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Manufacturing: A Regional Approach**

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## Technical and Structural Efficiency in Mexican Manufacturing: A Regional Approach\*

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**Abstract:** This paper applies a stochastic frontier approach to analyze the evolution of technical efficiency in manufacturing as a source of regional growth, taking as a unit of analysis the Mexican states in the period 1988-2008. The main findings of our analysis are threefold. First, technical efficiency was increasing over the analyzed period and acted as a mechanism to reduce the labor productivity gap across states. Second, Mexican regions can increase manufacturing production about one third, on average, using the same amount of inputs which implies ample potential for regional growth. Third, there exists a considerable difference in the level of technological development, measured in terms of structural efficiency, of the north and the central regions with respect to the south that partially explains the labor productivity gap among regions.

**Keywords:** Manufacturing, Mexican regions, Stochastic frontier, Structural efficiency, Technical efficiency.

**JEL Classification:** D24, L60, O18.

**Resumen:** El presente documento aplica la metodología de fronteras estocásticas de producción para analizar la evolución de la eficiencia técnica en la industria manufacturera como fuente de crecimiento económico regional durante el período 1988-2008. Tres son los principales hallazgos de nuestro estudio. Primero, la eficiencia técnica mostró un patrón de crecimiento en todas las regiones durante el período analizado y actuó como un mecanismo que redujo la brecha de productividad laboral entre los estados. Segundo, las economías regionales pueden incrementar su producción manufacturera en aproximadamente 30 por ciento, en promedio, utilizando el mismo nivel de insumos, lo que implica un amplio potencial para el crecimiento económico regional. Tercero, existen considerables diferencias en el nivel de desarrollo tecnológico, medido en términos de eficiencia estructural, de las regiones norte y centro con respecto al sur, situación que explica parcialmente la brecha de productividad laboral entre las regiones del país.

**Palabras Clave:** : Industria manufacturera, Economías regionales, Fronteras estocásticas, Eficiencia estructural, Eficiencia técnica.

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# 1. Introduction

Regional disparities are pervasive in Mexico, and manufacturing is not the exception. While this sector represents 22% of total economic activity in the north, its participation is about 8.1% in the south [Banxico, 2011a].<sup>1</sup> Differences are also observed in terms of labor productivity: value added per worker in manufacturing is about 55% higher in the north than in the south.<sup>2</sup> Not surprisingly, average household income is about 67% higher in the former than in the latter.<sup>3</sup>

Differences among regions in levels of value added per worker can be attributed to differences in physical capital, human capital, and productivity [Hall and Jones, 1999]. An important source of productivity is technical efficiency which refers to the ability of an economic unit to avoid waste by producing as much output as technology and input usage allow [Fried, Lovell, and Schmidt, 2008]. Therefore, technical efficiency indicates the potential for economic growth, holding inputs and technology constant, and it is also a source of convergence (or divergence) of labor productivity across regions.

For the measurement of technical efficiency it is necessary to compare actual performance with optimal (efficient) performance which is represented by the set of points that lie on the production frontier (the upper boundary of the production possibilities set). The central problem in the measurement of technical efficiency is to measure the distance between the production frontier and the input-output combination of each economic unit [Kumbhakar and Lovell, 2003]. Since the true frontier is unknown, the empirical approximation to it is commonly defined as best practice frontier. Most

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<sup>1</sup>Mexico is divided in four regions by applying the regionalization proposed by Banco de Mexico [2011a]. **North:** Baja California, Chihuahua, Coahuila, Nuevo Leon, Sonora and Tamaulipas; **North-Central:** Aguascalientes, Baja California Sur, Colima, Durango, Jalisco, Michoacan, Nayarit, San Luis Potosi, Sinaloa and Zacatecas; **Central:** Federal District, State of Mexico, Guanajuato, Hidalgo, Morelos, Puebla, Queretaro and Tlaxcala; **South:** Campeche, Chiapas, Guerrero, Oaxaca, Quintana Roo, Tabasco, Veracruz and Yucatan.

<sup>2</sup>Own calculations based on the 2009 Economic Census produced by INEGI, the national statistical office.

<sup>3</sup>Own calculations based on the 2010 National Household and Expenditure Survey (INEGI).

studies related to the measurement of technical efficiency have applied either non-parametric or parametric methods to estimate the frontier [Murillo and Vega, 2001].

The non-parametric approach is basically represented by data envelopment analysis (DEA) [Coelli, 2005], a mathematical programming approach to the construction of frontiers. It constructs a frontier envelopment surface that literally envelops the data set. The surface is determined by those economic units that lie on it (efficient units), while those units that lie beneath the surface are considered inefficient. One caveat of DEA is that all deviations from the efficient frontier are assumed to be under the control of the economic units. This assumption can produce biases in the estimated efficiency, since factors such as weather, luck, and uncertainty are not distinguished from the rest of the factors affecting technical efficiency.

