Geographic proximity, trade and economic growth: a spatial econometrics approach

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ABSTRACT
This paper examines economic growth in terms of ‘bilateral trade flow’ and ‘geographical distance’ using the spatial dynamic panel data model for the period 1992–2016. The findings illustrate that the effect of spatial spillover or spatial dependence is one of the main economic growth determinants. Also, we find out that spatial relationships across countries and the spatial effects of trade are quite relevant. A country’s economic growth is actually affected by the performance of its neighbours and trade partners. This result suggests that the spillover effects of geographical position and trade partners are the key determinants of economic growth. In fact, overlooking such factors can result in misspecification of models. In addition, the findings confirmed that growth rate of labour force has a negative impact on economic growth while the formation of gross fixed capital has a significant positive effect.

1. Introduction
Over the last two to three decades, a wide range of studies have explored the determinants of economic growth. In 1992, Mankiw et al. carried out extensive studies of the determination of economic growth in different countries. In recent years, some studies have used a more comprehensive list of variables that have included factors such as proximity and spatial position. According to Tobler’s first law of geography (1979), everything is related to everything else but adjacent things are more related than distant things. Overall, no region is isolated, but every region always has a dynamic status according to its correlation with other regions. In the real world, continuous exchanges of science, technology, communication, products, elements, and information occur. As a consequence, interactions among regions with close spatial positions are quite relevant. Accordingly, ignoring the spatial dependence in an econometric analysis while variables are spatially correlated would lead to bias in econometric estimations (Anselin 1988).

Thus, regional independency of other regions in the process of economic growth cannot be ignored. In the neoclassical growth theory, economies are assumed to be independent, not inter-connected. They do not affect each other in neoclassical exogenous growth models. However, the assumption that economies are independent from each other no longer holds as technological transfers, knowledge diffusions, labour migrations, institutional spillovers, contagious economic crises testify to the fact that economies are indeed ‘interacting’ with each other, or in spatial terms, they are actually spatially dependent (Ahmad and Hall 2017). In this case, the assumption of the neoclassical model of Solow and Swan (1956) is not established. Therefore, the theories of an open economy are acceptable. In an open economy, economies of each country become more dependent on one another. In recent progress, spatial econometrics have led to more powerful tools for the estimation of neighbourhood effects. Therefore, from a spatial econometrics perspective, geographical measures are superior due to the time-invariance and exogeneity advantages that are capable of overcoming the identification problem.

Nevertheless, spatial studies are gradually becoming the preferred method of all geographers, economists, political scientists, and sociologists. If firms are assumed heterogeneous and always interacting with one another, they will cause regions to be heterogeneous and interdependent even when located in different regions. Generally, proximity is one way of creating a spillover. In other words, investment in a region will benefit the host and the neighbouring countries, and thus play an important role in economic growth (Abreu, De Groot, and Florax 2005). In this case study, how a country’s growth rate can be related to the growth rates of its nearby countries will be discussed.

International trade has made an increasingly significant contribution to economic growth by experiencing...
an expansion of its dramatic economic growth. Jawaid and Waheed (2011) explained how an increase in terms of trade led to a more efficient allocation of resources which consequently led to high productivity and economic growth. Higher economic growth makes a base for a country to shift their resources to research and development and this leads to improvement of quality of products and export prices in turn leading to further improvement in terms of trade. The theoretical framework of growth and international trade reveals that trade stimulates long-term economic growth. Hence, trade, as a key element of development, has made a gradually significant contribution to economic growth in most countries. Overall, trade is believed to be one of several catalysts of productivity and growth, and therefore its contribution is contingent upon its weight in economic activity. Historical validation has shown that countries with a more open economy tend to be more productive than countries which only produce for their domestic markets. In addition, trade promotes the efficient allocation of resources and can lead to greater growth that might be transformed into greater factor accumulation, particularly for those economies associated with technology diffusion and knowledge spillovers.

Proximity is one way to create spillover. In other words, when a country invests in a region and trade, the benefits of investment or trade come to both the host country and its neighbouring nations, thus playing an important role in the growth of that country as well as its adjacent territories. Considering the importance of proximity and spatial position, in this study, the effect of growth spillover through trade and proximity based on the Solow Growth Model will be emphasized in an open economy by employing the dynamic spatial panel data model. Therefore, the spatial impact on trade and the effect of geographic proximity on economic growth will be examined.

2. Literature review

The theory of economic growth has evolved over the years. The standard neoclassical economic growth model was developed by Solow (1956) and Swan (1956) in the 1950s. In this model, the savings rate and the Malthusian labour growth are exogenously given. Solow developed an analysis of growth which is in different ways closely related to the one afforded by the neoclassical model. Swan gave an explicit commitment to a rather similar mathematical analysis. The Solow–Swan model is believed to show how the growth of capital stock, growth in the labour force and progress in technology interact and how they affect GDP. These functions are combined with the constant rate of payback and create a general equilibrium model. Labour grows at a constant rate, the level of technology and savings rate are constant over time while capital depreciates at a positive constant rate, that is, at each point in time, a constant fraction of the capital stock is depleted and therefore can no longer be used for production. In each second, the capital stock is a key determinant of the economy’s output, but might alter and this can lead to economic growth. Since Solow and Swan, the growth theory has evolved into an enormous body of literature and different types of models have been developed (see Barro and Sala-i-Martin 1995). The spatial Solow model assumes constant returns to scale and also explains convergence by decreasing marginal returns of capital. Hence, the growth process follows Verdoorn’s law, which relates to growth in GDP per capita to output growth and emphasizes an increasing return to scale. In each case, economic growth is associated with conditional convergence and spatial knowledge spillovers (Pfaffermayr 2009).

In recent years, changes in the structure of the global economy have led to greater dependence on economies and their impacts on each other. The results of recent studies indicate that the boundaries amongst countries have diminished, and international exchanges as well as joint transregional activities of countries have increased. In fact, a motivation for obtaining additional benefits is promoting the expansion and deepening of cooperation between countries. Economic cooperation can lead to increased trade, scaled up savings, technology transfer, and thus improve the economic prosperity and increase growth. These effects are achieved through proximity and common boundaries. Recent theoretical arguments maintain that in the new economic system, the status and direction of economic movement towards any country in addition to being influenced by its domestic conditions affect the position and direction of the movement of other countries. Proximity is one way of creating spillover. When a country invests in and improves technology, the return on investment is greater than the domestic interest it owns, consequently increasing productivity and benefiting neighbouring countries. Regional spillovers play a significant role in regional economic growth. In other words, with the improvement of the situation of one or more countries in a region, all the countries of that region will benefit. If the economic conditions are unfavourable in one country, it will have a detrimental effect on the region.

Spatial effects have a crucial impact on economic growth. Countries can have strong links through channels such as trade, technological diffusion, capital inflows, and common political, economic and social
policies. Thus, externalities can infringe country boundaries, influencing the explanation of growth. Trade agreements such as the Andean Pact, NAFTA, MERCOSUR and the European Economic Union (EEU), among others, are typical instances of interdependence among countries. Such agreements were designed to advocate trade and, consequently, growth. Another and possibly more important factor in explaining economic growth is technological diffusion between neighbouring economies. According to Ciccone (1996), the aggregate level of technology in each country is dependent on the aggregate level of technology of its neighbours as well as the externalities originated by capital accumulation within the country. Further evidence of spatial relationship across geographically close economies is offered by Calvo and Reinhart (1996) who contend that one means of the spread of contagion among regions is through technological factors and/or political instability. Therefore, a shock in any country can change the fundamentals of its neighbours as well as its own, and consequently affect its neighbours’ economic performance. Furthermore, spatial dependence might be impacted by regional political stability. This is exemplified in the foreign investment decisions towards a country which might be influenced by both the internal country’s conditions and the region’s political stability. Moreover, investors often do not differentiate between different macroeconomic fundamentals among countries. The authors claim that even if the fundamentals of a country have not been impacted by shocks emanating from its neighbours, investors will classify it with the economy that suffers from the adverse shock, consequently reducing its foreign investment (Ramírez and Loboguerrero 2002).

Furthermore, Empirical evidence suggesting that international trade affects economic growth positively by facilitating capital accumulation, industrial structure upgrading, technological progress, and institutional advancement exists. Increased imports of capital and intermediate products not available in the domestic market can result in the rise in the productivity of manufacturing (Lee 1995). More active participation in international markets by promoting exports leads to more intense competition and improvement in terms of productivity (Wagner 2007). Learning-by-doing might be faster in the export industry thanks to the knowledge and technology spillover effects.

