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Spatial Dependence Structure of Total Factor Productivity in Polish Local Administrative Districts

Abstract: The interaction between space (location) and the processes of accumulation (growth) is one of the most interesting and at the same time the most difficult areas of modern economic theory. The up till now empirical research on determinants of regional productivity in the case of Poland is however relatively scarce. Most studies focus on explaining the variation in regional income per capita mostly at NUTS–2 and NUTS–3 levels, and only a few take into account a highly spatially disaggregated NUTS–4 level. We aim to fill this important gap. The present article has several objectives. We try to explain the spatial patterns of productivity, to identify the spatial range of productivity spillovers empirically and to identify the determinants of the Total Factor Productivity (TFP) growth in Poland with the use of spatial econometric modeling and the extended version of the Nelson-Phelps (1966) model. The study adopts an NUTS-4 level of local administrative districts (powiats) which we find superior on both theoretical (market closing) and empirical grounds (spatial modeling). TFP in Poland assumes the highest values in the metropolitan centers and spreads out on their nearest surroundings with the maximum value for Warsaw. The secondary local hills in TFP are located in cities or towns with county rights. TFP, in general, shows a downward trend as one moves from the west to the east with the lowest values observed in the south-eastern part of Poland. The range of TFP spillover is found to be of roughly 175–200 km and is nonlinearly decreasing from the local productivity hills. Furthermore, the rate of growth of TFP shows spatial autocorrelation and is found to depend positively on the rate of increase in human capital endowment and on the gap from the leader under certain assumptions. We find no evidence of the channel through imports. However, the FDI channel is found to be robust and strong.

Keywords: TFP, regional development, determinants of productivity, regional economics, spatial econometrics

JEL: R11, R12, R13, C23

1. Introduction

Distance seems to matter in most economic processes. The gravity approach incorporating the negative impact of distance is one of the most robust empirical specifications explaining the intensity of relations. Furthermore, distribution of human activity is uneven both at international level and within countries. If distance matters and distribution of activity is uneven, then we should expect spatial patterns in regional TFP and diffusion of knowledge to emerge.

In the literature, technology and knowledge diffusion are analyzed theoretically and empirically both at an international and regional level. Neoclassical growth theory (Solow, 1956) attributes the increase in GDP per capita in the long run to the impact of exogenous technological change, and the rate of technological change is common to all economies. It can happen if we assume perfect diffusion of technology. At the same time, constant returns and zero transport cost are applied making the general framework aspatial. Differences in incomes are due to different capital endowments and initial knowledge stocks. In this setup, economic policy can affect the rate of economic growth only in the transition phase to the steady-state. The tendency towards absolute convergence in income levels is driven by the diminishing returns to capital (Barro, Sala-i-Martin, 2004).

The presented article has several objectives. First of all, we wanted to take a look at the spatial patterns of productivity at as low a level of spatial aggregation as possible. Unlike most of the previous regional analyses of the Polish economy, which were carried out mostly at the level of voivodships or sub-regions (i.e. Tokarski, Roszkowska, Gajewski, 2005; Tokarski, 2010) our study assumes the level of local administrative districts (LADs) called powiats (Nomenclature of Territorial Units for Statistics: NUTS–4). Given that the subject of the analysis is productivity characterizing the particular region, the study carried out at the level of voivodships would lead to too far-reaching generalizations. Each of the Polish voivodships is internally so highly diversified that it is hard to talk about the processes occurring simultaneously throughout the whole region. Certain economic and social relations are observed in the major cities, others in towns, and others all together in the rural counties. It should be noted that the LADs are much more homogeneous internally in comparison with the neighboring areas, and at the same time, in contrast to the sub-regions, constitute separate administrative units subject to the competent local authorities have some effect on the evolution of the socio-economic situation of the territory. We believe that the analysis of the mechanisms of change in productivity and its determinants in the Polish conditions should be carried out at the local level, especially if the purpose of the analysis is the identification of the endogenous potential of the region.

The second aim of the article was to identify the spatial range of productivity and knowledge spillovers empirically. Thirdly we try to outline the determi-

nants of TFP and its spatial dependence in Poland with the use of spatial econometrics tools.

The structure of the rest of the article is as follows. Section 2 shortly reviews the concept of total factor productivity and its determinants in the theoretical and empirical literature. Section 3 presents the model of Nelson and Phelps (1966) and its extensions. We also discuss its potential theoretical effects. In Section 4 we show the estimates of TFP in Polish LADs and its spatial correlation. Section 5 contains the estimation results of the model explaining TFP growth, and the last section concludes our research.

2. The role of TFP and its determinants – literature review

New growth theory models endogenized technological change pointing to the significance of purposeful research and development (hence R&D) activity (Romer, 1990) and/or human capital accumulation (Lucas, 1988). Economic policy can affect the rate of economic growth in the transition phase to the steady-state as well as in the steady-state leading to both effects on levels of income and effects on the rate of growth. Barro and Sala-i-Martin (2004), but also Aghion and Howitt (2009), stress the role of technology diffusion in both absolute and conditional convergence. It is mostly due to the fact that imitation and implementation of discoveries are cheaper than initial innovation. Imitation and adaptation, however, entail significant costs which can be lowered through more intense trade or better human capital endowment (Nelson, Phelps, 1966). Followers tend to grow faster the greater the gap from the leader. The gap, however, narrows down over time. Followers' growth rates tend to diminish the lower the gap between leader and followers, and finally, in the steady-state, they grow at the same rate.

