

ALTERNATIVE WEIGHTING SCHEMES IN SPATIAL ANALYSIS OF GDP PER CAPITA CONVERGENCE¹

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Abstract: The article analyzes conditional beta convergence in the EU28 countries with the use of spatial econometrics techniques. We consider alternative structure of the spatial weight matrix based on economic distances. Basing on the spatial Durbin-Watson model, two spatial specifications are tested, which make use of the volume of international trade and the inverted GDP per capita differences between the considered objects. We confirm the existence of GDP convergence and show that the gravity-models-type logic is superior to the approach based on inverted geographic distances.

Keywords: convergence, economic growth, spatial econometrics, Durbin-Watson

INTRODUCTION

The aim of the article is to validate whether there exists conditional β convergence in the EU28 countries. The concept of β convergence means that less developed countries (with lower GDP per capita) grow faster than the more developed ones. Although plenty of studies in this field exist and most of them confirm the existence of convergence among the EU countries [see e.g. European Commission 2009; Rapacki and Próchniak 2009; Kulhánek 2012; Stañisić 2012] but not all of them do [e.g. Monfort et al. 2013], most authors do not consider

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spatial dependence between the considered countries and those who do so, apply quite standard techniques of spatial econometrics.

In the spatial growth regression, weight matrices usually refer to the first, second etc. neighbors matrices or the inverted distance matrices [Conley and Topa 2002; Seya et al. 2012; Tian et al. 2010]. Although geography does matter for the evolution of income distribution (as confirmed on the basis of U.S. regions by [Rey 2001]), we consider alternative structure of the spatial weight matrix by incorporating the matrices based on inverted economic distances. This approach is supported by some other authors who suggest that trade flows [Aten 1996], institutional distances [Arbia et al. 2010], socio-economic distances represented by ethnic and occupation distances [Conley and Topa 2002] or demographic and income similarities [Case 1991] are the factors that matter in spatial interactions. In Poland, the first study of this type was carried out by Błaszczuk [1974].

Basing on the spatial Durbin-Watson (SDM) model two non-standard specifications are tested, which make use of the volume of international trade and the GDP per capita differences between the considered objects. These are compared with the usual weights based on inverted distances and the standard non-spatial panel data approach in the EU countries during 1993-2013.

MODEL OF CONVERGENCE WITH SPATIAL INTERACTIONS

The so called “Barro regression” [Barro and Sala-i-Martin 1992] is probably the most frequently found specification in empirical macroeconomics:

$$\Delta \ln GDP_{it} = \beta_1 \ln GDP_{i,t-1} + x_{it}' \gamma + \alpha_i + \varepsilon_{it}, \quad (1)$$

where GDP_{it} is the gross domestic product of the i -th country, $\ln GDP_{i,t-1}$ is the lagged value of the GDP of the i -th country, x_{it} represents a $k \times 1$ vector of growth factors for the i -th country in period t , ε_{it} is the error term, individual effects α_i are introduced in order to represent different steady states while the β_1 and γ are the structural parameters of the model. Usually it is also assumed (though often not mentioned) that $\text{corr}(\varepsilon_{it}; \varepsilon_{jt}) = 0$ for every $i \neq j$. This, followed by the specification of the model in which the GDP of i -th country is clearly a function of the i -th country's growth factors only, constitutes a dynamic panel data model with no spatial dependence in most cases estimated with the use of GMM with the Blundell and Bond's system-GMM being the first choice for most authors [Blundell and Bond 1998]. We also include it in this paper for reference.

The assumption of independency of the data generating processes through the sample is, however, disputable. Globalization of the world economies makes them at least potentially interact and it is possible that the economic situation of one country might have an impact on the rate of growth in another country. In order to overcome this problem, spatial econometrics techniques have been employed in the analysis of growth and also the GDP convergence itself. We consider a model, named spatial Durbin-Watson model (SDM):

$$\Delta \ln GDP_t = \beta_1 \ln GDP_{t-1} + \rho W \cdot \ln GDP_t + X_t \gamma + W \cdot X_t \cdot \theta + \alpha + \varepsilon_t, (2)$$