On the other hand, the parametric approach estimates the frontier by specifying a particular functional form. Within this approach, stochastic frontier analysis [Aigner, Lovell, and Schmidt, 1977, Meeusen and van Den Broeck, 1977, Kumbhakar and Lovell, 2003] attempts to separate the effects of efficiency from the effects of noise on output. One potential caveat of the stochastic frontier analysis is the assumption of homogeneous production functions across regions. Greene [2005] argued that unit-specific effects are an important source of heterogeneity that has been generally ignored in the empirical estimation of frontier functions. Therefore, a methodological challenge is to separate region-specific technological characteristics from technical efficiency. Alvarez [2007] and Kumbhakar and Wang [2005] incorporated time-invariant regional effects into the traditional stochastic frontier model: instead of assuming a single national or world frontier function, they introduced heterogeneity in the production frontier across regions. As noticed by Alvarez [2007], level differences among regional production functions can be interpreted as indicators of level differences of technological development at the regional level.

Our research is related to other studies that have measured technical efficiency for Mexican manufacturing at different levels of regional aggregation. Bannister and Stolp [1995] analyzed technical efficiency in a set of manufacturing industries for a cross section of Mexican states in 1985. By applying the DEA approach, they found that those states with a high concentration of industrial activity were closer to the frontier, while less industrialized states were consistently less efficient. Braun and Cullmann [2011] used a panel of municipality-level data to estimate technical efficiency in Mexican manufacturing (including oil-related industries) using data from the years 1989, 1999 and 2004. They applied the so called “true” random effects model [Greene, 2005] to overcome the problem that any unobserved and time-invariant municipality-specific effect is considered as technical inefficiency. Not only did they find considerable differences in terms of efficiency of the south with respect to the central region and the north, but they also found a pronounced variation of efficiency within states.

None of these studies presented results dealing with the evolution of technical efficiency across time and regions, neither did they explicitly estimate level differences of technological development at the regional level. Therefore, their results cannot be used to evaluate the impact of technical efficiency on the dynamics of labor productivity across states.

The aim of this paper is threefold. First, we will analyze the evolution of technical efficiency and its role as a mechanism to reduce (or increase) the labor productivity gap across states. Second, we will calculate the potential for regional growth that future efficiency gains could imply. Finally, we will introduce regional heterogeneity into the analysis to estimate structural efficiency (a more permanent form of efficiency) across regions. In order to do so, this study adopts a stochastic frontier specification that allows for time-varying technical efficiency based on the model proposed by Battese and Coelli [1992]. The employed specification takes regional heterogeneity into account to

calculate level differences among regional production functions. The model is estimated for the manufacturing sector using a panel over the period 1988-2008 where the units of analysis are the Mexican states.

The remainder of this paper is organized as follows. Section 2 introduces the stochastic frontier model and the econometric specification. Section 3 describes the data. Section 4 presents the main empirical results. Section 5 concludes. Technical details related to the applied methodology are presented in Appendices A and B. Tables and Figures are included in Appendix C.

## 2. Methodology

### 2.1. Technical and structural efficiency

An economy is geographically divided in  $m$  regions and  $n$  states. Region  $j = 1, \dots, m$  is composed by a group of  $n_j$  states, such that  $\sum_{j=1}^m n_j = n$ . In period  $t = 0, \dots, T$ , state  $i \in j$  produces based on its *stochastic* production frontier<sup>4</sup>

$$Y_{it}^s = \phi_j f(K_{it}, L_{it}, t; \beta) \exp(v_{it}) \quad (1)$$

where  $K_{it}$ , and  $L_{it}$  are, respectively, capital and labor;  $t$  is a time trend serving as a proxy for technical change;  $\beta$  is a parameter vector characterizing the structure of production technology; instead of assuming a single national frontier function for all states, heterogeneity is allowed by having region-specific shift parameters,  $\phi_j$ , indicating the relative level of technological development or *structural efficiency* of region  $j$ . This type of efficiency is related to time-invariant characteristics (weather, proximity to markets, institutional framework, etc.) observed in the regions where the states are

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<sup>4</sup>As in most regional studies, we assume the sum of all micro-units within each state as a single production unit.

located; the factor  $\exp(v_{it})$  takes into account all those factors that are not directly under the control of economic units by introducing random shocks  $v_{it}$  into the production process.

Economic units often produce less than they might because they are not making the most of their inputs given the current state of technological development. Based on Debreu [1951] and Farrell [1957], *technical efficiency* is defined as the ability to obtain maximum (potential) output from a given input vector. Formally, technical efficiency,  $E_{it}$ , is measured as the ratio of observed output  $Y_{it}$  to potential output  $Y_{it}^s$  (output at the frontier). Therefore, observed output is given by

$$Y_{it} = Y_{it}^s E_{it} \tag{2}$$

where  $E_{it} \in (0, 1]$ . Clearly, state  $i$  is operating at its maximum capacity in period  $t$  if  $E_{it} = 1$ ; otherwise it would be technically inefficient.

