTS4}} + \beta_{1,2}^{\text{NUTS4}}\mathbf{X}_{R2}^{\text{NUTS4}} + \boldsymbol{\varepsilon}_{R2}, \quad (5)$$

$$\mathbf{Y}_{R3}^{\text{NUTS4}} = \beta_{0,3}^{\text{NUTS4}} + q_{1,3}\mathbf{W}_{R3}\mathbf{Y}_{R3}^{\text{NUTS4}} + \beta_{1,3}^{\text{NUTS4}}\mathbf{X}_{R3}^{\text{NUTS4}} + \boldsymbol{\varepsilon}_{R3}, \quad (6)$$

$$\mathbf{Y}_{R4}^{\text{NUTS4}} = \beta_{0,4}^{\text{NUTS4}} + q_{1,4}\mathbf{W}_{R4}\mathbf{Y}_{R4}^{\text{NUTS4}} + \beta_{1,4}^{\text{NUTS4}}\mathbf{X}_{R4}^{\text{NUTS4}} + \boldsymbol{\varepsilon}_{R4}, \quad (7)$$

$$\mathbf{Y}_{R0}^{\text{NUTS4}} = \beta_{0}^{\text{NUTS4}} + q_{1}\mathbf{W}_{R0}\mathbf{Y}_{R0}^{\text{NUTS4}} + \beta_{1}^{\text{NUTS4}}\mathbf{X}_{R0}^{\text{NUTS4}} + \boldsymbol{\varepsilon}_{R0}, \quad (8)$$

where $\mathbf{Y}_{Ri}^{\text{NUTS4}}$ is a vector of the value of the explained process, $\mathbf{X}_{Ri}^{\text{NUTS4}}$ is a vector of the value of the explained process, $\beta_{0,\text{i}}^{\text{NUTS4}}, \beta_{0}^{\text{NUTS4}}, \beta_{1,\text{i}}^{\text{NUTS4}}, \beta_{1}^{\text{NUTS4}}$ denote structural parameters, $q_{1,\text{i}}$ and q_1 are spatial autoregression parameters, $\mathbf{W}_{Ri}$ denotes neighbourhood matrices, $\boldsymbol{\varepsilon}_{Ri}$ is white spatial noise, while Ri is *i*-th agricultural macroregion or area of Poland.

The application of the obtained empirical econometric models can be extended to analyse changes in the entire studied area (in the adopted subarea of conclusions). However, determining the evaluation of the microparameter and the interpretation of the spatial micro-dependencies for the

[1] It was assumed that each sub-area of conclusions was created on the basis of the boundaries of successive SGM agricultural macroregions, which results from the spatial economic study presented in the empirical part.

entire area requires averaging the impact of changes in the process X on the change in the process Y. Pietrzak (2013, pp. 133–138) proposed a set of four measures of spatial impact allowing interpretation of the average impact of the explanatory process X in econometric models with spatial autoregression. This set consists of the measure of the average direct impact A_D, the measure of the average indirect impact A_I, the measure of the average residual impact A_R and the measure of the average total impact A_T. With the knowledge of the final form of the econometric model (equations 4–7), the interpretation of the micro-dependencies for the entire sub-area of conclusions (Ri macroregion) can be approximated by measuring the average total impact A_T (zob. Pietrzak, 2018b, pp. 121–141).

The measure A_T is the sum of the measure of the average direct impact A_D, the measure of the average indirect impact A_I and the measure of the average residual impact A_R, which can be determined by the equation (see Pietrzak, 2013, pp. 133–138):

$$A_T = n^{-1}tr\big(\mathbf{S}(\mathbf{W})\big) + n^{-1}tr(\mathbf{W} * \mathbf{S}(\mathbf{W})^T) + n^{-1}tr(\mathbf{G} * \mathbf{S}(\mathbf{W})^T), \quad (9)$$

where the symbol tr means the trace of the matrix**,** ***G*** represents the matrix standardized by rows $\mathbf{F} = \mathbf{1} - \mathbf{I} - \mathbf{W}_B$, $\mathbf{1}$ is the one matrix, $\mathbf{I}$ is the unit matrix, $\mathbf{W}_B$ is the binary neighbourhood matrix, and the other designations are the same as for equations (1–8).