where $\ln GDP_t$ and $\ln GDP_{t-1}$ represent the $n \times 1$ vectors of the GDP of the n considered countries in period t (and $t-1$, respectively), X_t is the matrix of growth factors for particular countries in period t , such that

$$X_t = \begin{bmatrix} x_{1t}' \\ \vdots \\ x_{nt}' \end{bmatrix}$$

is a $n \times k$ matrix of growth factors in period t , whose i -th row represents the growth factors of the i -th country in that period, α is a $n \times 1$ vector of (time invariant) individual effects, ε_t is a $n \times 1$ vector of error terms in period t , θ is a $k \times 1$ vector of parameters that reflect the influence of growth factors for other countries on the rate of growth of the i -th country, ρ points out the importance of growth rates of other countries for the rate of growth of the i -th country, W is a spatial weights matrix which emphasizes which of the countries are interrelated stronger than others. If the error term is spherical and further $\theta = 0$ and $\rho = 0$, non-spatial model (1) comes up.

Most authors use either weights based on the inverse of geographic distance or on the fact of being (or not) neighbours, however such an approach seems disputable nowadays. A number of countries form clubs that cooperate between one another, while others do not follow this rule despite geographic closeness with Northern and Southern Korea being the best example. Also, the issue of geographic distance might be of great importance while the considered partners lay far apart, that is for example on different continents, yet the availability and relatively low transportation costs together with high globalization of contemporary world certainly reduce the importance of this factor in the case of relatively closer countries.

Two alternative specifications of the weighting matrix are then proposed. The first of them is based on the level of the exchange of goods in the considered pair of countries. It is likely that in the case of a pair of countries whose volume of trade is high, also the broadly understood economic changes in one of the partners shall have a serious influence on the other one's growth. A possible example is the CPI. Suppose that it increases vastly in one of the trade partners. In the case of high exchange of goods between the two considered countries, one can expect it to have a serious influence on the level of prices in the partnering countries and thus – indirectly – also on its GDP growth. That is why in the first alternative specification the weighting matrix is constructed with the use of the average volumes of trade between particular countries throughout the period of the analysis.

The other considered alternative stems partly from the logic of the gravity models. Those assume (among others) that the strength of trade relation in a pair of countries, measured by their volume of trade, depends upon their differences in the level of development. The countries that are similar in the sense of their GDP shall cooperate with greater strength, which means that the weak have greater trade

relationships with the weak, while the giants are more likely to cooperate with the giants [Śledziwska and Witkowski 2012]. We transmit the logic of the gravity models to the field of GDP growth in order to test whether the empirically confirmed property in the world of international trade can also be found in the case of growth. We thus construct the second alternative weighting matrix using as weights the inverted absolute differences in the level of GDP per capita measured in PPP. In all the considered cases we use the minmax transformation in order to standardize the weighting matrices [Kelejjan and Prucha 2010].

All the spatial models are estimated with the use of maximum likelihood implemented by Belotti et al. [2013]. The consistency of the GMM requires model (1) to be transformed to the

$$\ln GDP_{it} = (\beta_1 + 1)\ln GDP_{i,t-1} + x_{it}'\gamma + \alpha_i + \varepsilon_{it}, \quad (3)$$

and similarly, model (2) is transformed to

$$\ln GDP_t = (\beta_1 + 1)\ln GDP_{t-1} + \rho W \cdot \ln GDP_t + X_t\gamma + W \cdot X_t \cdot \theta + \alpha + \varepsilon_t \quad (4)$$

which changes nothing in terms of their meaning, but requires subtracting 1 from the estimate of the parameter on $\ln GDP_{i,t-1}$ or $\ln GDP_{t-1}$ in order to attain the convergence parameters.