Figure 1 illustrates the efficiency concepts presented above. For simplicity, we have not considered randomness into account. Consider two regions,  $A$  and  $B$ , with production frontiers  $Y_a^* = \phi_a X$  and  $Y_b^* = \phi_b X$ ,  $\phi_a > \phi_b$ , respectively.

Each region employs the same quantity  $\bar{X}$  of input  $X$ . As a result of the production process, regions  $A$  and  $B$  obtain output levels  $Y_a < \phi_a \bar{X}$  and  $Y_b = \phi_b \bar{X}$ , which implies that  $B$  is technically efficient (i.e.  $E_b = 1$ ) and  $A$  is operating below its frontier (i.e.  $E_a < 1$ ). With respect to structural efficiency, region  $A$  shows the largest shift parameter. Therefore,  $B$  is more technically efficient than  $A$ , but  $A$  observes a higher level of technological development than  $B$ .



## 2.2. Econometric specification

Taking the natural log of both sides of equation (2)

$$y_{it} = \alpha_j + \ln\{f(K_{it}, L_{it}, t; \beta)\} + v_{it} - u_{it} \quad (3)$$

where  $y_{it} = \ln Y_{it}$ ,  $\alpha_j = \ln \phi_j$  and  $u_{it} = -\ln E_{it}$ . Notice that  $u_{it} \geq 0$  since  $E_{it} \in (0, 1]$ ; hence  $u_{it} \geq 0$  represents a deviation from the frontier (technical inefficiency).

One disadvantage of the stochastic frontier approach is that it requires the definition of a specific functional form for the employed technology. A widely accepted specification characterized by its flexibility is the translog production frontier [Coelli, 2005]

$$y_{it} = \alpha_j + \beta_1 k_{it} + \beta_2 l_{it} + \beta_3 k_{it}^2 + \beta_4 l_{it}^2 + \beta_5 k_{it} l_{it} + \beta_6 t + v_{it} - u_{it} \quad (4)$$

where  $k_{it}$ , and  $l_{it}$  are, respectively, the logs of capital, and labor;  $t$  is a time trend capturing technical progress in the model. Note that it nests within the Cobb-Douglas function when  $\beta_3 = \beta_4 = \beta_5 = 0$ .

We follow Battese and Coelli [1992] by assuming  $u_{it} = \eta_t u_i = \exp[-\eta(t-T)]u_i$ . This specification has the advantage of having only one additional parameter to estimate, making computation simpler. Since  $\partial \ln u_{it} / \partial t = -\eta$ , technical inefficiency decreases, remains constant or increases over time, if  $\eta > 0$ ,  $\eta = 0$  or  $\eta < 0$ , respectively. Assuming a half-normal distribution for  $u_i$ : i.e.  $u_i \sim iid N^+(\mu, \sigma_u^2)$ , and a normal distribution for  $v_{it}$ : i.e.  $v_{it} \sim iid N(0, \sigma_v^2)$ , the model can be estimated by maximum likelihood to obtain estimators for  $\mu$ ,  $\sigma_u^2$ ,  $\sigma_v^2$ ,  $\eta$ , the parameters of equation (4) and technical efficiency  $E_{it}$  (see Appendix A).

### 3. Data

The empirical model is estimated for the manufacturing sector, excluding oil-related industries, using a balanced panel for the 31 Mexican states and the Federal District for the years 1988, 1993, 1998, 2003 and 2008. We use gross value added as a proxy for output (from now on we use the terms value added and output indistinctly),  $Y_{it}$ , and the stock of private capital as a measure of capital input,  $K_{it}$  (both  $Y_{it}$  and  $K_{it}$  are measured in constant 2003 pesos). Labor input,  $L_{it}$ , was obtained from the unadjusted total employment in manufacturing. These variables were obtained from the Economic Census of INEGI (the Mexican statistical office).

Similar to Duffy and Papageorgiou [2000] and Kneller and Stevens [2003], we weight labor force by the mean years of schooling of the workforce. Specifically, we define  $S_{it}L_{it}$  as a proxy measure for the human capital-adjusted labor input, where  $S_{it}$  is defined as the mean years of schooling of the population aged 15 and older. For the years 1988, 1998 and 2008 the sources of the schooling data are the General Censuses of Population and Housing 1990, 2000, and 2010, while for the years 1993 and 2003 we use the Counts of Population and Housing 1995 and 2005, respectively. Both sources of data are also produced by INEGI.

Table 1 presents the regional share of gross added value, employment, and the stock of capital, as well as the mean years of schooling per region. This table also introduces output per worker which, to make comparison easier, is expressed as the ratio to the maximum observed value across regions. The central region observed the highest level and the south the lowest level of output per worker all over the period. The north-central and the north regions increased its labor productivity relative to the central region between 1988 and 2008.

The north and the north-central regions increased their share in total gross value

added and employment over the analyzed period, particularly the north whose share in total added value went from 26% in 1988 to 35% in 2008. In the case of the north-central region, its participation went from 13% to 17% in the generation of value added, and its participation in the labor market went from 16% to 19% over the same period. In contrast, the central region considerably reduced its share in both total value added and total employment: its participation went from 56% to 41% in the former case, and from 48% to 38% in the latter. Finally, the south stagnated maintaining its participation in total value added and total employment around 6% and 9%, respectively, all over the 20-year period.