Substitution of the measure of the average total impact $A_T^{R\mathrm{i}}$ to the specification of spatial autoregression models determined by means of equations (4-7) can be used to formulate models expressing spatial micro-dependencies for the entire macroregion Ri. The value of the measure $A_T^{R\mathrm{i}}$ expresses the average strength of the micro-dependencies and can be equated with the microparameter estimate $\hat{\alpha}_{1,\mathrm{i}}$ determining the micro-dependencies at the level of the entire macroregion Ri. Therefore, the estimates of the microparameters $\alpha_{1,\mathrm{i}}$ can be expressed by measuring the average total impact of $A_T^{R\mathrm{i}}$. Specifications of micro-dependencies models for subsequent agricultural macroregions Ri are presented by means of equations:

$$Y^{R\mathrm{i}} = \hat{\alpha}_{0,\mathrm{i}} + \hat{\alpha}_{1,\mathrm{i}} X^{Ri}, \quad (10)$$

$$\hat{\alpha}_{0,\mathrm{i}} = \frac{\beta_{0,\mathrm{i}}^{\mathrm{NUTS4}}}{1 - q_{1,\mathrm{i}}}, \; \hat{\alpha}_{1,\mathrm{i}} = A_T^{Ri}, \quad (11)$$

where $Y^{R\mathrm{i}}$ and X^{Ri} stand for the values of the explained and explanatory process for the entire area of the macroregion Ri, $\hat{\alpha}_{0,\mathrm{i}}$ is estimate of constant, and $\hat{\alpha}_{1,\mathrm{i}}$ is estimate of the microparameter $\alpha_{1,\mathrm{i}}$.

Micro-dependencies models for agricultural macroregions Ri (equation 10) can be used to determine macro-dependencies for the area of Poland. The macro-dependencies will be a weighted average determined on the basis of established micro-dependencies, where the weight values will be determined on the basis of the spatial differentiation of the processes X and Y. The values of the process Y^{R0} for the entire area of Poland can be expressed as a weighted average of the values of the processes $Y^{R\mathrm{i}}$ related to four agricultural macroregions Ri:

$$Y^{R0} = \sum w_i \bar{Y}_i = w_1 Y^{R1} + w_2 Y^{R2} + w_3 Y^{R3} + w_4 Y^{R4}, \qquad (12)$$

where the weights w_i were determined on the basis of the share of the *i*-th agricultural macroregion in the total value of the process Y in Poland (area $R0$), and the other determinations are the same as in the case of equations (10-11).

Then, the equations of micro-dependencies models for Ri macroregions (equation 10) were substituted for equation (12), which allowed to derive the equation for the Y^{R0} process, related to the whole of Poland:

$$Y^{R0} = \left(\hat{\alpha}_{0,1} + \hat{\alpha}_{1,1} X^{R1}\right) w_1 + \left(\hat{\alpha}_{0,2} + \hat{\alpha}_{1,2} X^{R2}\right) w_2 + \left(\hat{\alpha}_{0,3} + \hat{\alpha}_{1,3} X^{R3}\right) w_3 + \left(\hat{\alpha}_{0,4} + \hat{\alpha}_{1,4} X^{R4}\right) w_4. \qquad (13)$$

In addition, in equation (13), X^{R0} was introduced in place of the $X^{R\mathrm{i}}$ processes, resulting in the equation expressed in the form:

$$Y^{R0} = \left(\hat{\alpha}_{0,1} + \hat{\alpha}_{1,1} \gamma_1 X^{R0}\right) w_1 + \left(\hat{\alpha}_{0,2} + \hat{\alpha}_{1,2} \gamma_2 X^{R0}\right) w_2 + \left(\hat{\alpha}_{0,3} + \hat{\alpha}_{1,3} \gamma_3 X^{R0}\right) w_3 + \left(\hat{\alpha}_{0,4} + \hat{\alpha}_{1,4} \gamma_4 X^{R0}\right) w_4, \qquad (14)$$

where $X^{Ri} = \gamma_i X^{R0}$.