The seminal theoretical model of Eaton and Kortum (2001; 2002) of innovation, growth, and trade with technology spillovers points to convergence in incomes. Lower barriers to trade stimulate research activity in which scale effects are present. With zero gravity, a costless trade; relative real wages depend only on relative research productivity with the size of the economy playing no significant role. Authors utilize patent citations as a measure of technological spillovers. Technological change, however, can be skill-based which could lead to technology-skill mismatch and thus non-convergence in TFP levels (Acemoglu, Zilibotti, 2001). Furthermore, Caselli and Coleman (2000) point to the role of factor endowments in the choice of the appropriate technology.

In a multi-country endogenous Schumpeterian growth model, Howitt (2000) shows that due to technology transfer, only R&D-performing countries converge

to parallel growth paths while all other countries stagnate in the long run. An increase in the investment rate or the R&D-subsidy rate in any R&D-producing country can increase overall growth rate. In an extension, Howitt and Mayer-Foulkes (2005) attribute the emergence of convergence clubs in income to R&D potential and knowledge diffusion. In their stylized model countries sort themselves into three groups: members of the highest group converge to a steady state where they perform leading edge R&D (at the global technology frontier), while the intermediate group converges to a steady-state where they only implement technologies developed elsewhere. High and intermediate group countries share the same growth rate in the long run as a result of technology transfer, but inequality between them increases. Countries in the lowest group grow at a slower rate and are unable to converge due to their inability to absorb knowledge from the global technology frontier. In this set-up, the initial distance to the border matters and countries lagging by a significant distance can be entrapped.

The presence of increasing returns to scale, both internal and external to a firm, allows for variation in space and uneven distribution of economic activity. In addition, non-zero transport cost can arise. Diffusion of technology is usually imperfect making the role of geographic distance a relevant issue in the short and long-run. Marshallian agglomeration economies can arise leading to the emergence of core and peripheral regions. These notions have been strengthened by the NEG literature (Krugman, 1991) and in particular by its dynamic models (e.g. Baldwin, Forslid, 2000) allowing for simultaneous knowledge spillovers and physical capital accumulation. Static core-periphery models can thus evolve showing an interesting and complex dynamics.

According to Keller (2000), international convergence in incomes per capita depends critically on technological knowledge spillovers which are geographically or spatially restricted. Keller using the data on innovation activity (R&D expenditures) at industry-level for industrialized countries over the period 1970–1995 found that technological knowledge was rather local than global, strong spatial patterns existed and persisted and furthermore, the benefits associated with international spillovers were declining with distance. Keller checked whether the distance affected the magnitude of productivity gains (measured by TFP) from each other's R&D expenditures. At the international level, the amount of technological knowledge was found to reduce by half every 1200 km with the crucial role of cultural proximity (linguistic skills). At the regional level knowledge endowments are unevenly distributed across the regions of each country (Iammarino, 2005). Regional and local innovation systems differ significantly. It is mostly attributed to tacit knowledge flows which are restrained by geographical distance.

Bottazzi and Peri (2003) estimated the effect of R&D externalities in generating innovation. Utilizing R&D and patent data for European regions over the period 1977–1995 they found that spillovers, being quite small, were localized (more

than in Keller's study) and existed only within a distance of 300 km. The estimates were robust to typical empirical problems: simultaneity, omitted variable bias, different specifications of distance functions, country and border effects. Doubling of the R&D spending in a region increases the output of new ideas in other regions within 300 km only by 2–3 percent, while it enhances the innovation of the region itself by 80–90 percent.

In the next research, Bronzini and Piselli (2009) analyzed the long-run relationship between TFP, R&D, human capital and public infrastructure in a panel of Italian regions over the period 1980–2001. Empirical evidence pointed to the existence of a long-run equilibrium between TFP levels and the three types of capital. Human capital turned out to affect TFP the most. Regional TFP was found to be increased by both the R&D activity and the public infrastructure endowment of neighboring regions. The Granger-causality tests supported the hypothesis that human capital and infrastructure Granger-cause productivity in the long-run while the opposite did not hold. Bi-directional causality was found in turn in the case of R&D activity.

Cappello (2009) using cognitive classification of spatial spillovers analyzed in a simple empirical growth model for 259 NUTS2 regions of the EU27 member states their role in regional development. She identified a tendency towards a diffused development in the Western as well as Eastern part of Europe. The expected result of growth spillovers, the impact of spatial proximity on the magnitude of growth spillovers changed when one controlled for settlement structures (agglomerated vs. peripheral regions).

Moreno, Paci and Usai (2005) investigated the spatial distribution of innovative activity and the role of technological spillovers in the process of knowledge creation across 138 regions of 17 countries in Europe over the period of 1978–1997 at sectoral level (3 digit ISIC sectors). The authors identified a strong initial central-periphery pattern of distribution of innovation activity with concentrations in Northern and Central regions with a tendency to decline (diffuse). They identified furthermore a robust and positive spatial autocorrelation in the innovative activity (patenting activity in a given region was correlated to innovation performance in adjacent regions). External effects were also identified pointing to the role of technology diffusion – positive impact of patenting and R&D expenditures of neighboring regions and in particular of first and second order neighbors – a distance of roughly 250 and 500 kilometers.

Sterlacchini (2008) adopted Fagerberg's technology-gap model of economic growth (Fagerberg, 1988) and examined the relationship between the economic growth of 12 European regions over the period 1995–2002 and their knowledge and human capital endowments. Strelacchini took into account foreign and domestic knowledge, the ability to utilize both sources and the distance from the technology frontier. He controlled for potential agglomeration effects by including the

log of population density. All variables were expressed as deviations from country means. The GERD and the share of the population with tertiary education were found to be the most important determinants of growth in incomes per capita.

