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RESEARCH

Spatial interaction and economic growth: a case of OECD countries

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Abstract

The Solow residual has presented an opportunity to researchers who have been attempting to explain the unexplained share of output. In pursuing this goal, the literature has relied on different models, estimators, and data sets. One such application is spatial models to estimate growth, but it remains rare in the literature. Such models allow us to determine whether the interaction among countries is significant. Additionally, it is possible to observe efforts to mimic different variables among countries thanks to indirect (spillover) effects. Therefore, using spatial models and data sets on founding OECD countries for the period 1996–2019, this article tests alternative weight matrices to clarify the mutual relationship among countries. The findings reveal that spatial models contribute to estimations by improving parametric results. Empirical evidence found that there are spatial interactions among countries. The spillover effect of technology growth is insignificant, while the direct effect is significantly positive. Investment growth is significantly positive except spillover effect. Human capital growth is significantly positive in any sense.

Keywords Regional economic growth, Technological innovation, OECD, Spatial analysis, Spatial Durbin model

Introduction

In the last century, increasing academic interest and effort have been devoted to economic growth. Following the introduction of the models of Harrod [29] and Domar [12], the Solow [67] and Swan [70] models opened a new avenue, and subsequent models began to test additional control variables. During this period, sources of economic growth were clearly defined in general, and capital was disaggregated into physical and human capital.

Moreover, following the economic fluctuations created by dramatic technological developments that required better-endowed labour, new types of models of economic growth were developed to incorporate variables capturing new requirements and developments. There has been a wide variety of applications ranging from cross-sectional to panel data sets, from standard estimators to more comprehensive estimators, or from basic theoretical models to extended or nontheoretical models. Economic growth theory and its applications are deserving of such academic attention because it is the key to human existence and the world, although perspectives differ on how it can be made sustainable or if that is possible. Some researchers contend that the growth path that the majority of the world desires is not sustainable, despite the formation of a new equilibrium tendency after any crisis, and it has been argued that advanced technologies will ensure a balance between supply and demand.

On the other hand, the Solow growth model is used as a benchmark model to attempt to understand the mechanism underlying growth. However, it has been noted that it cannot explain 85% of the source of growth. Therefore, subsequent researchers added missing components to growth models and sought to find the best-fitting models and estimators for the available data sets. Although the literature has been dramatically improved, there is room for further contributions, especially regarding interactions between countries in addition to the standard dependent–independent relationship. In this study,

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we would like to investigate if the contiguity relationship affects the growth path of the founder countries of the OECD and if indirect effects are valid.

Considering these facts and developments and in light of several attempts to estimate economic growth using analogous models with different estimators, the contribution of the present study is as follows:

Although various estimators have been used to estimate economic growth, spatial models remain rare, and according to the literature, if there is spatial dependence among units and if it is ignored, the estimation results may be biassed. Therefore, as test results indicate that there is spatial dependence among the countries we analyse, we robustly estimated economic growth using spatial models in addition to ordinary least squares (OLS). While Ertur et al. [15], Pribauer and Cuaresma [54], Seya et al. [64], Soundararajan [68] and estimated spatial models, they used only one weight matrix. Additionally, some spatial models allow us to separately estimate spillover (indirect) effects. Estimating such effects allows the researcher to observe mimicking technology and the interaction of human capital, investment, and population growth among countries. To this end, we rely on Nonneman and Vanhoudt's [49] model by using spatial econometric tools. Depending on this, the sign and significance of some variables change when spatial models are used that are more reliable to the theory, which may help us to understand the nature of growth.

The structure of the paper is as follows: In the next two sections, we present a brief review of some aspects of the relevant literature and detail economic/econometric theoretical models and data sets. Then, we discuss the results of our empirical analysis, and the final section presents the conclusions.

The literature overview

Following the pioneering attempts to create a neoclassical mathematical representation of economic growth by Harrod [30] and Domar [12], Solow [67] and Swan [70] advanced the field, and studies on exogenous economic growth emerged. Although their efforts received academic attention over time, critiques began to emerge. For example, it was argued that the Solow model failed to properly explain income differences among countries, and the Solow residual, the share of output left unexplained, has been heavily criticized [48, 45]. The facts and evidence reflect *at least one* omitted variable problem.