In the last step, the appropriate transformation of equation (14) allowed the determination of equations (15–16) defining the spatial macro-dependencies and the macroparameter estimate ($\hat{\alpha}_1$) for the whole of Poland:

$$Y^{R0} = \left(\hat{\alpha}_{0,1}\, w_1 + \hat{\alpha}_{0,2}\, w_2 + \hat{\alpha}_{0,3}\, w_3 + \hat{\alpha}_{0,4}\, w_4\right) + \left(\hat{\alpha}_{1,1}\, w_1 \gamma_1 + \hat{\alpha}_{1,2}\, w_2 \gamma_2 + \hat{\alpha}_{1,3}\, w_3 \gamma_3 + \hat{\alpha}_{1,4}\, w_4 \gamma_4\right) X^{R0}, \quad (15)$$

$$Y^{R0} = \hat{\alpha}_0 + \hat{\alpha}_1\, X^{R0}, \quad (16)$$

$$\hat{\alpha}_0 = \hat{\alpha}_{0,1}\, w_1 + \hat{\alpha}_{0,2}\, w_2 + \hat{\alpha}_{0,3}\, w_3 + \hat{\alpha}_{0,4}\, w_4, \quad (17)$$

$$\hat{\alpha}_1 = \hat{\alpha}_{1,1}\, w_1 \gamma_1 + \hat{\alpha}_{1,2}\, w_2 \gamma_2 + \hat{\alpha}_{1,3}\, w_3 \gamma_3 + \hat{\alpha}_{1,4}\, w_4 \gamma_4. \quad (18)$$

Equation (15) expresses the relationship between the microparameter estimates ($\hat{\alpha}_{1,i}$) for agricultural macroregions Ri and the macroparameter estimate ($\hat{\alpha}_1$) for the entire area of Poland. According to the equation presented, the macroparameter estimate value ($\hat{\alpha}_1$) depends on the values of the microparameter estimates ($\hat{\alpha}_{1,i}$) as well as on the weight set w_i and γ_i.

Results

In accordance with the research objective assumed, the article presents a spatial economic study on the development of agriculture in Poland. In the first step, a homogeneous system of sets of areal units was determined. In Pietrzak's work (2018b, pp. 107–121), it was shown that spatial data on agriculture in Poland related to the NUTS 4, NUTS 3 and NUTS 2 systems are characterized by causal homogeneity. This means that a homogeneous system of sets of areal units should be created out of these three sets of areal units. However, for research on the development of agriculture at a higher level of aggregation (at the agricultural macroregions level), the administrative set of SGM agricultural macroregions was taken. This set was included in an annex to the Treaty on Poland's accession to the European Union, signed in 2003 (see Skarżyńska *et al*., 2005, p. 16). The need to designate the SGM macroregions system resulted from the adjustment of agricultural accounts in Poland before 2004 to the EU system of collecting accountancy data from agricultural holdings (see Skarżyńska *et al*., 2005, pp. 7, 16). The specificity of the created agricultural macroregions is that they clearly differ from each other in the values of variables concerning the development of agriculture and are spatially homogeneous due to the level of this development (see Skarżyńska *et al*., 2005, pp. 12–19). This means that an set SGM agricultural macroregions can be added to a homogeneous system of sets of areal units as part of research on agriculture in Poland.

Both spatial economic analyses and regional statistics based on SGM macroregions should lead to the obtainment of correct results.