Moreover, an increase in economic growth permits a country to allocate more resources for research and development. More research activities in the country results in quality improvement, which benefit a country in the form of higher export prices, in turn, resulting in further improvement in terms of trade. Researchers do not agree on the impact of terms of trade on economic growth. However, from a general perspective we might expect that the volatility of terms of trade could have a negative effect on economic growth (Jawaid and Waheed 2011). Endogenous growth of an open economy is achieved through ‘learning by doing’ which exhibits diffusion of technology across countries and goods. International trade, which transfers advanced technology and knowledge, could increase the absorptive capacity of trading countries by promoting technological advancement. Increased productivity is similarly achieved through practice and innovation. Finally, international trade leads to robust institutional changes. International trade not only facilitates the trading of goods and services, but also concepts of market mechanisms (Sun and Heshmati 2010).

Several authors have studied determinants of economic growth emphasizing a spatial econometric approach (LeSage and Fischer 2008; Olejnik 2008; Fischer et al. 2009; Tian, Wang, and Chen 2010; Ramos, Suriñach, and Artís 2010; Lee and Yu 2012; Yu Ho, Wang, and Yu 2013; Caleb, Mazanai, and Dhoro 2014; Benos, Karagiannis, and Karkalakos 2015; Zahonogo 2016; Ahmad and Hall 2017) and obtained important results for the analysis of regional growth mechanisms. Their research has shown that the spatial effect favours economic growth.

More specifically, Lee and Yu (2012) did not investigate the effect of physical capital, the growth rate of the active labour force, and human capital on economic growth in their studies. Mankiw, Romer, and Weil (1992) and Ertur and Koch (2007) did not consider the spatial effects of trade on economic growth. Yu Ho, Wang, and Yu (2013) examined the spatial effects of geographic distance and trade which were measured only through the convergence of dynamic panel data and not the effect of spillovers. An important element that affects using one area over the other is the extent of geographical distance between these areas (Lipset, Seong, and Torres 1993). On the other hand, scientists like Yu Ho, Wang, and Yu (2013) believe that trade is the starting point of the growth process.

Thus, this paper aims to contribute to the debate on economic growth by directly addressing spatial effects. Specifically, the roles of both geographic proximity and trade in a spatial panel model that allows control of both spatial dependence and unobservable, time-invariant factors will be considered. This approach permits us to obtain more reliable parameters. Additionally, the accurate interpretation of the spatial parameters in this research allows the generation of more reliable results regarding the importance of geographic proximity, trade and their potential spatial spillovers.
3. Empirical model, estimation strategy and data set

The spatial model of this research is based on theoretical literature of research and previous studies derived from the model of Mankiw, Romer, and Weil (1992) which it is in the form of relation (1):

$$\Delta \ln Y_t = -(1 - e^{-ct})\ln Y_{t-1} - \frac{a(1 - e^{-ct})}{1 - \alpha} \ln N_t + g + \delta \ln A_{t-1}$$

$$+ \frac{a(1 - e^{-ct})}{1 - \alpha} \ln S_t + \ln A_{t-1} + g + \delta$$

(1)

The model considers the Cobb–Douglas product function $Y_t = K_t^\alpha H_t^\beta (L_t^{1-\alpha})$ in the model with human capital and $Y_t = K_t^\alpha (L_t^{1-\alpha})$ in the model without human capital where $0 < \alpha < 1^2$. Labour augments technological progress, $A$ grows at rate $g$ exogenously, i.e. $A_t = A_0 \exp(gt)$, and labour $L$ grows at rate $n$ exogenously, i.e. $L_t = L_0 \exp(nt)$. The explanatory variables include exogenous technical progress rate ($g$), labour growth rate ($N$), savings rate ($S$) and capital depreciation rate ($\delta$). An exogenous technical progress rate was assumed while the capital depreciation rate was considered to be constant across countries, i.e. $g + \delta = 0.05$, as in Mankiw, Romer, and Weil (1992), Islam (1995), Ertur and Koch (2007) and Yu Ho, Wang, and Yu (2013).

To incorporate the economic growth spillover effects relating to bilateral trade, Yu Ho (2013) augmented the empirical growth model with a spatial autoregressive term and specify a panel data model as follows:

$$DLnY_{it} = \lambda \sum_{j=1}^{n} w_{ij} \ln Y_{jt} + \gamma \ln Y_{it, t-1} + \beta_1 \ln(N_t) + 0.05 + \beta_2 \ln S_t$$

$$+ \delta_i + \mu_t + u_{it}$$

(2)

Where:

- $DLnY_{it}$ is real GDP per person employed (constant 2011 US$);
- $\ln Y_{it, t-1}$ is the growth rate of real GDP per person employed of the previous year;
- $N_t$ is the number of persons engaged (in millions), where $N_t+0.05$ proxies the sum of the working-age population growth rate, exogenous technical progress rate, and capital depreciation rate in the model;
- $\ln S_t$ is the Gross fixed capital formation (constant 2011 US$).

A spatial autoregressive term $\sum_{j=1}^{n} w_{ij} \ln Y_{jt}$ was included to estimate the spillover effects of growth for a country from its trade partners. There are two influential studies which consider international trade an important channel for transmitting growth across countries. Yu Ho’s study (2013) was employed for exploiting the panel structure, extending this idea to use bilateral trade flow (the sum of export and import flows) in the last period to construct the time-varying spatial weights, $W_t = [w_{ij}]_{i,j=1}^{n}$. The (i, j)th entry of the weight matrix $W_t$ is the bilateral trade flow (nominal US dollar value) of country i and j at the time $(t - 1)$ (In the spatial literature, the weight matrix is assumed to be exogenous to the dependent variable. Here, because DLnGDP$_{it}$ might affect the trade flow in time t, the trade flow was lagged one period to form the weight matrices in order to avoid the possible endogeneity problem). The diagonal elements of $W_t$ are all 0, and each $W_t$ is row normalized (since the weight matrices are all row normalized, it is immaterial whether nominal or real terms of the trade volume are used). The equation also includes a full set of country dummies, $\delta_i$. These country dummies capture any time-invariant country characteristics that affect its rate of technological progress. Additionally, a full set of time dummies $\mu_t$ is included to capture common shocks to the growth across countries. The error term $u_{it}$ captures all other omitted country factors, with $E(u_{it}) = 0$ for all $i$ and $t$.

In a recent study, Tao and Yu (2012) performed Monte Carlo experiments showing significant biases in regression estimates if a relevant spatial time lag is omitted, while there is no obvious efficiency loss if an irrelevant spatial time lag is included (Yu Ho, Wang, and Yu 2013). Therefore, the following SDPD model with a spatial time lag term was estimated as a robustness check: n(3). Equations (2) and (3) were estimated with the quasi-maximum likelihood estimation (QMLE) method proposed by Lee and Yu (2012) and Yu Ho, Wang, and Yu (2013).

$$\ln Y_{it} = \lambda \sum_{j=1}^{n} w_{ij} \ln Y_{jt} + \gamma \ln Y_{it, t-1} + \beta_1 \ln(N_t + 0.05) + \beta_2 \ln S_t$$

$$+ \delta_i + \mu_t + u_{it}$$

(2)

$$\ln Y_{it} = \lambda \sum_{j=1}^{n} w_{ij} \ln Y_{jt} + \rho \sum_{j=1}^{n} w_{ij,t-1} \ln Y_{jt-1}$$

$$+ \gamma \ln Y_{it-1} + \beta_1 \ln(N_t + 0.05) + \beta_2 \ln S_t$$

$$+ \delta_i + \mu_t + u_{it}$$

(3)

In the spatial literature, the weight matrix is assumed to be exogenous to the dependent variable. Here, because LnGDP might affect the trade flow in time t, the trade flow was lagged one period to form the weight matrices in order to avoid a possible endogeneity problem.

Studies using rigorous quantitative empirical tools on the influencing factors of economic growth through bilateral trade flow remain scarce. Anselin believes that the use of spatial measurement methods in the study of
resources and economic growth is essential. According to Anselin and Bera (1998), spatial autocorrelation can be loosely defined as the coincidence of value similarity with locational similarity. On the other hand, high or low values of a random variable tend to cluster in space (positive spatial autocorrelation) or locations tend to be surrounded by neighbours with very dissimilar values (negative spatial autocorrelation).

Before building the spatial econometric model for the impact of trade on economic growth, the existence of the spatial effect must be tested. This research utilized the LR test (likelihood ratio test) for spatial panel data derived. In these tests, whether or not the non-spatial model can be rejected is determined by the significance of the statistics. If the results of the LR test are not statistically significant, the traditional panel model should be chosen. If it is significant, then the spatial econometric model should be utilized to capture the spatiality.