Endogenous growth models created a new strand in this literature. The basic feature of endogenous growth models is that growth is taken as an internal result of the functioning of the economic system, not as a product of external forces [61]. New growth (endogenous) models have been put forward, arguing that neoclassical growth models are inadequate or even unable to explain growth. In this model, technological development is seen and internalized as the main source of growth. The assumption of diminishing returns of capital accumulation has here turned into the assumption of increasing returns. Capital no longer consists of only physical capital but also human capital. Specifically, Cass [11], Frankel [21], Grossman and Helpman [24], Romer [59], Aghion and Howitt [2], Lucas [44], Mankiw et al. [45] and Romer [60], argued how production functions are exhibited in terms of scale types, determined an optimum feasible growth path, and discussed the effects of intellectual capital, knowledge and skills, and human capital. The other model was introduced by Nonneman and Vanhoudt [49] as a critique of the Mankiw et al. [45] and might be one alternative to the Romer [60] model. Technological knowledge was later internalized and included as a factor in the model. Although the Nonneman and Vanhoudt model incorporates technological knowledge into the MRW model, the two models are considered to share the same assumptions [49].

There are different studies that include technological knowledge. For example, Falk [17], Falk [18], Porter and Stern [56], and Ülkü [74] estimated to use Romer [60] model covering human capital and innovation. Pohjola [55], Requena [58], Yoo [79], Yoo [80], Yoo [81], Yoo [82], and Keller and Poutvaara [35] used technological knowledge and/or innovation as control variables in the Mankiw et al. [45] or Solow [67] growth models. They have been estimated by adding R&D expenditures or patent numbers to the MRW [45] model, which has been expanded with the human capital factor to the neoclassical growth model. Others have performed estimations using R&D expenditures without a theoretical basis such as Bassanini and Scarpetta [10], Fernandez et al. [19], Hasan and Tucci [31], Inekwe [32], Lee [38], Meçik [46], Özcan and Arı [52], Pece et al. [53], Rehman et al. [57], Samimi and Alerasoul [62], Sandraoui et al. [63], and Silaghi et al. [65].

Methods: model and data sets

Economic model

Based on the discussions above and because we wish to include human capital and innovation in the same model, we relied on Nonneman and Vandhout's [49] model.

According to Nonneman and Vanhoudt [49], Y is the production function by

$$Y(t) = cL(t)^{(1-\sum_{j=1}^{m} a_j)} K_1(t)^{a_1}, \ldots, K_m(t)^{a_m} \quad (1)$$

with L (effective) labour, K_j capital of type j (j=1,...,m), c, and a_j constants. Since all production factors are paid their marginal product, these a_j's represent the respective factor shares in total income. Labour is assumed to grow exogenously at rate n due to population growth and exogenous growth in labour productivity (e.g. because of learning by doing). The model also assumes that a constant fraction s_j of output is invested in each type of capital. Defining k_j as the stock of capital of type j per unit of labour and y as output per unit of labour, the following set of differential equations governs the evaluation of the k_j's:

$$\frac{\mathrm{d}k(t)_j}{\mathrm{d}(t)} = s_j y(t) - (n+\delta)k(t)_j \quad \forall j = 1 \text{ to } m, \quad (2)$$

where δ_j's are the rates of depreciation of each type of capital.

In steady-state equilibrium, $(\frac{dk_{j_t}}{d_t} = 0)$ is calculated by substituting the production function (1) in differential Eqs. (2), taking logarithms, and solving.

This model has three types of capital (m=3), physical capital (k), human capital (h) and technological know-how (τ), and the capital accumulation equation is as follows:

$$s_j.c.k^{a_k+a_h+a_\tau} = (n+\delta)k(t)_j \quad (3)$$

$$k(t)_j^* = \left(\frac{s_j.c}{n+\delta}\right)^{1/1-(a_k+a_h+a_\tau)} \quad (4)$$

The logarithm of Eq. (4) is taken:

$$\ln k(t)_j^* = \frac{1}{1-(a_k+a_h+a_\tau)} \ln c + \frac{1}{1-(a_k+a_h+a_\tau)} \ln s_j - \frac{1}{1-(a_k+a_h+a_\tau)} \ln(n+\delta_j) \quad (5)$$