Assuming a constant nature of regularities between processes within a defined sub-area of conclusions, the analysis will concern spatial micro-dependencies. In the case of accepting a sub-area of conclusions that goes well beyond the borders of the macroregion, one should be aware that the identified economic regularity is a spatial macro-dependencies (see Pietrzak, 2018b, pp. 60–75). Therefore, the sub-areas of conclusions were determined on the basis of the borders of four SGM agricultural macroregions. It should be emphasized, however, that regularities between processes concerning the development of agriculture should be of a permanent nature within the borders of individual agricultural macroregions. Therefore, the determined economic dependencies for individual SGM agricultural macroregions can be defined as spatial micro-dependencies. In the case of analysis for an area significantly exceeding the borders of a single SGM macroregion, a change in the nature of the economic dependencies should be expected. In the case of accepting a sub-area of conclusions that goes well beyond the borders of the macroregion, one should be aware that the identified economic regularity is a spatial macro-dependencies. This means that the regularities established for the area of Poland should be treated as spatial macro-dependencies.

A characteristic feature of Poland's agriculture is the fragmentation of farms and the spatial diversity of agricultural culture and the level of its development (Michna, 2007, pp. 5–21). It can be stated that the spatial diversity of the agrarian structure in Poland is permanent, which results from economic, social and historical factors (see Pietrzak & Walczak, 2014, pp. 1036–1038; Walczak & Pietrzak, 2016, pp. 468–470). The consequence of the significant fragmentation of Polish agriculture is the low average area of farms. In Poland, the size of an agricultural holding is one of the most important variables determining its level of development, because small-scale farms are unable to generate an adequate level of income to function efficiently (see Michna, 2007, pp. 5–11). Too large fragmentation of farms means no possibility of progress, increasing technical equipment of labour through the purchase of new machines and a high level of unit production costs. This means that the faulty agrarian structure is becoming a strong destimulant of proper changes and development of agriculture (see Michna, 2007, pp. 5–13).

The article formulates a research problem in the form of a hypothesis that in Polish agriculture, the average size of farms in the studied region determines their level of technical equipment. The level of technical equipment of farms within a selected region is understood as the average number of tractors per farm. The hypothesis about the significant impact of the size of a farm in agriculture on the level of technical equipment is justified by the fact that the size of a farm is an important element of generating income by the farm. Given the importance of the farm size factor in obtaining agricultural income, the positive nature of this dependencies should be assumed for all agricultural macroregions. This is due to the fact that farms with a small area are not able to generate an adequate level of income enabling the purchase of specialized agricultural machinery and increasing the level of technical equipment (see Michna, 2007, pp. 11–21, Malaga-Toboła, 2010, pp. 143–147). The study used spatial data at the district level (NUTS 4) made available by the Central Statistical Office in connection with the publication of the results of the 2002 Agricultural Census.

In accordance with the assumed objective of the article, subsequent actions were carried out to determine the relationship between the macroparameter and the microparameters describing the adopted dependencies between selected processes in agriculture. Therefore, in the first stage of the study, an attempt was made to identify the economic dependencies assumed in the research hypothesis for the designated sub-areas of conclusions (successive SGM agricultural macroregions). Pietrzak (2018b, pp. 121–141) indicates the concentration of high data values and separately low values into clusters in the case of average size of farms. Therefore, in the first stage, the property of spatial autocorrelation was examined for the average size of farms and the level of their technical infrastructure. Identification of the occurrence of spatial autocorrelation was carried out using the Moran test (see Moran, 1948, pp. 243–251; Zeliaś (Ed.), 1991, pp. 102–107; Suchecki (Ed.), 2010, pp. 112–114). The obtained values of Moran *I* statistics and *p*-values of the test are presented in Table 1. In all of the cases examined, strong positive spatial autocorrelation was found for both processes.

Due to the identification of spatial autocorrelation properties for the selected processes, in the next step of the study the parameters of four spatial autoregression models for subsequent SGM agricultural macroregions were estimated. The adopted model specifications are consistent with the specifications recorded in the methodological part of the article using equations (4–7). The use of selected forms of econometric models should allow identification of economic dependencies assumed in the study for each of the agricultural macroregions.