One can consider limiting the set of growth factors that have a “spatial” influence, that is: that have an influence on the rate of growth of the “neighbors” to just those that are found significant in the sense of $\theta \neq 0$ since it is quite likely that only some of the x_{it} have an influence not only on the rate of growth of the i -th but also some other countries. We thus denote as \tilde{X}_t the matrix of those growth factors that are found significant in the sense of $\theta \neq 0$ (not just the $\gamma \neq 0$ and follow the same rule replacing θ with $\hat{\theta}$ and thus the model (4) is converted to:

$$\ln GDP_t = (\beta_1 + 1)\ln GDP_{t-1} + \rho W \cdot \ln GDP_t + X_t\gamma + W \cdot \tilde{X}_t \cdot \tilde{\theta} + \alpha + \varepsilon_t. \quad (5)$$

Last but not least, since a couple of models can be proposed considering the different weighting schemes, a procedure needs to be adopted in order to select one for the analysis. A choice of the best one can be made with the use of information criteria, which is the solution adopted in this paper: specifically the minimization of Schwarz criterion is used in this case, although the difference in the number of degrees of freedom between the particular models is small, thus other criteria would usually yield the same answer. It should be noticed that most researchers treat the weighting matrices as “given” and – in most cases – consider mostly the selection of a functional form of the model itself and to a much lower extent the shape of the W matrix. However, as it is shown in the empirical results in this paper, that need not be the always-best approach.

THE DATA

The analysis covers the 1993-2013 period and is based on 3-year subperiods (the first subperiod is 1993-1995 while the last one is 2011-2013). Under such an approach, GDP growth for a given subperiod is calculated as the difference between log GDP per capita levels in the last year of a given subperiod and the last year of a previous subperiod (divided by 3 to express annual changes). The initial GDP per capita is taken as GDP per capita level from the last year of a previous subperiod while explanatory variables are calculated as arithmetic averages for the years covered by a given subperiod (in the case of missing data, the required figures are imputed).

It is necessary to choose the set of explanatory variables which are treated as economic growth determinants in the regression equations. From the theoretical point of view, the appropriate variables are those that characterize different steady-states to which the individual economies are tending. In empirical studies numerous growth factors are tested whose choice is constrained by data availability. Also, it is impossible to include too many variables due to multicollinearity and insufficient degrees of freedom issue. In this study, 21 variables (in addition to the initial GDP per capita) were initially included in the growth regressions. Those are listed in Table 1.

Table 1. List of considered explanatory variables

Variable name	Variable description	Unit (scale)
Variables included in the final SDW models		
gdp0	Log of initial GDP per capita at PPP	Constant US\$
inv	Investment rate	% of GDP
open	Openness rate	(Exports + imports) / GDP
cab	Current account balance	% of GDP
life	Log of life expectancy at birth	Years
econfree_fi	Fraser Institute index of economic freedom	From 0=lowest to 10=highest
wgi	World Bank's worldwide governance indicator	From -2.5=lowest to +2.5=highest
Variables excluded from the final SDW models		
human_cap	Index of human capital*	From 1=lowest to 4=highest
school_tot	Average years of total schooling (age 15+)	Years
school_ter	Population (age 15+) with tertiary schooling	% of total population
edu_exp	Expenditure on education	% of GNI
exp	Exports of goods and services	% of GDP
fdi	Foreign direct investment, net inflows	% of GDP
gov_cons	General government consumption expenditure	% of GDP

Variable name	Variable description	Unit (scale)
infl	Inflation rate (annual)	%
cred	Annual change of the domestic credit provided by banking sector to GDP ratio	% points
dem_fh	Index of democracy (average of civil liberties and political rights according to Freedom House)	From 1=lowest to 7=highest (inverted scale)
fert	Log of fertility rate	Births per woman
pop_15_64	Population ages 15-64	% of total
pop_den	Log of population density	People/km ²
pop_gr	Population growth (annual)	%
pop	Log of total population	Persons

* Index of human capital per person, based on years of schooling and returns to education, taken from Penn World Table 8.0. Note that only a few of the above mentioned variables remain in the final specifications presented in this paper.

Source: Data taken from the Penn World Table 8.0, World Bank *World Development Indicators*, IMF *World Economic Outlook*, Fraser Institute, and Freedom House databases

Initial variants of the econometric model were estimated on the basis of the full set of growth factors. Then, the initial set has been reduced using backward elimination of the least significant variables yielding the final set of six growth factors included in the models discussed in the next section. Also we eliminate (with the use of a standard backward algorithm) the growth factors that are allowed to be significant determinants of other countries' growth.

