The role of knowledge in economic growth: A spatial analysis for Mexico

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Abstract

The aim of this research is to analyze the impact of the education level of the labor force, the accumulation of intellectual capital, the capacity for innovation, and the transfer of knowledge on the economic activity of Mexico's federal entities. To achieve this goal, various specifications for a panel model were calculated that take into account the spatial correlation patterns of economic activity and the unobservable claims of neighboring entities' production functions. The results suggest that by decreasing the proportion of workers with lower education levels, increasing the accumulation of intellectual capital, and intensifying the exchange of goods and services abroad, the production level increases.

Keywords: knowledge-driven economy; human capital; federal entities; regional calculations; panel model.

1. INTRODUCTION

In recent decades, the integration of economies has intensified as a result of globalization processes, allowing for a greater flow of goods, services, financial resources and knowledge. Economic theory, especially endogenous growth theory, argues that knowledge creation and transfer have a positive effect on production (Lucas, 1988; Romer, 1990). This phenomenon occurs not only in the place where the knowledge itself is created, but also in economies and regions that interact with generators of such knowledge (Lucas, 1988). Given this argument, the present research has the central goal of identifying relationships that exist between various forms of knowledge and state economic activity.

Currently, specialized literature indicates that there are different forms of knowledge. Economies have a stock, or accumulation, of knowledge that materializes in the quantity and quality of physical capital (Lucas, 1988). Likewise, a region's workforce holds a stock of knowledge—that is, its level of human capital. Becker (1994) indicates that the "human capital revolution" began with the work of Schultz (1961), Mincer (1958), and Rosen (1976), among others. He also suggests that education and training outside of school are the two most important forms of investment in human capital, and that those regions that show persistent economic growth tend to be linked to substantial increases in the level of education and training of the labor force. Meanwhile, Coleman (1988) argues that social capital within the nuclear family (the relationship between parents and children) has an important influence on children's education level.

Teece (1998) points out that the generation of new knowledge can materialize in the accumulation of intellectual capital, like patents or copyrights for example. This type of knowledge usually modifies the efficiency with which factors of production are used; however, economic agents may be excluded by way of property rights.

Other scholars, such as Arrow (1971), Lucas (1988) and Houghton and Sheehan (2000) argue that knowledge derives from a learning process known as learning-by-doing, *i.e.*, learning through experience. Such learning is usually connected to higher productivity associated with increases in exports of goods that were not originally produced; for example, the "economic miracles" in Korea, Taiwan, Hong Kong and Singapore. Lucas (1988) points out that these economies materialized their experience (learning-by-doing) with increased productivity in sectors which did not have a high level of specialization.

An increase in an economy's level of knowledge can be generated through various channels. The stock of talent depends on spending in research and development (R&D) carried out by a variety of economic agents, who also have the possibility of acquiring knowledge generated elsewhere. Like, for example, the purchase of high-tech machinery to achieve more efficient use of inputs from the production process (physical capital).

In terms of intangible capital, the purchase of licenses or the right to use patents represents an additional mechanism to increase the stock of knowledge, and therefore, increase efficiency in the use of factors of production. Similarly, education and training allow for higher-qualified human capital.

To identify the influence that knowledge accumulation has on economic growth, this work calculates certain specifications of a Cobb-Douglas type production function. These specifications make up nine panel data models that involve the use of fixed, random, dynamic, and spatial correlation effects.

The results suggest that: (1) the labor force's qualifications contribute significantly to the state income; (2) lower levels of workforce education are associated with less economic growth; (3) the estimated parameters associated with the number of researchers belonging to the National System of Researchers (NSR) are not statistically significant in most of the function specifications; (4) intangible capital shows a (limited) positive association with output level; (5) knowledge dissemination channels also play an important role in the level of production; (6) contrary to initial expectations, estimates suggest that an increase in the amount of foreign direct investment (FDI) is negatively associated with Gross Domestic Product (GDP), particularly in southern Mexico, and; (7) the degree of trade openness or amount of external trade is positively associated with production levels.

The remaining sections of this research article include, first, a review of empirical studies that justify the selection of the methodology used to answer the research question. Then, the panel model methodology used to identify the influence of different forms of knowledge at the production level is laid out. Following this the collection of materials used in the analysis is described, then the results of the set of estimated panel models are presented. Subsequently, a brief discussion of the results obtained is provided, and finally, a set of conclusions is discussed.

2. LITERATURE REVIEW: EMPIRICAL STUDIES

To identify the frontier of knowledge and select the appropriate methodology, a systematic review of literature addressing relevant empirical studies was carried out. When analyzing this set of studies, it can be observed that this branch of the literature focuses on countries belonging to the Organization for Economic Cooperation and Development [Spanish acronym OCDE], as is the case for Coe and Helpman (1995), Engelbrecht (1997), Kao *et al*. (1999), Frantzen (2000), Guellec and De La Potterie (2002) and Zhu and Jeon (2007). These authors argue that human capital affects total factor productivity, since it is considered an important vehicle of knowledge transfer. This phenomenon originates in the direct relationship that exists between the level of human capital and its ability to take advantage of productivity increases in other countries or regions with which there is a strong degree of connection (Nursamsu and Hastiadi, 2015).

Scholars such as Basant and Fikkert (1996) and Coe *et al*. (1997) indicate, for their part, that the transfer of knowledge through the acquisition of existing technologies has a positive effect on the level of production. Regarding the role that FDI plays in boosting economic activity, works by Coe and Helpman (1995) and Guellec and De La Potterie (2002) point out that if such investment is directed towards innovation, there is a positive association between FDI and the GDP. Coe and Helpman (1995) argue that these effects are enhanced when the degree of trade openness increases. However, other scholars such as Kao *et al*. (1999) and Mendoza-Cota (2011) show that FDI does not influence the level of production when said investment is not directed towards improving the efficient use of inputs.

The literature suggests the use of various methodologies to identify the relationship between forms of knowledge and income levels. This set of research highlights pooled data panel models (POLS), fixed effects models (FE), random effects models (RE), dynamic effects and spatial correlation. Regarding the latter, Naveed and Ahmad (2016) use spatial autoregressive models (SAR) and spatial Durbin models (SDM) to examine the indirect effects of technology and knowledge on production levels in neighboring regions. This implies that the ways knowledge influences economic activity is diluted across space.

Based on the review of empirical studies and the restrictions imposed by the availability of statistical information, this article analyzes the influence of certain forms of knowledge only on economic activity in Mexican states. These forms include: the labor force's education level, the accumulation of intellectual capital, the capacity for innovation and the transfer of knowledge and experience via the exchange of goods and services.

Some knowledge resources identified in the literature review are not directly observable, such as different modes of social capital and their influence on the formation of human capital, worker training, or any learning-by-doing process. These forms of knowledge are observable at the microeconomic level, *e.g*. in companies, but they fall outside the focus of this work (Basurto and Sánchez, 2020 can be consulted on this issue).