The obtained results of parameter estimation for final models are shown in Table 2. For all models, a significant impact of the explanatory process and the spatial lag of the explained process were found. In addition, the spatial autocorrelation property for the residual process was checked using the Moran test and this property was not found for each of the models. The results obtained allowed the identification of the economic dependencies assumed in the study for all SGM agricultural macroregions. The lowest regression parameter estimates were obtained for empirical models related to the macroregion $R1$ $\left(\hat{\beta}_{1,1} = 0.017\right)$ and the macroregion $R2$ $\left(\hat{\beta}_{1,2} = 0.021\right)$, which are characterized by a high level of concentration agrarian structure. Much higher values of the regression parameter estimates were obtained for the model related to the agricultural macroregion $R4$ $\left(\hat{\beta}_{1,4} = 0.049\right)$ and to the agricultural macroregion $R3$ $\left(\hat{\beta}_{1,3} = 0.041\right)$, which are characterized by a low concentration of arable land. The obtained estimates of the autoregression parameter $q_{1,i}$ for subsequent macroregions form a similar scheme as in the case of regression parameter estimates. The highest estimates of the autoregression parameter were obtained in empirical models for the macroregions $R4$ ($\hat{q}_{1,4} = 0.585$) and $R3$ ($\hat{q}_{1,3} = 0.544$) and significantly lower estimates in the case of empirical models related to the macroregions $R2$ ($\hat{q}_{1,2} = 0.438$) and $R1$ ($\hat{q}_{1,1} = 0.321$). This means that agricultural processes within regions characterized by a low concentration of arable land are marked by stronger positive spatial dependencies in comparison with regions with a high level of arable land concentration.

In the second stage of the study, spatial micro-dependencies were determined for subsequent SGM agricultural macroregions. For this purpose, the estimates of the parameters $\beta_{1,i}$ for individual macroregions calculated in the first stage were used. Based on the parameter estimates $\left(\hat{\beta}_{1,i}\right)$, the values of the measure of the total interaction A_T^{Ri} were determined in accordance with equation (9). This allowed determining the estimates of microparameters $\alpha_{1,i}$ for subsequent SGM agricultural macro-regions based on equations (10-11). For subsequent measures of the average total impact A_T^{Ri} *p*-value was also determined, which allowed the statistical significance of the microparameters $\alpha_{1,i}$ to be determined (see LeSage & Pace, 2009, pp. 34–43; Pietrzak, 2013, p. 149).

The obtained results allowed the interpretation of spatial micro-dependencies for subsequent SGM agricultural macroregions. All microparameters $\alpha_{1,i}$ proved to be statistically significant. The established micro-dependencies for the areas of single SGM agricultural macroregions should correctly reflect the dependencies between the size of farms in the region and the level of their technical utilities. In the case of micro-dependencies analysis, the highest estimates of the microparameters $\alpha_{1,i}$ were obtained for the model related to the agricultural macroregion R4 $\left(\hat{\alpha}_{1,4} = 0.095\right)$ and to the agricultural macroregion R3 ($\hat{\alpha}_{13} = 0.074$), which are characterized by a low level of concentration of agricultural land. In turn, the macroregions R1 and R2 with higher level of agrarian structure concentration received lower microparameter estimates: the macroregion R1 $(\hat{\alpha}_{1,1} = 0.023)$ and the macroregion R2 $(\hat{\alpha}_{1,2} = 0.034)$.

In the last step of the study, the relationship between spatial microparameters and the spatial macroparameter was determined. This allowed to determine the spatial macroparameter estimate describing the economic dependencies between the average size of farms in Poland and the level of its technical infrastructure. Therefore, on the basis of equations (15–18), the relationship between the microparameters $\alpha_{1,i}$ and the macroparameter α_1 was determined for the economic dependencies considered in the study. To determine the relation, the estimates of the microparameters $(\hat{\alpha}_{1,i})$ for four SGM agricultural macroregions were used (see Table 3). Then the macroparameter estimate $(\hat{\alpha}_1)$, was calculated, which amounted to 0.058 for the whole of Poland. The results obtained are presented in Table 4, where the weight values w_i and γ_i are also included. The designated macroparameter estimate should be interpreted as the average impact of farm size changes on the level of their technical infrastructure for the whole of Poland.