To solve the production function per worker, the logarithm of Eqs. (1) and (4) is taken, and Eq. (5) is written instead. After substituting the steady-state value of k^* into the production function, the steady-state output per worker is obtained from the following function:

$$\ln(y^*) = \frac{1}{1-\sum a} \ln c + \frac{a_1}{1-\sum a}[\ln(s_1) - \ln(n+\delta_1)] + \ldots + \frac{a_m}{1-\sum a}[\ln(s_m) - \ln(n+\delta_m)] \quad (6)$$

If we allow all is (j=k, h, and τ, i=countries) into the model, the steady-state output per worker is obtained from the following function:

$$\ln(y_i^*) = \frac{1}{1-(a_k+a_h+a_\tau)} \ln c + \frac{a_k}{1-(a_k+a_h+a_\tau)} \ln(s_{k_i}) + \frac{a_h}{1-(a_k+a_h+a_\tau)} \ln(s_{h_i}) + \frac{a_\tau}{1-(a_k+a_h+a_\tau)} \ln(s_{\tau_i}) - \frac{a_k+a_h+a_\tau}{1-(a_k+a_h+a_\tau)} \ln(n_i+\delta) + \varepsilon_i \quad (7)$$

$$\ln(y_i^*) = a_0 + a_1 \ln(s_{k_i}) + a_2 \ln(s_{h_i}) + a_3 \ln(s_{\tau_i}) - a_4 \ln(n_i+\delta) + \varepsilon_i \quad (8)$$

δ: 0.05 and is homogeneous for each type of capital, and Eqs. (7) and (8) show the growth model extended by Nonneman-Vanhoudt in which technological know-how is internalized.

Econometric model

Contiguity or neighbourhood is the relationship between two or more entities when they share an edge not only border or geographical closeness but also different intangible similarities. Tobler [71]'s famous equation is explain it very well: Everything is related to everything else but near things are more related than distant things. It is not wrong to say that the countries have interaction in terms of economic variables including economic growth. In broader perspective, spatial interaction typically refers to the aggregate flows of people, information, or goods across space as they move between a set of locations. As such, quantitative models of spatial interaction provide a mechanism to understand and predict components of spatial interaction systems and are typically constructed upon the hypothesis that flow volumes are a function of the potential at origins, the attractiveness of destinations [51, 77].

Even though some researches have been conducted to make this fact clear such as Alesina and Giuliano [3], Amidi et al. [4], Ertur and Koch [14], Ertur et al. [15], Evangelista et al. [16], Franco and Maggioni [20], Guiso et al. [27], Torres-Preciado et al. [73], and Yesilyurt et al. [78] and there is a room to contribute in this area considering not only geographical closeness but also intangible values such as cultural closeness.

Depending on this structure in this study, we tested whether contiguity relationships are important, and we followed the procedure to make a decision-correct model. Studies using spatial models typically employ the OLS estimator as a benchmark to compare spatial models. However, OLS estimation becomes unreliable if spatial effects are present. Therefore, we used a series of specification tests.

To this end, both conventional and new spatial specification tests were implemented to determine the best fit of the weight matrices and spatial models.

Specification tests

In the literature, Moran's I test and Lagrange multiplier (LM) tests are extensively used to determine accurate combinations of geographical weight matrices and spatial models. Moran's *I* test statistic as calculated by Anselin [5].

Because this area of study is dynamic, researchers regularly offer new approaches to determine the combinations of weight matrices and spatial models. One suggestion is to analyse the weight matrices' parametric indicators to test spatial links [14, 69]. On the other hand, the specification test used in the current study and introduced by LeSage [41, 42] depends on Bayesian specification procedures that rely on log marginal likelihoods of the models that specify alternative geographical weight matrix and spatial model combinations. The probability is derived as follows:

$$prob\left(M_i|y\right) = \frac{prob\left(y|M_i\right)prob\left(M_i\right)}{prob\left(y\right)}, \tag{9}$$

where $prob\left(M_i|y\right)$ indicates posterior model probabilities, $prob\left(y|M_i\right)$ is the marginal likelihood, and $prob(M_i)$ is the prior probability of model i, and we search for the highest probability to obtain an accurate specification.

