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A spatial econometrics analysis at the state and municipal level

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Abstract

This paper examines absolute manufacturing labour productivity convergence across Mexican states and municipalities between 1993 and 2018, using census data and employing spatial econometric techniques. It applies a novel approach (spatial econometrics and disaggregation at the municipal level) to show that there is absolute convergence in manufacturing productivity at both the state and municipal levels. The results show that there are significant productivity spillovers among states and municipalities; that is, high-level productivity states or municipalities have positive impacts on the productivity of neighbouring states or municipalities. The empirical evidence also shows that, on average, it takes a municipality 26.5 years to reduce 50% of the initial productivity gap, while for a state it takes 99.4 years.

Keywords: absolute convergence, panel data, spatial econometrics, manufacturing productivity, state and local convergence.

Introduction

Since the mid-1980s, Mexico has implemented profound economic and structural reforms, which modified substantially its previous pattern of economic development based on import substitution and widespread state intervention in investment and in the allocation of resources. The reforms favored, instead, a market-based approach to development, aimed at making manufacturing exports and private investment the new engines of economic growth (Moreno-Brid and Padilla Pérez, 2012). A key element of the new economic model has been trade policy reform, which began with the unilateral liberalization of international commerce in 1984. By 2020, free trade agreements had been signed with more than 40 countries, including the European Union and the recently renegotiated agreement with the United States and Canada.

The reforms resulted in noteworthy macroeconomic stability: annual inflation has remained at a single-digit level since 2000 and a long-term fiscal austerity policy was implemented. A second result of the new model was outstanding export performance. Between 1986 and 2018, Mexico's goods exports grew at an annual average rate of 9.9% (in current dollars). Mexico is by far the largest exporter in Latin America, contributing 42.4% of the region's total exports. In 2018, total goods exports amounted to US$ 451.1 billion, well above Brazil's US $239.5 billion.

Despite economic reforms, macroeconomic stability and outstanding economic performance, Mexico has experienced low and volatile economic growth. Between 1990 and 2018, its economy expanded only at 2.2% annually on average. Several studies have shown a close association between this modest economic growth and slow productivity growth in Mexico (ECLAC, 2016; López-Córdova and Rebolledo, 2016; McKinsey Global Institute, 2014; OECD, 2013; Kehoe and Ruhl, 2010). Productivity levels diverge significantly among Mexican states (ECLAC, 2016). Those gaps result from a wide array of factors such as sectoral specialization, the stock of financial and human capital, and institutions, among others.

The economic theory asserts that when countries open up their economies to international trade and financial flows, resulting in free movement of capital and labour, and there are no barriers to technology dissemination, low-income (and low productivity) ones grow faster than those with high income (and high productivity). This phenomenon is called economic convergence (Solow, 1956 and 1957; Jorgenson and Griliches, 1967). That is, poor countries grow faster than rich ones and therefore, in the presence of trade, experience accelerated rates of convergence (Barro and others, 1991; Barro and Sala-I-Martin, 1992; Fischer and Serra, 1996). Yet trade liberalization and international commerce have not always resulted in smaller income and productivity gaps among countries. Some authors suggest that trade accelerates convergence (Parikh and Shibata, 2004), while others suggest the opposite (divergence) (Zhang, 2001).

Aiming at determining whether productivity convergence takes place within a country, various studies have examined it among Mexican states. Some authors have found evidence that productivity gaps have decreased over time (e.g. Rodríguez-Gámez and Cabrera-Pereyra, 2019; López González and Cermeño Bazán, 2016; Asuad Sanén and Quintana Romero, 2008; Esquivel and Messmacher, 2002), while others argue that there has been a divergence (e.g Fonseca, Llamosas-Rosas and Rangel González, 2018; Garduno-Rivera, 2014; Rodríguez-Oreggia, 2007; Chiquiar, 2005).

To the best of these authors' knowledge, empirical studies that have analyzed productivity convergence in Mexico have not recognized the great importance that high productivity levels in one territory have in productivity levels of neighboring territories. Productivity externalities may arise from economic and productive linkages between neighboring territories (Bufetova, 2020; Zhang and Ji, 2019; Azorín and Sánchez 2015; Vaya and others, 2004; Rey and Le Gallo, 2009). To examine the impact of such interactions, it is important to conduct the analysis with geographical data as disaggregated as possible (municipalities), an approach that has been scantly followed by the existing literature.

This paper aims to analyze absolute convergence in productivity among Mexican states and municipalities between 1993 and 2018. The importance of potential spillover effects on productivity among states and municipalities is acknowledged and a spatial econometrics analysis is conducted. That is, it is recognized that factors that spur productivity within a municipality may have a positive impact also on neighboring municipalities. Spatial econometrics allows the estimation of the directions and magnitudes of such impacts.

This study focuses on manufacturing activities since: (i) manufacturing productivity has experienced higher growth rates in Mexico than other sectors (Padilla-Perez and Villarreal, 2017); (ii) data for estimating productivity at the municipal level is available only for the manufacturing sector, and (iii) the economic model implemented in Mexico since the mid-1980s has resulted in heterogenous sectoral specialization across Mexico's states, in particular within the manufacturing sector.

The paper is divided into four sections. The first section presents some relevant stylized facts and the review of the existing literature. The second section describes the data and offers a descriptive statistics analysis. The statistical methods are presented in the third section, in particular, exploratory and inferential methods which support the quantitative analysis. The fourth section summarizes the results and discusses the model fitting. The fifth section concludes.

I. Background

"Productivity is commonly defined as a ratio of a volume measure of output to a volume measure of input use" (OECD, 2001, p. 11). Productivity helps explain diverse phenomena closely related to economic growth such as technological change, efficiency, living standards, and real cost savings (OECD, 2001). Labour productivity is computed because it does not need to assume a close functional form, in contrast with total factor productivity (TFP).[1]

Free flows of labour, goods and services among Mexican states and municipalities, according to economic theory, are expected to lead to closing productivity gaps within the country (Easterly, Fiess and Lederman, 2003). Those flows spur knowledge dissemination and improve productivity in laggard regions. However, divergence or lack of convergence may occur if the labour force is not ready to receive these new inflows, and some basic technological capabilities and physical capital are not available in laggard territories (Abramovitz, 1986; Easterly, Fiess and Lederman, 2003).