Discussion

The analysis of spatial micro-dependencies and macro-dependencies is an integral part of spatial economic research. In such a case, one should consider the possibility of the occurrence of the Modifiable Areal Unit Problem and the related issue of the correctness of the implementation of subsequent stages of the study, which refer to posing a research problem, performing a spatial economic analysis and attempting to solve the research problem based on the conclusions obtained from the analysis (see Pietrzak, 2018b, pp. 37–60). Therefore, in the methodological part of this article, the following concepts were introduced: the causal homogeneity of spatial data, homogeneous system of sets of areal units and the area (sub-areas) of conclusions. Establishing a homogeneous system of sets of areal units as part of the spatial economic analysis stage is crucial because it allows us to draw the correct conclusions that will be used to solve the research problem. Finally, it should be generalised that as part of the research problem posed, there is only one homogeneous system of sets of areal units that allows identification and description of dependencies for the analysed socio-economic phenomena. A homogeneous system of sets of areal units determined as part of spatial economic analysis is a prerequisite for obtaining relevant results. However, one should be aware that the set of areal units used at selected levels of aggregation will never perfectly reflect the impact of real convolutions of the main causes (see Anselin, 1988, pp. 27; Hainnig, 2005, pp. 150–151; Pietrzak, 2018b , pp. 37–42).

In the case of a homogeneous system of sets of areal units, it can be stated that the selection of sets of areal units is limited from below and from above, in terms of the causal homogeneity of spatial data. This limitation lies in the fact that spatial data systems are usually not homogeneously causally at a very low or very high level of aggregation. Therefore, a homogeneous system of sets of areal units should be limited to causal homogeneity of spatial data at the appropriate levels of aggregation. This means that data that display causal homogeneity at a selected level of aggregation may lose this property at a higher level of aggregation. It should be emphasized that in the case of spatial data, estimating their causal homogeneity is very difficult. In each case, the decision as to the choice of a set of areal units and the determination of the causal homogeneity of spatial data must be made by the researcher in an arbitrary manner, but only within the research problem. Therefore, the researcher should establish a homogeneous system of sets of areal units based on available economic knowledge, results of previous research and own scientific experience (see Pietrzak, 2018b, pp. 37–42).

The article sets out a homogeneous systems of sets of areal units for spatial economic research on agriculture in Poland. The use of set of areal units from the adopted collection should ensure the correct analysis of phenomena related to the level of development of Polish agriculture. A homogeneous systems of sets of areal units was created out of four set: the NUTS 4 set of areal units at the lowest level of aggregation, the NUTS 3 set, the NUTS2 set and the set of SGM agricultural macroregions at the highest level of aggregation. The regions that make up each of the four sets of areal units should be internally homogeneous in terms of agricultural development and culture. In the research conducted it is possible to adopt other sets of areal units, where the spatial data referred to them will not have causal homogeneity. In this situation, spatial economic analysis will be based on spatial data that does not correctly reflect the impact of causes. The results obtained, regarding the properties of the processes and the dependencies between them, will be a reflection of the various weaves of causes. As a result of adopting a wrong set of areal units, the cognitive value of the results obtained will always be reduced. It should be emphasized, however, that the occurrence of such a situation does not exclude the obtained research results, since the cognitive value of these results depends on the extent to which causal homogeneity does not occur for the spatial data used (see Tobler, 1989, pp. 115–116; Hainnig, 2005, pp. 150–151; Pietrzak, 2018b, pp. 48–60).