Weight matrix

The weight matrix is exogenous in spatial model estimations. They are typically subject to row normalization to avoid the singular matrix problem that causes various types of biases. To overcome these undesirable possibilities, we tested alternative weight matrices in the present study. They are as follows:

(i) Binary weight matrices for geographical contiguity, (ii) second-order contiguity, (iii) Euclidean distance matrix, (iv) a weight matrix for specific distances that covers many alternatives from 2 to 30 km for this study.

Spatial modelling

In the literature, three main spatial models are tested: the spatial autoregressive model (SAR), spatial error model (SEM), and spatial Durbin model (SDM). Following the majority of the literature, we tested these models.

These three models can be identified by relying on a general nested spatial below [75]:

$$\begin{aligned} Y &= \alpha \iota_N + \rho WY + X\beta + WX\theta + \varepsilon, \\ u &= \lambda Wu + \varepsilon, \end{aligned} \tag{10}$$

where Y denotes an $N{\times}1$ vector of the dependent variable for every country in sample ($i{=}1,\ldots,N$); $\iota_N imath_N$ is an $N{\times}1$ vector of one associated with constant term parameter a; X is an $N{\times}K$ matrix of exogenous explanatory variables associated with the $K{\times}1$ vector β; $\varepsilon = (\varepsilon_{1,\ldots,}\varepsilon_N)^T$ is a vector of independently and identically distributed disturbance terms with zero mean and variance σ^2; W is an $N{\times}N$ non-negative spatial weight matrix describing the neighbour of a country, whose diagonal elements are 0 because a country cannot be its own neighbour; and WY represents the endogenous spatial lag, WX the exogenous spatial lags, and Wu the spatial lag among the error terms. The scalars ρ and λ, as well as the $K{\times}1$ vector of parameters θ, measure the strength of these spatial lags.

If λ and θ in the equation are equal to zero, the model is reduced to an SAR model; if ρ and θ are equal to zero, it is reduced to an SE model; and finally, if λ is equal to zero, it is reduced to an SDM. Therefore, all their theoretical structures are well known and described extensively in the literature (for example, in [13]. Because the SDM is preferred based on the specification tests, we focus solely on the SDM to save space.

As a variant of spatially lagged models, the SDM is as follows:

$$Y = \alpha \iota_N + \rho WY + X\beta + WX\theta + \varepsilon, \tag{11}$$

On the other hand, a change in any independent variable will also affect the dependent variable influencing the counterparts via contiguous relations. SDM estimation provides direct and indirect effects that may be vital to understanding the interaction between cross-sectional units such as countries [40]. LeSage & Pace [39] define the direct effect as the average diagonal element of the full N x N matrix of W expression on the right-hand side of Eq. 13; the indirect effect (i.e. country spillover effects in the current study) is the average row or column sum of the off-diagonal elements. This means that the direct effect measures the impact of the focal country itself, while the indirect effect measures the impact of neighbouring countries on the focal country [71]. Therefore, direct and indirect effects provide an opportunity to breakdown different types of mechanisms between dependent and independent variables.

Data sets

The present study covers 19 founding countries of the OECD and annual data sets for the 1996–2019 period (Table 1). The descriptive statistics are presented in Table 2. The data sets were deflated to 2015 prices.

Table 1 Country sample

Austria	Ireland	Switzerland
Belgium	Italy	Sweden
Germany	Netherlands	Turkey
Denmark	Luxembourg	USA
France	Norway	Great Britain
Greece	Portugal	
Iceland	Spain	

In the literature, various proxies have been used for these variables. For example, technology is proxied by patents or R&D expenditures. However, using patent data sets in addition to R&D expenditures to proxy for technology and innovation is also a common approach (e.g. [1, 6, 8, 25, 26]. Following this strand of the literature, patents were used to proxy for technology. Human capital is proxied by the schooling rate or mean years of schooling (MYS). We prefer MYS because it covers all types of schooling rates.

Descriptive statistics and the correlation matrix are reported in Table 3 and Table 4, respectively. In Table 3, the means, standard deviations, and maximum and minimum values are given.

According to Table 4, no correlation is larger than 0.51 among independent variables, which indicates that multicollinearity is not an issue in our estimations.

