THE EFFECT OF INFRASTRUCTURES ON TOTAL FACTOR PRODUCTIVITY AND ITS DETERMINANTS: A STUDY ON MEXICO*

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Resumen: Se analiza el impacto de las infraestructuras sobre la productividad total de los factores, PTF, y sus componentes: cambio técnico y cambio en eficiencia, en las entidades federativas en México. La metodología para obtener la PTF y sus componentes se basa en técnicas de fronteras no paramétricas Data Envelopment Analysis (DEA). En el análisis de la influencia de las infraestructuras sobre los componentes de la PTF se utilizan técnicas econométricas de datos de panel. Los resultados muestran la relevancia del cambio en la eficiencia, mientras que las infraestructuras afectan de manera positiva sólo a la PTF y al componente que hace referencia al cambio técnico.

Abstract: The objective of this research is to identify the effect which infrastructures have on Total Factor Productivity, TFP, and on its components: technical change and efficiency change, of the Mexican states. The methodologies employed are Data Envelopment Analysis to obtain TFP and their components, and panel data econometrics, particularly through the estimation of a model of fixed effects, to determine the effect of the infrastructures. The results show in the first place that technical efficiency is of greater importance to the composition of TFP. Likewise, the existence of a favorable effect of the infrastructures on TFP and its factors is verified.

Clasificación JEL/JEL Classification: D24, H54, O18, O47

Palabras clave/keywords: productividad total de los factores, infraestructuras, análisis regional y productividad y crecimiento, total factor productivity, infrastructures, regional analysis and productivity and growth.

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1. Introduction

The traditional literature on the determinants of production does not take into account the possible existence of inefficiency in the use of productive factors, or else it has used mean production functions, where it is assumed that all the productive units work efficiently in reaching the frontier of potential production. Nonetheless, the existence of breaches between the potential and observed technical efficiency has been recently recognized; breaches which come from the fact that the best practices in the productive process are not being utilized.

This fact has motivated a line of research based on nonparametric frontier techniques that allow contrasting the inefficient use of productive factors. The studies in this literature show empirical evidence and show the existence of inefficiencies in the use of private productive factors (Gumbau and Maudos, 1996, Beeson and Husted, 1989). Among the numerous works that are based on nonparametric techniques are those by Maudos, Pastor and Serrano (1998, 1999) and Salinas, Pedraja, and Salinas (2001), who analyze the Spanish regions. Domazlicky and Weber (1997) and Boisso, Grosskopf, and Hayes (2000) focus on the American economy; whilst Lynde and Richmond (1999) analyze the United Kingdom. Likewise, Kirkham and Boussabaine (2005) and Peñaloza (2006) apply the methodology to health systems in the United Kingdom and Colombia, respectively. Lucía *et al.* (2007) analyze public universities in Argentina.

In Mexico, few works incorporate the calculation of technical efficiency in production by means of nonparametric techniques. Among them one identifies Fuentes and Armenta (2006), who calculate a Malmquist index and decompose the factors that contribute to the improvement of productivity according to information from 133 enterprises located in the municipality of San Mateo Atenco, State of Mexico, Mexico; Sigler (2004) analyzes efficiency in economic research production in Mexico City; Nérvaez, Constantino y García (2007) and Salinas-Martinez, *et al.* (2009) apply their analysis to the sphere of health; Villareal and Cabrera (2007) propose different schemes to make the use of Data Envelopment Analysis (DEA) more efficient in order to solve problems of multiple criteria optimization; and Navarro and Torres (2006) apply it to the electricity-production industry in Mexico. In the analysis of technical efficiency, this methodology has been applied by Álvarez *et al.* (2008) to determine the technological frontier of the Mexican states. Nevertheless, there are no studies for this country that help understand the effects that infrastructures have on the total factor productivity and its components, technical change and efficiency change. Thus, the objective of this research is to analyze the effect that infrastructures exercise on TFP and its components in the context of the Mexican economy.