This paper aimed to investigate economic growth through bilateral trade flow and to determine factors affecting growth. The aggregate data in different geographic regions (such as countries) in this study included export and import matrix and bilateral trade regression analysis led to the probable spatial autocorrelation in the error terms. The spatial heterogeneity between the studied regions is of great importance as well. It is noteworthy that the term spatial heterogeneity mentions deviation from existing relationships between observations at the geographical location level in the space. For this purpose, due to the existence of spatial heterogeneity and spatial autocorrelation, spatial econometrics should be used. For describing spatial heterogeneity, a linear relationship is considered as follows:

$$y_i = W_i \beta_i + \varepsilon_i,$$

(4)

where $i$ stands for the countries gathered at $i = 1, \ldots, n$ points in space, $W_i$ represents a matrix of explanatory variables (distance and bilateral trade) by a related set of $\beta$ parameters, $y_i$ is the dependent variable at observation (or location) $i$ and $\varepsilon_i$ indicates a stochastic disturbance (random error). Equation (4) represents a spatial simple model (Lesage 1999). Causal relationships compared to single equation cross-sectional setting focus more on spatial econometrics in the long term. Panel data is generally more informative as they contain more variation and often less collinearity among the variables. The use of panel data results in a greater availability of degrees of freedom, and hence increases efficiency in the estimation. Panel data also allows for the specification of more complicated behavioural hypotheses, including the effects that cannot be addressed, using pure cross-sectional data (Elhorst 2014).

Autoregressive spatial models are mostly categorized into six different models: FAR, SAR, SEM, SDM, SAC and GSPRE.

$$y_{it} = a + \tau y_{it-1} + \rho \sum_{j=1}^{n} w_{ij} y_{jt} + \sum_{k=1}^{K} x_{itk} \beta_k + \sum_{k=1}^{K} \sum_{j=1}^{n} w_{ij} x_{itk} \theta_k + \mu_i + \gamma_t + \nu_{it}$$

(8)

$$\nu_{it} = \lambda \sum_{j=1}^{n} m_{ij} \nu_{jt} + \varepsilon_{it}$$

(11)

where $\theta$, $\lambda$, $\rho$ are the spatial parameters of the model. Given $\theta = 0$, the model is SAC; $\lambda = 0$ is SDM; $\lambda = 0$ and $\theta = 0$ are SAR; $\rho = 0$ and $\theta = 0$ are SEM; and $\lambda = 0$, $\theta = 0$, and $\mu_i = \varnothing \sum_{j=1}^{n} w_{ij} \mu_j + \eta_i$ are GSPRE. In fact, all the models consider a weight matrix but each in a different method.

After one by one estimation of five stipulations of Equation (11) in terms of both ‘Random’ and ‘Fixed Effects’, the ‘Hausman test’ was used to evaluate the random effects versus fixed effects (Baltagi 2005). It is noteworthy that the Hausman test can only be applied to SAR, SDM, and SEM models. The Hausman test cannot be applied to SAC and GSPRE models because the former was only assumed to be fixed and the latter is just random (Elhorst 2008). In addition, the LR test could be used to select a more appropriate functional form out of the five functional forms: SDM, SAR, SEM, SAC, and GSPRE. In order to compare the models using the LR test, one model was considered unrestricted and others considered restricted. Taking into account the number of constraints, the following four ways for comparing the models were possible: (1) SDM unrestricted model versus SAR restricted model where the given constraint is the weight matrix of variables; (2) SAC unrestricted model versus SEM restricted model where the constraint is the spatial correlation coefficient ($\rho$); (3) SAC unrestricted model versus the SAR restricted model where the constraint is the spatial correlation coefficient between error terms ($\lambda$), and (4) GSPRE unrestricted model versus the SEM restricted model. Here, the constraint is the
spatial correlation coefficient between trade variables (8). The LR test was carried out as follows:

\[
LR = -2(\text{Ln}L_R - \text{Ln}L_{UR})/x^2 > x^2_{(M)} \quad (12)
\]

In the LR test, hypothesis $H_0$ indicates accepting the restricted model and hypothesis $H_1$ indicates accepting the unrestricted model. Thus, if the amount of LR statistic exceeds the Chi-square table (with M degree of freedom which is the number of constraints), $H_0$ will be rejected and $H_1$ accepted and therefore the more accurate unrestricted model is selected. Finally, the form chosen among the five functional forms is based on superiority in two criteria: the number of significant coefficients and higher $R^2$ (Lesage 1999).

The spatial econometric panel models cannot be estimated by ordinary least squares (OLS) due to the simultaneity of the model as there are endogenous variables on the right-hand side of the equations. The OLS estimation might lead to an estimation bias or invalidity in the regression results. For this reason, the maximum likelihood (ML) was used to estimate the parameters of the spatial econometric models (Long, Shao, and Chen 2016).

The following four methods can be employed to represent spatial location: (1) determination of location on screen coordinates; (2) vector of distances, and (3) Geographically Weighted Regression (GWR) method and (4) GeoDist. In this study, GeoDist, which provides several geographical variables such as bilateral distances measured using city-level data to account for the geographic distribution of the population of each nation, was used. Since spatial matrix was used to represent spatial contiguity, spatial contiguity needed to be reflected as a matrix in the model. This technique reflects the relative position in the space of a single regional observation unit compared to others. The criteria of contiguity was determined using information obtained from distances between the capital cities of countries. In most of the spatial economics studies, zero and one matrix was used for a study of spatial effect. Weight matrix was employed to measure the spatial dependence or connectivity between the countries. This matrix determines the proximity which in turn influences the size of spatial spillovers across countries. Spatial econometrics has its roots in geography, so naturally, the weighting matrix in spatial studies is specified via the geographical notion of distance. Geographical matrix naturally assumes that the countries located closely would have a greater weight, or more spatial dependence between them, compared to countries located at a greater distance. The advantage of the geographical matrix is that it is unambiguously exogenous to the model, and therefore eliminates the problem of identification and causal reversions (Ahmad and Hall 2017). In the matrix $N \times N$ (N number of the countries), if countries were situated in near proximity to each other, then number one was used and for all other cases zero was used. A standard matrix was then needed to be devised. Each horizontal row was summed up to equal one. Because this matrix gives similar weights to all countries, it is apparently flawed. Therefore, a spatial weight matrix was used to solve this problem. In this matrix, each diagonal element equals $\frac{1}{d_{ii}}$ or $\frac{1}{d_{ij}}$. $d_{ij}$ is the distance between the capital of two countries. With this matrix, the proximate variable was used to study the spatial effect on economic growth. The geographical distance from any point in space calculates each point relative to fixed or central points; hence, observations that are closer together show a higher spatial dependence than those that are farther apart.

\[
d_{ij} = \left[ \begin{array}{ccc}
d_{i1} & \cdots & d_{ij} \\
\vdots & \ddots & \vdots \\
n_{i1} & \cdots & d_{nj}
\end{array} \right] \quad (13)
\]

where $d_{ij}$ is the great circular distance between the country’s capital $i$ and $j$. Elements in the main diagonal are set to zero by convention since a country cannot be a neighbour to itself. Since the data used in this study consists of $i = 1$ to $j = 25$ countries, the inverse distance weight matrix is as follows:

\[
w_{ij} = \frac{1}{d_{ij}} \quad (14)
\]

$A_{ij}$ is the sum of elements in each row of $w_{ij}$:

\[
A_{ij} = \left[ \begin{array}{c}
\sum \frac{1}{d_{ij}} \\
\vdots \\
\sum \frac{1}{d_{ij}}
\end{array} \right] \quad (15)
\]

\[
B_{ij} = \frac{w_{ij}}{A_{ij}} \quad (16)
\]

\[
C_{ij} = \text{Average } B_{ij} \quad (17)
\]

$W_{ij}$ is the distance matrix normalizes elements of which include zero and one.

\[
W_{ij} = \begin{cases} 
B_{ij} \geq C_{ij} & 1 \\
B_{ij} < C_{ij} & 0
\end{cases} \quad (18)
\]

Ertur and Koch (2011) assumed this approach to use bilateral trade flow (average over the period 1990–2000) as a spatial weight matrix in their empirical growth study with a cross-sectional group of countries.
Yu Ho’s (2013) method for exploiting the panel structure was employed in this research, extending this idea to use bilateral trade flow (the sum of export and import flows) in last period to construct the time-varying spatial weights, $W_t = \left[w_{ij}\right]_{j=1}^{n}$. The (i, j)th entry of the weight matrix $W_t$ is the bilateral trade flow (nominal US dollar value) of country i and j at time $(t - 1)$ (in the spatial literature, the weight matrix is assumed to be exogenous to the dependent variable. Here, because DLnGDP$_{it}$ might affect the trade flow in time t, we trade flow was lagger one period to form the weight matrices in order to avoid possible endogeneity problem). The diagonal elements of $W_t$ are all 0, and each $W_t$ is row normalized (since the weight matrices are all row normalized, it is unimportant whether nominal or real terms of the trade volume are used). The impact of geographic and trade characteristics on economic growth is described in the present paper. There is one important complication to our basic argument that geographic and trade variables can be used to construct an instrument for economic growth regression. Then, four matrices were created: export flow, import flow, bilateral trade, and geographical distance, the first three of which were multiplied in the geographical distance matrix. In contrast to conventional gravity equations for bilateral trade, this kind of trade equation includes only geographic characteristics: country sizes, their distances from one another, and whether they shared borders. This would ensure that the instrument depends solely on countries’ geographic characteristics and not on their economic growths or actual trading patterns. In considering the spatial effects of geographical distance, there was only one geographical distance matrix since geographical distance does not changeover time. The geographical distance from any point in space calculates each point relative to fixed or central points; hence, observations that are closer together show a higher spatial dependence than those that are at a greater distance.