Results

Following the relevant literature, models were estimated via OLS as a benchmark. Then, spatial tests and estimations were conducted to determine whether there were spatial effects[1] because spatial dependence affects estimation results and biases estimations if ignored. It is useful to use spatial models because of the rationale mentioned above and because spatial estimations can detect the type of spatial interaction present and its extent. Based on the weight matrix section above, we relied on Bayesian selection criteria in addition to conventional tests for robustness. To this end, we constructed four weight matrices depending on four interaction structures. First, considering whether countries share a common land or maritime border allows us to use a first-order binary contiguity matrix, W_1. The second is an inverse distance matrix based on the great circle distance between the capital cities of countries, W_2. Third, we use distance matrices to test whether spatial interaction among countries depends on alternative distances, W_3. The fourth matrix considers that the influence of a country might extend beyond its immediate neighbours; therefore, a second-order binary contiguity matrix is tested, W_4 [23, 66, 76].

In the first step, 17 alternative matrices for distances were considered to increase alternatives for comparison, and the matrix that considers interaction among countries within 1000 km produced the best parameters. Then, the best alternative of W_3 was tested against the others, W_1, W_2, and W_4. As shown in Table 5, the test confirmed that $W3$ is the preferred weight matrix.

For robustness, we applied conventional tests to determine the best combination of weight matrix and spatial model. The first step in conventional tests is Moran's I statistics, which indicate that there is spatial dependence in the SAR and SE models. Additionally, we applied the LM test to the data sets. According to Table 6, the LM and robust LM tests did not reject the null hypothesis; therefore, the SDM cannot be reduced to SAR or SE models. All these results confirm the conclusions that the Bayesian criteria suggest.

Finally, a log-likelihood test was applied to determine which type of spatial effects needed to be considered: SDM with spatial fixed effects was determined to be suitable for estimation (Table 7).

As a result, the generalized SDM with fixed effects is as follows:

Table 2 Definitions and source of the variables

ln (Ypc)	Natural log of real GDP (constant 2015 $) divided by working-age population (15–64) (MRW, 1992) used for growth-basic data source: The World Bank
ln (s_k)	Natural log of gross-fixed capital formation (constant 2015$) divided by GDP (constant 2015$) used for the investment rate-basic data source: The World Bank
ln (s_h)	Natural log of mean years of schooling used for human capital-basic data source: Barro-Lee data, Global_Data_Lab, and UNDP
ln (s_τ)	Natural log of patent stocks calculated from triadic patent families (Ulku, 2004) used for technological innovation-basic data source: OECD data
ln ($n + \delta$)	Natural log of working-age population growth (n) plus depreciation and technological growth rate ($g + \delta = 0.05$) (MRW, 1992)-basic data source: The World Bank

[1] Stata 14, Eviews 9 and MATLAB 13 were used to conduct the estimations.

Table 3 Descriptive statistics

	ln (Ypc)	ln (s_k)	ln (s_h)	ln (s_τ)	ln ($n+\delta$)
Mean	4.77	−0.68	1.04	3.08	−1.26
S. d	0.24	0.08	0.06	0.98	0.06
Minimum	3.98	−0.97	0.78	0.95	−1.52
Maximum	5.22	−0.29	1.14	4.90	−1.10
Observation	456	456	456	456	456

Table 4 Correlation matrix

	ln (Ypc)	ln (s_k)	ln (s_h)	ln (s_τ)	ln ($n+\delta$)
ln (Ypc)	1.00**				
ln (s_k)	0.07	1.00**			
ln (s_h)	0.73**	−0.09*	1.00**		
ln (s_τ)	0.32**	0.07	0.51**	1.00**	
ln ($n+\delta$)	0.13**	0.37**	−0.15**	−0.29**	1.00**

* shows 5% and ** shows 1% significance level based on the Pearson correlation coefficient table

Table 5 Probabilities of alternative weight matrices based on Bayesian criteria

Weight matrices	Prob
W1 (1–0 contiguity matrix)	0.0000
W2 (geographical coordinates matrix)	0.0000
W3 (a certain distance matrix)	1.0000
W4 (second degree contiguity matrix)	0.0000