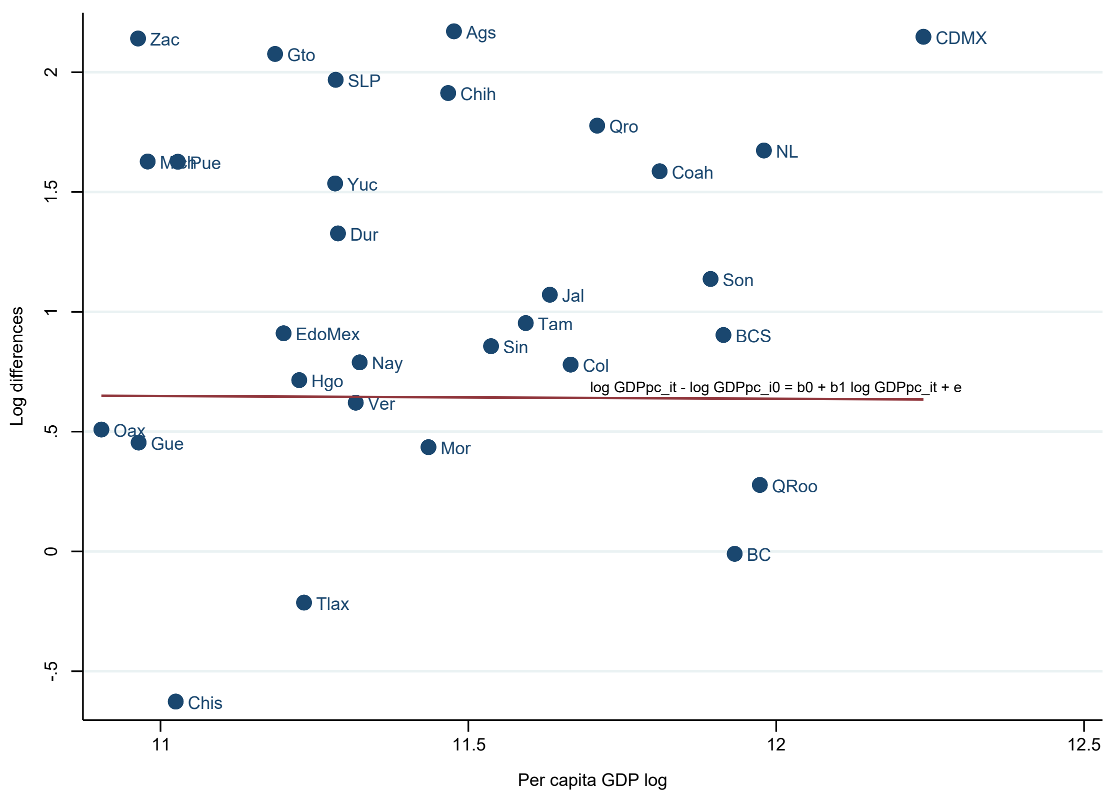
The existing empirical literature on productivity convergence in Mexico has not yet addressed the importance of productivity externalities among neighboring territories. Productivity externalities diffuse to close related territories. In other words, productivity spread is likely to be higher between geographically related units than others which are not located near to one another. The availability of advanced infrastructure, human resources, universities and technical schools, and health systems, among other factors, of a territory may have positive effects on the productivity of neighboring territories (Bufetova, 2020; Zhang and Ji, 2019; Azorín and Sánchez 2015; Vaya and others, 2004; Rey and Le Gallo, 2009).

1 To estimate TFP is necessary to adopt a specific production function (for instance, Cobb-Douglas, Leontief or translog). To do so, the assumptions on the functional form must be justified. In contrast, the estimation of labour productivity is straightforward concept and can be easily achieve with public available data.

Figure 1 presents GDP per capita and its average growth rate between 1993 and 2017 in Mexico's states. A slope close to 0 in the linear regression, depicted in the figure, shows that GDP per capita seems not to be converging (nor diverging) between the states during this period. Large gaps persist between Mexican regions: northern and central states have, in general, higher levels of GDP per capita that southern ones.

As a result of economic reforms, in particular openness to international trade and foreign direct investment (FDI) attraction, manufacturing activities in northern and central states have inserted successfully in global value chains, in high- and medium-technological intensity activities such as automotive, aerospace, electronics and medical devices, while in the south manufacturing has remained concentrated in agribusiness and other natural resources-based manufactures.

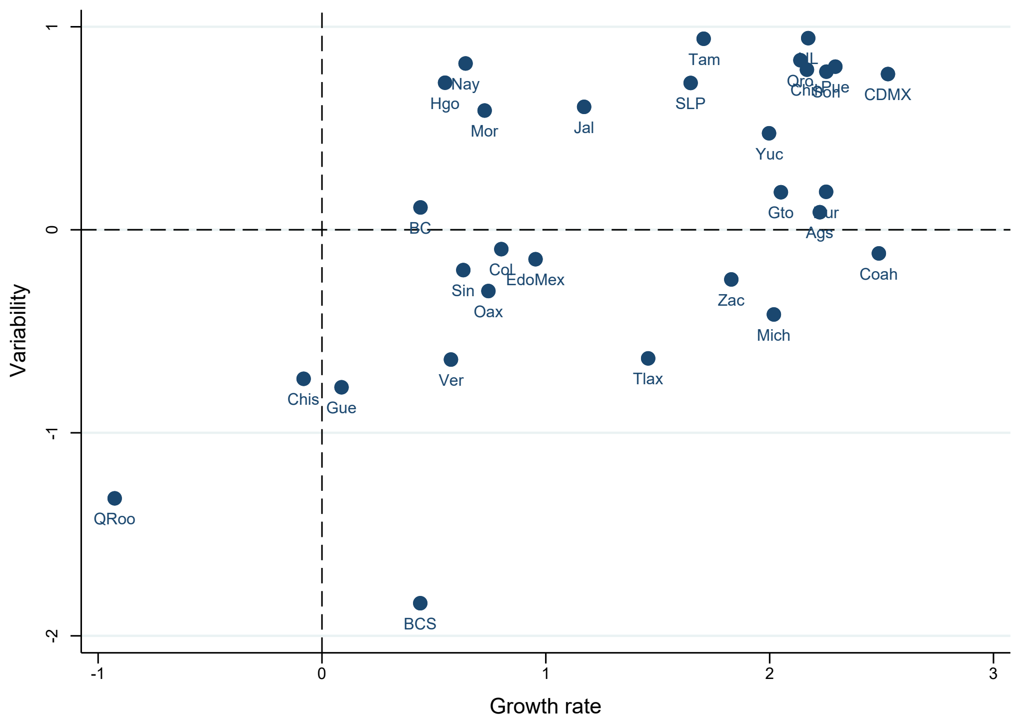
Figure 1
Mexico: GDP per capita and its average growth rate, 1993-2017
(Natural logarithms)



