Human Capital, Technological Know-How, Geographical Proximity and Trade in Economic Growth

A spatial econometrics approach

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1 Introduction

An important long-term goal of a government's economic policy is to encourage economic growth and keep the pace at a steady rate. Various models are employed to explain the economic growth, two in particular being the neo-Keynesian model (Harrod-Domar model) and the neoclassical model (Solow model). According to the Solow model (Solow, 1956; Swan, 1956), long-run economic growth can be explained by looking at capital accumulation, labour growth, and the gains in productivity are fueled by technological progress.

This model was put to test by Mankiw et al.. They found that *"the predictions of the Solow model are, to first approximation, consistent with the evidence."* However, the model *"does not correctly predicts the magnitudes"*, i.e., *"the effects of saving and population growth on income are too large"*. Hence, they augmented the classical Solow model by including accumulation of physical and human capital. This model was further augmented with accumulation of technological know-how by Nonneman & Vanhoudt as they felt this took into account all the relevent factors affecting economic growth. However, this model failed to explain how a country's economic growth is affected by the economic growth of neighbouring countries.

According to Tobler's first law of economic geography, *"everything is related to everything else, but near things are more related than distant things"*. I.e. there is no isolated region and every region is related more to neighbouring regions than distant regions. This might be due to continuous exchanges of infomation, science, technology, etc. Hence, interactions between areas in close proximity to one another are quite important. And not taking them into account can lead to biased estimates of coefficients (Andrew & Keith, 1981; Anselin, 1988; Floch & Le Saout, 2018) and faulty F tests and t tests (Dubé & Legros, 2014; Floch & Le Saout, 2018).

But, the Solow model does not takes into account the interdependency of economic growth between the regions. It is assumed within the model that the regions are independent from each other. However, the assumption that different economies are independent of one another is no longer valid as technological transfers, knowledge diffusions, labour migrations, institutional spillovers, contagious economic crises testify to the fact that economies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 & Hall, 2017; Amidi & Fagheh Majidi, 2020). Hence, we have, in recent years, studies which have included variables such as spatial proximity and position (Ertur & Koch, 2007; Ho et al., 2013; Amidi & Fagheh Majidi, 2020; Abbassi & Haq, 2022; Sun et al., 2022).

Consequently, it is permissible to embrace open economy theories as it allows an economy to be dependent on other economies. An increase in terms of trade resulted in more efficient resource allocation, which in turn produced high productivity and economic growth (Jawaid & Waheed, 2011). Relating to technology transfers, Schneider found that when compared to domestic technology, foreign technology has a greater impact on GDP growth. Frankel & Romer focused on the relation between trade and income. They found that trade has a large and robust positive effect on income. However, this effect was only moderately significant (Frankel & Romer, 2017). Ji et al. showed that exports lead to GDP growth and that the causality between GDP growth and exports is unidirectional, i.e., exports are a determinant of economic growth. Overall, trade is seen to be one of numerous factors that spurs productivity and growth, therefore, the amount of contribution it can make depends on how important trade is to overall economic activity (Amidi & Fagheh Majidi, 2020).

Given the significance of proximity and trade in economic growth, in this study, the impact of trade and proximity-based growth spillover on the Solow Model augmented with human capital and technological know-how will be stressed upon in an open economy by employing a dynamic spatial panel data model. Therefore, we will look at the spatial impact of trade and how economic growth is impacted by closeness.

2 Literature Review

The Solow model begins with the assumption that equality of aggregate demand and aggregate supply is a necessary condition for economic system's equilibrium (Sharipov, 2015). The model can show how three of economic growth are connected to each other, namely, investment, labour and technological progress. Saving rate tends to be an important factor in the determination of capital intensity. A higher rate of savings results in a larger stock of capital and, consequently, a higher level of output. A reason for ongoing economic development is population growth. However, if this is not accompanied by increasing investment, this will lead to a reduction in capital-labour ratio, and hence, lower output levels. Another reason for economic development is technical progress. According to the model, this is the only condition for continuous increase in the per capita standard of living (Solow, 1956; Swan, 1956).

Mankiw et al. looked at the Solow growth model's suitability for explaining the global variation in living standards. They augmented the textbook Solow model by adding both human and physical capital. As there is no actual variable for human capital accumulation, they used a proxy variable which measures approximately the the percentage of working-age population that is in secondary school. They found that population growth and savings are related to human capital, and hence, including it lowered the *"estimated effects of saving and population growth to roughly the values predicted by the augmented Solow model"* (Mankiw et al., 1992).

A further augmentation of Solow growth model was performed by Nonneman & Vanhoudt. They argued that the difference in the explanatory power of augmented Solow model in a broader sample vs the OECD sample was probably due to not all relevent factors of productions being included. Hence, they augmented the human capital augmented Solow model by including accumulation of technical know how (Nonneman & Vanhoudt, 1996). Their findings were consistent with those of Mankiw et al.. Their fully augmented Solow model was able to explain more variation in the data than the one by Mankiw et al.. Also, they found that the influence of human capital was far less important.