Maurseth and Verspagen (2002) addressed the pattern of knowledge flows indicated by patent citations between European regions. Knowledge spillovers were found to be strongly localized. Patent citations occurred more often between regions which belong to the same country and which are in geographical proximity. Patent citations were simultaneously found to be industry specific (indicative of the MAR-type spillovers) and occurred most often between regions that were specialized in industrial sectors with specific technological linkages between them.

Coe and Helpman (1995) studied the impact of trade on technology diffusion and found that international R&D spillovers were related to imports and in particular to the composition of imports. There exists a strong correlation between R&D embodied in (bilateral) trade flows and total factor productivity growth.

In their more recent and elaborate study, Coe, Helpman and Hoffmaister (2009) confirmed the impact of domestic and foreign R&D capital stocks on the TFP even after controlling for human capital. They extended the analysis by the inclusion of institutional variables, allowing for parameter heterogeneity based on institutional characteristics. The results suggested that institutional differences were significant determinants of TFP, and they had an impact on the degree of R&D spillovers. In a regional analysis, this could point to the necessity of accounting for variation in regional innovation systems.

According to Keller (2004), for most countries, foreign sources of technology are crucial (90 percent or more) in productivity growth. They are at the same time more valuable for small and relatively poorer countries. It could be related to the significance of the variation in domestic R&D investments. There is no indication that the process of international diffusion and thus learning is inevitable, simple or automatic. Imports are the major channel of international technology diffusion with no indication of learning-by-exporting effects. FDI effects are also present. However, the impact is highly asymmetric. Keller points that technological knowledge spillovers appear to be resulting from a deliberate commitment to learning and matching international performance standards through ongoing interactions with foreigners. At the same time, local efforts seem to be necessary for successful technology adoption.

3. The model of Nelson and Phelps – empirical specification

Abreu, de Groot and Florax (2004) applied the augmented version of the Nelson--Phelps model to investigate the spatial distribution of TFP growth rates in a sample of 73 countries over the period 1960–2000. In the original model, Nelson and Phelps (1966) argued that education could positively affect the speed of adoption of new technologies. They distinguished the theoretical level of knowledge from the prevailing (existing) level of technology. Similarly to the neoclassical growth model of Solow-Swan (Solow, 1956) with exogenous technological change, the theoretical level of knowledge T_t is assumed to grow exponentially at a constant, exogenous rate g:

$$T_t = T_0 e^{tg}, \tag{1}$$

Where T_0 is the initial stock of technology at the frontier and g is a positive rate of technological progress. The rate at which theoretical knowledge is turned into existing technology depends on two crucial parameters: the level of educational attainment of the adopters, and on the gap between the theoretical level of technology and the existing level of technology:

$$\frac{\dot{A}_t}{A_t} = \Phi(h)\left[\frac{T_t - A_t}{A_t}\right], \quad \Phi(0) = 0, \quad \Phi'(h) > 0, \tag{2}$$

where A_t is the existing level of technology, h represents the level of educational attainment. In the long run, the postulated growth rate of existing technology A_t is equal to the rate of increase of theoretical knowledge T_t and the technology gap is assumed to be constant.

Benhabib and Spiegel (1994) adapted the Nelson-Phelps model to study the effect of the human capital endowment in a growth accounting framework. They extended the original model by adding innovation term $g(h)$ which gives the impact of own capacity to develop knowledge on top of the ability to absorb external knowledge. The model took the following form:

$$\frac{\dot{A}_t}{A_t} = g(h) + c(h)\left[\frac{T_t - A_t}{A_t}\right]. \tag{3}$$

The theoretical level of knowledge T_t could be approximated by the level of knowledge of technology leader – the maximum TFP at time t representing technology frontier and the level of educational attainment is assumed to be con-

stant over time (equal to the average value over the period) and entered the equation in logarithm: $g(h) = c(h) = \ln(h)$. Abreu, de Groot and Florax (2004) utilized the following nested specification:

$$\frac{\dot{A}_t}{A_t} = \alpha + \beta_1 \ln(h_t) + \beta_2 \frac{\dot{h}_t}{h_t} + \beta_3 \ln(h_t) \left[\frac{(\max(A)_t) - A_t}{A_t} \right] + u. \tag{4}$$

In their study, they also utilized two types of spatial models: spatial lag (autoregressive) and the spatial error model.

The spatial interactions could be implemented in the form of three types of spatial econometrics models:
1) Spatial Autoregressive Model or Spatial Lag Model (SAR), in which the value of the dependent variable in a given region depends on the values of the same variable in neighboring regions;
2) Spatial Error Model (SEM), which analyses the process when the variable in the region is affected by random interference (disturbances) from neighboring regions;
3) Spatial Durbin Model (SDM), in which the spatial autoregression and at the same time, the impact of explanatory variables from neighbors are assumed.