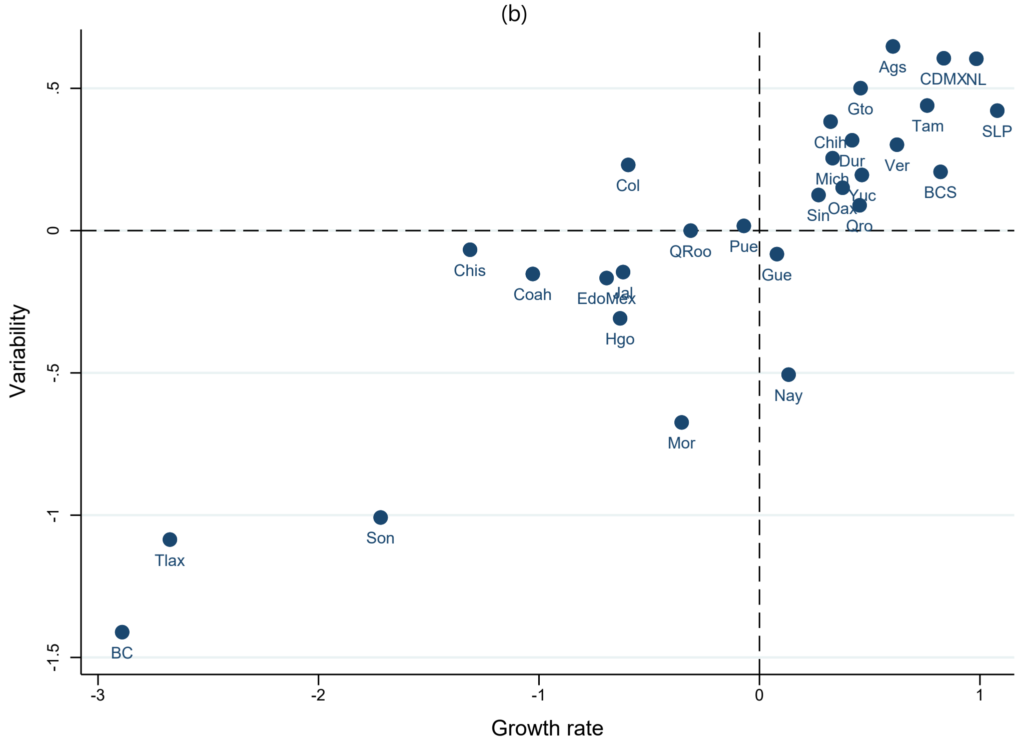
Source: Elaboration by the authors, on the basis of Instituto Nacional de Estadística y Geografía (INEGI), "PIB estatal (PIBE). Año base 2013", 2019 [online] https://www.inegi.org.mx/programas/pibent/2013/ [date of reference: 15 May 2019]; Consejo Nacional de Población (CONAPO), *Indicadores demográficos 1950-2050*, 2019 [online] https://datos.gob.mx/busca/dataset/proyecciones-de-la-poblacion-de-mexico- and-of-the-federal-entities-2016-2050 [date of reference: 15 May 2019].
Note: The graph excludes the state of Campeche and Tabasco, because oil activity.

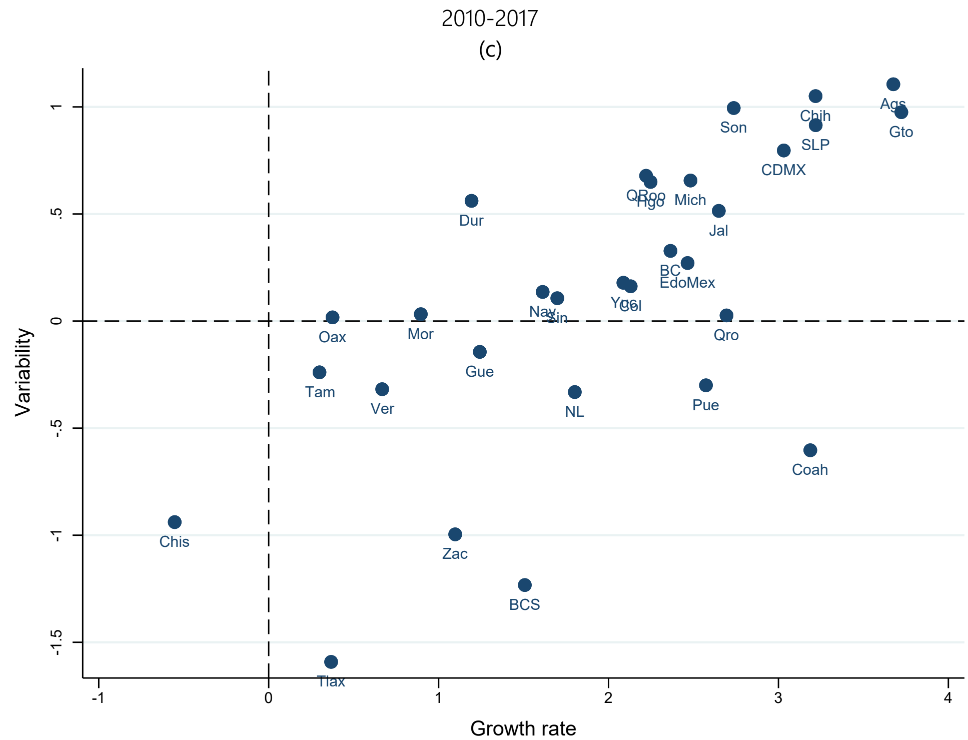
Figure 2 analyzes further the growth rates gaps and patterns; the analyzed period is divided into three sub-periods: 1994-2001, 2002-2009 and 2010-2017. In the first and third sub-periods (the first years after NAFTA entered into force and the years after the global financial crisis), growth rates seem to be diverging, while some convergence is observed in the second period. However, further analysis is needed, beyond this graphic method, to obtain a sound conclusion.

Figure 2
Mexico: GDP per capita average growth rate by state and its orthogonal vector, 1994-2017
1994-2001
(a)



2002-2009
(b)





Source: Elaboration by the authors, on the basis of Instituto Nacional de Estadística y Geografía (INEGI), "PIB estatal (PIBE). Año base 2013", 2019 [online] https://www.inegi.org.mx/programas/pibent/2013/ [date of reference: 15 May 2019]; Consejo Nacional de Población (CONAPO), *Indicadores demográficos 1950–2050*, 2019 [online] https://datos.gob.mx/busca/dataset/proyecciones-de-la-poblacion-de-mexico- and-of-the-federal-entities-2016-2050 [date of reference: 15 May 2019].
Note: The graph does not include the states of Campeche and Tabasco, because their large oil extraction activity distorts the data comparative analysis.

Several papers show that these divergent patterns of economic growth in Mexico are not random. They respond rather to the quantity and quality of the production factors available in the Mexican states. Therefore, the authors argue that behind this GDP per capita growth gap, there is a similar or higher productivity gap. Yet, the size of this gap is not enough evidence to conclude that productivity within Mexico has followed diverging paths over time.

Regional convergence in Mexico has been widely studied. Mallick and Carayannis (1994), Esquivel (1999), Esquivel and Messmacher (2002), and Chiquiar (2005) published seminal papers. The first three documents concluded that there was productivity convergence among Mexican states in the studied period, while the last one found no convergence. These documents make use of different econometric techniques and data, as well as productivity convergence estimations.

Chiquiar (2005) studied productivity convergence before and after the outset of trade liberalization in the mid-1980s, including the first years the North American Free Trade Agreement (NAFTA) entered into force. He found that there was not convergence among Mexican states in the studied period. By the same token, Aroca, Bosch and Maloney (2005), and Rodríguez-Oreggia (2007) did not find evidence of convergence. They introduced the club convergence concept, and supplemented econometrics with spatial statistics and transition matrices to estimate productivity performance.