"Knowledge accumulated in one country depends on knowledge accumulated in other countries" (Ertur & Koch, 2007). This can happen due to international spillovers resulting from technology transfers, foreign direct investments, human capital externalities, etc. However, the model developed by Mankiw et al. does not takes into account the knowledge interdependence between the countries. Hence, a model was developed by Ertur & Koch which takes into account the technological interdependence among countries and they also examined the impacts of spillover effects. They found that the countries cannot be treated as spatially independent from each other and that growth models should take into account the spatial interactions because of technological interdependence. Since these effects are not captured by the variables in the textbook Solow model, hence, it is incorrectly specified (Ertur & Koch, 2007).

Yu & Lee took a spatial dynamic panel data approach towards studying the regional growth convergence in U.S. economy. Their approach is different than that of Ertur & Koch as they use a spatial dynamic panel data approach due to which they can *"avoid the omitted variable bias involving cross sectional equations and pure dynamic panel"* Yu & Lee (2012).

Ertur & Koch and Yu & Lee use a spatial weight matrix which is time-invariant. This is constructed from physical distance between economies, thereby assuming that the relative dependencies among different economies are constant over time (Ho et al., 2013). Hence, Ho et al. use a time varying spatial weights matrix and employ spatial panel data approach to estimate the Solow growth model. Rather than creating spatial weight matrix with geographic distances, they used the approach also used by Ertur & Koch (Ertur & Koch, 2011) in which the weight matrix was a bilateral trade flow matrix, i.e., sum of imports and exports. Ho et al. extended the idea of such a matrix by using bilateral trade flow of the previous time period and created a time varying spatial weight matrix. The results of their analysis do show that there is a positive spillover effect of growth from one country to its trade partners through bilateral trade.

Amidi & Fagheh Majidi examined the economic growth from perspectives of *bilateral trade flow* and *geographical distances*. This is done by using a spatial weights matrix which is made by using geographical distance, imports, exports, bilateral trade flows or a combination of geographical distances multiplied with the other three. They also find that the effect of spatial spillover is one of the key determinants of economic growth (Amidi & Fagheh Majidi, 2020).

Hence, with this study we desire to contribute to the topic of economic growth while taking into account the spatial spillovers. We do this by estimating a spatial panel data model with time varying spatial weights to estimate the further augmented Solow model by Nonneman & Vanhoudt. This study differs from the existing body of literature, since, we estimate the Solow model in a spatial-panel setting and also see the effects of two new additional variables - human capital and technological know-how.

3 Data

The data for this study was collected from Eurostat, CEPII and UNDP for countries in the European Union. The table below (table 1) shows which variables come from which dataset. The variables Real GDP (2010), Gross Fixed Capital Formation and Gross Expenditure on R & D variables were divided by the variable Working Age Population to create the following variables - Real GDP (2010) per person employed, Gross Fixed Capital Formation per person employed and Gross Expenditure on R & D per person employed. Bilateral Trade Flows from the CEPII dataset are used to create import, export and bilateral trade flow matrices (more in section 4). Merging

Data Set	Variable	Time Period
Eurostat	Real GDP (2010)	1975-2021
	Working Age Population	1960-2020
	Gross Fixed Capital Formation	1975-2021
	Gross Expenditure on R & D	1981-2020
UNDP	Human Development Index	1990-2019
CEPII	Bilateral Trade Flows	1995-2020

Table 1: Datasets and Variables

these datasets together we get the final data for 25 countries in european union from 1991 till 2019. However, this data is an unbalanced panel data. In this study we use panel data, since, it provides more accurate inference of model parameters, is able to capture much more complex behaviour (Hsiao, 2005), is generally more informative as it has more variation and less collinearity among varibales (Amidi & Fagheh Majidi, 2020). All the variables other than bilateral trade flows are log transformed.

4 Model

The model of this study is based on the model derived by Nonneman & Vanhoudt (1996). Their production function is of the following form:-

$$Y_t = c.L_t^{(1-\Sigma_{i=1}^{m}\alpha_i)}.\prod_{i=1}^{m} K_{it}^{\alpha_i}$$

with L as effective labour, K as capital of type i ($i = 1,...,m$), c and α_i are constants. Putting $i = 1$, we will get the textbook Solow model which only has physical capital. $i = 2$ forms the model by Mankiw et al. which has the physical as well as human capital. However, putting $i = 3$, we will get the production defined by Nonneman & Vanhoudt. Solving for their model, we get the following steady state equation (Pohjola, 2000):-

$$\begin{aligned}
\Delta ln(y_{tj}) = \theta lnA + at + \theta\frac{\alpha_k}{1-\beta}lns_{kj} + \theta\frac{\alpha_h}{1-\beta}lns_{hj} + \theta\frac{\alpha_\tau}{1-\beta}lns_{\tau j} \\
-\theta\frac{\beta}{1-\beta}ln(a+n_j+\delta) - \theta ln(y_0) + \varepsilon_j,
\end{aligned}$$

$$\lambda = \beta(a+n+\delta),$$

$$\theta = (1-e^{-\lambda t}),$$

$$\beta = \alpha_k + \alpha_h + \alpha_\tau$$

where, s_k is share of physical capital in GDP, s_h is the share of human capital in GDP, s_τ is the share of R & D in GDP, n is the population growth rate, δ

& a are the rate of depreciation and technology growth defined exogenously and is equal to 0.05 and ε is the error term, λ is the speed of convergence and $\Delta ln(y_{tj})$ is the economic growth rate. The error term, here, reflects the differences due to technology, resource endowment, climate and institutions (Pohjola, 2000).