Table 6 Tests for spatial autocorrelation in the OLS estimation model

W3	Test statistics	Prob
Moran's I	0.23 (7.04)	0.00
LM Lag	30.68	0.00
RLM Lag	23.30	0.00
LM Error	62.50	0.00
RLM Error	55.13	0.00

$$\begin{aligned}\ln(Ypc)_{it} =& \alpha_0 + \alpha_1 \ln(s_k)_{it} + \alpha_2 \ln(s_h)_{it} \\ &+ \alpha_3 \ln(s_\tau)_{it} - \alpha_4 \ln(n+\delta)_{it} \\ &+ \delta_1 w * \ln(s_k)_{it} + \delta_2 w * \ln(s_h)_{it} \\ &+ \delta_3 w * ln(s_\tau)_{it} - \delta_4 w * ln(n+\delta)_{it} + \varepsilon_{it}\end{aligned} \quad (12)$$

where i stands for cross-sectional id (i,.., N), t stands for time period ($i=1$,.., T).

Table 7 Log-likelihood matrix for spatial models

	SAR	SEM	SDM
No fixed effect	**233.86**	**293.88**	**456.89**
Spatial fixed effect	**1078.04**		**1083.26**
Time fixed effect	**233.71**		**-1803.67**

Table 8 OLS versus SDM estimation results

Variables	OLS	SDM	Direct	Indirect	Total
ln(s_k)	0.184* (11.81)	0.354*** (15.24)	0.356*** (14.976)	0.041 (1.050)	0.396*** (8.216)
ln(s_h)	2.958*** (22.865)	0.941*** (14.595)	0.955*** (16.074)	0.361*** (3.681)	1.316*** (15.394)
ln(s_τ)	−0.004 (−0.456)	0.058*** (5.141)	0.058*** (5.270)	−0.013 (−0.982)	0.044*** (2.835)
ln($n+\delta$)	0.936*** (6.853)	−0.125*** (−3.665)	−0.119*** (−3.451)	0.116* (1.775)	−0.003 (−0.039)
Constant	3.008*** (15.674)				
W*dep.var		0.147*** (2.661)			
R- square	0.609	0.781			
log-likelihood		1083.259			

Dependent variable ln(Ypc): Natural log of real GDP divided by working-age population (15–64). The OLS model expresses the results of traditional economic analysis in the second column. The SDM results start in the third column. The direct, indirect, and total effects are given in the following columns. *t*-stats are given in parenthesis. *, ** and *** indicate significance at the 0.10, 0.05, and 0.01 levels, respectively

In Table 8, we report the OLS and SDM estimation results, including direct effects, indirect effects and total effects, based on weight matrix W_3.[2]

The interaction parameter of per capita GDP ($W * dep.var$) is positive and significant, which indicates that spatial interaction among countries is confirmed.

Changing the size, significance, and sign of some coefficients is an absorbing result of SDM estimation over OLS estimation. For example, while the impact of the investment rate was 0.18 and significant in OLS, it was 0.35 and highly significant in the SDM, confirming the results of Basile [9] and Torres-Preciado et al. [73]. Additionally, the sign of population growth turned from positive to negative when moving from OLS to the SDM, which is in line with the theory. The sign and significance of technology growth also changed. It was insignificantly negative in OLS but significantly positive in the SDM.

[2] LeSage and Dominguez [40] noted that the parameters of OLS and spatial counterparts cannot be reliably compared. Therefore, while not comparing them directly, we used them to present the contribution of spatial estimations.

Discussions

Effect of cultural similarities, general notion of bilateral trust, religion, and being ally and hostile [76] besides geographical closeness are important in terms of economic interaction. There are countless researches in this context. For example, Alesina and Giuliano [3], Amidi et al. [4], Evangelista et al. [16], Franco and Maggioni [20], Guiso et al. [27], and Torres-Preciado et al. [73] presented these types of facts are effective economic development in various dimensions. This research would like to contribute a geographical closeness dimension.

The investment growth coefficient is significantly positive in OLS and highly significant positive in the SDM. The coefficient in the SDM is double the size of the OLS coefficient. In the literature, there is almost consensus on the contribution of investment growth to growth because it increases productive capacity. On the other hand, considering direct and indirect effects may help to uncover different mechanisms between it and growth. When the direct effect of investment growth on growth is significantly positive but is not greater than 1, growth increases with investment growth but less than proportionally, and its indirect effect on growth is insignificantly positive. This means that improvements in investment growth clearly influence the focal country in a positive way, while the interaction effect is not clear. It seems that interactions among neighbouring countries' investments vary as follows: The first is the complementary effect. If neighbours have different endowments, then they invest in complementary industries that trigger one another's investment. The second is the competition effect: If their customer portfolios and focal sectors are the same, the investments of neighbours spur the countries' investments as in an arms race. Similarly, the competition effect may occur because of destructive competition.