A second wave of studies came along with new econometric approaches and data availability. Asuad Sanén and Quintana Romero (2008) estimated beta and sigma convergence using spatial econometrics, covering a few years after NAFTA was implemented. Carrion-i-Silvestre and German-Soto (2009 and 2010) and Cabral and Mollick (2012) used panel data to estimate convergence among Mexican states. These authors concluded that there has been convergence among Mexican states. In contrast, Baylis, Garduño-Rivera and Piras (2009) made use of data at the municipal level and argue that NAFTA resulted in wealthy regions around the border and larger municipalities growing faster than the rest, therefore increasing regional disparities. Ruiz Ochoa (2010) implemented a Weighted Least Squares (WLS) econometric technique to find conditional convergence among states. Gómez-Zaldívar and Ventosa-Santaulária (2012) examined time series and highlighted the stochastic convergence definition.

A third group of studies came ahead as more data on trade liberalization and NAFTA became available. Hernández Malvaez and Gómez Zaldívar (2015) lengthened the period of study, as well as López González and Cermeño Bazán (2016), Fonseca, Llamosas-Rosas and Rangel González (2018), Rodríguez-Gámez and Cabrera-Pereyra (2019), and Mendoza-Velázquez and others (2019). Díaz-Dapena and others (2019) did not expand the time period but expanded the disaggregation and examined regional convergence at the municipal level. Rodríguez-Gámez and Cabrera-Pereyra (2019) applied spatial econometrics, but in a cross-section analysis. However, these studies are not conclusive as some demonstrate regional productivity convergence and some lack of convergence.

Previous empirical studies have highlighted, in general, a process of regional convergence in Mexico since the economic reforms implemented since mid-1980s (see table 1). After such reforms, most of them show a divergence process.

Table 1
Mexico: economic convergence, main studies carried out

Paper published	Principal indicator	Data at level	Type of convergence	Methods	Period	Results
Mallick and Carayannis (1994)	GDP per capita	State level	Absolut convergence	Ordinary Least Squares (OLS)	From 1970 to 1985	Converged
Esquivel (1999)	GDP per capita	State level	Absolut convergence and sigma convergence	OLS, Nonlinear Least Squares (NLS) and Seemingly Unrelated Regression (SUR)	From 1940 to 1995	Converged
Esquivel and Messmacher (2002)	GDP per capita	State level	Absolut convergence and sigma convergence	OLS	From 1960 to 2000	Converged
Chiquiar (2005)	GDP per capita	State level	Conditional and absolute convergence	NLS	From 1970 to 2001	No converged
Aroca, Bosch and Maloney (2005)	GDP per capita	State level	Convergence clubs	Some elements of spatial econometrics	From 1970 to 2002	No converged

Paper published	Principal indicator	Data at level	Type of convergence	Methods	Period	Results
Rodríguez-Oreggia (2007)	GDP per capita	State level	Absolut and sigma convergence, conditional convergence	OLS	From 1970 to 2001	No converged
Asuad Sanén and Quintana Romero (2008)	GDP per capita	State level	Beta and sigma convergence	Spatial econometrics	From 1940 to 2001	Converged
Carrion-i-Silvestre and German-Soto (2009)	GDP per capita	State level	Stochastics and beta convergence	Panel data	From 1940 to 2001	Converged
Baylis, Garduño-Rivera and Piras (2009)	Total value added/ workers	Municipality level	Conditional convergence	Feasible General Least Square (FGLS), Spatial Econometrics	From 1981 to 2004	No converged
Ruiz Ochoa (2010)	GDP per capita	State level	Conditional convergence	Weighted Least Squares (WLS)	From 1900 to 2004	Converged
Gómez-Zaldívar and Ventosa-Santaulária (2012)	GDP per capita gap	State level	Stochastics and beta convergence	Time series	From 1940 to 2009	Converged
Cabral and Mollick (2012)	GDP per capita	State level	Conditional and absolute convergence	OLS, fixed effects and dynamic panel.	From 1993 to 2006	Converged
Garduno-Rivera (2014)	Production per worker (total value added/L)	Municipality level	Conditional convergence	OLS, Random and Fixed Effects Panel, Spatial Econometrics	From 1989 to 2004	No converged
Hernández Malvaez and Gómez Zaldívar (2015)	GDP per capita	State level	Beta and sigma convergence	Spatial Econometrics, Cross Section	1940, 1976 and 2013	Converged
López González and Cermeño Bazán (2016)	GDP per capita	State level	Convergence clubs	Panel Data, FGLS	From 1940 to 2013	Converged
Fonseca, Llamosas-Rosas and Rangel González(2018)	GDP per capita	State level	Conditional and Absolut convergence	Random Effects Panel Data, FGLS	From 1994 to 2015	No converged
Rodríguez-Gámez and Cabrera-Pereyra (2019)	Total value added/total pop	State level	Conditional and Absolut convergence	Cross Section, Spatial Econometrics	From 1999 to 2014	Converged
Díaz-Dapena, Fernández-Vázquez, Garduño-Rivera and Rubiera-Morollon (2019)	Total value added/ non-agricultural total pop	Municipal level	Regional convergence	Random Effects Panel Data, Two Stages General Least Squares (2SGLS)	From 1980 to 2008	Do not converge at state level, clubs converged
Mendoza-Velázquez, German-Soto, Monfort and Ordóñez (2019)	Income per capita	State level	Conditional convergence	Time series econometrics	From 1940 to 2015	Do not converge, clubs converged

Source: Elaboration by the authors.

A thorough search of the existing literature yielded no documents that examine productivity convergence in a specific sector (manufacturing), except for the convergence of clubs. By the same token, they have paid scant attention to the importance of spatial effects. The first law of geography emphasizes that all territories or regions can have effects on the object of study, but the closest elements may have greater effects (Tobler, 1970). This paper aims to address this gap in the extant literature. The main hypothesis of this paper is that when productivity externalities are integrated into the analysis, applying spatial econometric techniques, there is significant evidence of productivity convergence among states and municipalities in Mexico.

II. Data and descriptive statistics

To test the hypothesis, data on manufacturing labour productivity, disaggregated by state and municipality in Mexico, are used. The source is the Economic Censuses of 1994, 1999, 2004, 2009, 2014 and 2019, which record the previous year activity. The main variables used to estimate labour productivity are gross aggregated production value (GAPV) and employed population. The consumer price index is employed to compute deflation. Table 2 shows gross aggregated value and employed population at both state and municipal level.

Table 2
Mexico: gross aggregated average value and average employed population at state and municipal level, 1993-2018
(Value in millions of Mexican pesos, 2018=100)

Year	Gross aggregated average value at state level	Gross aggregated average value at municipal level	Average employed population at state level	Average employed population at municipal level
1993	5 279.58	79.8	100 326	1 387
1998	15 366.72	237.9	130 481	1 763
2003	28 576.37	462.0	131 206	2 037
2008	44 095.40	661.9	145 658	2 101
2013	52 263.94	751.3	158 545	2 202
2018	95 144.70	1348.4	202 907	7 132

Source: Elaboration by the authors.