In general, an econometric model taking into account the spatial interactions can be written as follows:

$$y_i = \alpha + \rho \sum_{j=1}^{n} w_{ij} y_j + \sum_{k=1}^{K} x_{ik} \beta_k + \sum_{k=1}^{K} \sum_{j=1}^{n} w_{ij} x_{jk} \theta_k + \nu_i$$

$$\nu_i = \lambda \sum_{j=1}^{n} w_{ij} \nu_i + \varepsilon_i \qquad i = 1, ..., n \tag{5}$$

where: w_{ij} is the element of spatial weights matrix that determines the relative geographic localization of region i to the region j, x_k – the explanatory variables in the econometric model, ρ – a coefficient of a spatial autoregression, λ – a coefficient of the spatial correlation of error, ε – stochastic disturbances meeting the classic assumptions. In a model defined above, if:
1) $\lambda = 0$ and θ parameters are equal, we deal with SAR model,
2) $\rho = 0$ and θ parameters are equal, the model is SEM,
3) $\lambda = 0$ we estimate SDM.

In the present study, acknowledging the importance of international knowledge diffusion, we further augment the empirical specification of Abreu, de Groot and Florax (2004) by incorporating the collective impact of imports suggested by the literature of the subject on the growth of productivity. The extended model in the spatial lag version takes the following functional form:

$$\frac{\dot{A}_t}{A_t} = \alpha + \beta_1 \ln\left(h_t\right) + \beta_2 \frac{\dot{h}_t}{h_t} + \beta_3 \ln\left(h_t\right)\left[\frac{\left(\max(A)_t\right) - A_t}{A_t}\right] + \beta_4 \ln\left(m_t\right) + \rho W \frac{\dot{A}_t}{A_t} + u, \quad (6)$$

where $\ln(m_t)$ is the log of imports in relation to GDP of a given region. We expect that its impact on the TFP growth is statistically significant and positive.

It is worth noting that not only import but different channels of TFP diffusion from foreign sources can be considered. It may apply in particular to the impact of foreign direct investments and the presence of multinational enterprises. The channel has been analyzed, and partial evidence exists. For instance, Hejazi and Safarian (1999) identified significant R&D spillovers in FDI from largest industrial countries to smaller OECD Member States. Xu (2000) found that technology transfer of US multinationals contributed to productivity growth but only in the group of developed economies.

4. The estimates of TFP in Polish LADs and its spatial patterns

The value of TFP in Polish LADs was estimated in two stages. The procedure of estimating the TFP in Polish LADs has been described in details in Ciołek and Brodzicki (2016). First, we estimated values of GDP for the LADs. We used data published by the Central Statistical Office on GDP in Polish sub-regions and disaggregated it using information about income taxes in the regions. This method was based on the assumption that taxes are associated with the production emerging in the region. Then we assumed various production functions for different groups of LADs and estimated the Cobb-Douglas type production function with varied elasticities for:
1) rural LADs (37),
2) rural LADs with small towns (69),
3) industrial LADs, LADs with medium size cities and LADs surrounding metropolises (92),
4) metropolises and big cities (45),
5) other LADs (136).

The classification was carried out using a statistical cluster analysis with the Ward procedure, which took into account first of all the structure of the economy of individual regions.

The value of TFP was calculated using the following formula:

$$TFP_{it} = \frac{y_{it}}{k_{it}^{\alpha_G}} \quad i = 1,\ldots,n \qquad t = 1,\ldots,T \qquad G = 1,\ldots,5, \qquad (7)$$

where y_{it} is GDP per worker in county i in year t, k_{it} – capital per worker, α_G – estimated elasticity in production function in a group of LADs G. In such a way we estimated series of TFP in Polish LADs for years 2003–2013. In Figure 1 we illustrated the spatial dispersion of TFP in the year 2013 compared to the average for Poland (Poland = 1).
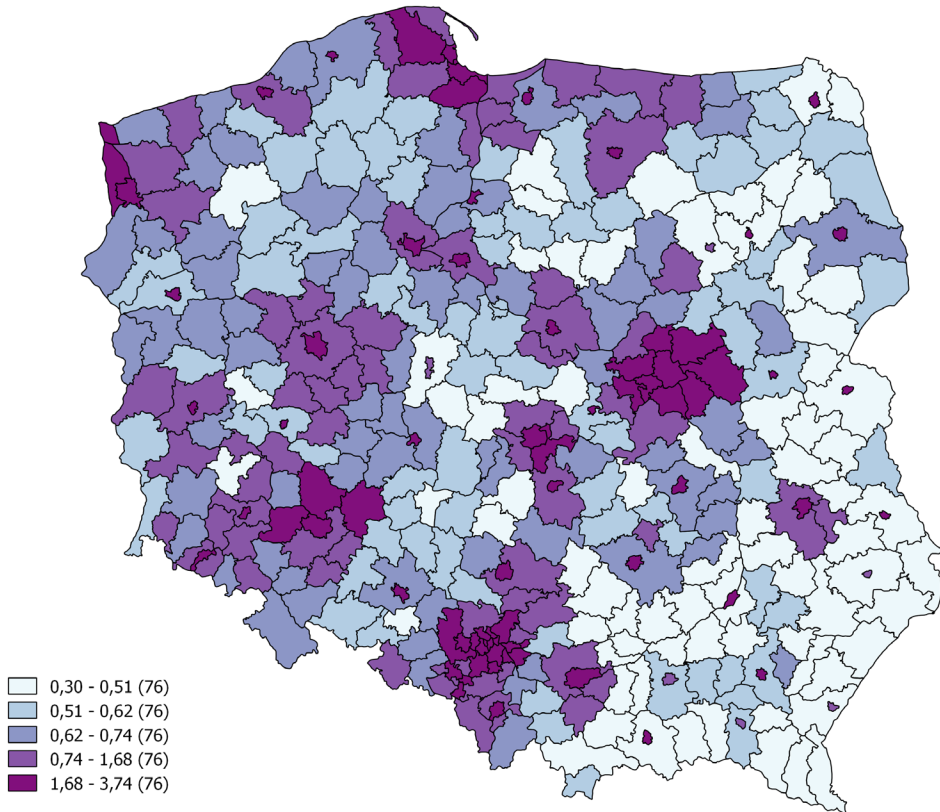