In order to achieve this objective, the study is structured as follows: in section two the employed methodology is developed; in the third section, the databases and information sources we employed are exposed; in the fourth section, results are shown; and finally, the main conclusions are presented.

2. Methodology

The calculation of inefficiency is generally the main motivation for studying production frontiers. There are two approaches in the construction of frontiers: one of them is based on the techniques of mathematical programming, while the other uses econometric tools. The main advantage of mathematical programming or Data Envelopment Analysis (DEA) approximation lies in the fact that it is not necessary to impose an explicit functional form on the data; however, the obtained frontier might be deformed if the data are polluted by statistical disturbance. On its own, the econometric approximation introduces an error term and imposes a functional form for technology. This research is focused on the nonparametric approximation.

The techniques of DEA, are stated below, and the Malmquist index, necessary to preserve the nonparametric approach, is defined. From the nonparametric viewpoint, the measurements of efficiency developed by Farrell (1957) are empirically implemented using DEA. Farrell proposed that the efficiency of a decision unit comprise two components: "technical efficiency, which reflects the ability to obtain the most output for a given set of inputs, and "price or allocative efficiency which reflects the ability to use the inputs in optimal proportions, given their respective prices. Both measurements are combined to obtain "economic efficiency. This analysis draws attention to the output-oriented efficiency measurements, which respond to the question of how to maximize output without altering the necessary amount of inputs.[1]

The DEA model upon which the calculation of technical and scale efficiency is carried out is that developed in Seiford and Thrall

[1] Equivalently, the input-oriented measurements of efficiency preserve the output level constant, allowing us to calculate to which extent it is possible to reduce the amount of inputs.

(1990).[2] The aim of this and other DEA models lies in constructing a frontier of possibilities of nonparametric production, which envelops the data.

Considering N Decision Making Units (DMUs),[3] each DMU consumes M *inputs* to produce S *outputs*. Specifically, DMU_j consumes X_{ji} of *input* i and produces Y_{jr} of *output* r. It is assumed that $X_{ji} \geq 0$ and $Y_{jr} \geq 0$. Likewise, X and Y are matrices of size $M \times N$ and $S \times N$, which contain the totality of *inputs* and *outputs*, respectively, corresponding to the N DMUs considered (in this study the j-th DMU makes reference to the j-th Mexican state, with j=1, 2, ..., 32). For a DMU, its *input/output* ratio provides a measurement of efficiency. In mathematical programming this ratio, which is minimized, becomes the objective function of the analyzed DMU. On its own, the incorporation of normalized restrictions reflects the condition that the *input/output* ratio of each DMU must be superior to one so that the frontier calculated envelopes the different *input-output* combinations corresponding to the totality of DMUs considered; therefore, the mathematical program that provides the ratio of efficiency follows the expression:

$$Min \;\; v^T x_0 / u^T y_0$$

subject to

$$v^T x_j / u^T y_j \geq 1 \qquad j = 1, 2, ..., N$$

$$u \geq 0$$

$$v \geq 0$$

where the variables u and v are vectors of size $S \times 1$ and $M \times 1$, respectively. Hence, from this program we can obtain the optimal weights $u*$ and $v*$ associated with the *inputs* and *outputs*. Nonetheless, this last problem provides an infinite number of solutions, for which the restriction $\mu^T y_0 = 1$ is incorporated and leads to obtain μ and ν as a result of the transformation:

$$\underset{\mu,\;\;\nu}{Min} \;\; \nu^T x_0$$

subject to

[2] The standard models of constant and variable returns to scale, which carry out the calculation of technical and scale efficiencies, are developed in Fare, Grosskopf and Lovell (1994).