3. METHODOLOGY

Panel models are used to identify the relationship between knowledge and level of production. According to Cameron and Trivedi (2005), a panel model —in its simplest form—can be estimated like a POLS model, which is defined as follows:

$$y_{it} = \alpha + X'_{it}\beta + u_{it} \quad (1)$$

where y_{it} is the level of production level for state *i* in year *t*, α denotes a constant term, X'_{it} represents the set of explanatory variables for income of state *i* in year *t*, vector β represents the parameters associated with each explanatory variable, and u_{it} is the error term.

In the case of the POLS model, it is assumed that the explanatory variables are exogenous and there is no correlation between them and the error term; that is, $E(u_{it} \mid X'_{it}) = 0$, where $u_{it} = \alpha_i + \varepsilon_{it}$. If there is a correlation between the error term u_{it}, and explanatory variables X'_{it}, the estimated parameters, $\hat{\beta}$, in equation (1) will show bias. When this occurs, FE or RE panel models may be used. The former assumes that there is a correlation between individual effects and explanatory variables, and that there is no correlation between the error term, individual effects, and the set of explanatory variables. Accordingly, we have $E(\alpha_i \mid X'_{it}) \neq 0$ and $E(\varepsilon_{it} \mid \alpha_i, X'_{it}) = 0$. In the latter case, it is assumed that the individual effects component, α_i, is purely random and there is no correlation between these effects and the explanatory variables. As such, it is expected that $E(\alpha_i \mid X'_{it}) = 0$ and $E(\varepsilon_{it} \mid \alpha_i, X'_{it}) = 0$.

To differentiate between the POLS, FE and RE models, the Hausman test (Hausman, 1978)— which compares the parameters estimated in the FE and RE, $\hat{\beta}_{FE}$ and $\hat{\beta}_{RE}$, models—is used to identify whether the differences between these parameters are statistically significant or not. If individual effects are fixed, then the parameters found in the POLS and RE models are inconsistent and, therefore, the FE model is preferred.

The Hausman test[1] statistic is calculated based on the differences between parameters $\hat{\beta}_{FE}$ and $\hat{\beta}_{RE}$, weighted by variance and defined as follows:

$$H = (\hat{\beta}_{FE} - \hat{\beta}_{RE})' [Var(\hat{\beta}_{FE}) - Var(\hat{\beta}_{RE})]^{-1} (\hat{\beta}_{FE} - \hat{\beta}_{RE}) \quad (2)$$

In order to incorporate dynamic elements of the explanatory variables, a panel model is estimated using the Generalized Moments Method (GMM), where lags in the explanatory variables are used as instruments of the main equation.

To complete the analysis, various specifications of FE and RE panel models—that take into account spatial correlation patterns—are estimated. The spatial autoregressive model (SAR) assumes that the level of economic activity of state *i* is associated with the levels of economic activity of neighboring states *j*, and is defined as:

$$y_{it} = \rho W y_{it} + X_{it}'\beta + \alpha_i + \varepsilon_{it} \quad (3)$$

where *W* is a matrix with dimensions $i * i$ and inputs $w_{ij} \in W$, which indicate the associated weight, or proximity, to each element *i* and *j.* The diagonal elements in the matrix, *W* and w_{ii}, are assigned the value of 0 to avoid the contradiction of a state neighboring itself. Parameter ρ indicates the degree of association between the levels of economic activity in state *i* and neighboring states *j*.[2]

The above specifications assume that there is no spatial correlation between the error terms. In some cases, relevant unobservable variables are part of the error term, *e.g*. physical capital or natural capital. To corroborate that the omitted variables do not create bias in the estimated parameters, the spatial autocorrelation model (SAC) assumes that there is a spatial correlation between the error terms. Thus, the SAC model assumes that $\varepsilon_{it} = \lambda W \varepsilon_{it} + v_{it}$, where λ measures the correlation between spatially lagged errors, ε_{it}, and v_{it} is the error term which follows an i.i.d distribution for the individual and time components.

From expression (3) a specific case emerges; when it is assumed that $\rho = 0$ and $\varepsilon_{it} = \lambda W \varepsilon_{it} + v_{it}$, a spatial error correlation model (SEM) can be estimated (Anselin, 2013).

4. DATA

To estimate the set of models defined above, statistical information was collected for Mexico's 32 states during the 2007-2016 period. The dependent variable, y_{it}, is defined as the state GDP measured in 2013 prices.

For the purposes of presentation, figure 1.1 shows average annual GDP per capita for the period in question. A certain degree of correlation can be observed between different states' levels of economic activity; for example, the economic dynamism of Mexico's northern border seems to drive the level of production in states such as Nuevo León, Sonora, Coahuila, Chihuahua and Tamaulipas. On the other hand, the South and certain states in the center of the country are characterized as regions with low levels of economic activity.

In terms of the workforce, the Economically Active Population (EAP) is used for each state. The Ministry of Labor and Social Welfare publishes the number of people who make up the EAP in each state annually, for the period of 2005-2017. Since worker education levels play an important role in the adaptation of knowledge to existing production processes, the transfer of knowledge and the generation of new knowledge which drives economic activity, the EAP is used according to education level for the set of calculations. Figures 1.2-1.5 show the average proportion of the EAP that has primary, middle school, high school and higher education, respectively. In some cases, a certain degree of spatial correlation is observed between the GDP and the EAP's education level—for example, in states along the northern border and Mexico City where elevated levels of production and workers with higher education are observed.

For Mexico, the National Institute of Statistics and Geography [Spanish acronym INEGI] publishes annual data on gross fixed capital formation at the national level; however, such information is not available at the state level. Despite the institute's efforts to construct such indicators for states based on economic censuses, they are only available for 2003, 2008 and 2013, which limits the present analysis. Therefore, for this research state governments' gross fixed capital formation in the 2003-2016 period was used as a proxy variable for physical capital formation (see figure 1.6).

States' capacity to generate new knowledge—and its relationship to the level of production—are approximated using the number of researchers who belong to the NSR of the National Council for Science and Technology [Spanish acronym CONACYT]. CONACYT publishes an annual series with the total number of researchers who belong to the NSR for the 2005-2017 period. Based on this statistical information, the number of NSR researchers per 100,000 inhabitants is calculated; figure 2.1 shows the average numbers of NSR researchers during this period.

Following from the literature review, the number of patents can be used as a proxy for the intellectual capital of a region or economy. The Mexican Institute of Industrial Property also publishes an annual series with the number of patents per state entity for the 2003-2017 period. As a way to homogenize intellectual capital, the number of patents per 100,000 inhabitants is used. Figure 2.2 shows the geographical distribution of the average number of patents during the period of analysis.