The next step is to analyze annual dispersion of GDP per capita growth rates among states. Since the data are intercensal, this analysis shows the evolution of one of the convergence indicators over time. The regionalization developed by Cabral and Mollick (2012) is useful for this goal.[2] For the complete period, without considering the global financial crisis year and a first stage of economic recovery (2009 to 2010), the standard deviation among border states is greater (4.1) than among southern and central states (3.6 in both cases).

Before examining convergence, some further dispersion analysis is needed. If the analysis is conducted again dividing the studied period into three subperiods (1993-2001, 2002-2009, 2010-2017), different dispersions are found. Between 1993 and 2001, the standard deviation of border states is almost 1 point higher than that of southern states (5.9 versus 4.6). The standard deviation in northern and central states averages 4.5 and 4.9, respectively. Between 2002 and 2009, the dispersion in border states decreases to 3.2 standard deviations, while it also decreased to 3.5 in the north, 3.0 in the center, and 3.4 in the south. In the last subperiod (2010-2017), the standard deviation in border states was 2.1, 2.2 in the center, 2.9 in the north and 3.6 in the south.

To begin the spatial exploration of the data, the neighboring weights matrix at the state and municipal level shows that states have up to eight neighboring elements, while all states have at least one contiguous state. The contiguity relationships that are the basis for estimating the W matrix are shown on map 1.

Map 1
Mexico: states contiguity relations

Source: Elaboration by the authors, on the basis of L. Anselin, I. Syabri and Y. Kho, "GeoDa: An introduction to spatial data analysis", *Geographical Analysis*, 38 (1), 2006, pp. 5-22.
Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

The estimation of global spatial correlation statistics shows that there is indeed spatial correlation in the data, therefore the estimation of productivity convergence should consider spatial effects. However, this spatial correlation might be not originated directly in the variable of interest (labour productivity). For example, the global correlation statistic of state-level manufacturing labour productivity, Moran's I, shows that spatial autocorrelation is not explicitly defined.

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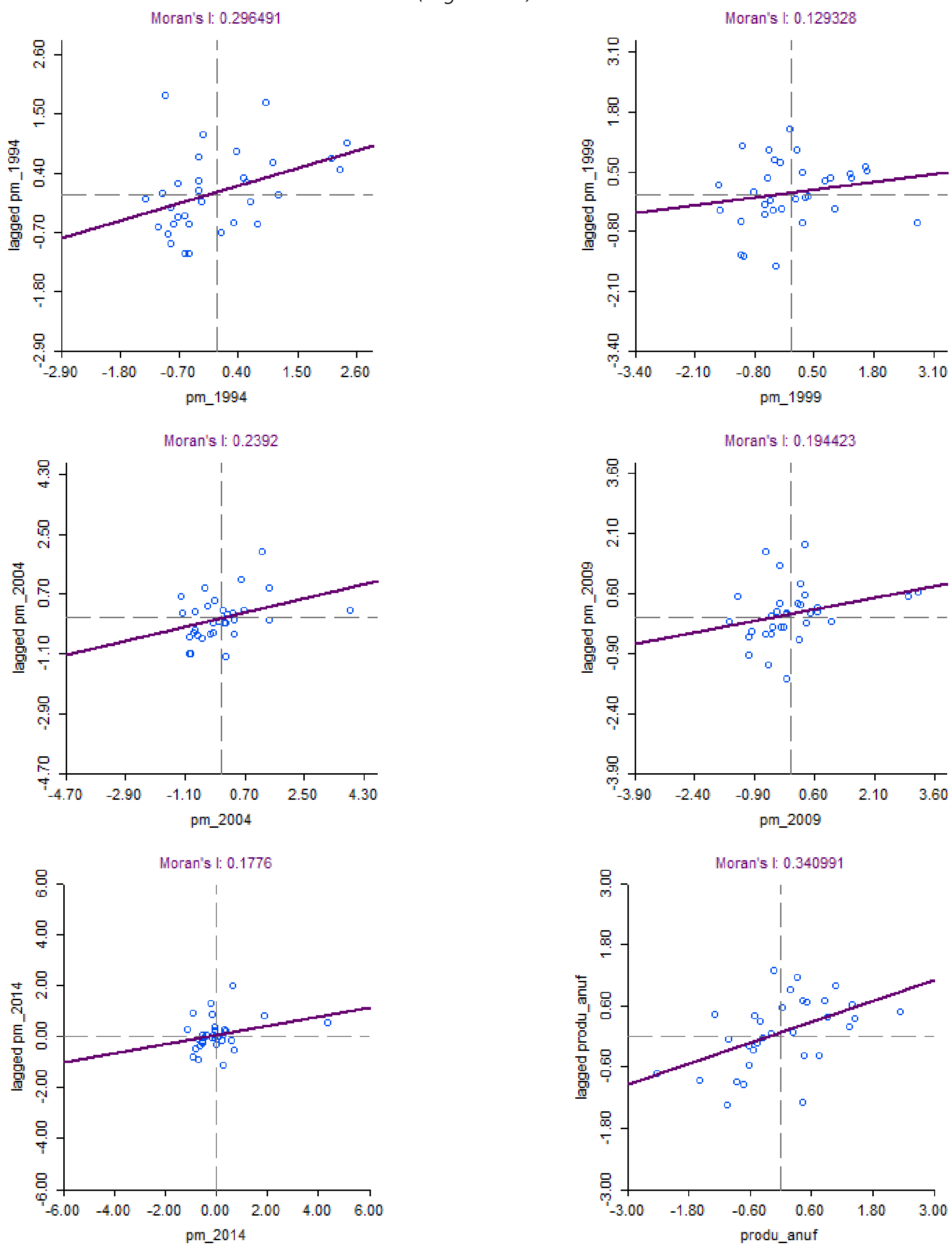
2 The border region comprises the states of Baja California, Chihuahua, Coahuila de Zaragoza, Nuevo León, Sonora and Tamaulipas (all of them are share their northern border frontier with US states). The northern region includes Aguascalientes, Baja California Sur, Durango, Nayarit, San Luis Potosí, Sinaloa, Zacatecas. The central region comprises Mexico City, Colima, Guanajuato, Hidalgo, Jalisco, Michoacán de Ocampo, the State of Mexico, Puebla, Queretaro, Tlaxcala and Veracruz. The southern region includes Campeche, Chiapas, Guerrero, Morelos, Oaxaca, Quintana Roo, Tabasco and Yucatan.

Figure 3 shows the dispersion diagrams of manufacturing labour productivity versus its spatial lag for different censuses (1994, 1999, 2004, 2009, 2014 and 2019). The results of Moran's I global spatial autocorrelation tests, in levels, show that for 1994, 2004 and 2019, with a 95% confidence level, the null hypothesis of spatial randomness is rejected, while in 2009 and 2014 it is rejected with a 90% confidence level. For 1999, there is insufficient information to rule out the null hypothesis of spatial randomness.