The third is the wealth effect, in which the accumulation of wealth may flow to nearer countries to invest because of cultural similarities and closeness in the long term. Of course, there may be a divergence effect if neighbouring countries suffer from various types of conflicts. The fourth is the collaboration effect based on international economic agreements among countries that may cause investment by counterparts. The fifth is the substitution effect that occurs if countries focus on similar sectors, they face the same customer portfolio, and investmenting neighbour/close countries affect others conversely. As a result, some factors positively influence neighbouring countries' investment, while others negatively influence it. In some cases, one type of factor overrides others; then, one country might be affected positively or negatively, or the effect might be unclear. Therefore, because the indirect effect of investment growth is insignificant, the spillover effect of investment growth in the current study is unclear, and neither impact is dominant. This evidence is reasonable because global capital is not endless, which may prevent the creation of spillover effects on investment growth. The total effects are in line with the direct effects. On the other hand, Torres-Preciado et al. [73] estimated that the direct effect of investment growth on growth is insignificantly positive, while the indirect and total effects are significantly positive. Basile [9] estimated the effect of investment growth on growth to be significantly positive in both OLS and an SDM.

The influence of growth human capital as is proxied by MYS in the OLS and SDM estimations are 2.96 and 0.94, respectively, and both are significantly positive in line with the relevant literature. Regarding this variable, proxies vary from schooling to education expenditure, education participation rate, etc., and the majority of them have similar results [7, 28, 37, 45, 72]. Overall, the results of the SDM seem more in line with the relevant literature. On the other hand, the direct, indirect and total effects of the growth of human capital are positively significant influences on growth. Additionally, the direct and total effects are highly significant. This result indicates that the growth of human capital of the focal country has a significantly positive influence on its own growth and that the focal country is also positively influenced by neighbouring countries' growth of human capital. Some of the literature that used spatial models is in line with our results, but others have reached inconsistent conclusions. For example, Torres-Preciado et al. [73] estimated that the growth of human capital has a significantly positive direct effect on growth. They find that the indirect effect on growth is insignificantly negative, while the total effect on growth is insignificantly positive. Amidi et al. [4] estimated that the growth of human capital has a negative indirect effect on growth. However, they found that the direct and total effects of the growth of human capital are positive. According to Evangelista et al. [16], the growth of human capital has a significantly positive direct effect on growth.

According to Islam [33], MRW [45], Nonneman and Vanhoudt [49], Ogbeifun and Shobande [50], Keller and Poutvaara [35], and Solow [67], the effect of the population growth rate[3] on economic growth is negative and adversely affects economic growth. In the present study, the effects of the population growth rate in the OLS and SDM estimations are significantly positive and negative, respectively. Because the specification tests preferred the SDM over OLS, we rely on the SDM results,

[3] This variable combines labour augmenting technology, population growth rate and deprecation rate of capital that all decreases capital labour ratio. After this point, population growth rate will refer three of them.

which are more reliable because the population growth rate decreases the capital–labour ratio. Additionally, the OECD data sets feature relatively high technology levels, and technology has developed rapidly in these countries. The negative effect of the depreciation rate of technology is more influential in these data sets, which acts in line with the population growth rate. The other dimension of SDM estimation is to provide direct and indirect effects. These effects may help to understand various additional mechanisms operating between the population growth rate and growth. The direct effect of the population growth rate (with depreciation) is negative and significant and may suffer from the same mechanism as mentioned above. Additionally, the impact of spillovers via indirect effects that are significantly positive that increasing population in neighbouring countries may create demand for focal country while depreciation rate of capital of neighbours make focal country relatively advantageous. The total effect operates in the same direction as the direct effect but is insignificant and close to zero because of the countervailing impacts of direct and indirect effects. The studies used spatial models on growth and found mixed results that weight matrices and data sets used might create some controversial results. For example, Basile [9] estimated that the effect of population growth on growth is significantly positive in OLS, but the SDM result is insignificantly positive. Seya et al. [64] estimated that the effect of population growth on growth is significantly positive using the SDM. Ertur and Koch [14] estimated the effects of the interaction variable of population growth in several models that are sometimes positive and/or insignificant.