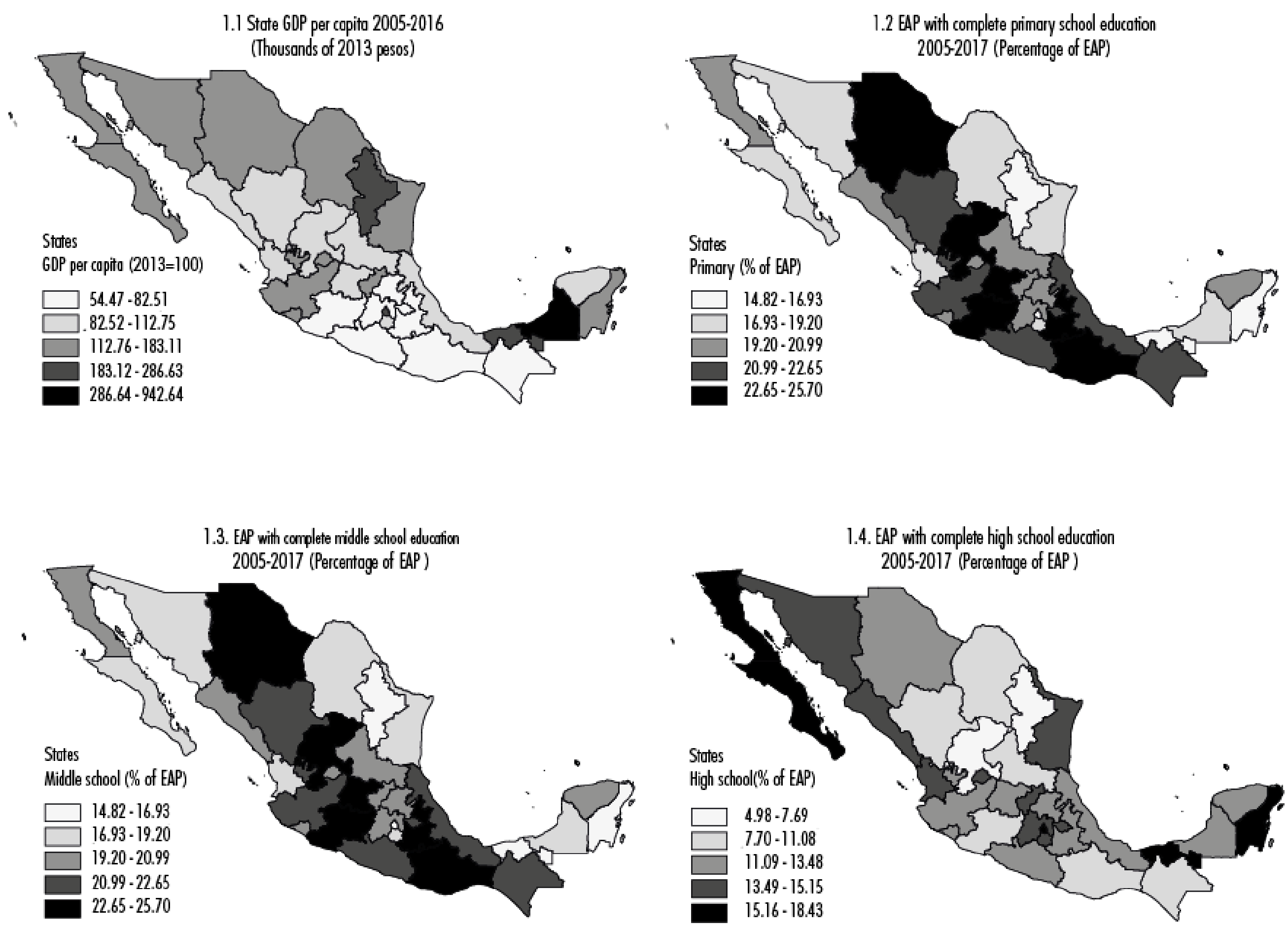
The set of calculations uses FDI as a percentage of GDP to approximate the degree of transmission of knowledge generated in other countries to local economies. INEGI publishes an annual series of FDI by state during the 2003-2017 period. Figure 2.3 shows the spatial distribution of average FDI as a percentage of GDP in the 2003-2017 period. FDI flows appear to reside in states with higher levels of human capital, more capacity to generate or adapt new knowledge, and incomes above those of other states.

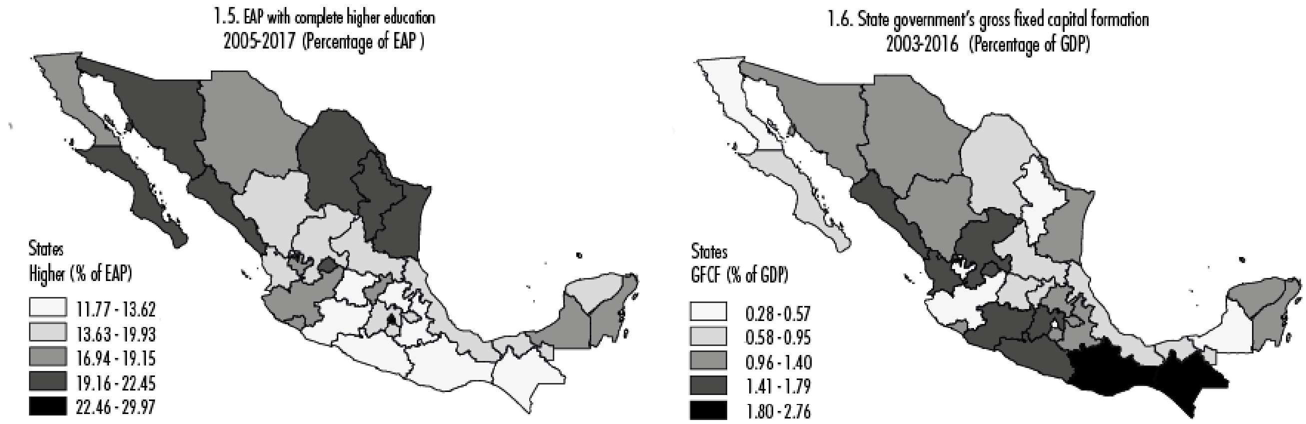
The intensity of interactions between two economies is measured through the ratio of exports and imports to GDP, which is considered to be a proxy variable for the degree of trade openness. INEGI discloses the value of exports by state for the 2007-2016 period, however, the value of imports is not available at the state level.

According to figure 2.4, the southern states show the least intense levels of trade in goods and services with other countries—especially with the United States—due to the high costs of transporting goods, while the northern states are usually more connected to the North American market.

Subject to the availability of information, a panel-type database was constructed to identify the influence of various types of knowledge on state production levels, and which contains complete statistical information for the variables described above for the 2007-2016 period.