EMPIRICAL RESULTS

The results of the final models are reported in Table 2. Columns 1-3 refer to SDM models with three different types of including spatial effects while Column 3 concerns the reference Blundell and Bond's GMM system estimator model. For the sake of conciseness, we do not show neither estimates of the initial models based on a greater number of variables.

As regards a given country's growth factors, it turns out that investment rate, the degree of openness, current account surplus, life expectancy, large scope of economic freedom and good quality of governance all lead to a more rapid economic growth of the considered countries. This finding is confirmed both by the reference model as well as by the three alternative SDM approaches with spatial interactions.

Table 2. Spatial Durbin-Watson model for the EU28 countries with (1) inverted geographical distances, (2) inverted GDP per capita differences, (3) volume of trade weights and (4) Blundell and Bond's no spatial effects model (reference model)

regressor	geographic weights (1)	GDP difference weights (2)	volume of trade weights (3)	non-spatial Blundell and Bond (4)
country's growth factors				
gdp0	0.7811***	0.7338***	0.7001***	0.5236***
Inv	0.0088***	0.0069***	0.0086***	0.0143***
Open	0.0005***	0.0003***	0.0004**	0.0007***
Cab	0.0048***	0.0026**	0.0027*	0.0040***
Life	1.0159***	1.2287***	1.1122***	1.8047***
econfree_fi	0.0496***	0.0314***	0.0499***	0.0385***
Wgi	0.0312*	0.0717***	0.0970***	0.2296***
spatial effects (other countries' growth factors)				
gdp ³	-0.7269	-0.0006***	-0.0026***	-
Open	-	-	0.0000**	-
Inv	1.0210***	0.0002***	-	-
Cab	0.6474***	-	-0.0001***	-
Life	-	-	0.0050***	-
econfree_fi	-2.0812**	-	0.0004*	-
Wgi	-	0.0022***	-	-
selected statistics				
initial GDP per capita in untransformed model (p/a) ¹	-0.0730***	-0.0887***	-0.1000***	-0.1588***
β coefficient ²	7.6%	9.3%	10.5%	17.3%
BIC	-454.33	-471.41	-432.61	-
R ² within	0.9035	0.9082	0.8821	-
R ² between	0.9958	0.9965	0.9962	-
R ² overall	0.9835	0.9846	0.9800	-

¹Calculated as: (coefficient on gdp0 minus 1) divided by 3; ²Calculated as: $\beta = (1/t)\ln(1+\beta_1 t)$, where β_1 is the coefficient on initial GDP per capita in untransformed model (per annum) while t is equal to 1; ³Other countries' level of GDP per capita in the current period. *** - significant on 1%, ** - significant on 5%, * - significant on 10% significance level. Number of observations: 196 with $n=28$, $T=7$

Source: own calculations

It is always an issue how to construct the "best" weighting matrix as long as the assumed criterion is economically sound. Here the assessment of properties of the three SDM models with alternative weights is made on the basis of BIC criterion. It turns out that the model with inverted income distances as weights is found to be best (in terms of the BIC). The SDM model with geographic weights

proves to be notably worse while the model with weights based on the volume of trade is the weakest of the considered ones. Hence, differences in GDP per capita work better as the factor responsible for weighting the other country's growth determinants. This result can be explained by several reasons.

First of all, in the globalized world geographical distances play a diminishing role in determining spatial interactions between countries. This argument is of special importance in the case of one economic and political integration group, like the European Union. The reduction in trade barriers and the facilitation of migration of inputs (labor and capital) all lead to a decreasing role of geographical distances as a factor responsible for the impact of one country's economic performance on its neighbors. Second, it turns out that the volume of international trade is not a strong factor linking the countries either. Indeed, the volume of exports and imports rather depends on the size of a given country. For example, big countries like Germany or Poland record greater volumes of exports and imports in absolute terms while their shares in GDP are usually lower as compared to smaller countries like Slovakia or Estonia. Third, it is the relative level of development which is the most important factor responsible for mutual interactions between countries. This outcome shows that rich EU members are affected by rich EU neighbors while poor member states are influenced by the other poor EU neighbors. This finding is of great importance and it shows the nature of spatial interactions between the considered countries. Hence, the weight matrixes with inverted geographical distances – the approach which dominates in the literature – are not the best way of including spatial effects in the econometric model. Distances in GDP per capita levels seem to be better, at least inside one international organization like the European Union.