To take into account the consequences of bilateral trade's spillover effects on economic growth, we need to add some spatial terms into the model equation. These spatial terms can take many forms. Hence, as we are going to use a spatial dynamic model specification and there can be one or more spatial terms in a model, therefore, we specify a general equation of our model which will be of the following form:-

$$\begin{aligned}\Delta ln(y_{it}) = \alpha + \eta ln(y_{it-1}) + \rho \sum_{j=1}^{n} w_{ijt} ln(y_{it}) + \sum_{k=1}^{K} x_{itk}\beta_k \\ + \sum_{k=1}^{K}\sum_{j=1}^{n} w_{ijt} x_{itk}\theta_k + \mu_i + \gamma_t + v_{it}, \\ v_{it} = \lambda \sum_{j=1}^{n} w_{ijt} v_{it} + \varepsilon_{it}\end{aligned}$$

where ρ, θ and λ are the spatial parameters of the model. If $\theta = 0$, then the model is SAC; $\lambda = 0$, then model is SDM; $\lambda = \theta = 0$, then the model is SAR; $\rho = \theta = 0$, then the model is SEM; $\rho = 0$, the the model is SDEM; $\rho = \lambda = 0$, then the model is SLX; $\rho \neq \theta \neq \lambda \neq 0$, we have the manski model. $\Delta ln(y_{it})$ is the differential log of Real GDP (2010) and is used as a proxy for economic growth; $ln(y_{t-1})$ is the log of gdp at time $t-1$. And the following variables are present in x:-

$ln(s_k)$: log of share of Gross Fixed Capital Formation in GDP,

$ln(s_h)$: log of human development index; used as a proxy for human capital,

$ln(s_\tau)$: log of share of Gross Expenditure on R & D in GDP,

$n+0.05$: n is the population growth rate; $n+0.05$ proxies the population growth rate and the depreciation rate

We have 7 model specifications which we can estimate. However, which one specifies the correct data generating process is still to be decided. The most general specification (manski model) can be used as a starting point and move towards the other models depending on if $\rho = 0$ or $\theta = 0$ or $\lambda = 0$ or if a certain combination of the three is equal to 0. In Figure 1, we can

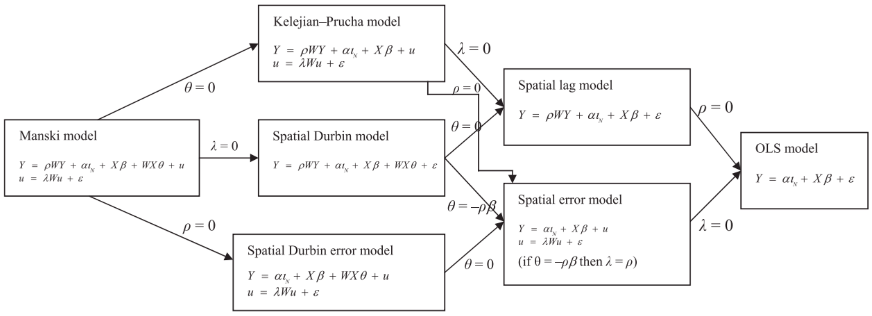

Figure 1: Relationship between different spatial models. Source: Elhorst (2010)

see that how all the spatial specification are nested under manski model. However, one should not begin with this model specification, since, the parameter estimates cannot be interpreted in a meaningful way (Elhorst, 2010). This is due to no distinction between the effect of lagged X's (WX) and lagged Y (WY). Hence, on should start from one of the following three model specifications - Spatial Durbin (SDM), Spatial Durbin Error (SDEM) or Kelejian-Prucha (SAC) model specification.

LeSage (2014) says that one should not use the SAC specification as *"it poses the greatest problems in estimation and inference"*. He proposes that one should start with SDM or SDEM. For choosing between the two, he proposes that a researcher should ask themselves if their model requires them to take into account global spillover effect (neighbours are affected, neighbours of neighbours are affected, neighbours of neighbours of neighbours are affected and so on) or local spillover effects (only direct neighbours are affected). Economic growth in one economy affects the growth in neighbouring economies. Since the economies are open today, economic growth in one economy can affect the economic growth in neighbours of neighbours and so on. This can be due to global interdependence on foreign direct investment, technological transfers, human capital externalities, etc (Ertur & Koch, 2007). So, in this paper, we take the route of global spillovers and proceed with SDM model and its nested forms. SDM has three nested forms - SAR, SLX and SEM. Hence, we will compare our unrestricted model specification, i.e., SDM, with the restricted specifications, i.e., SAR, SLX and SEM by using likelihood ratio test. This test will tell us if using an unrestricted model over the restricted model improves the goodness of fit significantly or not.