Figure 1. EAP production and composition and gross fixed capital formation

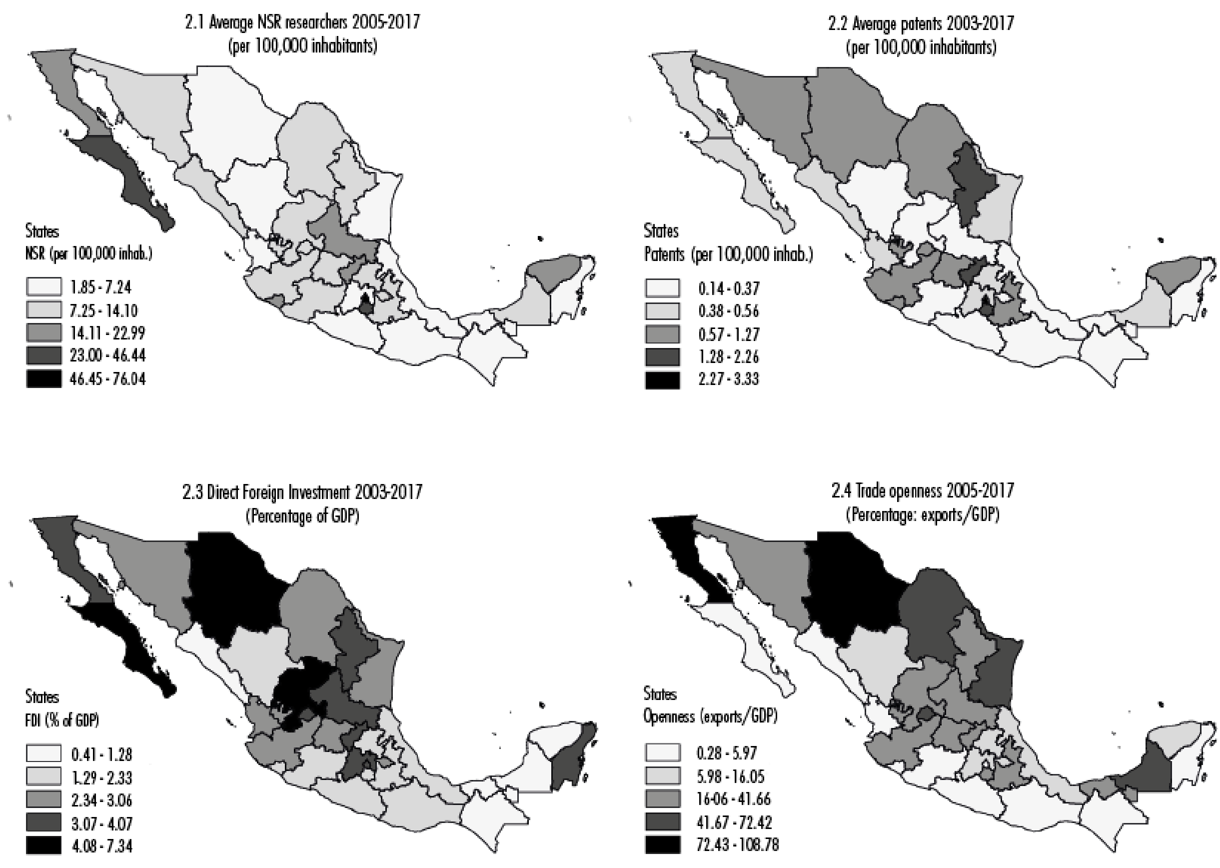




Notes: GDP: Gross Domestic Product; EAP: Economically Active Population.

Source: prepared by the authors with data from the System of National Accounts (INEGI, 2019).

Figure 2. NSR researchers, patents, FDI and trade openness



Notes: GDP: Gross Domestic Product; NSR: National System of Researchers; FDI: Foreign Direct Investment.

Source: prepared by the authors with data from the System of National Accounts (INEGI, 2019).

5. RESULTS

The set of calculations includes the following models: POLS, FE, RE, GMM, SAR-FE, SAR-RE, SEM-FE, SEM-RE, and SAC-FE; in all cases, the variable logarithm is used. Table 1 presents statistics for the Hausman test, which suggests that the FE model is preferred over the POLS and RE specifications. The Hausman test also indicates that the SAR-EA and SEM-EA models can be ruled out. Therefore, attention can be focused on the parameters estimated in FE, GMM, SAR-FE, SEM-FE and SAC-FE models.[3]

Table 1. Tests of correct specifications for panel model

Comparison of models	Test	Chi-2	Prob>Chi-2	Result
FE *vs.* RE	Hausman	42.96	0.00	FE
SAR-FE *vs.* SAR-RE	Hausman	27.77	0.01	SAR-FE
SEM-FE *vs.* SEM-RE	Hausman	21.84	0.04	SEM-FE

Source: prepared by the authors based on their own estimations.

Table 2 shows the estimated parameters for each of the panel model specifications. According to parameters estimated by the FE model, the labor force contributes 27.61% of the total value production. State governments' efforts to increase physical capital in their territories does not seem to have a significant impact on production. This result may be due to the fact that the amount of such investments (between 0.28 and 2.76% of the GDP) is not enough to boost economic growth.

Table 2. Estimated parameters of panel models

Variables	FE GDP	GMM GDP	SAR-FE GDP	SEM-FE GDP	SAC-FE GDP
Eap	0.2761**	0.4778***	0.2588**	0.3875***	0.1094*
	(0.1116)	(0.1779)	(0.1011)	(0.1070)	(0.0652)
eap*eap with higher education (%)	0.0021	0.1124***	0.0005	0.0002	0.0036
	(0.0054)	(0.0178)	(0.0049)	(0.0050)	(0.0032)
eap*eap with high school education (%)	0.0011	-0.0081	0.0004	0.0018	0.0096***
	(0.0036)	(0.0067)	(0.0033)	(0.0033)	(0.0026)
eap*eap with middle school completed (%)	0.0019	0.0053	-0.0011	-0.0047	0.0215***
	(0.0070)	(0.0209)	(0.0064)	(0.0067)	(0.0042)
eap*eap with incomplete middle school (%)	-0.0049**	0.0152**	-0.0043**	-0.0049**	-0.0044***
	(0.0021)	(0.0060)	(0.0019)	(0.0019)	(0.0014)
eap*eap with primary school education (%)	-0.0195***	-0.0231	-0.0156***	-0.0183***	-0.0052
	(0.0059)	(0.0186)	(0.0054)	(0.0057)	(0.0032)
government's gross fixed capital formation	-0.0011	0.1116***	0.0036	0.0073	0.0106**
	(0.0082)	(0.0389)	(0.0075)	(0.0079)	(0.0048)
nsr (per 100,000 inhab.)	0.0402	0.0209	0.0325	0.0492**	-0.0204
	(0.0258)	(0.0350)	(0.0234)	(0.0240)	(0.0157)
patents (per 100,000 inhab.)	0.0098*	0.0155	0.0096*	0.0098**	0.0037
	(0.0055)	(0.0275)	(0.0050)	(0.0049)	(0.0035)
fdi (% of GDP)	-0.0064*	-0.1654***	-0.0066**	-0.0079**	-0.0066***
	(0.0037)	(0.0256)	(0.0034)	(0.0034)	(0.0025)
trade openness (exports/GDP)	0.0329**	0.1197***	0.0209*	0.0169	0.0433***
	(0.0134)	(0.0158)	(0.0125)	(0.0130)	(0.0088)
Spatial correlation					
Rho (ρ)			0.2289***		0.5216***
			(0.0606)		(0.0584)
Lambda (λ)				0.2610***	-0.9387***
				(0.0674)	(0.0621)
Variance					
Sigma2_e			0.0023***	0.0023***	0.0012***
			(0.0002)	(0.0002)	(0.0001)
Constant	9.5227***	1.2732***			
	(1.4350)	(0.4441)			
Observations	320	288	320	320	320
R-squared	0.67	0.84	0.64	0.74	0.42
Number of states	32	32	32	32	32