0,30 - 0,51 (76)
0,51 - 0,62 (76)
0,62 - 0,74 (76)
0,74 - 1,68 (76)
1,68 - 3,74 (76)

Figure 1. Estimates of Total Factor Productivity (various production functions)
in Polish LADs in the year 2013 (average for Poland = 1)

Source: own elaboration

Analyzing the spatial distribution of TFP, it is clear that TFP in Poland assumes the highest values in the metropolitan centers and spreads out to their nearest surroundings. The maximum value TFP characterizes the Warsaw metropolis, the Upper Silesian urban area, or surroundings of Tri-City, Poznan, Wroclaw, Szczecin, Krakow, and Lodz. We also notice local hills in the distribution of TFP. In line with the postulates of the new growth theory and the new economic geography, they are located in cities or towns with county rights and thus can be considered local or regional growth centers. At the same time, the TFP shows a down-

ward trend as we move from the west to the east, which is more or less consistent with the general regularities identified for the Polish economy. The lowest values of TFP, relative to the average, are observed in the south-eastern part of Poland (podkarpackie, świętokrzyskie and part of malopolskie).

For comparison, in Figure 2 we present the estimated values of TFP in 2013 in the case when we assume the same production function for all LADs – the assumption adopted by Abreu, de Groot and Florax (2004).

0.45 – 0.77 (76)
0.77 – 0.91 (76)
0.91 – 1.03 (76)
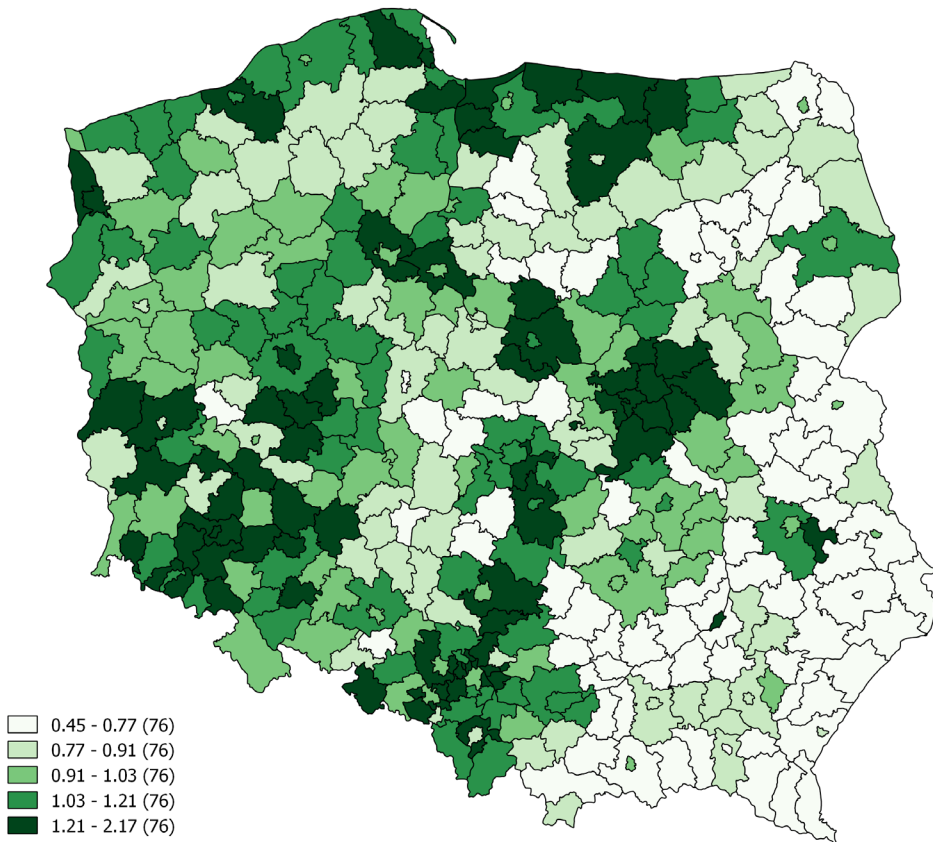1.03 – 1.21 (76)
1.21 – 2.17 (76)

Figure 2. Estimates of TFP in Polish LADs in the year 2013
(average for Poland = 1) – the same production functions for all LADs

Source: own elaboration

As we can see, the general image of the spatial distribution of TFP in Polish LADs seems not to be significantly different from that shown in Figure 1. However, the correlation coefficient between both variants of TFP is equal to just 0.66 so is rather low. In further analysis, we would present and compare the results obtained with both variants of TFP.

To analyze the nature of the spatial interdependencies of TFP in the LADs, we used the tools of spatial econometrics. The crucial element in spatial analysis is the spatial weights matrix which reflects the geographical location of the units. In our research, we defined a number of spatial matrices based on the geographical distances. For each matrix, we calculated the value of the Moran I statistics and the spatial autoregression coefficients in SAR model. The results are presented in Table 1.