Another variable is the growth of technology, which is proxied by patents. In the nonspatial literature, growth of technology produced significantly positive results, such as Hasan and Tucci [31], Kanwar and Evenson [34], Pece et al. [53], Rehman et al. [57], Torres-Preciado et al. [73], and Ülkü [74]. Additionally, some studies have used the growth of R&D spending as a proxy for the growth of technology [17, 22, 43, 49], and their results are similar to those of previous studies. In the present study, while growth of technology is insignificantly negative in OLS, it is highly positive and significant in the SDM. On the other hand, the direct effect of technology growth on growth is positive and significant, while its indirect effect is insignificant. The total effect is positive and nearly significant. It seems that the growth of technology is important for the focal country's growth, but the spatial diffusion effects on growth are not clear during the period under analysis. Similar to the current study, Evangelista et al. [16] and Torres-Preciado et al. [73] estimated a direct effect of growth of technology on growth that is significantly positive, while the indirect effect of growth of technology on growth is insignificant. Because the technology levels of the countries differ and intellectual property laws are strong in OECD countries (at least stronger than in other countries), technology may not be easily adopted and *imitated* by other countries. Therefore, the insignificance of the indirect effect of technology growth is reasonable. At least regarding the data sets we used, there is no clear evidence of a spillover effect of technology growth.

Conclusion

The growth literature continuously expands and changes. Since the Solow-Swan model, much like the wider world, the nature of economies, features of factors and analysis techniques and tools have been improving and changing, and the models that shed light on the determinants of growth have also changed. Specifically, some endogenous growth models define the relationships among variables, but they are not easy to estimate. This structural issue has generated asymmetry, as some studies have used other models, such as that of Nonneman and Vanhoudt, but claimed to estimate the Romer endogenous model. Others have not relied on any theoretical model, despite estimating models similar to those of the Nonneman and Vanhoudt Model or MRW model. In this study, we provided an overview the literature.

OECD founder countries are in Europe except the USA. Our results confirm that not only economic variables but also interaction among them is important in economic growth. It means contiguity interaction might be effective on regional development around these countries. There are many studies estimating the growth of OECD countries; however, few of them have used spatial models. These models are important if data sets have spatial dependency that might bias estimates. Our tests and estimations revealed that spatial dependence is valid in the data sets used. Thanks to the SDM, we were able to investigate some additional facts. We found empirical evidence that there are spatial interactions among countries since the interaction parameter of growth ($W * dep.var$) is significantly positive. This is an evidence that growths of countries interact each other as expected. Reflecting the contribution of the SDM, the sign of population growth turns from positive to negative, and the spillover effect of population growth is significantly positive, which may indicate a demand effect from neighbouring countries on the focal country as well as exchanging habits and experiences that affects production process. Additionally, the sign and significance of technology became significantly positive. It is difficult to say whether there is a tendency to mimic and imitate other countries' technology because the spillover effect is insignificant, which may be reasonable because intellectual property laws are relatively strong in

OECD countries. In any case, abusing technologic intellectual rights is a reality but it seems at least that disturbing effect is minimal in OECD founder countries. The impact of investment growth was highly positive and significant, which is attributable to the direct and total effects. The indirect effect is insignificant, which indicates that there is no spillover effect among neighbours because global savings stock is limited. The growth of human capital coefficients in every case was significant and positive, including the spillover effect, confirming that it is important not only locally but also in a broader sense. This is an evidence that how human capital is important for societies. Following studies can expand data sets in terms of time and space to have additional evidences effect of contiguity relations.

Abbreviations

GDP	Gross domestic product
LM	Lagrange multiplier
MRW	Mankiw, Romer and Weil
MYS	Mean years of schooling
OECD	The Organization for Economic Co-operation and Development
OLS	Ordinary least square
R&D	Research and development
SAR	Spatial autoregressive model
SDM	Spatial Durbin model
SEM	Spatial error model

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