[3] DMU refers to "Decision Making Unit", a broader term than that of Firm.

$$\mu^T y_0 = 1$$
$$\nu^T X - \mu^T Y \geq 0$$
$$\mu^T \geq 0$$
$$\nu^T \geq 0$$

Whose dual problem is:

$$Max \;\; \phi$$
$$\phi, \; \lambda$$

subject to

$$X\lambda \leq x_0$$
$$\phi y_0 - Y\lambda \leq 0 \tag{2.1}$$
$$\lambda \geq 0$$

Where ϕ is a scalar and λ is a vector $N \times 1$. The process is repeated for each DMU_j, introducing into the previous problem $(x_0, y_0) = (x_j, y_j)$. A DMU is inefficient if $\phi^* < 1$ and efficient if $\phi^* = 1$. Thereby, all the efficient DMU are located at the frontier of production possibilities. Nonetheless, a DMU might be located at the frontier ($\phi^* = 1$) and be inefficient. The imposed restrictions lead to efficiency at the point (x_0, y_0) for an optimal λ^* when these are equally fulfilled, therefore $x_0 = X\lambda^*$ and $y_0 = Y\lambda^*$. An inefficient DMU may become more efficient when it is projected on the frontier. Nevertheless, it is necessary to distinguish between a frontier point and an efficient frontier point. For an output orientation the projection $(x_0, y_0) \to (x_0, \phi^* y_0)$ always leads to a frontier point, but technical efficiency is only reached if $x_0 = X\lambda^*$ and $\phi^* y_0 = Y\lambda^*$, for every optimal λ^*. Thus in order to reach technical efficiency both restrictions must be fulfilled.

The stated model supposes constant returns to scale; in this case the input-oriented and output-oriented measurements of efficiency are equivalent (Fare and Lovell, 1978). Nevertheless, imperfections in the market and financial restrictions, among others, lead to sub-optimal DMUs. For this reason, Banker, Charnes and Cooper (1984) extend the model by introducing variable returns to scale, which allows the estimation of scale efficiencies. For this purpose, it is necessary to incorporate the restriction $e^T\lambda = 1$ (“e” is a vector whose components are 1 and has a size of $N \times 1$) in the model (2.1.), obtaining:

$$\underset{\phi,\lambda}{Max} \ \ \phi$$

subject to

$$X\lambda \leq x_0$$

$$\phi \ y_0 - Y\lambda \leq 0 \tag{2.2}$$

$$\lambda \geq 0$$
$$e^T\lambda = 1$$

Analytically, the restriction $e^T\lambda = 1$ generates a requirement of convexity which forces the efficient frontier of production possibilities to be composed of segments that join the extreme points. Hence, a measurement of "pure" technical efficiency (without scale efficiencies) is attained. Nevertheless, the measurements of scale efficiency obtained through this method do not indicate when a DMU operates in an area of increasing or decreasing returns to scale. So, we consider an alternative model, incorporating the restriction $e^T\lambda \leq 1$ (increasing returns to scale not permitted) in the model (2.1):

$$\underset{\phi,\lambda}{Max} \ \ \phi$$

subject to

$$X \ \lambda \leq x_0$$
$$\phi \ y_0 - Y\lambda \leq 0 \tag{2.3}$$
$$\lambda \geq 0$$
$$e^T\lambda \leq 1$$

The nature of the scale efficiencies for a particular DMU is determined comparing the measurements of technical efficiency obtained from the implementation of the models (2.2), where variable returns to scale are assumed, and (2.3) where only decreasing returns to scale are permitted. Thus, if these coincide in both models, then the DMU under consideration presents decreasing returns to scale (or, conversely, increasing returns to scale).

2.1. *Measurement of TFP and its components*

To carry out this analysis we made use of panel data, so that it is possible to calculate the Malmquist index following the methodology proposed by Fare *et al.* (1994). This index allows the growth of productivity to be decomposed into two components: changes in technical efficiency and changes in technology along time. As previously mentioned, the measurement of technical efficiency might be oriented towards input (when, given an output level, the amounts of the different inputs that will be consumed are minimized) or toward the output (when, for a given level of inputs, output is maximized). For the empirical application, attention will be paid to the calculation of technical efficiency based on an output orientation.