To take into account the spatial spillover effects, we create four different spatial weight matrices which can be categorized into 2 groups - one on the basis of geographical distances and three on the basis of bilateral trade flows. A matrix based on geographical distances assumes that countries located near have a greater weight than those located further. We therefore create an inverse distance matrix where each element of the matrix is equal to $\frac{1}{d_{ij}}$, where d_{ij} is the distance between the capital of country i and j. In an inverse distance matrix the weight of the nearer countries is large, however, as the distance increases, the weight drop drastically. We then row normalize this matrix where each element is w_{ij}. Then we create a distance threshold for each row which is average of each row (c_i). Finally, we create the following spatial weight matrix:-

$$W^*_{ij} = \begin{cases} 1, & w_{ij} \geq c_i \\ 0, & w_{ij} < c_i \end{cases}$$

This matrix is constructed for all the years separately as the data is unbalanced panel data and then stacked together block diagonally to create a spatial weight matrix for panel data.

Bilateral trade flow matrices are of three types - import, export and bilateral trade flows. These matrices were developed Ho et al. (2013). They exteneded the idea of Ertur & Koch by employing a time-varying spatial weight matrix using bilateral trade flows (sum of import and export), $W_t = [w_{ij,t}]^n_{i,j=1}$. Here, the (i, j)th entry in the matrix W_t is the bilateral trade flow or import or export of country i to j in the time period $(t-1)$. The export and import matrices are row normalized. And the bilateral trade flow matrix is the sum of row normalized export and import matrix.

5 Results

For the four spatial matrices, we estimate the SAR, SAC, SEM and SDM fixed effects model. In table 2, we have the descriptive statistics for all the variables of 25 EU countries during the period of 1991-2019.

Table 3 shows the results of the likelihood ratio test of SDM against SAR, SEM and SLX. These tests are reported for the 7 matrices types. H0 column shows the restriced model and H1 shows the unrestricted model. The result column show which model should be chosen according to the test performed.

In tables 4 - 10, we can see the results of our spatial fixed effects models for different weights matrices. Looking at the results for *Geographical Distance* matrix type, we can see that the SDM model tends to perform better that the three resticted models. This is why we SDM model in table

	$\Delta ln(gdp)$	$ln(gdp_{t-1})$	$ln(s_k)$	$ln(s_h)$	$ln(s_\tau)$	$n+0.05$
Min.	-0.157	8.384	-3.571	-0.375	-1.204	0.015
1st Qu.	0.010	9.679	-1.624	-0.201	3.493	0.046
Median	0.024	10.332	-1.522	-0.153	5.000	0.051
Mean	0.024	10.238	-1.526	-0.160	4.696	0.051
3rd Qu.	0.042	10.868	-1.433	-0.110	6.087	0.055
Max.	0.214	11.829	-0.601	-0.046	7.049	0.094
Std Dev	0.035	0.756	0.183	0.065	1.678	0.009

Table 2: Descriptive Statistics during 1991-2019

Matrix Type	H0	H1	χ^2	Result
Geographical Distance	SAR	SDM	33.064***	SDM
	SEM	SDM	35.850***	SDM
	SLX	SDM	160.396***	SDM
Import	SAR	SDM	4.722	SAR
	SEM	SDM	4.743	SEM
	SLX	SDM	216.086***	SDM
Export	SAR	SDM	20.466***	SDM
	SEM	SDM	23.850***	SDM
	SLX	SDM	161.125***	SDM
Bilateral Trade Flow	SAR	SDM	9.071.	SDM
	SEM	SDM	11.732*	SDM
	SLX	SDM	193.280***	SDM
Geographical distances & Import	SAR	SDM	8.498.	SDM
	SEM	SDM	18.993***	SDM
	SLX	SDM	192.118***	SDM
Geographical distances & Export	SAR	SDM	11.884*	SDM
	SEM	SDM	14.501**	SDM
	SLX	SDM	163.824***	SDM
Geographical distances & Bilateral Trade Flow	SAR	SDM	4.519	SAR
	SEM	SDM	17.777**	SDM
	SLX	SDM	185.132***	SDM

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 3: Likelihood Ratio Tests

4. There, we have the results for the spatial models using the geographical distance matrix. We report the results for SAR, SEM, SDM and SLX model. From that table, we can see that for the SDM specification, the signs of temporal lag of GDP, physical capital(s_k), human capital (s_h), technological know-how (s_τ) and population growth rate ($n+0.05$) are negative, posi-

tive, positive, positive and negative. And these coefficients are statistically significant. The signs of spatially lagged coefficients we can see that the signs of physical, human capital, technological know-how and population growth rate are positive, negative, positive and negative. This tells us that the human capital and the population growth rate of one country's neighbours tends to affects it negatively. ρ is positive and significant indicating that the geographical dimension is quite important between the countries.