$E_{ij}$ is the export flow between country’s i and j. The elements in the main diagonal are set to zero by convention since a country cannot export to itself. Thus, $Export_{ij}$ (export flow matrix) will be as per below:

$$Export_{ij} = \left[\begin{array}{c} E_{11} \\ \vdots \\ E_{n1} \\
E_{1j} \\ \vdots \\ E_{nj} \end{array}\right] / \left[\sum_{j=1}^{n} E_{ij}\right] \quad (19)$$

where $l_{ij}$ is the import flow between country’s i and j. The elements in the main diagonal are set to zero by convention since a country cannot import to itself. Thus, $Import_{ij}$ (import flow matrix) is as follows:

$$Import_{ij} = \left[\begin{array}{c} \sum_{j=1}^{n} l_{ij} \end{array}\right] \quad (20)$$

Bilateral trade matrix is as follows:

$$Bilateral \text{ Trade}_{ij} = Export_{ij} + Import_{ij} \quad (21)$$

In our model, spatial panel data for 25 countries which were chosen because of the availability of complete data-sets were used. Sample selection was based on the restriction of data. The countries included in the model were: Austria, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Latvia, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden. The data covers the period 1992–2016. The variables used were as follows: differential log of GDP as a proxy of annual economic growth (DLNGDP); annual log of GDP (t-1) (LNGDP (t-1)); annual gross fixed capital formation (constant 2010 US$ (LNC)); human capital; Combined annual growth rate of labour force, exogenous technical progress rate and capital depreciation rate $(N + g + \delta)$.

## 5. Results

All the research data were collected from the World Bank, IMF, CEPII and Penn World Table 9 (PWT 9.0)-Groningen University. The descriptive statistics of the variables are presented in Table 1.

| 25 country | Min | Max | Mean | SD |
|------------|-----|-----|------|----|
| N + g + $\delta$ | -9.9 | 10.9 | 0.36 | 1.69 |
| LNC | 19.98 | 27.35 | 24.45 | 24.45 |
| LNGDP(t-1) | 9.86 | 11.89 | 10.98 | 10.98 |
| DLNGDP | -0.54 | 0.217 | 0.017 | 0.04 |

Source: Research findings.
Table 2. Estimation of panel spatial model using bilateral trade flow matrix.

| Variable  | GS PRE Random effects | SAC Fixed effects | Fixed effects | Random effects | Fixed effects | Random effects | Fixed effects | Random effects |
|-----------|-----------------------|------------------|--------------|---------------|--------------|---------------|--------------|---------------|
| Constant  | 0.448***              | −0.226           | −0.591***    | −0.983***     |
|           | (3.41)                | (−1.52)          | (−6.03)      | (−4.17)       |
| LNGDP(t-1)| −0.119***             | −0.137***        | −0.149***    | −0.133***     |
|           | (−6.79)               | (−9.08)          | (−10.75)     | (−11.95)      |
| LNcapital| 0.036***              | 0.087***         | 0.087***     | 0.089***      |
|           | (4.30)                | (9.00)           | (13.28)      | (15.01)       |
| (N + 0.05)| −0.009***             | −0.008***        | −0.008***    | −0.009***     |
|           | (−10.28)              | (−8.78)          | (−9.26)      | (−9.33)       |
| LNGDP(t-1)*W | 0.319***        | 0.408***         | 0.408***     | 0.406***      |
|           | (7.61)                | (17.25)          | (17.26)      | (16.83)       |
| capital*W | 0.940***              | 0.298***         | 0.4195***    | 0.411***      |
|           | (26.85)               | (6.38)           | (18.19)      | (17.17)       |
| ρ         | 0.186                 | 0.197            | 0.197        | 0.197         |
|           | (0.74)                | (0.74)           | (0.74)       | (0.74)        |
| LN  | 1236.77               | 1262.24          | 1166.03      | 1244.25       |
|        |                       | 1167.31          | 1248.77      | 1187.8        |
|        |                       | 1263.91          |             |              |

*, **, and *** denote significance at 10%, 5%, and 1% level. The numbers in the () are the t-statistic.

Table 3. Results of selection model tests . . . with bilateral trade flow matrix (GS PRE random).

| Hypothesis H0 | Hypothesis H1 | Value of the test statistic (P-value) | The test result |
|---------------|---------------|--------------------------------------|----------------|
| (restricted model) | (unrestricted model) | (P-value) |                         |
| Hausman test  | SDM random    | SDM fixed                             | H = 15.39 (0.0015) | SDM fixed |
| (to select the random effects and the fixed effects model) | SAR random    | SAR fixed                             | H = 15.98(0.0011) | SAR fixed |
|               | SEM random    | SEM fixed                             | H = 16.64 (0.0008) | SEM fixed |
| LR test (for nested models) | SAR fixed    | SAR fixed                             | LR = −40.98() | |
|               | SEM fixed     | SAC fixed                             | LR = −192.42() | |
|               | SAR fixed     | SAC fixed                             | LR = −189.86() | |
|               | SEM random    | GS PRE random                         | LR = 14.96(0.0048) | GS PRE random |

The results of the LR test to select the most appropriate model are shown in Table 3. Based on the LR test, only GS PRE was significant and subsequently GS PRE was selected.

According to Table 2, based on the GS PRE model, the coefficients of the log of the GDP, the gross fixed capital formation and the growth rate labour force were negative, positive and negative, respectively. The significance of these coefficients means the meaning of spatial correlation in the performance relation is based on bilateral trade flow. Furthermore, the spatial autocorrelation coefficient λ indicates that the value of this coefficient is statistically significant and positive so the bilateral trade dimension is of particular importance between the countries. It shows that at a certain period in time, countries which enjoy a year of economic growth have on average the potential to grow even more the following year. Indirectly, spillover affects the economic growth of neighbouring countries. If the average weighted economic growth of neighbouring countries increases by 1%, its economic growth will increase by 0.940%.

According to Table 5, the Hausman test shows that in the SDM, SAR and SEM models, the fixed effects model was superior to the random-effects model. Since in the three models, the fixed effects model was superior to the random-effects model, it is, therefore, more appropriate. Moreover, the results of the LR test to select the most appropriate model are shown in Table 5. Based on the Hausman test, four models exist for the LR test: comparison between the fixed SAR and fixed SDM models, the fixed SEM and fixed SAC models, the fixed SAR and fixed SAC models and the random SEM and random GS PRE models. Based on the results, SAC model in two states and SDM model in one state were fixed and in one random case, SEM was selected. Based on the results SEM model in one state, and SAC and SDM model in another state were fixed and in one random case, SEM was selected. Based on the Hausman test, the last model was rejected because it was based on random effects. $R^2$ was 0.0088, 0.0055 and 0.0001 in the SAC, SEM and SDM models, respectively. Thus, since the SAC model had the largest $R^2$, it was more likely to be accepted and as a result selected as the most
Table 4. Estimation of panel spatial model using geographical distance matrix.

| Variable          | GSPRE Random effects | SAC Fixed effects | SEM Fixed effects | SAR Random effects | SDM Random effects |
|-------------------|----------------------|-------------------|------------------|-------------------|-------------------|
| Constant          | −0.2                 | −0.09***          | 0.07             | 0.3***            |
|                   | (−1.46)              | (−1.47)           | (0.232)          | (3.58)            |
| LNGDP(t-1)        | −0.14***             | −0.16***          | −0.07***         | −0.16***          |
|                   | (−9.74)              | (−9.72)           | (−1.40)          | (−9.21)           |
| LNcapital         | 0.07***              | 0.09***           | 0.04***          | 0.09***           |
|                   | (8.92)               | (13.21)           | (6.28)           | (12.64)           |
| (N + 0.05)        | −0.008***            | −0.008***         | −0.007***        | −0.009***         |
|                   | (−7.50)              | (−8.09)           | (−7.16)          | (−8.03)           |
| LNGDP(t-1) *W     | 0.06***              | 0.05***           | 0.005***         | 0.002***          |
| capital *W        | −0.04***             | −0.02***          | −0.04***         | −0.02***          |
| (N + 0.05)*W      | 0.002***             | 0.001***          | 0.002***         | 0.001***          |
| ρ                 | 0.11                 | 0.11***           | 0.31***          | 0.31***           |
|                   | (1.17)               | (5.14)            | (128.66)         | (113.15)          |
| λ                 | −0.05                | 0.01***           | 0.01***          | 0.01***           |
|                   | (−0.91)              | (8.92)            | (9.57)           | (9.57)            |
| ⊗                 | 0.12***              |                  |                  |                  |
| LNL               | 1129.30              | 1209.75           | 1205.88          | 884.90            |

*, **, and *** denote significance at 10%, 5%, and 1% level. The numbers in the () are the t-statistic.