In this article the change in productivity is calculated as the geometric mean of two Malmquist production indexes. In order to define the Malmquist index based on the output, it will be assumed that in each period $t = 1, ..., T$, the technology of production S^t models the transformation of inputs, $X^t \,\epsilon\, \Re_+^N$ into outputs, $Y^t \,\epsilon\, \Re_+^M$.

$$S^t = \{(X^t, Y^t) : X^t \text{ can produce } Y^t\} \tag{2.4}$$

On its own, the function of distance from the output is defined as:

$$\begin{aligned} D_0^t(X^t, Y^t) &= \inf\left\{\phi : (X^t, Y^t/\phi) \in S^t\right\} \\ &= \left(\sup\left\{\phi : (X^t, \phi Y^t) \in S^t\right\}\right)^{-1} \end{aligned} \tag{2.5}$$

This function is defined as the reciprocal of the maximum proportional expansion of the output vector Y^t, given the inputs X^t, and it completely characterizes technology. In particular $D_0^t(X^t, Y^t) \leq 1$ if and only if $(X^t, Y^t) \,\epsilon\, S^t$. Additionally, $D_0^t(X^t, Y^t) = 1$ if and only if (X^t, Y^t) is at the technological frontier. In the terminology used by Farrell (1957) this occurs when production is technically efficient.

From the definition of the distance function it is seen that it is first-degree homogenous in outputs. In addition, it is the reciprocal of the measurement of technical efficiency in Farrell (1957).

To obtain the Malmquist index it is necessary to define the distance functions in relation to two different periods such that:

$$D_0^t(X^{t+1}, Y^{t+1}) = \inf\left\{\phi : (X^{t+1}, Y^{t+1}/\phi) \in S^t\right\} \tag{2.6}$$

The distance function corresponding to (2.6) measures the maximum reciprocal change in output required to make (X^{t+1}, Y^{t+1}) feasible with relation to technology in t. Similarly, the distance function can be defined as that which measures the maximum proportion of change in output necessary for (X^t, Y^t) to be feasible in relation to technology in $t+1$, which will be called $D_0^{t+1}(X^t, Y^t)$. Hence, the index of productivity in Malmquist output is defined as:

$$M^t = \frac{D_0^t(X^{t+1}, Y^{t+1})}{D_0^t(X^t, Y^t)} \tag{2.7}$$

where technology in t is the reference technology. Alternatively, a Malmquist index can be defined on the basis of the $t+1$ period:

$$M^{t+1} = \frac{D_0^{t+1}(X^{t+1}, Y^{t+1})}{D_0^{t+1}(X^t, Y^t)} \tag{2.8}$$

The election of either reference technology turns out to be a relevant issue. Because of this, in order to solve the problem that might be posed by the consideration of a fixed technology, Fare *et al.* (1994) define the Malmquist index of productivity change based on the output as the geometrical mean of Malmquist indexes (2.7) and (2.8), previously specified:

$$M_0(X^{t+1}, Y^{t+1}, X^t, Y^t) = \tag{2.9}$$
$$\left[\left(\frac{D_0^t(X^{t+1}, Y^{t+1})}{D_0^t(X^t, Y^t)}\right)\left(\frac{D_0^{t+1}(X^{t+1}, Y^{t+1})}{D_0^{t+1}(X^t, Y^t)}\right)\right]^{1/2}$$

Or equivalently:

$$M_0(X^{t+1}, Y^{t+1}, X^t, Y^t) = \frac{D_0^{t+1}(X^{t+1}, Y^{t+1})}{D_0^t(X^t, Y^t)} \times \tag{2.10}$$
$$\times \left[\left(\frac{D_0^t(X^{t+1}, Y^{t+1})}{D_0^{t+1}(X^{t+1}, Y^{t+1})}\right)\left(\frac{D_0^t(X^t, Y^t)}{D_0^{t+1}(X^t, Y^t)}\right)\right]^{1/2}$$