This pattern was observed, to a lesser extent, in the stock of capital during the 1988-2008 period. The north and the north-central regions increased their share in the stock of capital from 25% and 19% to 30% and 22%, respectively, while the participation of the central region and the south was reduced by 3 and 5 percentage points, respectively.

The average years of schooling for individuals aged 15 and over in the north was 7.2 in 1990, while individuals living in the south spent, on average, 5.3 years in school. In 2010, the gap among regions was reduced, with the north and the south showing, on average, 9.3 and 7.9 years of education, respectively.

## 4. Empirical results

Table 2 reports maximum likelihood estimates of the model of equation (4) and, for comparison purpose, a Cobb Douglas specification ( $\beta_3 = \beta_4 = \beta_5 = 0$ ), with (Models 2 and 4) and without (Models 1 and 3) regional fixed effects.

We conduct a series of misspecification tests to identify an appropriate functional form for the frontier. The first test shows that the translog functional form is preferred to the Cobb-Douglas: the likelihood ratio test rejects the hypothesis that  $\beta_3 = \beta_4 =$

$\beta_5 = 0$  at the 1% level ( $\chi_3^2 = 12.73$ ) (the Cobb-Douglas specification has also been rejected by other studies in the context of efficiency analysis [Kumbhakar and Wang, 2005, Kneller and Stevens, 2003]). The second test rejects the hypothesis that region specific effects are not statistically different from zero: the likelihood ratio test rejects the hypothesis that  $\alpha_i = \alpha_j, i \neq j$ , at the 1% level for both the translog ( $\chi_3^2 = 11.75$ ) and Cobb-Douglas ( $\chi_3^2 = 15.76$ ) specifications. Given these results, the translog specification with regional fixed effects (Model 2) represents the best specification among the 4 analyzed models presented in Table 2.

The significant value obtained for  $\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$  indicates that technical efficiency contributes to explain the difference in production across states that is not accounted by the input variables. Therefore, ignoring this fact would imply to assume that deviations from the production frontier are totally due to factors outside the control of the economic units when they are not. Similar to Kneller and Stevens [2003] and Kumbhakar and Wang [2005], the coefficient associated to the trend variable, commonly known as technical change, is negative. It is associated to the output variation that is not explained by either a change in input usage or efficiency improvements.

Using the estimates presented in table 2, it is possible to estimate technical efficiency for each state  $i$  and each period  $t$ ,  $E_{it}$ , by applying the minimum-squared-error predictor presented in Appendix A. Technical efficiency of region  $j$  at  $t$ ,  $E_{jt}$ , is obtained as the ratio of observed to efficient regional output. Formally,

$$E_{jt} = \frac{\sum_{i \in j} Y_{it}}{\sum_{i \in j} Y_{it}^s} = \frac{\sum_{i \in j} Y_{it}}{\sum_{i \in j} E_{it}^{-1} Y_{it}} \quad (5)$$

where  $Y_{it}^s = E_{it}^{-1} Y_{it}$  comes from equation (2). Analogously, overall technical efficiency in period  $t$ ,  $E_t$ , is given by

$$E_t = \frac{\sum_i Y_{it}}{\sum_i E_{it}^{-1} Y_{it}} \quad (6)$$

Table 3 presents the values of technical efficiency. Technical efficiency observed a positive pattern along the period 1988-2008 for all regions. The overall technical efficiency went from 0.537 in 1988 to 0.764 in 2008 (an annual rate of growth of 1.7%). That is, in 1988 Mexican manufacturing produced 53.7% of its maximum attainable output, while in 2008 this value increased to 73.6%. A back of the envelope calculation shows that Mexico could increase their output in manufacturing by 36% without increasing capital and/or labor. Specifically, the north, the north-central, the central, and the south regions could increase their output by 38.9%, 32.0%, 37.0%, and 30.9%, respectively, without adding more inputs to the production process. This result shows the ample potential that improvements in technical efficiency could imply for economic growth.

Our estimates indicate that the most technically efficient regions in 2008 were the north-central (0.758) and the south (0.764). These regions observed annual growth rates of technical efficiency of 1.4% and 1.5%, respectively, from 1988 to 2008. The central region (0.730) and the north (0.720) obtained the greatest gain in efficiency, growing at an annual rate of 1.7% and 1.9%, in that order. Coincidentally, economic activity in the central region and the north is more associated to the dynamics of the U.S. economy than the rest of the country [Banxico, 2011b]. This fact is consistent with other studies concluding that a higher degree of integration to international markets, especially after the implementation of the North American Free Trade Agreement (NAFTA) in 1994, enhanced manufacturing productivity in Mexico, particularly on firms located in northern states [López-Córdova, 2003].