Table 5. Results of selection model tests … with geographical distance matrix (SAC fixed).

| Hypothesis H0 (restricted model) | Hypothesis H1 (unrestricted model) | Value of the test statistic (P-value) | The test result |
|----------------------------------|------------------------------------|--------------------------------------|----------------|
| Haussman test (to select the random effects and the fixed effects model) | SDM random | SDM fixed | H = 17.67(0.0005) | SDM fixed |
|                                  | SAR random | SAR fixed | H = 43.54(0.0000) | SAR fixed |
|                                  | SEM random | SEM fixed | H = −15.75(0.0000) |                  |
| LR test (for nested models)      | SAR fixed | SDM fixed | LR = 138.393(0.0000) | SEM fixed |
|                                  | SEM fixed | SAC fixed | LR = 7.7418(0.0517) | SEM fixed |
|                                  | SAR fixed | SAC fixed | LR = 649.6816(0.0000) | SAC fixed |
|                                  | SEM random | GSPRE random | LR = 1.2458(0.7420) | SEM random |

appropriate model. In fact, the ‘fixed SAC model’ compared to other spatial models better explains the impact of economic growth as well as the spatial correlation coefficient between the error and the spatial correlations.

According to Table 4, based on the SAC model, the economic growth of the previous period had a negative impact on economic growth. With an increase of one dollar, the gross fixed capital formation of 0.08 increased economic growth between countries. With an increase in the labour force, economic growth decreased by as much as 0.007 units. Furthermore, Stability of ρ indicates that if the average weighted economic growth of neighbouring countries increases by 1%, economic growth will increase by 0.11% and λ will not be significant.

The results of the LR test to select the most appropriate model are shown in Table 7. Based on the LR test, only GSPRE was significant and consequently GSPRE was selected.

According to Table 6, based on GSPRE model, the sign of the coefficients of the log of the GDP, the gross fixed capital formation and growth rate labour force were negative, positive and negative, respectively. The significance of these coefficients means the meaning of spatial correlation in the performance relation is based on geographical distance and export flow. In addition, the spatial autocorrelation coefficient λ indicates that the value of this coefficient was statistically significant and positive and therefore the export and the geographical dimensions were of particular importance between the countries. It shows that at a certain period of time, countries which enjoy a year of economic growth have on average the potential to grow even more the following year. Indirectly, spillover affects the economic growth of neighbouring countries. Ceteris Paribus, if the average weighted economic growth of neighbouring countries increases by 1%, its economic growth will increase by 2.420%.

The results of the LR test to select the most appropriate model are shown in Table 9. Based on the LR test, only GSPRE is significant and consequently, GSPRE has been selected.

According to Table 8, based on GSPRE model, the sign of the coefficients of the log of the GDP and the growth
rate labour force were negative. The coefficient of gross fixed capital formation was not significant. The significance of these coefficients means that the meaning of spatial correlation in the performance relation is based on geographical distance and import flow. Furthermore, the spatial autocorrelation coefficient \( \lambda \) indicates that

### Table 6. Estimation of panel spatial model using geographical distance & export flow matrix.

| Variable          | GS PRE Random effects | SAC Fixed effects | Fixed effects | Random effects | SEM Fixed effects | Random effects | SAR Fixed effects | Random effects | SDM Fixed effects | Random effects |
|-------------------|-----------------------|-------------------|---------------|---------------|------------------|---------------|------------------|---------------|------------------|---------------|
| Constant          | 0.25***               | 0.373***          | 0.073         | -0.239**      | (4.27)          | (1.20)        | (7.31)          | (8.93)        |                  |               |
| LGDP(t-1)         | -0.034***             | -0.074***         | -0.023***     | -0.121***     | (-2.15)         | (-1.11)       | (-0.166)       |               |                  |               |
| LNcapital         | 0.0057***             | 0.019             | 0.002***      | 0.0076***     | (2.45)          | (4.36)        | (7.31)          | (8.93)        |                  |               |
| (N + 0.05)        | -0.007***             | -0.007***         | -0.006***     | -0.008***     | (-7.44)         | (-6.28)       | (-8.64)         | (-9.95)       |                  |               |
| LGDP(t-1) *W      |                       |                   |               | 0.032         |                  |               |                  |               |                  |               |
| capital *W        |                       |                   |               | 0.014         |                  |               | 0.022**         | (3.82)        |                  |               |
| (N + 0.05)*W      |                       |                   |               | 0.173***      |                  |               | 0.010**         | (1.83)        |                  |               |
| \( \rho \)        | 2.57***               | 2.43***           | 2.166***      |                | (17.37)         | (19.02)       | (14.77)         |               |                  |               |
| \( \lambda \)     | 2.420***              |                   |                | 2.23***       | (19.13)         | 1.975***      | (15.36)         | (13.56)       |                  |               |
| \( \varpi \)      | -2.857***             | -1.14***          | 2.10***       |                | (-3.30)         | (0.07)        | (-0.07)         |               |                  |               |
| LNL               | 1190.996              | 1269.35           | 1188.93       | 1253.00       | 1174.14         | 1262.54       | 1192.82         | 1290.9        |                  |               |

*, **, and *** denote significance at 10%, 5%, and 1% level. The numbers in parentheses are the t-statistic.

### Table 7. Results of selection model tests with geographical distance & export flow matrix (GS PRE random).

| Hypothesis H0 (restricted model) | Hypothesis H1 (unrestricted model) | Value of the test statistic (P-value) | The test result |
|----------------------------------|-----------------------------------|--------------------------------------|-----------------|
| Hausman test (to select the random effects and the fixed effects model) | SDM random | SDM fixed | SDM fixed |
| SAR random | SAR random | SAR fixed | SAR fixed |
| SEM random | SEM random | SEM fixed | SEM fixed |
| LR test (for nested models) | SAR fixed | SDM fixed | LR = 37.36 (1) |
| SAR fixed | SAC fixed | LR = 160.84 (1) |
| SAR fixed | SAC fixed | LR = 190.42 (1) |
| SEM random | GSPRE random | LR = 124.008 (0.0000) | GSPRE random |

### Table 8. Estimation of panel spatial model using geographical distance & import flow matrix.

| Variable          | GS PRE Random effects | SAC Fixed effects | Fixed effects | Random effects | SEM Fixed effects | Random effects | SAR Fixed effects | Random effects | SDM Fixed effects | Random effects |
|-------------------|-----------------------|-------------------|---------------|---------------|------------------|---------------|------------------|---------------|------------------|---------------|
| Constant          | 0.2432***             | 0.257***          | 0.086         | -0.189*       | (2.63)           | (1.39)        | (1.68)           |               |                  |               |
| LGDP(t-1)         | -0.0385*              | -0.042***         | -0.034***     | -0.092***     | (-1.80)          | (-4.23)       | (-6.77)          | (-9.66)       |                  |               |
| LNcapital         | 0.008                 | 0.009             | 0.012***      | 0.0499***     | (1.21)           | (4.60)        | (6.45)           | (9.07)        |                  |               |
| (N + 0.05)        | -0.0067***            | -0.007***         | -0.006***     | -0.008***     | (-7.27)          | (-6.56)       | (-8.71)          | (-9.98)       |                  |               |
| LGDP(t-1) *W      |                       |                   |               | -0.006        |                  |               | 0.0049          | (0.07)        |                  |               |
| capital *W        |                       |                   |               | 0.018         |                  |               | 0.134            | (3.54)        |                  |               |
| (N + 0.05)*W      |                       |                   |               | 0.021***      |                  |               | 0.013**          | (4.10)        |                  |               |
| \( \rho \)        | 2.651***              |                   | 2.009***      | 1.87***       | (25.97)          | (18.01)       | (15.40)          | (13.18)       |                  |               |
| \( \lambda \)     | 2.139***              | -1.729***         | 2.139***      | 1.636***      | (19.68)          | (19.69)       | (15.40)          | (13.18)       |                  |               |
| \( \varpi \)      | -0.618                |                   | -0.618        |                | (-0.37)         |               |                  |               |                  |               |
| LNL               | 1199.82               | 1293.77           | 1199.75       | 1262.6        | 1187.6           | 1271.64       | 1204.69          | 1289.57       |                  |               |

*, **, and *** denote significance at 10%, 5%, and 1% level. The numbers in parentheses are the t-statistic.
Table 9. Results of selection model tests … with geographical distance & import flow matrix (GSPRE random).