Figure 3
Mexico: cross-section diagnostic tests for spatial correlation in manufacturing labour productivity, at the state level, 1993-2018
(Logarithms)



Source: Elaboration by the authors, on the basis of L. Anselin, I. Syabri and Y. Kho, "GeoDa: An introduction to spatial data analysis", *Geographical Analysis*, 38 (1), 2006, pp. 5-22.

Productivity spatial randomness can be also tested through a linear regression. The global spatial correlation statistic applied on residuals (such as Moran´s I, Geary´s C, Getis and Ord's G, as well as Lagrange multipliers) show that there is spatial correlation. That is, the residuals show that there is a spatial structure behind it (see table 3). When the test is applied, it rejects the null hypothesis that the residuals do not have a spatial correlation, but it is inconclusive to reject the null hypothesis on the spatially lagged dependent variable. Therefore, a model with a spatial error should be applied (Elmessih Shehata, 2016).

The spatial dimension comes from the economic and productive interaction between neighboring states and municipalities (trade of goods and services, employment and education-related commuting, joint production activities). Human resources, infrastructure, education and research organizations, and health systems, among others, of a state or municipality may have positive effects on labour productivity of neighboring states and municipalities. As a result, statistics applied to residuals show high spatial correlation (see table 3).

Table 3
Diagnostic tests of spatial correlation in a linear regression

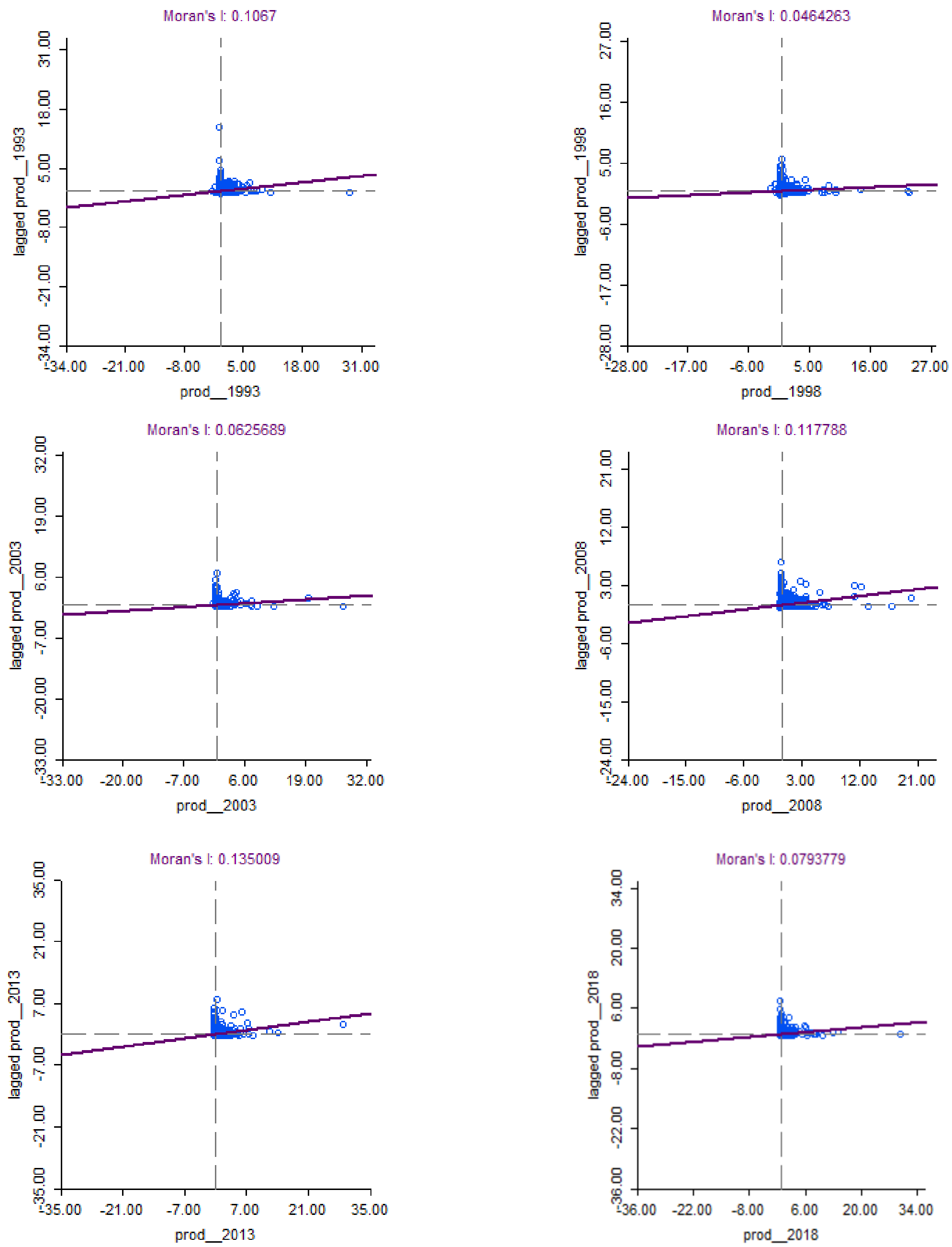
Statistic	Standardized value	P value
Spatial error		
Moran´s I	0.3813	0.0000
Geary´s C	0.4966	0.0082
Getis & Ords´s G	-1.5969	0.0000
Spatial Lag		
Lagrange Multiplier (Anselin)	38.4115	0.0000
Robust Lagrange Multiplier	1.4656	0.2260

Source: Elaboration by the authors.
Note: In the residual's spatial correlation tests, the Ho: $\lambda = 0$, where λ is the interaction coefficient between the explanatory variable and the spatial weights matrix. The hypothesis test on spatial lag is Ho: $\rho = 0$, where ρ is the coefficient of interaction between the explanatory variable and the matrix of spatial weights.

By the same token, spatial correlation at municipal level should be examined. The global spatial correlation statistics show that there is spatial correlation in each of the studied years, therefore the estimation should consider spatial effects. The Moran´s I of global spatial correlation is calculated for manufacturing labour productivity at the municipal level, for each year, as shown in figure 4. The results demonstrate there is spatial autocorrelation. Specifically, when Moran´s I statistic with a spatial delay are applied to the variable of interest, the test results are conclusive, and the non-autocorrelation null hypothesis is rejected.

The statistical inference can be strengthened by estimating productivity through a linear regression and applying several spatial correlation statistics (Moran´s I, Geary´s C, Getis and Ord's G, as well as Lagrange multipliers) on residuals, as it was done at the state-level. Table 4 shows spatial correlation indicators at the municipal level.