From the import matrix in table 3, we can see from the result column that SDM should not be restricted to SLX. But it should be restricted to either SAR specification or SEM. We will settle this question by employing a Lagrange Multiplier test. This test will clearly tell us if a SAR specification is better or a SEM specification is better. Table 12 shows the test results for lagrange multiplier test. These results show us that we should choose a SAR specification. Hence in table 5, we choose the SAR specification. The spatial autocorrelation parameter (ρ) is significant and positive. The significant ρ indicates that dimension of bilateral trade is important and shows that there is spillover of economic growth. The signs of temporal lag of GDP, physical capital, human capital, technological know-how and population growth rate are negative, positive, positive, positive and negative. However, the coefficient of s_τ statistically insignificant.

Looking at the likelihood ratio test results for export matrix in table 3, we can see in the result column that SDM column shouldn't be restricted to either of its restricted forms. Hence, in table 6, we choose SDM specification. The signs all the coefficients are similar to those in table 4. Three of the four spatially lagged variables have insignificant coefficients. Coefficient of s_τ is again insignificant. ρ is positive and significant. This tells us that the dimension of bilateral trade is important for economic growth process.

In table 3, the result for the likelihood ratio test of bilateral trade flow matrix shows that SDM model shouldn't be resticted. And hence, we choose the SDM specification in the table 7. The signs of the coefficients are similar to those in table 4 and 6. s_τ is still statistically insignificant. ρ is positive and significant indicating that bilateral trade flow dimension is important between countries for economic growth.

The results for table 8 and 9 are similar. For both of them we choose the SDM specification based on the results of likelihood ratio test from table 3. ρ is positive and statistically significant indicating that the dimensions of geographical distances & import together and geographical distances & export together are important between countries.

	SAR	SEM	**SDM**	SLX
Intercept	1.456***	1.465***	**1.699***	2.299***
	(0.177)	(0.184)	**(0.180)**	(0.215)
$ln(y_{t-1})$	-0.120***	-0.119***	**-0.149***	-0.189***
	(0.016)	(0.016)	**(0.016)**	(0.019)
$ln(s_k)$	0.058***	0.048***	**0.056***	0.071***
	(0.007)	(0.007)	**(0.007)**	(0.008)
$ln(s_h)$	0.304***	0.426***	**0.665***	0.761***
	(0.068)	(0.087)	**(0.101)**	(0.122)
$ln(s_\tau)$	0.005.	0.004	**0.006***	0.008*
	(0.002)	(0.002)	**(0.002)**	(0.003)
$n+0.05$	-1.093***	-0.994***	**-1.074***	-1.195***
	(0.178)	(0.175)	**(0.177)**	(0.213)
$ln(s_k)*W$			**0.044****	0.091***
			(0.014)	(0.016)
$ln(s_h)*W$			**-0.618***	-0.699***
			(0.111)	(0.133)
$ln(s_\tau)*W$			**0.021***	0.018***
			(0.004)	(0.005)
$(n+0.05)*W$			**-0.372**	-1.640***
			(0.387)	(0.455)
ρ	0.538***		**0.526***	
	(0.039)		**(0.040)**	
λ		0.598***		
		(0.037)		
Log Lik	1339.704	1338.311	**1356.236**	1276.038
AIC	-2615.408	-2612.622	**-2640.473**	-2482.076

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 4: Unbalanced Spatial Panel Models using geographical distance matrix

Looking at the likelihood ratio test results for geographical distance and export matrix, we can see that SDM model shouldn't be restricted to SEM or SLX. However, it should be restricted to SAR model. Hence, we choose the SAR specification in table 10. The signs of coefficients are similar to those in table 6. ρ is positive and significant and we can conclude that geographical distances and trade flows between countries are important for

	SAR	SEM	SDM	SLX
Intercept	**1.417*****	1.490***	1.500***	2.001***
	(0.176)	(0.180)	(0.189)	(0.233)
$ln(y_{t-1})$	**-0.117*****	-0.122***	-0.127***	-0.159***
	(0.015)	(0.016)	(0.016)	(0.020)
$ln(s_k)$	**0.052*****	0.048***	0.048***	0.062***
	(0.006)	(0.007)	(0.007)	(0.009)
$ln(s_h)$	**0.333*****	0.472***	0.555***	0.561***
	(0.070)	(0.093)	(0.107)	(0.134)
$ln(s_\tau)$	**0.004**	0.005*	0.004.	0.006***
	(0.002)	(0.002)	(0.002)	(0.003)
$n+0.05$	**-1.071*****	-0.982***	-1.063***	-1.169***
	(0.169)	(0.168)	(0.169)	(0.220)
$ln(s_k)*W$			0.012	0.072***
			(0.010)	(0.020)
$ln(s_h)*W$			-0.193**	-0.453***
			(0.069)	(0.157)
$ln(s_\tau)*W$			0.005	0.011***
			(0.004)	(0.008)
$(n+0.05)*W$			-0.181	-1.790***
			(0.254)	(0.537)
ρ	**0.636*****		0.617***	
	(0.038)		(0.040)	
λ		0.699***		
		(0.036)		
Log Lik	**1321.526**	1321.515	1326.360	1215.844
AIC	**-2579.052**	-2579.031	-2580.721	-2361.688

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 5: Unbalanced Spatial Panel Models using import matrix

economic growth. s_τ is still insignificant.