It is worth emphasizing that the identification of spatial macro-dependencies based on the use of econometric models is the first step in most spatial economic studies. In the research conducted, spatial macro-dependencies are most often determined for the entire country or for a group of countries. Despite the lower cognitive value, when compared to the spatial micro-dependencies, the results obtained regarding spatial macro-dependencies can also be the basis for scientific conclusions and constitute valuable material to solve the research problem undertaken. According to the methodology presented in the article, further analysis of the research problem should lead to testing for causal homogeneity of the spatial data and establishing a homogeneous system of sets of areal units. All this allows narrowing the area of conclusions and the selection of appropriate research tools and, as a consequence, the identification of spatial micro-dependencies. It should be emphasized that spatial micro-dependencies have a higher cognitive value compared to macro-dependencies, because their interpretation guarantees the drawing of correct conclusions, which, in turn, translates into the quality of the solution to the research problem.

An economic study carried out in the article showed that the identification of spatial micro-dependencies allows the determination of the macro-parameter estimate as a linear combination of the estimates of the micro-parameters. This procedure significantly enriches the performed spatial economic research, since it creates the opportunity to compare the designated macroparameter estimate with those obtained on the basis of econometric models. It also gives an opportunity to understand how micro-dependencies from individual sub-areas of conclusions make up the macro-dependencies image for the entire research area. Calculation of the macro-parameter estimate requires the knowledge of microparameter estimates and determining the appropriate set of weights (see equations 15–18). It should be noted that the macroparameter estimate is similar to the micro-parameters estimates in the case of similarity of their values and similar weight values. However, when the microparameters estimates differ significantly from each other, this may significantly affect the obtained macro-parameter estimate. This effect can be further enhanced by the difference in weight values.

Conclusions

The subject matter discussed in the article is related to the analysis of spatial micro-dependencies and macro-dependencies and the process of establishing relationships between them. The search for a bridge between the results of microeconomics and the theory of macroeconomics is one of the most important problems posed by economists. The problem of determining the relationship between micro-dependencies and macro-dependencies was put forward by Pawłowski in the case of research based on time series. In the article, this problem was extended for spatial economic research based on spatial data. The inclusion of the spatial aspect in the problem of establishing the relationship between micro-dependencies and macro-dependencies indicated the need to link it with the Modifiable Areal Unit Problem. The article reviews the literature which examines the issue of linkages between the concepts of micro-dependencies and economic macro-dependencies. The issue of the Modifiable Areal Unit Problem in the aspect of spatial economic research and the related issue of their correctness were also considered. The methodological part of the article describes the concepts of causal homogeneity of spatial data, a homogeneous system of sets of areal units, the area and sub-areas of conclusions. Also, a distinction between spatial micro-dependencies and spatial macro-dependencies was made. The research objective of the article was to determine the relationships between the microparameters and the macroparameter as part of the analysis of phenomena related to the development of agriculture in Poland.

In accordance with the research objective assumed, a study was conducted on identifying economic dependencies regarding the impact of average size of farms in a given region on the level of their technical infrastructure. The article determines a homogeneous system of sets of areal units for research on the development of Polish agriculture, where the set of SGM agricultural macroregions was used in the analysis. Therefore, the economic dependencies determined for individual SGM macroregions were defined as spatial micro-dependencies, and the spatial macro-dependencies was determined for the whole of Poland. On the basis of the obtained results regarding the identification of micro-dependencies, the relation between the microparameters for agricultural macroregions and the macroparameter was established. This allowed the macroparameter estimate to be determined based on a linear combination of the microparameters estimates and the adopted weight sets. The article ended with a discussion in which the conclusions drawn from theoretical considerations as well as empirical research were presented. The study extended the problem posed by

Pawłowski by spatial aspects, where the author's measures of average spatial impact were used to determine micro-dependencies for the entire macroregion.