Table 1. Statistics of the TFP spatial autoregression for various spatial weights matrices

Distance in weights matrix	Moran I statistic	Number of significant relations	Coefficient of spatial autoregression	Change rate of coefficient
50 km	0.3466	38	0.034	
75 km	0.4065	76	0.211	0.177
100 km	0.3435	89	0.365	0.154
125 km	0.2900	102	0.475	0.110
150 km	0.2440	116	0.550	0.075
175 km	0.2147	132	0.576	0.026
200 km	0.1784	148	0.566	−0.010
225 km	0.1538	161	0.586	0.020
250 km	0.1296	164	0.569	−0.017
275 km	0.1086	165	0.583	0.013
300 km	0.0878	173	0.641	0.058
Neighbourhood matrix	Moran I statistic	Number of significant relations	Coefficient of spatial autoregression	
I order	0.4642	132	0.263	
I and II order	0.3345	205	0.372	

Source: own elaboration

Below we present dependence of the spatial correlation coefficient of TFP on the adopted spatial weights matrix for distance (Figure 3) and the changes of this factor (Figure 4).

The coefficient of spatial correlation as well as the number of significant relations increases as the distance in spatial weights matrices increases. The coefficient of spatial correlation more or less stabilizes around 175 kilometers and is relatively stable till 275 km and then rises once again. We interpret it as the range of spatial spillover in productivity which is not far from previously discussed estimates from the empirical literature (e.g. Bottazzi, Peri, 2003). The subsequent s

increase from 275 km onwards could be best described as the impact of the next metropolitan areas in Poland. Most of them are separated by a distance of roughly 250–300 km from each other due to the second nature characteristics of the economic geography of Poland.
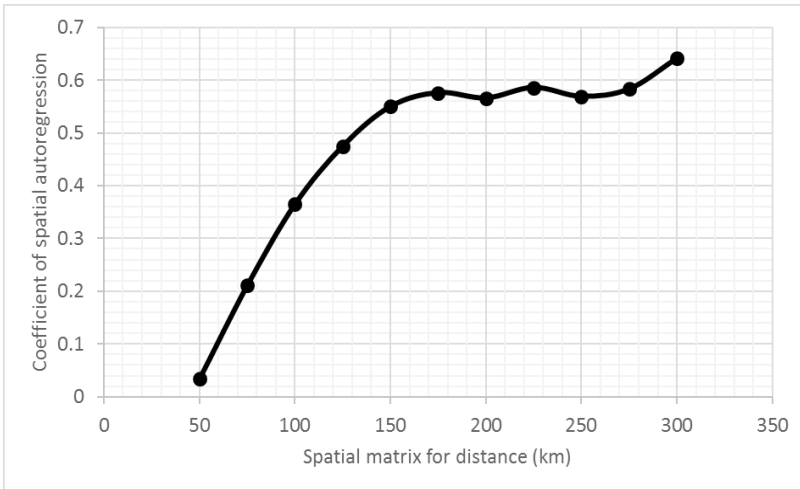

Figure 3. The values of coefficient of spatial autoregression depending on the weights matrix of TFP in Polish LADs
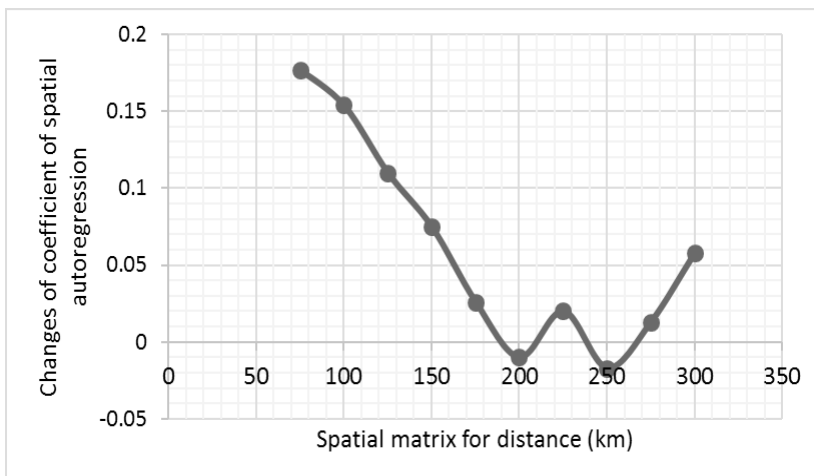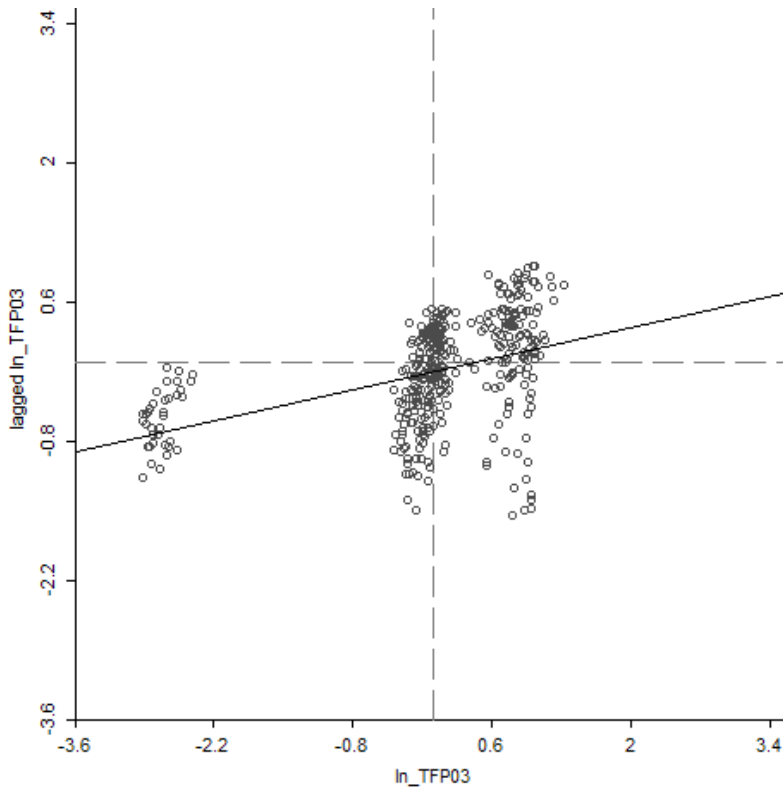
Source: own elaboration