Notes: robust standard errors in parentheses; *** p <0.01; ** p <0.05; * p <0.1

Source: prepared by the authors.

The proportion of the workforce that has completed middle school, high school and higher education has a positive impact in addition to that of the total EAP on states' economic performance. However, the coefficients associated with those proportions are not statistically significant. Under this specification, highly-qualified human capital does not appear to have a significant impact on income levels. On the other hand, states with high proportions of their EAP with incomplete middle school and primary school tend to register lower production values. The FE model suggests that a 10% increase in the number of NSR researchers is associated with a non-significant effect on the state GDP. In terms of intangible knowledge, the FE model indicates that when this knowledge increases by 10%, states show an increase in production levels on the order of 0.10%. Therefore, the existence of intangible capital is associated with increases in states' levels of economic activity of limited magnitude.

The FE model shows a negative and significant relationship between FDI and GDP, contradicting initial expectations. The authors argue that this relationship may be due to the omission of relevant variables in the production function, *e.g.* natural capital or a suitable measure of physical capital. In addition, the destinations of FDI may not be linked to the promotion of knowledge transfer-related activities. On the other hand, the degree of trade openness maintains a positive and significant relationship with the level of production. The corresponding parameter suggests that when the degree of openness increases by 10%, the GDP level grows by an average of 0.33%, suggesting that a knowledge transmission channel exists via the trade of goods and services purchased abroad, and that such interactions lead to slightly higher production levels.

In order to verify the consistency of the above results, a GMM model is estimated to incorporate dynamic effects of explanatory variables. Table 2 suggests that when incorporating these effects, a direct and significant contribution is observed in the proportion of workers with higher education and in gross fixed capital formation carried out by state governments on their income. The other results are consistent with FE model estimates. Using the correct specification tests from table 1, table 2 shows the results of the SAR-FE, SEM-FE and SAC-FE models. Results from the SAR-FE model are consistent with those of the FE panel model. In addition to the relationships identified in the FE model, this model pinpoints the degree of spatial correlation between levels of economic activity in neighboring states $(\rho = 0.23)$. The value of parameter ρ indicates that the growth (or decline) of a state benefits (or harms) neighboring states. This result suggests that development projects often have multiplier impacts—not only in the area of interest, but in neighboring entities as well.

Table 2 shows the parameters estimated for the SEM-FE model. In general, the coefficients associated with direct effects are consistent with the results of the FE and SAR-FE models. The statistical significance of the parameter associated with spatial correlation of errors suggests that there is a correlation pattern in the unobserved heterogeneity of neighboring states. Since, for example, the amount of the private sector's gross fixed capital formation or natural capital are part of the error term, the statistical significance of parameter λ could be capturing the spatial linkage of these variables.

Considering that the SAR-FE and SEM-FE models indicate a certain degree of spatial correlation between neighboring states in terms of the economic activity level and unobservable production factors—that is, $\rho \neq 0$ and $\lambda \neq 0$ —the SAC-FE model parameters are estimated. Table 2 shows that both the state income and error terms of neighboring states are linked. The coefficients associated with parameters $\rho = 0.52$ and $\lambda = -0.94$ are statistically significant. Likewise, it is expected that when the EAP and its proportions with higher education, high school and middle school educations increase by 10%, the state GDP will increase by 1.10, 0.04, 0.096 and 0.22%, respectively. It is observed that when government investment in fixed capital increases by 10%, the GDP is expected to increase by 0.11%. These results confirm the hypothesis that higher levels of human capital allow states to aspire to higher levels of economic activity, and that this dynamism is diluted geographically, generating a multiplier effect in the surrounding regions.

6. DISCUSSION

The results of this research suggest that the knowledge economy has a weak association with state levels of growth. Despite the fact that the proportion of workers with low levels of education maintains a negative relationship with state income, the proportion of highly qualified workers tends to show limited or no association with it.

According to the OCDE (2019a), 82% of Mexicans between 25 and 64 years old do not have a higher education—this being below the organization's average (63%). This could explain the non-significant association between state income and the highly skilled workforce. Policy measures that promote education for the workforce must be accompanied by a strengthening of the university-industry relationship. The aforementioned study (OCDE, 2019b) indicates that almost one in two graduates of higher education has a job that does not require their qualifications and more than 25% work in the informal economy, yet more than half of companies have difficulties filling their openings. In this sense, the disconnection between the goals of educational policy and the needs of the labor market could be an argument to explain the null association between the qualification of the labor force and state income. Under the above circumstances, relevant stakeholders—the federal government, state governments, businesses, and workers—could initiate a dialogue to align education policy goals and industry requirements.

The number of NSR researchers is associated with higher production levels; however, this relationship is not significant. This result can be explained by the disconnection between research centers and companies and the fact that only 33% of researchers in Mexico belong to the NSR, of which an even smaller proportion develop technology which is applied to production processes (FCCT, 2016). Furthermore, some studies argue that the knowledge generated by research may or may not be used in the production processes that are carried out in the region where they are produced, as opposed to other regions (Acs *et al*., 2002). To verify the foregoing hypothesis, the spatial correlation between NSR researchers and regional income level would have to be analyzed. However, this phenomenon would have to be identified by using microeconomic information or expanding the scale of this work, *e.g*. including information at the company level or for a group of countries.

Previous research finds a positive relationship between the number of patents and income level; however, this association is not significant (Guzmán *et al*., 2018). In the present work a positive relationship is identified, and in most cases, is significant. Some studies argue that the number of patents generated by residents of a region may not be representative of the vigor with which knowledge is produced, and that the usage of such knowledge is not limited to the region where it was created. Under these circumstances, the coefficients shown in table 2 measure the direct association with local income, which underestimates its total effect. To measure the total impact of patents, the spatial correlation between this variable and state income could be incorporated.