In future empirical studies, the analyses made regarding the development of agriculture in Poland may be extended to identify other economic micro-dependencies and macro-dependencies and to analyse the relationships between them. These dependencies may concern subsequent aspects of the farm production process, including the agrarian structure of farms in the region, animal and crop production efficiency, and mineral fertilizer consumption. It should be emphasized that the subject of the research conducted in the article may be any economic phenomena, the choice of which depends solely on the adopted research problem. Thus, the research methodology presented should be used in subsequent spatial economic research to confirm its usefulness in the field of spatial statistics and econometrics.

However, attention should be paid to the research limitations of the approach presented in the article, where the main limitations include the lack of data availability at a sufficiently low level of aggregation. As part of official statistics, spatial data is not usually made public for all levels of aggregation. In most cases, data is published for higher aggregation levels than the ones they were actually collected at. Nevertheless, the progress observed in recent years in the area of increasing the effectiveness of official statistics and the decreasing cost of collecting and sharing data at low levels of aggregation raise expectations that these restrictions may have lesser practical significance in the future.

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Annex

Table 1. Moran test results

SGM agricultural macroregions		
Macroregion $R1$		
Spatial process	Moran *I* statistics	p-value
Average size of farms	0.246	~0.00
Level of technical infrastructure	0.311	~0.00
Macroregion $R2$		
Spatial process	Moran *I* statistics	p-value
Average size of farms	0.204	~0.00
Level of technical infrastructure	0.390	~0.00
Macroregion $R3$		
Spatial process	Moran *I* statistics	p-value
Average size of farms	0.421	~0.00
Level of technical infrastructure	0.611	~0.00
Macroregion $R4$		
Spatial process	Moran *I* statistics	p-value
Average size of farms	0.433	~0.00
Level of technical infrastructure	0.682	~0.00
Poland area $R0$		
Spatial process	Moran *I* statistics	p-value
Average size of farms	0.533	~0.00
Level of technical infrastructure	0.522	~0.00

Table 2. Results of estimation of the parameters of models for SGM macroregions

Model for macroregion $R1$			**Model for macroregion $R2$**		
Parameter	Parameter estimate	p-value	Parameter	Parameter estimate	p-value
$\beta_{0,1}$	0.189	~0.00	$\beta_{0,2}$	0.191	~0.00
$\beta_{1,1}$	0.017	~0.00	$\beta_{1,2}$	0.021	~0.00
$q_{1,1}$	0.321	~0.00	$q_{1,2}$	0.438	~0.00

Table 2. Continued

Model for macroregion $R3$			Model for macroregion $R4$		
Parameter	Parameter estimate	p-value	Parameter	Parameter estimate	p-value
$\beta_{0,3}$	0.164	~0.00	$\beta_{0,4}$	0.144	~0.00
$\beta_{1,3}$	0.041	~0.00	$\beta_{1,4}$	0.049	~0.00
$q_{1,3}$	0.544	~0.00	$q_{1,4}$	0.585	~0.00

Table 3. Evaluation of micro-dependencies for SGM agricultural macroregions

Macroregion R1			Macroregion R2		
Microparameter	Estimate	p-value	Microparameter	Estimate	p-value
$\alpha_{0,1}.$	0.231	-	$\alpha_{0,2}.$	0.306	-
$\alpha_{1,1}.$	0.023	~0.00	$\alpha_{1,2}.$	0.034	~0.00
Macroregion R3			**Macroregion R4**		
Microparameter	Estimate	p-value	Microparameter	Estimate	p-value
$\alpha_{0,3}.$	0.277	-	$\alpha_{0,4}.$	0.344	-
$\alpha_{1,3}.$	0.074	~0.00	$\alpha_{1,4}.$	0.095	~0.00

Table 4. Macro-dependencies analysis for the area of Poland

Macro-dependencies for Poland		Adopted weight values w_i and γ_i				
		Weight w_i	w_1	w_2	w_3	w_4
Macroparameter	Macroparameter estimate	Weight values	0.23	0.26	0.33	0.18
α_1	0.058	Weight γ_i	γ_1	γ_2	γ_3	γ_4
α_0	0.291	Weight values	1.73	1.22	0.83	0.40