Figure 4
Mexico: cross-section diagnostic tests for spatial correlation in manufacturing labour productivity, at the municipal level, 1993-2013
(Logarithms)



Source: Elaboration by the authors, on the basis of L. Anselin, I. Syabri and Y. Kho, "GeoDa: An introduction to spatial data analysis", *Geographical Analysis*, 38 (1), 2006, pp. 5-22.

Table 4
Diagnostic tests of spatial correlation in a linear regression

Statistic	Standardized value	P value
Spatial Error		
Moran´s I	2.33	0.020
Geary´s C	3.54	0.060
Getis & Ords´s G	6.11	0.013
Spatial Lag		
Lagrange Multiplier (Anselin)	0.35	0.56
Robust Lagrange Multiplier	2.92	0.09

Source: Elaboration by the authors.
Note: In the residual's spatial correlation tests, the Ho: $\lambda = 0$, where λ is the interaction coefficient between the explanatory variable and the spatial weights matrix. In the tests of the spatial lag, the null hypothesis is Ho: $\rho = 0$, where ρ is the interaction coefficient between the explanatory variable and the spatial weights matrix.

The analysis conducted above shows that there is spatial correlation among states and municipalities, therefore it must be considered in the econometric model to examine convergence. A second conclusion is that an error model should be implemented, since the spatial error test rejected the null hypothesis (no spatial interaction), at 5% significant level.

III. Empirical strategy

To analyze the convergence between Mexican states and municipalities, manufacturing labour productivity is defined as follows:

$$\dot{y}_{i,t} = \frac{VAB_{i,t}}{PO_{i,t}} \qquad (1)$$

where $VAB_{i,t}$ corresponds to the value added of the manufacturing sector of the state or municipality *i* in year *t*, while $PO_{i,t}$ is the number of workers employed in the manufacturing sector.

This estimate considers potential spatial correlation among geographical administrative units. States or municipalities with high or low productivity may influence, positively or negatively, the productivity of their neighboring states or municipalities. Therefore, before estimating convergence, it was demonstrated that there is spatial correlation among geographical administrative units.

First, a spatial weight matrix (w) is estimated. This matrix allows the implementation of any type of spatial cut estimate (Drukker and others, 2013). Matrix W is defined as follows:

$$\mathrm{w} = \begin{bmatrix} 0 & w_{1,2} & \cdots & w_{1,n} \\ w_{2,1} & 0 & \dots & w_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n,1} & w_{n,2} & \dots & 0 \end{bmatrix}$$

where W is an NxN spatial matrix. There are two main types of matrices in which the analysis can be based: contiguity and distance matrices. The former is built with the contiguity of geographic polygons of the spatial units, while the latter is based on the distances between geographic points.[3] Due to the type of data available for the analysis, the contiguity matrix is used to perform the analysis.

Second, global spatial correlation statistics were used: Moran´s I, Geary´s C and Getis and Ord's G (Pisati, 2001). Moran's I is a technique to capture the global spatial correlation as follows:

$$I = \left(\frac{N}{\sum_i \sum_j w_{i,j}}\right) \frac{\sum_i \sum_j w_{i,j}(X_i-\bar{X})(X_j-\bar{X})}{\sum_i (X_i-\bar{X})^2} \qquad (2)$$

where $w_{i,j}$ is the matrix of spatial weights; $(X_j - \bar{X})\,(X_j - \bar{X})$ is the covariance between states labour productivity and $\sum_i (X_i - \bar{X})^2$ is the variance. Since firm-level data are not available, the state contiguity matrix is used. Two indices were also used, in addition to the Geary's C and the Getis and Ord's G. Geary's C is an overall measure of dissimilarity, while the latter makes use of agglomeration measures. Geary's C is calculated as follows:

$$C = \left(\frac{N-1}{\sum_i \sum_j w_{i,j}}\right) \frac{\sum_i \sum_j w_{i,j}\left[(X_i-\bar{X})-(X_j-\bar{X})\right]^2}{N\sum_i (X_i-\bar{X})^2} \qquad (3)$$

where the elements of the equation are the same as those described above (equation 3). In addition, G of Getis and Ord's is calculated as follows:

$$G = \frac{\sum_i \sum_j w_{i,j}(X_i)(X_j)}{\sum_i \sum_j (X_i)(X_j)} \qquad (4)$$

where X only takes positive values, and $w_{i,j}$ corresponds to the array of spatial weights. Once spatial correlation has been verified, the specification of the spatial econometrics model is presented.

The first assumption is that the manufacturing sector produces according to a Cobb-Douglas function. In addition, it is assumed that this same relationship between production factors occurs in all states of Mexico. Following the generalization of Mankiw, Romer and Weill (1992) and Islam (1995), and in order to examine convergence from a spatial econometric outlook (Ertur and Koch, 2007; Elhorst, 2009), the absolute convergence equation can be described as the Spatial Error Durbin model (SDEM):

$$\Delta\dot{y}_{i,t} = \alpha + \rho ln\dot{y}_{i,t-1} + v_{i,t} \qquad (5)$$

$$v_{i,t} = \gamma \sum_{j=1}^{N} w_{i,t}\, v_{i,j,t} + e_{i,t} \qquad (6)$$

where $\Delta\dot{y}_{i,t}$ corresponds to per capita productivity growth rate of state i in time t; $ln\dot{y}_{i,t-1}$ is the natural logarithm of lagging per capita productivity, and $w_{i,t}$ is an element of the N x N matrix of spatial weights W, which captures the spatial structure throughout the Mexican states. The productivity growth rate is measured as the logarithmic difference of per capita income in respect

3 The contiguity criterion must be indicated when the matrix is built. In general, there are three contiguity criteria: Rook, Bishop, and Queen (Baronio, Vianc and Rabanal, 2012). In the first two, they define the neighbor as the one that only touches the geographic polygon at certain points, while the last criterion considers the other polygon as a neighbor (or neighbor) that touches the polygon of interest at any point. In this case, the matrices were standardized, and the Queen type contiguity was taken to construct the matrix.

to its own lag ($\Delta\dot{y}_{i,t} = \ln\dot{y}_{i,t} - \ln\dot{y}_{i,t-1}$). The W matrix is designed to capture two different structures: a contiguity structure or a distance-based weight structure. Absolute convergence is observed when ρ is negative and significant. The convergence rate, λ, can be obtained from ρ, such that $\lambda = -\frac{\ln(1+\rho)}{t}$, and t is the time period.

A first approach for testing absolute convergence is derived from the inclusion of time and state-specific effects in equation (7). This allows different states or municipalities to converge towards various levels of productivity, depending on their own condition and the influence of their neighboring states. As a result, SDEM takes the following specification:

$$\Delta y_{i,t} = \alpha + \mu_i + \eta_t + \rho ln y_{i,t-1} + v_{i,t} \qquad (7)$$

In the next section, equation (7) is estimated using alternative econometric techniques employing data for Mexico at the state and municipal level.