The estimated value of the parameter  $\eta$  is associated to the existence of two widely applied concepts of convergence:  $\beta$ -convergence and  $\sigma$ -convergence [Young, Higgins, and Levy, 2008, Barro and Sala-i Martin, 1992]. In the present context,  $\beta$ -convergence in efficiency scores occurs when less efficient states tend to improve efficiency faster than more efficient ones. When the dispersion of technical efficiency across states falls

over time, there is  $\sigma$ -convergence in efficiency scores. In particular, if  $\eta$  is strictly positive then both types of convergence are guaranteed (see Appendix B). Hence, the estimated value of  $\eta$  (0.036) implies the existence of  $\beta$ -convergence and  $\sigma$ -convergence for the analyzed data set. This result is in coherence with the evolution of the standard deviation of efficiency scores (Table 3), and the correlation between technical efficiency in 1988 and its rate of growth over the studied period (-0.981).

Although growth in technical efficiency is directly related to the growth of added value per worker, the existence of convergence in technical efficiency does not guarantee convergence in labor productivity. To test this hypothesis, we analyze the effect of technical efficiency on convergence in labor productivity by estimating the following equations

$$\frac{\ln(Y_{i2008}/L_{i2008}) - \ln(Y_{i1988}/L_{i1988})}{\Delta t} = \lambda_0 + \lambda_1 \ln(Y_{i1988}/L_{i1988}) + \epsilon_i \quad (7)$$

$$\frac{\ln E_{i2008} - \ln E_{i1988}}{\Delta t} = \alpha_0 + \alpha_1 \ln(Y_{i1988}/L_{i1988}) + \zeta_i \quad (8)$$

where  $\Delta t = 2008 - 1988 = 20$  and  $Y_{it}/L_{it}$  is the level of value added per worker in state  $i$  at period  $t$ .

Table 4 presents the results of the OLS estimation of equations (7) and (8) with and without regional fixed effects. The results appearing in the third and fourth rows of Table 4 show the existence of a  $\beta$ -convergence process in output per worker. The negative and significant estimate of  $\lambda_1$  imply a negative relationship between the initial level of value added per worker and the growth rate of labor productivity.

The empirical evidence supports the existence of convergence in both technical efficiency and value added per worker. However, convergence in technical efficiency

does not necessarily contribute to convergence in labor productivity. Its contribution will depend on the sign of the parameter  $\alpha_1$  [Gumbau-Albert, 2000]. The results presented in the first and second rows of Table 4 indicate that technical efficiency acted as a mechanism for convergence in labor productivity since the estimate of  $\alpha_1$  is both negative and statistically significant for both specifications: *i.e.* states with lower initial levels of labor productivity observed higher growth rates of technical efficiency.

In the case of structural efficiency, the central region and the north are the most efficient regions in Mexico<sup>5</sup> (Table 2), followed by the north-central region and the south, in that order. To make comparison easier, structural efficiency of region  $j$  (Table 3) is expressed as the ratio to the maximum estimated structural efficiency across regions (the central region in this case).<sup>6</sup> Our calculations imply the existence of time-invariant factors that systematically make the north, the north-central, and the south regions produce about 92.5%, 78.3%, and 73.5%, respectively, of the output that they would have produced if they had showed the same level of structural efficiency than the central region.

Other studies have found regional differences in terms of efficiency. Bannister and Stolp [1995] calculated indices of technical efficiency for each of seven two-digit industries (including oil-related industries) for a cross section of Mexican states in 1985. By applying the DEA approach, they found that those states characterized by a high concentration of industrial activity were on the frontier, or closer to it, for most industries. Braun and Cullmann [2011] used a panel of municipality-level data to estimate technical efficiency in Mexican manufacturing (including oil-related industries) using data from the Economic Censuses implemented in 1989, 1999 and 2004. They applied the so called “true” random effects model [Greene, 2005] to overcome the problem that

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<sup>5</sup>Since  $\alpha_j = \ln \phi_j$ ,  $\phi_j$  is estimated as  $\exp(\alpha_{north} + \alpha_j)$ , for regions other than the north, where  $\alpha_j$  is the regional fixed effect. In the case of the north, its structural efficiency is estimated as  $\exp(\alpha_{north})$ .

<sup>6</sup>Formally, it is expressed as  $\frac{\phi_j}{\max_j(\phi_j)}$ .

any unobserved and time-invariant municipality-specific effect is considered as technical inefficiency. Similar to Bannister and Stolp, they found considerable differences in terms of technical efficiency of the south with respect to the central region and the north.

Differences on structural efficiency across regions can be associated to historical and institutional factors [Acemoglu and Johnson, 2001]. Under the lens of the new economic geography [Krugman, 1991, Schmutzler, 1999], they can be related to the interaction of location, scale economies and transportation costs, particularly the proximity of northern states to the biggest market in the world and the characteristics and distribution of transport infrastructure.<sup>7</sup> For instance, the most concentrated and largest industries in Mexico tend to be located in the north and the central regions [Trejo, 2010] and are better connected to the U.S. than those located in the south [Dávila, Kessel, and Levy, 2002].