Scholars such as Ros (2013, 2015) emphasize the gap in income levels (development) that exists between northern and southern Mexico. Table 3 shows the estimated parameters for the set of explanatory variables in table 2 for both regions;[4] in general, the results are consistent with the estimates found in table 2. In some cases, production in the north of the country tends to show a direct and significant association with the proportion of workers with higher education, while the proportion of workers with incomplete middle school and primary school education tends to be associated with lower income levels. Meanwhile, southern Mexico does not show a clear relationship between the qualification of its workers and its income, which could indicate a greater degree of disconnection between educational program goals and the requirements of the labor market.

The government's gross fixed capital formation maintains a positive and significant relationship with the level of production in the north of the country, while in the south this association is not statistically different from 0. This result provides empirical evidence for the assertions made by Ros (2015), who argues that a large investment of fixed capital is needed in southern Mexico to encourage the income level. According to the GMM and SEM-FE models, the number of NSR researchers is usually associated with higher levels of production in the north of the country. The relationship between patents and income does not show a clear, differentiated relationship between northern and southern Mexico.

Table 2 suggests a negative relationship between FDI and output at the state level. While table 3 indicates that this relationship manifests significantly in southern Mexico, in the northern part of the country it is not statistically different from 0. Chiatchoua *et al*. (2016) find that FDI tends to decrease employment in the primary sector and destabilize employment in the tertiary sector. In this sense, FDI could have a negative impact on southern states' income indirectly through employment, since agriculture, forestry and tourism activities represent an important part of the GDP.

To corroborate the consistency of the findings, the total national GDP is replaced with the GDP of the manufacturing industries; results are generally similar to those in table 1. This confirms the disassociation between the number of NSR researchers and manufacturing production, and the weak association between the number of patents and production. Additionally, a greater association is observed between the intensity of foreign trade and manufacturing GDP. Furthermore, spatial correlation patterns are maintained.[5]

Certain forms of knowledge accumulation could be correlated and, perhaps, have implications for the results obtained here. For example, the number of NSR researchers could be directly associated with a higher number of patents, or FDI with the degree of linkage the corresponding state has with the exterior. In general, high correlation values are not observed, except in cases regarding the structure of the EAP by education level and the number of patents and NSR researchers. In the first case, it is expected that the EAP interactions-EAP proportions by educational level are directly correlated, since the EAP is an element of these interactions. In the second case, a correlation coefficient of 0.60 is observed, which could suggest that a larger number of researchers results in higher levels of intellectual property, and that its association with income manifests via patents. Yet when the number of NSR researchers is removed from the estimations, the statistical significance of the coefficient associated with number of patents is not modified.[6]

Table 3. Estimated parameters for panel models (North and South)

Variables	*FE GDP*		*GMM GDP*		*SAR-FE GDP*		*SEM-FE GDP*		*SAC-FE GDP*	
	North	*South*	*North*	*South*	*North*	*South*	*North*	*South*	*North*	*South*
Eap	0.2980**	0.1743	0.8995***	0.5574**	0.2132**	0.1787	0.4414***	0.1934	0.0577	-0.0319
	(0.1193)	(0.2205)	(0.1325)	(0.2279)	(0.0935)	(0.2023)	(0.0927)	(0.2169)	(0.1146)	(0.1204)
eap*eap with higher education (%)	0.0148*	0.0027	0.0115	0.0921***	0.0065	0.0026	0.0052	0.0025	0.0132***	0.0084
	(0.0079)	(0.0085)	(0.0096)	(0.0258)	(0.0063)	(0.0077)	(0.0056)	(0.0077)	(0.0050)	(0.0054)
eap*eap with high school education (%)	0.0017	0.0073	-0.0067	0.0333**	-0.0018	0.0072	0.0023	0.0073	0.0100***	0.0165***
	(0.0045)	(0.0065)	(0.0041)	(0.0164)	(0.0036)	(0.0059)	(0.0031)	(0.0059)	(0.0034)	(0.0042)
eap*eap with middle school completed (%)	0.0141	-0.0042	0.0126	-0.0059	0.0076	-0.0045	-0.0028	-0.0049	0.0260***	0.0243***
	(0.0096)	(0.0114)	(0.0170)	(0.0224)	(0.0075)	(0.0105)	(0.0071)	(0.0108)	(0.0064)	(0.0072)
eap*eap with incomplete middle school (%)	-0.0035	-0.0055	-0.0050*	-0.0072	-0.0039**	-0.0054	-0.0059***	-0.0053	-0.0054***	-0.0002
	(0.0023)	(0.0042)	(0.0026)	(0.0093)	(0.0018)	(0.0039)	(0.0015)	(0.0039)	(0.0016)	(0.0028)
eap*eap with primary education (%)	-0.0128	-0.0082	-0.0157	0.0268	-0.0054	-0.0080	-0.0139**	-0.0082	0.0047	0.0201***
	(0.0085)	(0.0106)	(0.0128)	(0.0252)	(0.0067)	(0.0097)	(0.0061)	(0.0097)	(0.0065)	(0.0069)
government's gross fixed capital formation	0.0027	0.0027	0.0376**	0.0213	0.0127*	0.0030	0.0261***	0.0031	0.0157**	0.0115
	(0.0096)	(0.0143)	(0.0184)	(0.0539)	(0.0076)	(0.0131)	(0.0077)	(0.0131)	(0.0065)	(0.0076)
nsr (per 100,000 inhab.)	0.0063	0.0430	0.1007***	-0.0227	0.0081	0.0417	0.0515**	0.0426	0.0032	-0.2343***
	(0.0295)	(0.0538)	(0.0203)	(0.0485)	(0.0230)	(0.0495)	(0.0205)	(0.0491)	(0.0199)	(0.0504)
patents (per 100,000 inhab.)	-0.0069	0.0140*	0.0997***	0.0210	-0.0083	0.0140*	-0.0127**	0.0141*	-0.0014	-0.0067
	(0.0081)	(0.0080)	(0.0137)	(0.0308)	(0.0063)	(0.0072)	(0.0053)	(0.0073)	(0.0056)	(0.0049)
fdi (% of GDP)	0.0054	-0.0094*	0.0022	-0.1600***	0.0022	-0.0094**	-0.0037	-0.0094**	-0.0032	-0.0067**
	(0.0072)	(0.0048)	(0.0147)	(0.0316)	(0.0056)	(0.0044)	(0.0050)	(0.0044)	(0.0053)	(0.0031)
trade openness (exports/GDP)	0.0528**	0.0190	0.0453***	-0.0123	0.0209	0.0181	0.0087	0.0175	0.0227	0.0130
	(0.0230)	(0.0199)	(0.0087)	(0.0239)	(0.0184)	(0.0188)	(0.0157)	(0.0192)	(0.0164)	(0.0135)
Spatial correlation										
Rho (ρ)					0.5009***	0.0175			0.2769**	0.4349***
					(0.0710)	(0.0923)			(0.1220)	(0.0977)
Lambda (λ)							0.6558***	0.0252	-0.4758***	-1.0664***
							(0.0635)	(0.1053)	(0.1633)	(0.0911)
Variance										
Sigma2_e					0.0012***	0.0030***	0.0010***	0.0030***	0.0008***	0.0014***
					(0.0001)	(0.0003)	(0.0001)	(0.0003)	(0.0001)	(0.0002)
Constant	7.6596***	10.5041***	-0.4762*	-0.9073						
	(1.5230)	(2.8866)	(0.2880)	(0.6240)						
Observations	160	160	144	144	160	160	160	160	160	160
R-squared	0.813	0.518	0.982	0.931	0.807	0.586	0.942	0.602	0.776	0.058
Number of states	16	16	16	16	16	16	16	16	16	16