| Variable                  | Hypothesis H0 (restricted model) | Hypothesis H1 (unrestricted model) | Value of the test statistic (P-value) | The test result |
|---------------------------|----------------------------------|-----------------------------------|--------------------------------------|-----------------|
| Houseman test (to select the random effects and the fixed effects model) | SDM random fixed effects         | SDM fixed                         | H = 5.40 (0.1449)                     | SDM random fixed |
| LR test (for nested models) | SAR fixed effects                | SAR fixed                         | H = 131.20 (0.0000)                   | SAR fixed       |
|                           | SEM fixed                        | SEM fixed                         | H = −3.48 (0.0004)                    |                 |
|                           | GSPRE random fixed effects       | GSPRE fixed                       | H = 128.09 (0.0000)                   |                 |

Table 10. Estimation of panel spatial model using geographical distance & bilateral trade flow matrix.

| Variable                  | GSPRE Random effects | SAC Fixed effects | SEM Random effects | SAR Random effects | SDM Random effects |
|---------------------------|----------------------|------------------|-------------------|-------------------|------------------|
| Constant                  | 0.3027*** (3.11)     | 0.295*** (2.65)  | −0.32*** (−3.29)  | 0.007*** (1.36)   | 0.0936 (1.36)    |
| LNGDP(t−1)                | −0.066 (−1.33)       | −0.097*** (−10.51) | −0.129*** (−9.52) | −0.099*** (−10.87) | −0.155*** (−10.48) |
| LNcapital                 | 0.018 (0.87)         | 0.0109 (1.04)    | 0.063*** (8.05)   | 0.058*** (12.35)  | 0.057*** (8.92)  |
| (N + 0.05)                | −0.007*** (−6.71)    | −0.007*** (−7.06) | −0.008*** (−9.42) | −0.08*** (−9.17)  | −0.007*** (−10.2) |
| LNcapital *W              |                      |                   |                   |                   | 0.0301 (0.82)    |
| Capital *W               | 0.002 (0.24)         | 0.079*** (3.99)  | 0.006** (2.26)    |                   |                  |
| (N + 0.05) *W            |                      |                   |                   | 0.0128*** (4.68)  |                   |
| p                        | 1.332*** (21.96)     | 0.97*** (15.75)   | 0.934*** (15.39)  | 1.073*** (17.91)  | 0.871*** (13.30) |
| λ                        | 1.137*** (18.90)     | 1.14*** (19.42)   | 1.020*** (15.31)  |                   |                  |
| | −0.210975               | 1282.09             | 1194.74           | 1258.16           | 1191.42           |                  |
| LNL                       | 1194.63              | 1282.09           | 1194.74           | 1258.16           | 1191.42           | 1267.72           | 1193.76           | 1290.37           |

*, **, and *** denote significance at 10%, 5%, and 1% level. The numbers in the () are the t-statistic.

the value of this coefficient was statistically significant and positive, so import and geographical dimension are of particular importance between the countries. It shows that at a certain period in time, countries which enjoy a year of economic growth have on average the potential to grow even more the following year. Indirectly, spillover affects the economic growth of neighbouring countries. Ceteris Paribus, if the average weighted economic growth of neighbouring countries increases by 1%, its economic growth will increase by 2.139%.

The results of the LR test to select the most appropriate model are shown in Table 11. Based on the LR test, only GSPRE was significant and consequently selected. Also, Summary of all model selection and results for the selected model were cited in Table 12 and Table 13, respectively.

According to Table 10, based on the GSPRE model, the sign of the coefficients of the log of the GDP and the gross fixed capital formation were not significant. The sign of the coefficient of the growth rate labour force was negative. The significance of these coefficients means that the meaning of spatial correlation in the performance relation is based on geographical distance and bilateral trade flow. Additionally, the spatial autocorrelation coefficient λ indicates that the value of this coefficient was statistically significant and positive indicating that bilateral trade and geographical dimension are of particular importance between the countries. It shows that at a certain period in

Table 11. Results of selection model tests … with geographical distance & bilateral trade flow matrix (GSPRE random).

| Variable                  | Hypothesis H0 (restricted model) | Hypothesis H1 (unrestricted model) | Value of the test statistic (P-value) | The test result |
|---------------------------|----------------------------------|-----------------------------------|--------------------------------------|-----------------|
| Hausman test (to select the random effects and the fixed effects model) | SDM random fixed effects         | SDM fixed                         | H = 116.61 (0.0000)                     | SDM fixed       |
| LR test (for nested models) | SAR fixed effects                | SAR fixed                         | H = −15.92 (0.0004)                    | SAR fixed       |
|                           | SEM fixed                        | SEM fixed                         | LR = −4.68 (0.0004)                    |                 |
|                           | GSPRE random fixed effects       | GSPRE fixed                       | LR = −117.4 (0.0004)                   |                 |
|                           | SDM fixed                        | SDM fixed                         | LR = −181.34 (0.0004)                  |                 |
|                           | SAC fixed                        | SAC fixed                         | LR = −174.7 (0.0004)                   |                 |
|                           | SEM random                       | SEM fixed                         | LR = −4.68 (0.0004)                    |                 |
|                           | GSPRE random fixed effects       | GSPRE fixed                       | LR = −117.4 (0.0004)                   |                 |

* *** denotes significance at 10%, 5%, and 1% level. The numbers in the () are the t-statistic.
time, countries which enjoy a year of economic growth have on average the potential to grow even more the following year. Indirectly, spillover affects the economic growth of neighbouring countries. Ceteris Paribus, if the average weighted economic growth of neighbouring countries increases by 1%, its economic growth will increase by 1.137%.

We also estimate the export matrix and the import matrix, to summarize the text we have removed them. For the export matrix and the import matrix, based on the LR test, the results show that SAC and GSPRE model was significant and therefore selected, respectively. Notably, for the export matrix, the coefficient log of the GDP and the gross fixed capital formation are negative and positive, respectively. When a country invests in technology and improves its technology, the return on investment is greater than the domestic interest it owns, its productivity increases and neighbouring countries benefit. In other words, with the improvement of the situation of one or more countries in a region, all the countries in the region will benefit. In addition, an increase in physical capital is followed by the country’s production capacity which will increase economic growth. Capital outflow occurs from countries with high capital stock to countries of low capital stock. Moreover, an increase in openness increases capital flow. Indeed, when capital is transferred from rich to poor countries, then poor countries can experience higher economic growth. The coefficient of the growth rate labour force is negative. When the final productivity of the workforce is zero, the coefficient of labour force growth rate is negative. As a result, unemployment surges in the country; therefore, even a greater labour force entering the production process does not increase production. An increase in the growth rate of the labour force does not necessarily result in a higher production capacity as it will reach saturation point, consequently reducing GDP growth and having a negative impact. On the other hand, in Solow’s model, economic growth increases due to the lower returns of capital to the

Table 12. Summary of model selection.

| Model with different matrix | Import flow matrix | Export flow matrix | Bilateral trade flow matrix | Geographical distance matrix | Geog. & import flow | Geog. & export flow | Geog. & bilateral trade flow |
|-----------------------------|-------------------|-------------------|-----------------------------|-----------------------------|---------------------|---------------------|-----------------------------|
| Hausman test                |                   |                   |                             |                             |                     |                     |                             |
| SDM fe vs SDM re            | -117.36           | 143.50            | 15.39                       | 17.67                       | 5.40                | 28.98               | 116.61                      |
|                             | (0.0000)          | (0.0015)          | (0.0005)                    | (0.1449)                    | (0.0000)            | (0.0000)            | (0.0000)                    |
| SAR fe vs SAR re            | 16.06             | 209.49            | 15.98                       | 43.54                       | 131.20              | 143.46              | -15.92                      |
|                             | (0.0011)          | (0.0000)          | (0.0000)                    | (0.0000)                    | (0.0000)            | (0.0000)            |                             |
| SEM fe vs SEM re            | 16.50             | -16.75            | 16.64                       | -15.75                      | -3.48               | 18.66               | 18.30                       |
|                             | (0.0009)          | (0.0008)          | ()                         | ()                          | ()                  | ()                  | ()                          |
| LR test                     |                   |                   |                             |                             |                     |                     |                             |
| SDM fe vs SAR fe            | -1.894            | -62.68            | -40.98                      | 138.39                      | -34.18              | -37.36              | -4.68                       |
|                             | (0.0000)          | (0.0000)          | (0.0000)                    | (0.0000)                    | (0.0000)            | (0.0000)            |                             |
| SAC fe vs SEM fe            | -190.66           | -193.04           | -192.42                     | 7.7418                      | -188.04             | -160.84             | -174.7                      |
|                             | (0.0000)          | (0.0000)          | (0.0517)                    | (0.0000)                    | (0.0000)            | (0.0000)            |                             |
| SAC fe vs SAR fe            | -188.02           | 247.6             | -189.86                     | 649.6816                    | -212.34             | -190.42             | -181.34                     |
|                             | (0.0000)          | (0.0000)          | (0.0000)                    | (0.0000)                    | (0.0000)            | (0.0000)            |                             |
| GSPRE re vs SEM re          | 24.28             | 44.24             | 14.96                       | 1.2458                      | 125.56              | 124.008             | 127.06                      |
|                             | (0.0001)          | (0.0001)          | (0.0048)                    | (0.7420)                    | (0.0000)            | (0.0000)            | (0.0000)                    |