## 5. Conclusions

This paper estimated a translog stochastic frontier function to measure technical and structural efficiency in regional manufacturing over the period 1988-2008. Due to regional differences in terms of institutional framework, local policies, climate, culture, agglomeration economies, infrastructure, access to relevant markets, etc., the production frontiers may be region specific. To account for these differences, regional fixed effects are incorporated into the econometric specification. Under the assumption that regional technical characteristics are time invariant, it is possible to identify and sepa-

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<sup>7</sup>A recent interview survey implemented by Banco de Mexico showed that the majority of company directors in the north, north-central and central regions think that regional infrastructure is adequate for economic growth. The opposite was observed in the south where less than a third of the interviewees were satisfied with the current state of regional infrastructure. Specifically, two thirds of the interviewed directors in the south considered new investments on transport infrastructure a priority for regional development [Banxico, 2011c].



rate technical efficiency from its structural, more permanent, counterpart.

On the basis of the obtained results it can be concluded that

1. The regional estimates of technical efficiency were increasing over the analyzed period: overall technical efficiency went from 53.7% in 1988 to 76.4% in 2008, which implies an improvement in the use of resources between 1988 and 2008.
2. The evolution of technical efficiency was characterized by the existence of both  $\sigma$  and  $\beta$  convergence in efficiency scores. Moreover, technical efficiency acted as a mechanism for convergence in labor productivity across states: *i.e.* states with lower initial levels of labor productivity observed higher growth rates of technical efficiency.
3. Although technical efficiency is similar across regions, with the north-central region and the south showing a slightly higher degree of technical efficiency than the other two regions, there exists a considerable difference in the level of structural efficiency of the north and the central regions with respect to the south that partially explains the labor productivity gap among regions. Applying a back of the envelope calculation, the south produced 73.5% of the output that it would have produced if it had showed the same level of structural efficiency than the central region. These results are consistent with the findings of Bannister and Stolp [1995] and Braun and Cullmann [2011] who found that northern and central states tend to be more efficient than the rest of states.
4. The results indicate ample potential for economic growth even after considering heterogeneity in the level of technological development: Mexican regions can increase their manufacturing production about 36%, on average, using the same amount of inputs.

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# Appendix A: Log-likelihood function and efficiency

## scores

The model proposed by Battese and Coelli [1992] implies the following density function for  $\xi_i = (\xi_{i1}, \dots, \xi_{iT})$ <sup>8</sup>

$$f_{\xi_i}(\xi_i^*) = \frac{1 - \Phi(-\bar{\mu}_i/\bar{\sigma}_i) \exp[-\frac{1}{2}[(\xi_i^* \xi_i^* / \sigma_v^2) + (\mu/\sigma_u)^2 - (-\bar{\mu}_i/\bar{\sigma}_i)^2]]}{(2\pi)^{T/2} \sigma_v^{T-1} [\sigma_v^2 + \sigma_u^2 \sum_{t=1}^T \eta_t^2]^{\frac{1}{2}} [1 - \Phi(-\mu/\sigma_u)]} \quad (9)$$

where  $\xi_{it} = v_{it} - u_{it}$  and  $\xi_i^*$  is a possible value on the support of the random vector  $\xi_i$ .

Based on  $f_{\xi_i}$  and using the reparameterization proposed by Battese and Corra [1977], as suggested by Battese and Coelli, for a balanced panel of  $n$  states over  $T$  periods, the log-likelihood function is given by

$$\begin{aligned} \ln L &= -\frac{nT}{2} [\ln(2\pi) + \ln(\sigma^2)] - \frac{n(T-1)}{2} \ln(1-\gamma) \\ &\quad - \frac{1}{2} \sum_{i=1}^n \ln[1 + (\sum_{t=1}^T \eta_t^2 - 1)\gamma] - n \ln[1 - \Phi(-\mu/(\gamma\sigma^2)^{\frac{1}{2}})] \\ &\quad - \frac{1}{2} n [\mu/(\gamma\sigma^2)^{\frac{1}{2}}]^2 + \sum_{i=1}^n \ln[1 - \Phi(-\bar{w}_i)] + \frac{1}{2} \sum_{i=1}^n \bar{w}_i^2 \\ &\quad - \frac{1}{2} \sum_{i=1}^n \sum_{t=1}^T \frac{(\xi_{it}^*)^2}{(1-\gamma)\sigma^2} \end{aligned}$$

where  $\xi_{it}^* = y_{it} - \alpha_j - \beta_1 k_{it} - \beta_2 l_{it} - \beta_3 k_{it}^2 - \beta_4 l_{it}^2 - \beta_5 k_{it} l_{it} - \beta_6 t$ ,  $\sigma^2 = \sigma_u^2 + \sigma_v^2$ ,  $\Phi(x)$  is the cumulative distribution function of the standard normal evaluated at  $x$  and

$$\bar{w}_i = \frac{\mu(1-\gamma) - \gamma \sum_{t=1}^T \eta_t \xi_{it}^*}{[\gamma(1-\gamma)\sigma^2 [1 + (\sum_{t=1}^T \eta_t - 1)\gamma]]^{\frac{1}{2}}}$$

Estimates of the coefficients  $\alpha_j$ ,  $\beta_k$ ,  $\eta$ ,  $\mu$ ,  $\sigma_v$  and  $\sigma_u$  can be obtained by maximizing

<sup>8</sup>See Battese and Coelli (1992) for details on the derivation of the log-likelihood function presented in this section.

the log likelihood function presented above.