Notes: robust standard errors in parentheses; *** $p<0.01$; ** $p<0.05$; * $p<0.1$

Source: prepared by the authors.

This research contributes to the current debate around strengthening the link between universities or research centers and industry. The results suggest that economic policy should place special emphasis on strengthening the knowledge economy by joining the interests of society, government, companies and research centers.

7. CONCLUSIONS

The results of this work suggest that states with smaller proportions of workers with basic education tend to see lower production levels, confirming that lower levels of human capital limit state economic growth. Additionally, a weak relationship is observed between the proportion of workers with higher education and the level of production. This suggests a disconnection between the goals of educational and industrial policies.

Regarding the number of NSR researchers, the estimated production function indicates that if the number of researchers increased by 10%, there would be a null effect on state GDP. The Scientific and Technological Advisory Forum (FCCT, 2016) indicates that in the period from 1993 to 2011, 33% of all researchers in Mexico were members of the NSR, and a smaller proportion of NSR researchers—especially in the areas of engineering, biotechnology and agriculture science—were linked to technological innovation in the productive sector. This implies that most NSR researchers produce basic scientific knowledge and very few focus on producing applied technological knowledge[7] , and justifies the statistical insignificance of the NSR and state production.

The level of intangible capital shows a positive association with state output levels in most estimates. A 10% increase in the number of patents is expected to increase income by on average 0.10% of the state GDP. The foregoing suggests that the accumulation of intangible capital promotes state economic development in a limited way. It is important to highlight that the use of patents is not limited to domestic companies, *i.e.* those belonging to the same state; therefore, this result should be interpreted in consideration of that limitation. Some states may benefit from the stock of knowledge generated in other regions. Unfortunately, the lack of statistical information at the macroeconomic level limits detailed analysis of patent use.

Knowledge dissemination channels also play an important role at the level of state income. The degree of trade openness, especially with the United States, positively impacts production. By increasing the amount of exports—as a proportion of the GDP—by 10%, income is expected to rise by 0.40% compared to the current level. However, foreign direct investment flows seem to have a negative effect on state output, especially in the southern Mexico. This result may be due to the omission of relevant variables in the production function, such as the lack of information on importation of goods and services at the state level and the proportion of imports and exports of high-tech goods. Or it could be related to the impact of FDI at the level of employment in the primary and tertiary sectors in southern Mexico.

Scholars such as Ros (2013, 2015) suggest that the gap in production and development levels between the north and south of the country could be closed with significant investments in physical capital. When differentiating between north and south, this study finds that in the north there is a direct association between the proportion of workers with higher education and the level of output, while in the south the proportion of workers with a primary school education or incomplete middle school education tends to be associated with lower production levels. Governmental gross fixed capital formation is associated with higher output levels in the north, while this ratio is not statistically different from 0 in the south. This provides additional empirical evidence to what Ros (2015) argues regarding the need to increase investment in southern Mexico. Additionally, in some cases it is found that the number of NSR researchers is associated with higher levels of production in northern Mexico, suggesting that strengthening the link between universities or research centers and industry represents a useful instrument in promoting economic growth.

When interpreting the results of this work, the reader should consider the following: the lack of statistical information regarding states' available stocks of knowledge or physical capital flows limits the analysis. Although the spatial correlation of the error term was taken into account—which contains variables such as physical capital and natural capital—in the panel models it is impossible to incorporate such production factors into the set of calculations. As an extension of this research project, the estimation of a microeconomic-level model that incorporates the heterogeneity of economic agents into the analysis is suggested.

The number of patents and researchers belonging to the NSR per inhabitant may not be adequate measures of intellectual capital and states' capacities for innovation, respectively. It could be argued then that in Mexico there is a disconnect between the accumulation of intellectual capital, the production of new scientific knowledge and production processes; therefore, its association with economic growth is limited. Likewise, the number of NSR researchers may not reflect the innovative capacity of some states, since there are research institutes and centers—especially private ones—whose researchers do not belong to the NSR, and which could be more vigorously linked to the productive sector. Therefore, the findings of this research should be read in view of this set of limitations.

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BIBLIOGRAPHY

Acs, Z. J., Anselin, L. and Varga, A. (2002), "Patents and innovation count as measures of regional production of new knowledge", *Research Policy*, vol. 31, no. 7, DOI <https://doi.org/10.1016/S0048-7333(01)00184-6>

Anselin, L. (2013), *Spatial Econometrics: Methods and Models*, vol. 4, Springer Science & Business Media, DOI <https://doi.org/10.1007/978- 94-015-7799-1>

Arrow, K. J. (1971), "The economic implications of learning by doing", *Readings in the Theory of Growth,* London, Palgrave Macmillan.

Basant, R. and Fikkert, B. (1996), "The effects of R&D, foreign technology purchase, and domestic and international spillovers on productivity in Indian firms", *The Review of Economics and Statistics*, DOI <https://doi.org/10.2307/2109920>

Basurto, S. and Sánchez, G. (2020), *Technical efficiency in small and medium- sized firms: a stochastic frontier analysis.* Under publication.

Becker, G. S. (1994), "Human capital revisited", *Human capital: A theoretical and empirical analysis with special reference to education*, 3rd edition, Chicago, The University of Chicago Press.

Cameron, A. C. and Trivedi, P. K. (2005), *Microeconometrics: Methods and applications,* Cambridge, Cambridge University Press.

Chiatchoua, C., Castillo, O. N. and Santibáñez, A. L. V. (2016), “Inversión Extranjera Directa y empleo en México: análisis sectorial”, *Economía Informa*, 398, DOI <10.1016/j.ecin.2016.04.004>

Coe, D. T. and Helpman, E. (1995), “International R&D spillovers”, *European Economic Review*, vol. 39, no. 5, DOI <https://doi.org/10.1016/0014-2921(94)00100-E>

______, Helpman, E. and Hoffmaister, A. W. (1997), “North-south R&D spillovers”, *The Economic Journal,* vol. 107, no. 440, DOI <https://doi.org/10.1111/1468-0297.00146>

Coleman, J. S. (1988), “Social capital in the creation of human capital”, *American Journal of Sociology*, 94, S95-S120, The University of Chicago Press.