Figure 4. Changes in the coefficient of spatial autoregression of TFP in Polish LADs

Source: own elaboration

Figure 5. Moran scatterplot of ln(TFP) in 2003

Source: own elaboration

In Table 1 we presented statistics for different weights matrices. Taking into account not only the value of Moran I statistics but also a number of statistically significant relations, we decided to implement the first and the second order neighborhood matrix (W_1&2). This choice also aims at solving the problem that some cities with county rights are surrounded by rural LADs and therefore, according to the first order neighborhood definition, have only one neighbor. In fact, these are cities and their influence is much wider. In Figure 5, we present the Moran scatterplot of ln(TFP) in the year 2003 for W_1&2.

5. The Nelson-Phelps model of TFP growth in Poland

The next stage of our research is the estimation of the model defined by the formula (6) in which A_t is represented by estimated values of TFP in Polish LADs, and the human capital endowment is measured by the share of the population with

completed tertiary education. The potential foreign impact on TFP growth is repre-sented firstly by the log of the ratio of imports to GDP and secondly by FDI meas-ured as the log of the number of significant (above 1M USD) foreign investments in a particular LADs (the data provided by the PAIiIZ, 2015). To avoid the problem of zero values of FDI in calculating the logarithm of the variable each observation has been scaled by adding the number of 0.0001.

We conducted analysis for two series of the TFP:
1) with the assumption of the identical production function for all LADs,
2) with the assumption of the various production function for groups defined above.

The estimation results for the first variant are presented in Table 2 and for the second in Table 3. Not surprisingly they significantly differ, which requires a more detailed description.

Table 2. Spatial models of TFP growth in Polish LADs in 2003–2013 (identical production functions for all LADs)

Dependent variable	the growth of TFP (in identical production functions)			
Model Regressor	SAR	SEM	SAR	SEM
Constant	−0.167*** (0.033)	−0.092*** (0.027)	−0.171*** (0.033)	−0.094*** (0.029)
Spatial autoregres.	0.237*** (0.068)	–	0.250*** (0.069)	–
Spatial error autocorr.	–	0.542*** (0.093)	–	0.551*** (0.092)
Nelson-Phelps term	0.095*** (0.010)	0.115*** (0.011)	0.096*** (0.010)	0.115*** (0.011)
ln(human capital)	−0.294*** (0.036)	−0.349*** (0.039)	−0.301*** (0.036)	−0.350*** (0.038)
human capital growth	0.535*** (0.045)	0.526*** (0.046)	0.531*** (0.045)	0.531*** (0.046)
ln(import/GDP)	–	–	−0.040 (0.025)	−0.027 (0.024)
ln_FDI	–	–	0.062*** (0.002)	0.063*** (0.023)
Adj. R-squared	0.57	0.60	0.58	0.31
Moran's I (error)	7.439 [0.000]	7.439 [0.000]	7.665 [0.000]	7.665 [0.000]
LM (lag)	15.117 [0.000]	15.117 [0.000]	16.591 [0.000]	16.591 [0.000]
Observations	379	379	379	379

Source: own elaboration

Table 3. Spatial models of TFP growth in Polish LADs in 2003–2013 (different production functions for LADs)

Dependent variable	the growth of TFP (different production functions)			
Model Regressor	SAR	SEM	SAR	SEM
Constant	–0.209*** (0.030)	–0.188*** (0.031)	–0.220*** (0.031)	–0.198*** (0.033)
spatial autoregres.	0.288*** (0.090)	–	0.284*** (0.090)	–
spatial error autocorr.	–	0.419*** (0.108)	–	0.430*** (0.107)
Nelson-Phelps term	–0.0003** (0.0001)	–0.0003** (0.0001)	–0.0003** (0.0001)	–0.0003** (0.0001)
ln(human capital)	0.026 (0.025)	0.026 (0.027)	0.020 (0.025)	0.021 (0.027)
human capital growth	0.568*** (0.049)	0.588*** (0.051)	0.576*** (0.049)	0.598*** (0.051)
ln(import/GDP)	–	–	–0.009 (0.028)	–0.014 (0.028)
ln_FDI	–	–	0.001** (0.000)	0.001** (0.000)
Adj. R-squared	0.34	0.35	0.35	0.36
Moran's I (error)	4.517 [0.000]	4.517 [0.000]	4.420 [0.000]	4.420 [0.000]
LM (lag)	14.116 [0.000]	14.116 [0.000]	12.246 [0.000]	12.246 [0.000]
Observations	379	379	379	379

Source: own elaboration

Assuming identical production functions for all LADs, we observe clearly that in the SAR model the spatial autoregression is statistically significant and positive – the TFP growth rate of neighboring regions influences the TFP growth of a given region. The SEM gives similar results. The importance of the Nelson-Phelps term accounting for the gap in TFP is also significant and positive – the higher the growth rate of TFP, the greater the distance from the leader. On the other hand, the impact of the average level of human capital endowment turned out to be negative, which may indicate there is the negative impact of own capacity to develop new knowledge or to absorb external knowledge. It should be noted, however, that the impact of the growth in the human capital endowment is critical and positive, so it is crucial for technological progress.