All the models confirm the existence of conditional β -convergence. The confirmation of existence of the catching up process among the EU countries is in line with the economic theory and the other empirical studies which is another argument for the economic validity of the considered models. The SDM model with inverted income distances as weights shows that β convergence parameter equals 9.3%. It is a significantly lower estimate than in the case of the reference (non-spatial) model where β amounts to 17.3%. This outcome is likely to show that the standard approach to economic growth modelling might result in artificially high estimates of the pace of convergence. A large part of the pace of convergence reported by standard econometric models with no spatial effects might not be the convergence itself – it is the effect of the impact of the other countries' growth factors (including the level of GDP) on the rate of economic growth of a given country. Indeed, such a supposition is reflected very well by the estimated coefficients for the variables responsible for spatial effects. Column 2 in Table 2 shows that the other countries' level of GDP per capita negatively affects the rate of economic growth of a given country. It means that if neighbor countries become richer the pace of economic growth in a given country is slower. The responsibility

of this interaction for explaining a large part of the pace of convergence is strengthened by the fact that the considered SDM model includes income differences as weights (most weighted are the countries with similar level of economic development). Thus, the SDM model shows that a negative relationship between economic growth and a given country's initial GDP per capita level is not so strong because part of this relationship is caused by a negative impact of GDP in neighboring countries on the rate of economic growth in a given country. However, the standard approach without spatial dependence does not account for this possibility and associates the full aforementioned effect to the classical convergence process.

It is worth to add that a negative relationship between the level of GDP in the other countries and a given country's growth rate refers to the convergence mechanism which is of supply-side in its nature. In contrast, demand-side linkages between the countries theoretically indicate rather the existence of a positive relationship between the other countries' GDP and a given country' economic growth: if neighbors are richer our exports are likely to rise fostering economic growth while a recession or a slowdown in neighbor countries is likely to drop our exports and output growth. These short-term demand-side relationships have not been evidenced in this study – partly because of the fact that the analysis is based on 3-year time spans to exclude the impact of short-term cyclical fluctuations.

The SDM model with inverted income distances (Table 2, column 2) also shows the impact of some other neighboring countries' growth factors on GDP dynamics in a given country. It turns out that the spatial estimate for the investment rate is positive and statistically significantly different than zero. It means that higher investment rate in other countries accelerates the pace of economic growth in a given country. This result points to very beneficial effects of investments in the EU as a whole. It turns out that higher investment rate leads to the acceleration of GDP growth not only inside a given economy but also in the other EU countries. Such positive spillovers can be treated as a novum given the existing literature. While a lot of theoretical and empirical analyses shows beneficial spillover effects of investments among the firms at the microeconomic level, our study widens this perspective as it indicates large beneficial spillover effects among the EU countries at the macroeconomic level. Hence, any increase in investment rate regardless of the country or region has a positive impact on economic growth of the EU as a whole (of course, the strength of this impact is different as reflected by the weight matrix).

Another result of spatial examination is the positive and statistically significant spatial coefficient for wgi variable. It shows that good quality of governance is beneficial not only for a given country but also for the other countries. This result indicates beneficial effects of institutional spillovers among the EU countries. A good quality of institutions in a given country is a significant factor of economic growth for all the EU countries (of course, with different weights as reflected by the weighting matrix). Hence, it is necessary for the EU

politicians and policy makers to enforce institutional reforms in all the EU member states to accelerate economic growth in the whole European Union.

Finally, it is worth to add that all the relationships interpreted here on the basis of regression equations do not formally indicate the existence of causal relationship. Causality is very hard to measure. Although there are formal econometric tests to verify the direction of causal relationship (e.g. Granger tests), such a formal approach has a lot of shortcomings and – as we believe - it is better to analyze causality using narrative-descriptive methods as it is done in this study.