We present the summary of all the selected models in the table 11 for each matrix type. From this summary we can see that that the sign of temporal lag of y is negative and is significant. The negative sign of this coefficient is confirmed by Amidi & Fagheh Majidi. The coefficient for physical capital ($ln(s_k)$) is positive and significant. The spatial studies done

	SAR	SEM	**SDM**	SXL
Intercept	1.536***	1.639***	**1.614*****	2.250***
	(0.178)	(0.189)	**(0.192)**	(0.234)
$ln(y_{t-1})$	-0.126***	-0.133***	**-0.136*****	-0.181***
	(0.016)	(0.016)	**(0.016)**	(0.019)
$ln(s_k)$	0.060***	0.053***	**0.054*****	0.062***
	(0.007)	(0.007)	**(0.007)**	(0.008)
$ln(s_h)$	0.360***	0.562***	**0.576*****	0.840***
	(0.072)	(0.104)	**(0.109)**	(0.134)
$ln(s_\tau)$	0.004	0.003	**0.004**	0.004
	(0.002)	(0.002)	**(0.002)**	(0.003)
$n+0.05$	-1.098***	-0.983***	**-1.103*****	-1.133***
	(0.173)	(0.169)	**(0.174)**	(0.209)
$ln(s_k)*W$			**0.018.**	0.176***
			(0.010)	(0.032)
$ln(s_h)*W$			**-0.192****	-0.974***
			(0.070)	(0.172)
$ln(s_\tau)*W$			**0.005**	0.044***
			(0.004)	(0.010)
$(n+0.05)*W$			**-0.111**	-2.702***
			(0.260)	(0.600)
ρ	0.715***		**0.695*****	
	(0.028)		**(0.030)**	
λ		0.772***		
		(0.024)		
Log Lik	1310.135	1308.443	**1315.018**	1239.806
AIC	-2556.271	-2552.886	**-2558.037**	-2409.612

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 6: Unbalanced Spatial Panel Models using export matrix

on Solow model also seem to confirm this (Ertur & Koch, 2007; Fischer, 2011; Ho et al., 2013; Park & Seo, 2016; Zhong & Huang, 2018; Amidi & Fagheh Majidi, 2020). The coefficient of human capital ($ln(s_h)$) is also positive and significant across all the chosen models and this can be seen in some spatial studies (Fischer, 2011; Park & Seo, 2016; Abbassi & Haq, 2022). The coefficient for technological know-how ($ln(s_\tau)$) is positive and usually not significant across the models. This is supported by one spatial

	SAR	SEM	**SDM**	SLX
Intercept	1.458***	1.554***	**1.530******	2.129***
	(0.175)	(0.184)	**(0.188)**	(0.235)
$ln(y_{t-1})$	-0.120***	-0.127***	**-0.130******	-0.168***
	(0.015)	(0.016)	**(0.016)**	(0.020)
$ln(s_k)$	0.055***	0.050***	**0.050******	0.060***
	(0.006)	(0.007)	**(0.007)**	(0.009)
$ln(s_h)$	0.344***	0.521***	**0.561******	0.664***
	(0.070)	(0.099)	**(0.107)**	(0.134)
$ln(s_\tau)$	0.004	0.004·	**0.004**	0.006***
	(0.002)	(0.002)	**(0.002)**	(0.003)
$n+0.05$	-1.079***	-0.982***	**-1.079******	-1.143***
	(0.169)	(0.168)	**(0.170)**	(0.214)
$ln(s_k)*W$			**0.013**	0.130***
			(0.010)	(0.025)
$ln(s_h)*W$			**-0.184****	-0.798***
			(0.069)	(0.173)
$ln(s_\tau)*W$			**0.005**	0.029***
			(0.004)	(0.010)
$(n+0.05)*W$			**-0.091**	-3.098***
			(0.254)	(0.628)
ρ	0.348***		**0.340******	
	(0.017)		**(0.018)**	
λ		0.378***		
		(0.015)		
Log Lik	1321.394	1320.063	**1325.929**	1229.289
AIC	-2578.788	-2576.126	**-2579.859**	-2388.578

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 7: Unbalanced Spatial Panel Models using bilateral trade flow matrix

study which is present on this topic (Cartone et al., 2021). The coefficient of population growth $(n+0.05)$is negative and significant and this results is also supported by the spatial studies (Ertur & Koch, 2007; Fischer, 2011; Ho et al., 2013; Park & Seo, 2016; Amidi & Fagheh Majidi, 2020; Cartone et al., 2021; Abbassi & Haq, 2022).