If we extend the model by accounting for the potential foreign sources of TFP growth, it is evident that the log of the ratio of imports to GDP, in contrast to Coe and Helpman (1995), has no impact on the rate of increase of TFP. However, the

impact of the log of FDI is statistically meaningful and positive. FDI proves to have an impact on regional TFP in line with Hejazi and Safarian (1999) or Xu (2000) findings for states. The lack of impact of the channel through imports could be due to problems in ascribing import data to the level of LADs and will require further verification.

Turning now to the second case – different production functions for groups of LADs depending on their type – we observe that once again the spatial autoregression is positive in SAR models, and the spatial error autocorrelation is positive in SEM. The Nelson-Phelps term accounting for the gap in TFP is statistically significant once again. However, its impact is now negative in contrast to the results discussed above – the higher the growth rate of TFP, the smaller the gap from the leader. The magnitude of the impact is, however, weak – close to zero. Similarly to the previous result, the impact of the human capital endowment on the rate of growth of the TFP is negative. Notwithstanding, the impact of the increase in the human capital endowment is once again positive and statistically significant with a large magnitude. In the last two columns, we extend the model by accounting for the potential foreign sources of TFP growth. The channel through imports is statistically insignificant in contrast to a robust channel through FDI.

6. Conclusions

TFP in Poland assumes the highest values in the metropolitan centers and spreads out on their nearest surroundings. The maximum value TFP is not surprisingly identified for Warsaw. It is high for other metropolitan areas identified in the ESPON study. The secondary local hills in TFP are located in cities or towns with county rights. TFP, in general, shows a downward trend as one moves from the west to the east with the lowest values observed in the south-eastern part of Poland.

The range of TFP spillover is found to be of roughly 175–200 kilometers and is nonlinearly decreasing from the hills and is not different from results in other studies on Western European states (e.g. Bottazzi, Peri, 2003).

Similarly, to Abreu, de Groot and Florax (2004) we stress that the application of the original model of Nelson and Phelps (1966) to the regional domain requires allowing for spatial dependence and thus necessitates the use of spatial econometric modeling. We extend their version of the original model by allowing for the FDI and trade channel or foreign sources of TFP growth.

The empirical results prove that the rate of growth of TFP shows spatial autocorrelation and is found to depend in particular on the rate of increase in human capital endowment and positively on the gap from the leader under certain assumptions. In contrast to Coe and Helpman (1995), we find no evidence of the channel through imports. The FDI channel is however found to be robust and

strong and in line with the results of Hejazi and Safarian (1999) or Xu (2000). The results differ to some extent depending on the method applied to the calculation of TFP which requires further analysis. Moreover, to draw more general conclusions, the analysis should be applied to other states and their regions observed over longer time horizons. Data-allowing this will be performed in our future research work.

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Przestrzenne współzależności całkowitej produktywności (TFP) w polskich powiatach

Streszczenie: Interakcje między przestrzenią (lokalizacją) a procesami akumulacji (wzrostem) to jeden z najbardziej interesujących i jednocześnie najtrudniejszych obszarów badawczych nowoczesnej teorii ekonomii. Jak dotąd badania empiryczne odnoszące się do problematyki produktywności na poziomie regionalnym są stosunkowo rzadkie. Większość badań w przypadku Polski stara się wyjaśnić zróżnicowanie dochodu *per capita* na poziomie województw i podregionów, a tylko nieliczne badania dotyczą powiatów. Niniejszy artykuł ma za zadanie wypełnić tę istotną lukę poznawczą. Artykuł ma kilka celów. Po pierwsze, prezentuje zróżnicowanie produktywności w Polsce oraz jej przestrzenne współzależności. Po drugie, stara się zidentyfikować determinanty wzrostu TFP z wykorzystaniem ekonometrycznego modelowania przestrzennego i rozszerzonej wersji modelu Nelsona-Phelpsa. W badaniu przyjęto wysoce zdezagregowany poziom analizy: NUTS–4, czyli poziom powiatów, który autorzy uznają za adekwatny zarówno z perspektywy teoretycznej (domykanie się rynków), jak i empirycznej (modelowanie przestrzenne). TFP w Polsce przyjmuje najwyższe wartości w ośrodkach metropolitalnych (z maksimum dla Warszawy) i w ich najbliższym otoczeniu. Identyfikuje się także ośrodki wzrostu TFP zlokalizowane w miastach na prawach powiatu. Ogólnie rzecz biorąc, TFP wykazuje tendencję spadkową przy przesuwaniu się z zachodu na wschód, przy czym najniższe wartości obserwuje się w południowo-wschodniej części Polski. Zakres oddziaływania TFP na obszary sąsiednie sięga około 175–200 kilometrów, a jego siła zmienia się nieliniowo. Ponadto tempo wzrostu TFP wykazuje przestrzenną autokorelację i zależy od tempa wzrostu kapitału ludzkiego oraz od dystansu

do technologicznego lidera. W artykule nie wykazano pozytywnego wpływu importu na wzrost TFP, jednakże wpływ FDI okazuje się być silny i dodatni.