CONCLUDING REMARKS

This study develops the current state of knowledge on real economic convergence by introducing spatial effects to the growth model and assessing the existence of convergence on the basis of spatial relationships. In the paper we propose an alternative structure of weights, based on economic distances. Those are constructed in two ways: (1) with the use of the volume of trade between particular countries, (2) on the basis of inverted differences between the level of GDP per capita of different countries. This procedure can be viewed as robustness check to inverted geographic distances as the main determinant of the strength of cross-sectional correlation. We estimate appropriate spatial Durbin-Watson models for the 28 EU countries over the 1993-2013 period.

We confirm the existence of GDP convergence and show that the model with inverted GDP per capita distances is superior to the approaches based on inverted geographic distances and the volume of trade. The SDM model with inverted GDP per capita distances as weights shows that β convergence parameter equals 9.3%. It is a significantly lower estimate than in the case of the non-spatial model where β amounts to 17.3%. This outcome is likely to show that the standard approach to economic growth modelling might result in artificially high estimates of the pace of convergence.

REFERENCES

- Arbia G., Battisti M., Di Vaio G. (2010) Institutions and Geography: Empirical Test of Spatial Growth Models for European Regions, "Economic Modelling", Vol. 27, pp. 12-21.
- Aten B. (1996) Evidence of Spatial Autocorrelation in International Prices, "Review of Income and Wealth", Vol. 42, pp. 149-163.
- Barro R.J., Sala-i-Martin X. (1992) Convergence, "Journal of Political Economy", Vol. 100, pp. 223-251.
- Belotti F., Hughes G., Mortari A.P. (2013) XSMLE – A Command to Estimate Spatial Panel Models in Stata, Material from the 2013 German Stata Users Group Meeting.
- Błaszczuk D. (1974) Model ekonometryczny handlu międzynarodowego w 1967 r., "Ekonomista", No. 5, pp. 1095-1106.

- Blundell R., Bond S. (1998) Initial Conditions and Moment Restrictions in Dynamic Panel Data Models, "Journal of Econometrics", Vol. 87, pp. 115-143.
- Case A.C. (1991) Spatial Patterns in Household Demand, "Econometrica", Vol. 59, pp. 953-965.
- Conley T.G., Topa G. (2002) Socio-Economic Distance and Spatial Patterns in Unemployment, "Journal of Applied Econometrics", Vol. 17, pp. 303-327.
- European Commission (2009), Five Years of an Enlarged EU. Economic Achievements and Challenges, "European Economy", No. 1/2009, Brussels.
- Kelejian H.H., Prucha I.R. (2010) Specification and Estimation of Spatial Autoregressive Models with Autoregressive and Heteroskedastic Disturbances, "Journal of Econometrics", Vol. 157, pp. 53-67.
- Kulhánek L. (2012), Real Convergence in Central European EU Member States, in: Proceedings of the 1st International Conference on European Integration 2012, ICEI 2012 (eds. Honová I., Melecký L., Staníčková M.), 1st International Conference on European Integration, Ostrava, VŠB – Technical University of Ostrava, pp. 161-170.
- Monfort M., Cuestas J.C., Ordóñez J. (2013), Real Convergence in Europe: A Cluster Analysis, "Economic Modelling", Vol. 33, pp. 689-694.
- Rapacki R., Próchniak M. (2009) The EU Enlargement and Economic Growth in the CEE New Member Countries, "European Economy. Economic Papers", No. 367.
- Rey S.J. (2001) Spatial Empirics for Economic Growth and Convergence, "Geographical Analysis", Vol. 33, pp. 195-214.
- Seya H., Tsutsumi M., Yamagata Y. (2012) Income Convergence in Japan: A Bayesian Spatial Durbin Model Approach, "Economic Modelling", Vol. 29, pp. 60-71.
- Stańisić N. (2012) The Effects of the Economic Crisis on Income Convergence in the European Union, "Acta Oeconomica", Vol. 62, pp. 161-182.
- Śledziwska K., Witkowski B. (2012) Światowy kryzys gospodarczy a handel międzynarodowy, "Ekonomista", No. 4, pp. 427-448.
- Tian L., Wang H.H., Chen Y. (2010) Spatial Externalities in China Regional Economic Growth, "China Economic Review", Vol. 21, pp. S20-S31.