The coefficients of spatially lagged human capital $(ln(s_h)*W)$ and pop-

	SAR	SEM	**SDM**	SLX
Intercept	1.426***	1.307***	**1.548*****	2.135***
	(0.184)	(0.198)	**(0.197)**	(0.230)
$ln(y_{t-1})$	-0.115***	-0.105***	**-0.127*****	-0.170***
	(0.016)	(0.017)	**(0.016)**	(0.020)
$ln(s_k)$	0.053***	0.052***	**0.048*****	0.062***
	(0.007)	(0.007)	**(0.007)**	(0.009)
$ln(s_h)$	0.293***	0.283***	**0.495*****	0.602***
	(0.074)	(0.081)	**(0.112)**	(0.117)
$ln(s_\tau)$	0.002	0.003	**0.003**	0.005***
	(0.002)	(0.002)	**(0.002)**	(0.003)
$n+0.05$	-1.198***	-1.096***	**-1.156*****	-1.203***
	(0.178)	(0.178)	**(0.177)**	(0.219)
$ln(s_k)*W$			**0.025****	0.063***
			(0.010)	(0.016)
$ln(s_h)*W$			**-0.256***	-0.325***
			(0.072)	(0.119)
$ln(s_\tau)*W$			**0.009***	0.005***
			(0.004)	(0.004)
$(n+0.05)*W$			**-0.703****	-1.141***
			(0.265)	(0.366)
ρ	1.051***		**0.987*****	
	(0.064)		**(0.067)**	
λ		1.129***		
		(0.065)		
Log Lik	1294	1287.819	**1302.796**	1217.154
AIC	-2524	-2511.638	**-2533.593**	-2364.309

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 8: Unbalanced Spatial Panel Models using geographical distance and import matrix

ulation growth ($(n+0.05)*W$) are both negative. However, the coefficient for lagged population growth is not significant in all the models. These results cannot be usually found in the literature as most spatial studies on the topic do not use a SDM specification. If they do, then, they do not have human capital as an independent variable. In the literature the coefficient for spatially lagged population growth is usually insignificant. Hence, it is difficult to know if we have the correct sign in our results.

	SAR	SEM	**SDM**	SLX
Intercept	1.548***	1.453***	**1.709*****	2.183***
	(0.189)	(0.201)	**(0.202)**	(0.237)
$ln(y_{t-1})$	-0.126***	-0.116***	**-0.137*****	-0.181***
	(0.017)	(0.017)	**(0.017)**	(0.020)
$ln(s_k)$	0.059***	0.056***	**0.054*****	0.071***
	(0.007)	(0.007)	**(0.007)**	(0.009)
$ln(s_h)$	0.343***	0.393***	**0.535*****	0.662***
	(0.076)	(0.092)	**(0.116)**	(0.120)
$ln(s_\tau)$	0.003	0.002	**0.003**	0.005
	(0.003)	(0.002)	**(0.003)**	(0.003)
$n+0.05$	-1.161***	-1.115***	**-1.134*****	-1.082***
	(0.184)	(0.180)	**(0.184)**	(0.223)
$ln(s_k)*W$			**0.031****	0.044*
			(0.011)	(0.019)
$ln(s_h)*W$			**-0.220****	-0.420**
			(0.075)	(0.130)
$ln(s_\tau)*W$			**0.007**	0.014**
			(0.004)	(0.005)
$(n+0.05)*W$			**-0.679.**	-1.119**
			(0.275)	(0.359)
ρ	1.455***		**1.335*****	
	(0.087)		**(0.093)**	
λ		1.129***		
		(0.065)		
Log Lik	1279.380	1287.819	**1286.725**	1215.637
AIC	-2494.760	-2511.638	**-2501.450**	-2361.274

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 9: Unbalanced Spatial Panel Models using geographical distance and export matrix

The coefficient for spatially lagged physical capital is positive and in most models it is also significant. And this result is not supported by spatial studies. The sign of this coefficient is usually positive (Ertur & Koch, 2007; Amidi & Fagheh Majidi, 2020). Only Abbassi & Haq have found the sign of this coefficient to be positive. The coefficient for spatially lagged technological know-how ($ln(s_\tau)$) is positive and only significant in 2 models.

	SAR	SEM	SDM	SAC
Intercept	**1.437*****	1.316***	1.563***	2.207***
	(0.183)	(0.196)	(0.196)	(0.235)
$ln(y_{t-1})$	**-0.116*****	-0.105***	-0.128***	-0.176***
	(0.016)	(0.017)	(0.016)	(0.020)
$ln(s_k)$	**0.054*****	0.051***	0.050***	0.066***
	(0.007)	(0.007)	(0.007)	(0.009)
$ln(s_h)$	**0.305*****	0.322***	0.496***	0.602***
	(0.073)	(0.087)	(0.112)	(0.118)
$ln(s_\tau)$	**0.002**	0.003	0.002	0.004
	(0.002)	(0.002)	(0.002)	(0.003)
$n+0.05$	**-1.179*****	-1.097***	-1.147***	-1.142***
	(0.177)	(0.177)	(0.177)	(0.220)
$ln(s_k)*W$			0.023*	0.061**
			(0.010)	(0.019)
$ln(s_h)*W$			-0.224**	-0.305*
			(0.072)	(0.126)
$ln(s_\tau)*W$			0.007.	0.007
			(0.004)	(0.004)
$(n+0.05)*W$			-0.604*	-1.291***
			(0.266)	(0.370)
ρ	**0.669*****		0.627***	
	(0.043)		(0.045)	
λ		0.732***		
		(0.043)		
Log Lik	**1296.700**	1292.482	1303.514	1216.445
AIC	**-2529.401**	-2520.964	-2535.029	-2362.890

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 10: Unbalanced Spatial Panel Models using geographical distance and bilateral trade flow matrix

However, we cannot compare this with any other study as there is no studies present with this coefficient.