Table 13. Summary of results for the selected model.

| Model with different matrix | Import flow matrix | Export flow matrix | Bilateral trade flow matrix | Geographical distance matrix | Geog. & import flow | Geog. & export flow | Geog. & bilateral trade flow |
|-----------------------------|-------------------|-------------------|-----------------------------|-----------------------------|---------------------|---------------------|-----------------------------|
| Constant                    | 0.365**           | 0.448***          | 0.2432***                   | 0.25***                     | 0.3027***           | 0.3027***           |                             |
|                             | (2.55)            | (3.41)            | (2.63)                      | (4.27)                      | (3.11)              |                     |                             |
| LNGDP(t-1)                  | -0.102***         | -0.140***         | -0.119***                   | -0.13***                    | -0.0385*            | -0.034***           | -0.066                      |
| (-5.45)                     | (-10.87)          | (-6.79)           | (-9.43)                     | (-1.80)                     | (-4.00)             | (-1.33)             |                             |
| LNcapital                   | 0.033***          | 0.087***          | 0.036***                    | 0.08***                     | 0.008               | 0.0057***           | 0.018                       |
| (3.56)                      | (13.90)           | (4.30)            | (11.14)                     | (1.21)                      | (2.45)              | (0.87)              |                             |
| (N + 0.05)                  | -0.009***         | -0.009***         | -0.009***                   | -0.007***                   | -0.006***           | -0.007***           | -0.007***                   |
| (-10.36)                    | (-9.74)           | (-10.28)          | (-7.48)                     | (-7.27)                     | (-7.44)             | (-6.71)             |                             |
| LNGDP(t-1) *W              |                   |                   |                             |                             |                     |                     |                             |
| capital *W                  |                   |                   |                             |                             |                     |                     |                             |
| (N + 0.05)*W               |                   |                   |                             |                             |                     |                     |                             |
| p                           | 0.646***          | 0.11***           |                             |                             |                     |                     |                             |
|                             | (7.65)            | (5.14)            |                             |                             |                     |                     |                             |
| λ                           | 1.795***          | 0.611***          | 0.940***                    | -0.05                       | 2.139***            | 2.420***            | 1.137***                    |
|                             | (27.18)           | (6.53)            | (26.85)                     | (-0.91)                     | (19.68)             | (19.13)             | (18.90)                     |
| φ                           | 0.636312          | 0.186             | -0.618                      | -2.857***                   | -0.210975           |                     |                             |
|                             | (1.28)            | (0.74)            | (-0.37)                     | (-3.30)                     |                     |                     |                             |
| LNL                         | 1235.36           | 1258.74           | 1236.77                     | 1209.75                     | 1199.82             | 1190.996            | 1194.63                     |
workforce by increasing physical capital and reducing labour force growth rates. When measuring the factors affecting economic growth such as the formation of gross fixed capital formation and growth rate labour force, it is necessary to determine the position and proximity of the desired location that the model measures to avoid the heterogeneity variance. The significance of these coefficients means that the meaning of spatial correlation is based on export flow. In addition, the spatial autocorrelation coefficient $\lambda$ indicates that the value of this coefficient is statistically significant and positive, so the export dimension is of particular importance between countries. It shows that at a certain period in time, spillover affects the economic growth of neighbouring countries. If the average weighted economic growth of neighbouring countries increases by 1%, its economic growth will increase by 0.611%. Also, for the import matrix, the coefficients of the log of the GDP, the gross fixed capital formation and the growth rate labour force were negative, positive and negative, respectively. The significance of these coefficients means that the meaning of spatial correlation in the performance relation is based on import flow. Moreover, the spatial autocorrelation coefficient $\lambda$ indicates that the value of this coefficient is statistically significant and positive, so the import dimension is of particular importance between countries. It shows that at a certain period of time, countries which enjoy a year of economic growth have on average the potential to grow even more the following year. Indirectly, spillover affects the economic growth of neighbouring countries. If the average weighted economic growth of neighbouring countries increases by 1%, its economic growth will increase by 1.795%.

6. Discussion and conclusion

A spatial dynamic panel data approach was employed to estimate the augmented Solow growth model with a sample of 25 EU countries over the period 1992–2016. Spatial effects and spillover effects were confirmed in these countries. Consequently, a country’s growth rate was related to the growth rates of its neighbouring countries. The research illustrated that there was a positive spillover effect of the growth of one country to its neighbouring countries in the spatial dynamic panel data model. Thus, traditional estimation techniques might lead to biased-estimated parameters due to the disregard of spatial spillover effects of variables. In all groups, coefficient of the log of GDP and the growth rate labour force were negative and significant. Furthermore, the coefficient of the gross fixed capital formation showed a positive effect on economic growth. Therefore, trade and distance appear to raise economic growth by spurring the accumulation of physical capital and increasing output for given levels of capital. Concurrently, the economic growth of the previous period and the growth rate labour force showed a negative impact on the economic growth. As a result, trade and distance seem to decrease economic growth by spurring the economic growth of the previous period and the growth rate labour force. The gross fixed capital formation had a positive impact on economic growth. The spatial autoregressive coefficient spillover had a positive effect on economic growth. The spatial autocorrelation coefficient had a positive effect implying that a country will maintain a business relationship with countries that have high commercial, technical, knowledge and capital flows. The coefficient of the growth rate of labour force on economic growth was negative and this was confirmed by Yu Ho, Wang, and Yu (2013) and Benos, Karagiannis, and Karkalakos (2015). The sign of the coefficient of the gross fixed formation was positive and confirmed by Olejnik (2008), LeSage and Fischer (2008), Fischer et al. (2009), Yu Ho, Wang, and Yu (2013) and Benos, Karagiannis, and Karkalakos (2015). The sign of the coefficient log of the GDP was negative and confirmed by Yu Ho, Wang, and Yu (2013).

When a country invests in technology and improves it, the return on investment is greater than the domestic interest it owns, its productivity increases and neighbouring countries benefit. In other words, with the improvement of the situation of one or more countries in a region, all the countries in the region will benefit and this will, in fact, create a positive growth cycle in the region. In addition, with the increase in physical capital, the country’s production capacity increases and with economic growth, GDP growth will increase, too.

Capital outflow occurs from countries with high capital stock to countries with a low capital stock. Moreover, as openness increases capital flow also increases. The lesser amount of capital in poorer countries results in a higher economic growth compared to richer countries. When the final productivity of the workforce is zero, the sign of the coefficient of the growth rate of the labour force will be negative leading to unemployment in the country. Greater labour force entering the production process does not increase production. A rise in the growth rate of the labour force does not inevitably lead to greater production and GDP growth. The reason for this might be that the labour force growth rate has reached saturation point. On the other hand, in the Solow’s model, economic growth increases due to the lower returns of capital to the workforce by increasing physical capital and reducing labour force growth rates. Spatial spillover sometimes arises from distance, trade or
human capital. Trade has the same justification as geographical proximity. Spatial spillover of technology, information, management, and intermediate goods occur through trade. Thus, trade also affects economic growth through spatial spillover.

We are aware that the LR Test suggests controlling the spatial interaction amongst the data improves the fit of the model above and beyond a non-spatial model. Moreover, when we consider our SAC models, the growth rate of neighbouring regions has a positive and statistically significant effect denoted by $\rho$. This is in line with the studies by O’Connor, Doyle, and Doran (2018), Abate (2016), LeSage and Fischer (2008) and Bishop (2008) which provide support for the theory that employment growth rates of neighbouring countries positively affect the growth rate of a particular country, thus reinforcing the theory of spatial spillovers. We note that significant spatial spillovers are evident, thus providing direct evidence that geography, in terms of neighbouring regions, matters. Based on the need to explore the effect of spillover on growth, the main contribution of this research consists of capital and technology upgrading, capital and technical transfer, labour force expertise and knowledge spillover being considered the main drivers of knowledge spillover. The existing literature describes spillover as the process whereby the capital or labour force improvement of one country can bring advantages to another country, usually characterized by cultural and geographic proximity. In other words, this has resulted in knowledge spillover whereby knowledge from one country is positively spread to other countries to improve their growth level.

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**References**

Abate, G. D. 2016. “On the Link between Volatility and Growth: A Spatial Econometrics Approach.” *Spatial Economic Analysis* 11 (1): 27–45. doi:10.1080/17421772.2015.1045021.