Engelbrecht, H.-J. (1997), “International R&D spillovers, human capital and productivity in OECD economies: An empirical investigation”, *European Economic Review*, vol. 41, no. 8, DOI <https://doi.org/10.1016/S0014-2921(96)00046-3>

Foro Consultivo Científico y Tecnológico A.C. (FCCT) (2016), *El Sistema Nacional de Investigadores en números*. Recovered from <http://www.foroconsultivo.org.mx/libros_editados/SNI_en_numeros.pdf>

Frantzen, D. (2000), “Innovation, international technological diffusion and the changing influence of R&D on productivity”, *Cambridge Journal of Economics,* vol. 24, no. 2, DOI <https://doi.org/10.1093/cje/24.2.193>

Guellec, D. and De La Potterie, B. v. P. (2002), “R&D and productivity growth”, *OECD Economic Studies,* vol. 2001, no. 2, DOI <https://doi. org/10.1787/16097491>

Guzmán, A., Gómez Víquez, H. and López Herrera, F. (2018), “Patentes y crecimiento económico, el caso de México durante el TLCAN”, *Economía: teoría y práctica* (SPE4), Mexico, DOI <http://dx.doi.org/10.24275/etypuam/ne/ e042018/guzman>

Hausman, J. A. (1978), “Specification tests in econometrics”, *Econometrica: Journal of the Econometric Society*, vol. 46, no. 6, DOI <10.2307/1913827>

Houghton, J. and Sheehan, P. (2000), A primer on the knowledge economy, Centre for Strategic Economic Studies, Australia, Victoria University. Instituto Nacional de Estadística y Geografía (INEGI) (2019), *Banco de Información Económica*. Recovered from <https://www.inegi.org.mx/sistemas/ bie/?>

Kao, C., Chiang, M.-H. and Chen, B. (1999), “International R&D spillovers: an application of estimation and inference in panel cointegration”, *Oxford Bulletin of Economics and statistics,* vol. 61, no. S1, DOI <https://doi. org/10.1111/1468-0084.0610s1691>

Lucas Jr, Romer E. (1988), “On the mechanics of economic development”, *Journal of Monetary Economics*, vol. 22, no. 1, DOI <https://doi. org/10.1016/0304-3932(88)90168-7>

Mendoza-Cota, J. E. (2011), “Impacto de la inversión extranjera directa en el crecimiento manufacturero en México”, *Problemas del Desarrollo. Revista Latinoamericana de Economía*, vol. 42, no. 167, DOI <http://dx.doi. org/10.22201/iiec.20078951e.2011.167.27720>

Mincer, J. (1958), “Investment in human capital and personal income distribution”, *Journal of Political Economy*, vol. 66, no. 4, The University of Chicago Press.

Naveed, A. and Ahmad, N. (2016), “Technology spillovers and international borders: a spatial econometric analysis”, *Journal of Borderlands Studies,* vol. 31, no. 4, DOI <https://doi.org/10.1080/08865655.2016.1188 669>

Nursamsu, S. and Hastiadi, F. F. (2015), “Analysis of international R&D spillover from international trade and foreign direct investment channel: evidence from Asian newly industrialized countries”, *Journal of Economic Cooperation & Development,* vol. 36, no. 2, Turkey.

Organización para la Cooperación y Desarrollo Económicos (OECD) (2019a), “El futuro de la Educación Superior en México: promoviendo calidad y equidad”. Technical report. Recovered from <https://scholar.google.es/ scholar?hl=es&as_sdt=0%2C5&q=OECD+%282019a%29%2C+%E2%80%9CEl++Futuro+de+la+Educaci%C3%B3n+Superior+en+M%C3 %A9xico%3A+Promoviendo+Calidad+y+Equidad%E2%80%9D.+Reporte+t%C3%A9cnico.&btnG=>

______ (2019b), “La Educación Superior en México: resultados y relevancia para el mercado laboral”. Technical Report. Recovered from <http://www. oecd.org/about/secretary-general/estudios-de-la-ocde-sobre-educacion- superior-en-mexico-january-2019-sp.htm>

Romer, P. M. (1990), “Endogenous technological change”, *Journal of Political Economy,* vol. 98, no. 5 (part 2), DOI <https://doi.org/10.1086/261725>

Ros, J. (2013), *Algunas tesis equivocadas sobre el estancamiento económico de México*, Mexico, El Colegio de México AC-UNAM. Available at <https:// www.jstor.org/stable/j.ctt14jxqmz>

______ (2015), *¿Cómo salir de la trampa del lento crecimiento y alta desigualdad?*, Mexico, El Colegio de México AC-UNAM. Available at <https://

www.jstor.org/stable/j.ctt19qghp7>

Rosen, S. (1976), “A theory of life earnings”, *Journal of Political Economy*, vol. 84, no. 4 (part 2), S45-S67, The University of Chicago Press.

Schultz, T. W. (1961), “Investment in human capital”, *The American Economic Review*, vol. 51, no. 1, American Economic Association.

Teece, D. J. (1998), “Capturing value from knowledge assets: The new economy, markets for know-how, and intangible assets”, *California Management Review*, vol. 40, no. 3, DOI <https://doi.org/10.2307/41165943>

Zhu, L. and Jeon, B. N. (2007), “International R&D spillovers: Trade, FDI, and information technology as spillover channels”, *Review of International Economics,* vol. 15, no. 5, DOI <https://doi.org/10.1111/j.14679396.2007.00691.x>

[1] The null hypothesis in the Hausman test states that there are no significant differences between $\hat{\beta}_{FE}$ and $\hat{\beta}_{RE}$, —that is, $H_0: \hat{\beta}_{FE} = \hat{\beta}_{RE}$, since both estimators are consistent and the individual effects are purely random. On the other hand, the alternative hypothesis suggests that there are significant differences between $\hat{\beta}_{FE}$ and $\hat{\beta}_{RE}$, meaning that $H_1: \hat{\beta}_{FE} \neq \hat{\beta}_{RE}$, given that $E(\alpha_i \mid X_{it}') \neq 0$.

[2] Note that when $\rho = 0$, the SAR model is reduced to one of the POLS, FE or RE models, depending on the result of the Hausman test.

[3] These are available by request from the authors

[4] More disaggregation of information could significantly reduce estimates' degree of freedom, and therefore, present a high bias.

[5] Estimations available upon request from the authors.

[6] Table of partial correlation coefficients available upon request to the authors.

[7] See the creation of the Innovation Stimulus Program. This program, created by CONACYT, allocates economic resources to encourage entrepreneurs to generate technological innovations, with the aim that these innovations promote economic development in Mexico.