Battese and Coelli showed that the minimum mean squared error predictor of the technical efficiency,  $E_{it}$ , is given by

$$E[E_{it}|\xi_i] = \frac{1 - \Phi[\eta_t \bar{\sigma} - (\bar{\mu}_i/\bar{\sigma})]}{1 - \Phi[-(\bar{\mu}_i/\bar{\sigma})]} \exp[-\eta_t \bar{\mu}_i + \frac{1}{2} \eta_t^2 \bar{\sigma}^2] \quad (10)$$

where

$$\bar{\mu}_i = \frac{\mu \sigma_v^2 - \sigma_u^2 \sum_{t=1}^T \xi_{it} \eta_t}{\sigma_v^2 + \sigma_u^2 \sum_{t=1}^T \eta_t^2} \quad (11)$$

$$\bar{\sigma}^2 = \frac{\sigma_v^2 \sigma_u^2}{\sigma_v^2 + \sigma_u^2 \sum_{t=1}^T \eta_t^2} \quad (12)$$

## Appendix B: Convergence in Efficiency Scores

Since  $u_{it} = \eta_t u_i = \exp[-\eta(t - T)]u_i$  and  $u_{it} = -\ln(E_{it})$ , we have

$$\begin{aligned}\ln(E_{it}) &= -\eta_t u_i \\ &= -\exp(-\eta t) \exp(\eta T) u_i \\ &= \exp(-\eta t) (-u_{i0}) \\ &= \exp(-\eta t) \ln(E_{i0})\end{aligned}\tag{13}$$

For  $\eta > 0$  we have

$$\frac{\partial \ln E_{it}}{\partial t \partial E_{i0}} = \frac{-\eta \exp(-\eta t)}{E_{i0}} < 0\tag{14}$$

Therefore, there is an inverse relationship between the growth in technical efficiency and its initial level ( $\beta$ -convergence) as long as  $\eta > 0$ .

Finally, we show that  $\eta > 0$  implies  $\sigma$ -convergence. From (13) we have  $E_{it} = \exp(\eta_t u_i)$ . By the Delta method

$$\text{Var}(E_{it}) \approx \eta_t^2 \exp(2\eta_t E[u_i]) \sigma_u^2\tag{15}$$

Since  $\eta_t$  is decreasing in  $t$  when  $\eta > 0$ , and  $E[u_i] \geq 0$  ( $u_i \geq 0$ ), we obtain  $\sigma$ -convergence.



## Appendix C: Tables and Figures

Table 1: Summary statistics at the regional level

	Year	North	North Central	Central	South
Gross value added <sup>a</sup> ( $Y$ )					
	1988	0.26	0.13	0.56	0.06
	1993	0.25	0.16	0.53	0.06
	1998	0.31	0.17	0.46	0.05
	2003	0.34	0.16	0.44	0.06
	2008	0.35	0.17	0.41	0.06
Total employment <sup>a</sup> ( $L$ )					
	1988	0.28	0.16	0.48	0.08
	1993	0.30	0.17	0.45	0.09
	1998	0.35	0.17	0.40	0.08
	2003	0.36	0.18	0.38	0.08
	2008	0.34	0.19	0.38	0.09
Stock of capital <sup>a</sup> ( $K$ )					
	1988	0.25	0.19	0.43	0.13
	1993	0.27	0.23	0.39	0.10
	1998	0.29	0.19	0.41	0.10
	2003	0.31	0.19	0.40	0.09
	2008	0.30	0.22	0.40	0.08
Value added per worker <sup>b</sup> ( $Y/L$ )					
	1988	0.80	0.70	1.00	0.64
	1993	0.71	0.80	1.00	0.57
	1998	0.77	0.87	1.00	0.54
	2003	0.82	0.77	1.00	0.65
	2008	0.95	0.83	1.00	0.62
Mean years of schooling <sup>c</sup> ( $S$ )					
	1990	7.2	6.1	6.3	5.3
	1995	8.1	7.0	7.2	6.3
	2000	8.2	7.3	7.8	6.5
	2005	8.9	8.1	8.2	7.3
	2010	9.3	8.6	8.8	7.9

<sup>a</sup> Regional share.

<sup>b</sup> Normalized by  $\max\{Y_j/L_j\}$  at each period.

<sup>c</sup> Population aged 15 and over.

Source: INEGI, own calculations.