Abreu, M., H. L. De Groot, and R. J. Florax. 2005. “A Meta-Analysis of $\beta$-Convergence: The Legendary 2%.” *Journal of Economic Surveys* 19 (3): 389–420. doi:10.1111/j.0950-8408.2005.00253.x.

Ahmad, M., and S. G. Hall. 2017. “Economic Growth and Convergence: Do Institutional Proximity and Spillovers Matter?” *Journal of Policy Modeling* 39: 1065–1085. doi:10.1016/j.jpolmod.2017.07.001.

Anselin, L. 1988. *Spatial Econometrics: Methods and Models*. MA: Boston. doi:10.1007/978-94-015-7799-1.

Anselin, L., and A. Bera. 1998. “Spatial Dependence in Linear Regression Models with an Introduction to Spatial Econometrics.” In *Handbook of Applied Economics Statistics*, edited by A. Ullah and D. Giles, 237–289. New York: Marcel Dekker.

Baltagi, B. H. 2005. *Econometric Analysis of Panel Data*. 3rd ed. England: JW & Sons.

Barro, R. J., and X. Sala-i-Martin. 1995. *Economic Growth Advanced Series in Economics*. New York, London and Montreal: McGraw-Hill.

Belotti, F., G. Hughes, and A. P. Mortari. 2013, June. “XSMLE-A Command to Estimate Spatial Panel Models in Stata.” *German Stata Users Group Meeting*, Potsdam, Alemania, 1–36.

Benos, N., S. Karagiannis, and S. Karkalakos. 2015. “Proximity and Growth Spillovers in European Regions: The Role of Geographical, Economic and Technological Linkages.” *Journal of Macroeconomics* 43: 124–139. doi:10.1016/j.jmacro.2014.10.003.

Bishop, P. 2008. “Diversity and Employment Growth in Sub-regions of Great Britain.” *Applied Economics Letters* 15 (14): 1105–1109. doi:10.1080/13504850600993572.

Caleb, G., M. Mazanai, and N. L. Dhoro. 2014. “Relationship between International Trade and Economic Growth: A Cointegration Analysis for Zimbabwe.” *Mediterranean Journal of Social Sciences* 5 (20): 621.

Calvo, G. A., L. Leiderman, and C. M. Reinhart. 1996. Inflows of Capital to Developing Countries in the 1990s. *Journal of economic perspectives* 10, no. 2: 123–139.

Ciccone, A. 1996. Externalities and Interdependent Growth: Theory and Evidence. *Economics working paper* 194. doi:10.2139/ssrn.47585.

Elhorst, J. P. 2008. “Serial and Spatial Autocorrelation.” *Economics Letters* 100 (3): 422–424. doi:10.1016/j.econlet.2008.03.009.

Elhorst, J. P. 2014. *Spatial Econometrics from Cross-Sectional Data to Spatial Panels Springer*. Vol. 479. Heidelberg: Springer.

Ertur, C., and W. Koch. 2007. “Growth, Technological Interdependence and Spatial Externalities: Theory and Evidence.” *Journal of Applied Econometrics* 22 (6): 1033–1062. doi:10.1002/(ISSN)1099-1255.

Ertur, C., and W. Koch. 2011. “A Contribution to the Theory and Empirics of Schumpeterian Growth with Worldwide Interactions.” *Journal of Economic Growth* 16 (3): 215. doi:10.1007/s10887-011-9067-0.

Fischer, M. M., M. Bartkowska, A. Riedl, S. Sardadvar, and A. Kunnert. 2009. “The Impact of Human Capital on Regional Labor Productivity in Europe.” *Letters in Spatial and Resource Sciences* 2 (2): 97–108. doi:10.1007/s12076-009-0027-7.

Ho, C.-Y., W. Wang, and J. Yu. 2013. “Growth Spillover Through Trade: a Spatial Dynamic Panel Data Approach.” *Economics Letters* 120, No 3 3 120: 450-453. doi:10.1016/j.econlet.2013.05.027.

Islam, N. 1995. “Growth Empirics: A Panel Data Approach.” *The Quarterly Journal of Economics* 110 (4): 1127–1170. doi:10.2307/2946651.

Jawaid, S. T., and A. Waheed. 2011. “Effects of Terms of Trade and Its Volatility on Economic Growth: A Cross Country
Empirical Investigation.” *Transition Studies Review* 18 (2): 217–229. doi:10.1007/s11300-011-0201-7.

Lee, J. W. 1995. “Capital Goods Import and Long-run Growth.” *Development Economics* 48 (1): 91–110. doi:10.1006/0304-3878(95)00015-1.

Lee, L. F., and J. Yu. 2012. “QML Estimation of Spatial Dynamic Panel Data Models with Time Varying Spatial Weights Matrices.” *Spatial Economic Analysis* 7 (1): 31–74. doi:10.1080/17421772.2011.647057.

LeSage, J. P. 1999. “The Theory and Practice Of Spatial Econometrics.” *Ohio University* Toledo, Toledo. Ohio 28: 11.

LeSage, J. P., and M. M. Fischer. 2008. “Spatial Growth Regressions: Model Specification, Estimation and Interpretation.” *Spatial Economic Analysis* 3 (3): 275–304. doi:10.1080/17421770802353758.

Lipset, S. M., K. R. Seong, and J. C. Torres. 1993. “A Comparative-Analysis of the Social Requisites of Democracy.” *International Social Science Journal* 45 (2): 154–175.

Long, R., T. Shao, and H. Chen. 2016. “Spatial Econometric Analysis of China’s Province-level Industrial Carbon Productivity and Its Influencing Factors.” *Applied Energy* 166: 210–219. doi:10.1016/j.apenergy.2015.09.100.

Mankiw, N. G., D. Romer, and D. N. Weil. 1992. “A Contribution to the Empirics of Economic Growth.” *The Quarterly Journal of Economics* 107 (2): 407–437. doi:10.2307/2118477.

O’Connor, S., E. Doyle, and J. Doran. 2018. “Diversity, Employment Growth and Spatial Spillovers Amongst Irish Regions.” *Regional Science and Urban Economics* 68: 260–267. doi:10.1016/j.regsciurbeco.2017.11.002.

Olejnik, A. 2008. “Using the Spatial Autoregressively Distributed Lag Model in Assessing the Regional Convergence of Per-capita Income in the EU25.” *Papers in Regional Science* 87 (3): 371–384. doi:10.1111/pirs.2008.87.issue-3.

Pfaffermayr, M. 2009. “Conditional β-and σ-convergence in Space: A Maximum Likelihood Approach.” *Regional Science and Urban Economics* 39 (1): 63–78. doi:10.1016/j.regsciurbeco.2008.06.004.

Ramírez, M. T., and A. M. Loboguerrero. 2002. “Spatial Dependence and Economic Growth: Evidence from a Panel of Countries.” *Borradores de Economia Working Paper*, 206.

Ramos, R., J. Suriñach, and M. Artís. 2010. “Human Capital Spillovers, Productivity and Regional Convergence in Spain.” *Papers in Regional Science* 89 (2): 435–447. doi:10.1111/j.1435-5957.2010.00296.x.

Solow, R. M. 1956. “A Contribution to the Theory of Economic Growth.” *The Quarterly Journal of Economics* 70 (1): 65–94. doi:10.2307/1884513.

Sun, P., and A. Heshmati. 2010. *International Trade and Its Effects on Economic Growth in China*.

Swan, T. W. 1956. “Economic Growth and Capital Accumulation.” *Economic Record* 32 (2): 334–361. doi:10.1111/ecor.1956.32.issue-2.

Tao, J., and J. Yu. 2012. “The Spatial Time Lag in Panel Data Models.” *Economics Letters* 117 (3): 544–547. doi:10.1016/j.econlet.2012.07.025.

Tian, L., H. H. Wang, and Y. Chen. 2010. “Spatial Externalities in China Regional Economic Growth.” *China Economic Review* 21: 520–531. doi:10.1016/j.chieco.2010.05.006.

Tobler, W. R. 1979. “Smooth Pycnophylactic Interpolation for Geographical Regions.” *Journal of the American Statistical Association* 74 (367): 519–530. doi:10.1080/01621459.1979.10481647.

Wagner, J. 2007. “Exports and Productivity: A Survey of the Evidence from Firm Level Data.” *The World Economy* 30 (1): 60–82. doi:10.1111/twec.2007.30.issue-1.

Yu Ho, C., W. Wang, and J. Yu. 2013. “Growth Spillover through Trade: A Spatial Dynamic Panel Data Approach.” *Economics Letters* 120: 450–453. doi:10.1016/j.econlet.2013.05.027.

Zahonogo, P. 2016. “Trade and Economic Growth in Developing Countries: Evidence from sub-Saharan Africa.” *Journal of African Trade* 3 (1–2): 41–56. doi:10.1016/j.joat.2017.02.001.