IV. Results

Results at state level. Table 5 shows the results of the state-level productivity convergence estimation. It presents three estimates of the absolute convergence parameter, making use of different techniques: linear regression of combined data (Pooled OLS), panel data and fixed effects, and spatial panel data (Belotti, Hughes and Piano Mortari, 2016; Elmessih Shehata, 2016; Pisati, 2001). The first two models are used as a benchmark to compare the results when spatial panel data are introduced (third model). The absolute magnitude of the coefficient increases as more structure is incorporated in the estimation. Pooled OLS and panel data does not show convergence among Mexican states. However, when spatial correlation is considered, the regression coefficient indicates absolute convergence. The errors spatial correlation coefficient, λ, is statistically significant at 5%. Therefore, when productivity externalities among states are included in the econometric analysis, then absolute convergence is demonstrated.

Table 5
Mexico: estimates of the absolute convergence parameter, at the state level, 1993-2013

Parameters	Pooled OLS	Panel data, fixed effects	Spatial panel data, fixed effects
γ	0.05	0.07	-0.16**
	(0.07)	(0.09)	(0.09)
μ_i	0.47*	0.50*	
	(0.09)	(0.10)	
λ			0.13*
			(0.02)
σ_ϵ^2			0.37*
			(0.16)
Speed of convergence (b)[a]	0.2%	0.3%	0.7%
Half life[b]	355.17	256.12	99.39
R^2 adj	0.00	0.00	0.00
Akaike Information Criteria (AIC)	297.85	290.25	255.66
Bayesian Information Criteria (BIC)	303.55	295.95	264.22

Source: Elaboration by the authors.

Note: * statistically significant coefficients at 95% confidence level; ** statistically significant coefficients at 90% confidence level.

[a] The convergence rate is calculated as $b = -\frac{\ln(1+\gamma)}{T}$.

[b] The half-life indicator is calculated as $v_{media} = \frac{\ln(2)}{b}$.

The convergence speed rate and the half-life indicator are two statistics commonly calculated in the convergence literature. The former estimates how fast the manufacturing sector converges into the equilibrium state, while the latter computes how long it would take to fill a half of the initial gap, at that given rate (Arbia, 2006). The convergence speed is within the parameters set up by Barrow's empirical regularity, called "iron law", of 2%. The computations also show that, with these convergence rates, the states that present the largest productivity lags would take 99.39 years to reach a half of the lag.

To verify the goodness of fit, the adjusted R square and Akaike and Bayesian information criteria were used. The criteria are used to determine which model is best explained by the included variables. Although the variables included in the regression models are the same, it is appropriate to evaluate the adjustment to different models, as well as considerations of the data generation process (DGP). The adjusted R square is barely modified since, in all models, the variance explained by the independent variable is the same. However, as noted in all specifications, the statistic improves as the spatial correlation of the data is modeled. In addition, when the regression model based on data groups is adapted to a panel model, the information criteria improved. The model with the lowest information criteria is chosen. In both cases, the Akaike and Bayesian criteria suggest that the spatial correlation model of errors provides the best fit.

Results at municipal level. Table 6 shows the results of productivity convergence at the municipal level. As in the state-level analysis, three estimates of the absolute convergence parameter are presented: linear regression of pooled data (Pooled OLS), panel data with fixed effects and spatial panel data with fixed effects (Belotti, Hughes and Piano Mortari, 2016; Elmessih Shehata, 2016; Pisati, 2001). The size of the coefficient increases as more structure is incorporated into the regressions. Similarly, to the state-level analysis, spatial regression coefficients show absolute convergence, in contrast to pooled OLS and panel data fixed effects. The convergence parameter estimator increases by one hundredth, in absolute terms, compared to the fixed effects estimator. The errors spatial correlation coefficient, λ, is statistically significant at 5%.

Table 6

Mexico: estimates of the absolute convergence parameter, at the municipal level, 1993-2018

Parameters	Pooled OLS	Panel data, fixed effects	Spatial panel data, fixed effects
$\boldsymbol{\gamma}$	1.04*	1.01*	-0.48*
	(0.02)	(0.02)	(0.01)
$\boldsymbol{\mu_i}$	3.55	3.51	
	(0.08)	(0.09)	
λ			0.12*
			(0.00)
$\boldsymbol{\sigma_\epsilon^2}$			1.84*
			(0.03)
Speed of convergence (b)[a]	2.85%	2.79%	2.62%
Half life[b]	24.31	24.82	26.50
$\boldsymbol{R^2}$ adj	0.32	0.32	0.26
Akaike Information Criteria (AIC)	54 068.97	29 199.14	26 401.17
Bayesian Information Criteria (BIC)	54 082.96	29 212.51	26 421.89

Source: Elaboration by the authors.

Note: * statistically significant coefficients at 95% confidence level; ** statistically significant coefficients at 90% confidence level.

[a] The convergence rate is calculated as $b = -\frac{\ln(1+\gamma)}{T}$.

[b] The half-life indicator is calculated as $v_{media} = \frac{\ln(2)}{b}$.

The convergence rate is within the parameters established by Barrow's empirical regularity of 2%. In addition, if the OLS results are used the municipality with the largest productivity gap would need 24.31 years on average to reach a half of the lag. In the panel regression, 24.82 years would be needed, while with third estimate the time is increased to 26.5 years. In order to assess the goodness of fit, adjusted R square and information criteria like Akaike and Bayesian are used. R squared increases when the spatial error model is used, which indicates a better fit. These information criteria indicate that the third model better adjusts the data than the other two.

V. Conclusions

The empirical data shows that after profound economic and structural reforms, there has not been convergence among Mexico's states in terms of economic growth rates. The existing literature presents heterogenous results regarding convergence in productivity levels. Yet previous studies have not considered the importance of spatial correlation to examine productivity convergence.

This document aims to assess whether there is convergence in manufacturing labour productivity between 1993 and 2018 among Mexican states and municipalities, through panel-type estimation techniques (fixed effects and fixed effects with spatial errors). The econometric analysis shows that there is productivity convergence in the studied period, when spatial panel data analysis is applied, in contrast to previous studies that have made use of alternative techniques such as pooled OLS and panel data fixed effects. That is, when productivity externalities among neighboring states and municipalities are integrated into the econometric analysis, there is positive and significant evidence of convergence in the manufacturing sector in the studied period. In effect, Rodrik (2013) argues that non-conditional convergence can occur in certain sectors of the economy. Depending on the sector concerned, this could lead the other sectors, regions or states towards general convergence, contingent to the linkages that the sector has with the other sectors of the economy.

In terms of public policy, there is a need for regional strategies that stimulate productivity in territories that have been less favored. These strategies should go beyond administrative boundaries, given the importance of productivity externalities among neighboring territories. More infrastructure is also needed to facilitate linkages and connection among states and municipalities. Fostering links between high- and low-productivity economic sectors or activities, for instance manufacturing and agriculture, could lead to increasing convergence.

Lines of future research are the analysis of σ convergence, and conditional convergence, to unravel the conditions under which convergence is taking place. The study of the impact of the current economic and social crisis due to the COVID-19 pandemic on convergence among states and municipalities is also a line of future research.

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