Table 2: Estimation results

	Translog		Cobb-Douglas	
	Model 1	Model 2	Model 3	Model 4
$k$	-0.243 (0.412)	-0.189 (0.395)	0.468*** (0.045)	0.463*** (0.042)
$l$	0.741 (0.585)	0.779 (0.563)	0.652*** (0.053)	0.587*** (0.054)
$k^2$	-0.093*** (0.026)	-0.083*** (0.026)		
$l^2$	-0.075** (0.039)	-0.072* (0.038)		
$kl$	0.192*** (0.056)	0.173*** (0.056)		
Trend	-0.111*** (0.038)	-0.085** (0.035)	-0.126*** (0.041)	-0.097*** (0.035)
North-Central		-0.167* (0.095)		-0.164* (0.096)
Central		0.078 (0.086)		0.096 (0.086)
South		-0.231** (0.105)		-0.278*** (0.105)
Constant	0.175 (2.675)	-0.142 (2.521)	-2.715*** (0.414)	-2.045*** (0.475)
$\eta$	0.028*** (0.011)	0.036** (0.014)	0.031** (0.013)	0.045*** (0.016)
$\sigma_v^2 + \sigma_u^2$	0.053 (0.007)	0.047 (0.006)	0.058 (0.008)	0.049 (0.006)
$\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$	0.240*** (0.087)	0.148** (0.072)	0.223*** (0.088)	0.121* (0.066)
Log-likelihood	7.292	13.166	-1.078	6.801
$N$	160	160	160	160

s.e. in parenthesis. Significance: \*\*\*= 1% level; \*\*= 5% level; \*=10% level.

Table 3: Technical and structural efficiency in manufacturing

	Technical <sup>a</sup> ( $E_{jt}$ )					Structural <sup>b</sup> ( $\phi_j$ )
	1988	1993	1998	2003	2008	
North	0.506	0.566	0.624	0.673	0.720	0.925
North-Central	0.579	0.631	0.677	0.720	0.758	0.783
Central	0.534	0.589	0.640	0.686	0.730	1.000
South	0.574	0.622	0.673	0.718	0.764	0.735
Overall	0.537	0.594	0.645	0.691	0.735	
Standard deviation	0.085	0.077	0.069	0.061	0.053	

<sup>a</sup> Technical efficiency is measured as the ratio of the sum of observed output to the sum of potential output.

<sup>b</sup> Normalized by  $\max_j(\phi_j)$ .

Table 4: Productivity convergence and technical efficiency

	Efficiency growth		Productivity growth	
$\ln(Y_{1988}/L_{1988})$	-0.006*** (0.001)	-0.004*** (0.001)	-0.022*** (0.008)	-0.025*** (0.008)
North-Central	-0.001 (0.002)		-0.004 (0.010)	
Central	0.002 (0.002)		-0.008 (0.011)	
South	0.000 (0.002)		-0.030*** (0.010)	
Constant	-0.014* (0.008)	-0.008 (0.006)	-0.144*** (0.048)	-0.170*** (0.044)
Adjusted $R^2$	0.308	0.322	0.386	0.218
$N$	32	32	32	32

s.e. in parenthesis. Significance: \*\*\*= 1% level; \*\*= 5% level; \*=10% level.

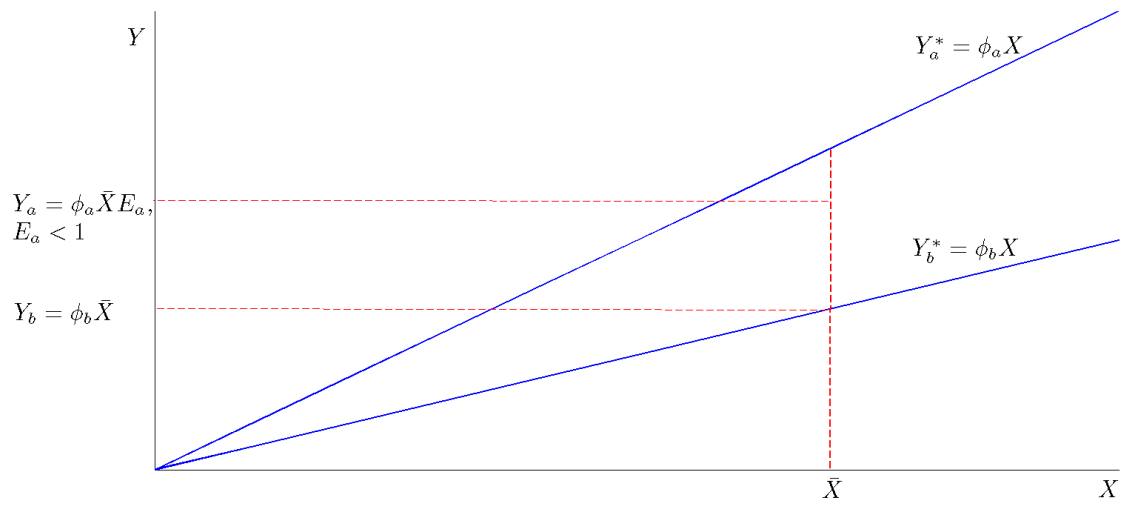


Figure 1: Structural and technical efficiency