	Georaphical Distance (SDM)	Import (SAR)	Export (SDM)	Bilateral Trade Flow (SDM)	Georaphical Distance & Import (SDM)	Georaphical Distance & Export (SDM)	Georaphical Distance & Bilateral Trade Flow (SAR)
Intercept	1.699***	1.417***	1.614***	1.530***	1.548***	1.709***	1.437***
	(0.180)	(0.176)	(0.192)	(0.188)	(0.197)	(0.202)	(0.183)
$ln(y_{t-1})$	-0.149***	-0.117***	-0.136***	-0.130***	-0.127***	-0.137***	-0.116***
	(0.016)	(0.015)	(0.016)	(0.016)	(0.016)	(0.017)	(0.016)
$ln(s_k)$	0.056***	0.052***	0.054***	0.050***	0.048***	0.054***	0.054***
	(0.007)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
$ln(s_h)$	0.665***	0.333***	0.576***	0.561***	0.495***	0.535***	0.305***
	(0.101)	(0.070)	(0.109)	(0.107)	(0.112)	(0.116)	(0.073)
$ln(s_\tau)$	0.006*	0.004	0.004	0.004	0.003	0.003	0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
$n+0.05$	-1.074***	-1.071***	-1.103***	-1.079***	-1.156***	-1.134***	-1.179***
	(0.177)	(0.169)	(0.174)	(0.170)	(0.177)	(0.184)	(0.177)
$ln(s_k)*W$	0.044**		0.018.	0.013	0.025**	0.031**	
	(0.014)		(0.010)	(0.010)	(0.010)	(0.011)	
$ln(s_h)*W$	-0.618***		-0.192**	-0.184**	-0.256*	-0.220**	
	(0.111)		(0.070)	(0.069)	(0.072)	(0.075)	
$ln(s_\tau)*W$	0.021***		0.005	0.005	0.009*	0.007	
	(0.004)		(0.004)	(0.004)	(0.004)	(0.004)	
$(n+0.05)*W$	-0.372		-0.111	-0.091	-0.703**	-0.679.	
	(0.387)		(0.260)	(0.254)	(0.265)	(0.275)	
ρ	0.526***	0.636***	0.695***	0.340***	0.987***	1.335***	0.669***
	(0.040)	(0.038)	(0.030)	(0.018)	(0.067)	(0.093)	(0.043)
Log Lik	1356.236	1321.526	1315.018	1325.929	1302.796	1286.725	1296.700
AIC	-2640.473	-2579.052	-2558.037	-2579.859	-2533.593	-2501.450	-2529.401

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Since these are SDM and SAR specification, therefore, there is no λ coefficient.

Table 11: Summary of the selected models

6 Conclusion

In this study, we employed a spatial dynamic panel data approach on the further augmented Solow model on a sample of 25 countries present in the European Regions during the period 1991-2019. From the analysis performed, it was found that spatial spillovers are present in these countries, since, the spatial autocorrelation parameter (ρ) is positive and significant in all the models. Thus, telling us that bilateral trade flows and geographic distances tend to create growth spillovers. This can be due to the fact that countries which tend to be near each other or tend to trade more with each other have higher amount of sharing of knowledge, technology, management, goods, labour, etc.

Hence, these two dimensions are quite important . It was also found that economic growth is dependent on physical capital and human capital. However, there is uncertainty regarding the effect of technological know-how on economic growth, since, its coefficients were usually insignificant. This can be due to the fact that the proxy for technological know-how (gross expenditure on R & D) might not be a good proxy. Also, population growth rate ($n+0.05$) had negative effect on economic growth. This might be due to the fact that increase in labour force does not lead to an increase in GDP (Amidi & Fagheh Majidi, 2020).

From the coefficients of spatially lagged variables, we found that increase in the physical capital and technological know-how of the neighbours leads to an increase in the economic growth. And increase in human capital and population growth rate of neighbouring countries has a negative effect on the economic growth rate. However, the coefficients for technological know-how and population growth rate of the neighbouring regions are quite insignificant. Hence, their signs cannot be trusted.

The main contribution of this research was to see the if there are spillover of economic growth due to the spatial proximity or trade between countries while also looking at the effect of human capital and technological know-how. In conclusion, we have seen spillover of economic growth and human capital does have a positive and significant effect on economic growth. However, technological know-how does not has a positive but insignificant effect on economic growth.

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A Lagrange Multiplier Test

Test	Test Statistic
LMerr	424.16***
LMlag	464.62***
RLMerr	3.058.
RLMlag	43.521***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 12: Lagrange Multiplier Test Results