Expression (2.10) allows the evolution of productivity to be divided into two components. The first one refers to the change in efficiency, whose improvements are considered evidence of the "catching up; this is to say, of the approaching of each of the DMUs to the efficient frontier.[4] On its own, the second component indicates

[4] Using nonparametric programming methods, an efficient frontier is built for Mexico based on all of the states of the sample.

how technical change varies; in other words, how the displacement of the efficient frontier generates innovation. Improvements in the Malmquist index of productivity change lead to values above 1, and the same occurs to each of its components. Moreover, it is noteworthy that this decomposition provides an alternative to contrast convergence in productivity growth, as well as to identify innovation.

In the empirical evidence the Malmquist productivity index will be calculated using the aforementioned nonparametric programming techniques;[5] then, in order to calculate the productivity of the k' DMU between t and $t+1$, it is necessary to solve four problems of linear programming: $D_0^t(X^t, Y^t)$, $D_0^t(X^{t+1}, Y^{t+1})$, $D_0^{t+1}(X^t, Y^t)$ and $D_0^{t+1}(X^{t+1}, Y^{t+1})$. In order to do so, we make use of the fact that the output distance function is reciprocal to the measurement of Farrells outward-oriented technical efficiency.

We consider $k = 1, 2, ..., K$ DMU using $n = 1, 2, ..., N$ $X_n^{k,t}$ inputs in each period $t = 1, 2, ..., T$. These inputs are used to produce $m = 1, ..., M$ outputs. Therefore, for each $k' = 1, ..., K$ we calculate:

$$\left(D_0^t(X^{k',t}, Y^{k',t})\right)^{-1} = \max\ \phi^{k'}$$

subject to

$$\phi^{k'} y_m^{k',t} \leq \sum_{k=1}^{K} \lambda^{k,t} y_m^{k,t} \tag{2.11}$$

$$\sum_{k=1}^{K} \lambda^{k,t} x^{k,t} \leq x_n^{k',t}$$

$$\lambda^{k,t} \geq 0$$

The calculation of $D_0^{t+1}(X^{k',t+1}, Y^{k',t+1})$ is carried out as in (2.11), substituting $t+1$ in t. Two of the distance functions used in the construction of the Malmquist index require information on the periods; the first of them is computed for observation k' as:

$$\left(D_0^t(X^{k',t+1}, Y^{k',t+1})\right)^{-1} = \max \phi^{k'}$$

subject to

[5] DEA model oriented toward output stated in Seiford and Thrall (1990) is noticeably modified when time variation is considered.

$$\phi^{k`} y_m^{k`,t+1} \leq \sum_{k=1}^{K} \lambda^{k,t} y_m^{k,t} \tag{2.12}$$

$$\sum_{k=1}^{K} \lambda^{k,t} x^{k,t} \leq x_n^{k`,t+1}$$

$$\lambda^{k,t} \geq 0$$

In (2.12) observations of t and $t+1$ appear simultaneously, as the technology in relation to which $(X^{k`,t+1}, Y^{k`,t+1})$ is evaluated is that corresponding to t. In (2.11) $(X^{k`,t}, Y^{k`,t}) \epsilon S^t$, and therefore $D_0^t(X^{k`,t}, Y^{k`,t}) \leq 1$. Nevertheless, in (2.12) $(X^{k`,t+1}, Y^{k`,t+1})$ does not have to belong to S^t, so $(X^{k`,t+1}, Y^{k`,t+1})$ can take values above 1. The last problem of linear programming to be solved is also a mixed problem, such as (2.12) but transposing t and $t+1$.

To analyze the changes in scale efficiencies, the distance functions will be also calculated under variable returns to scale (see Banker, Charnes and Cooper, 1984), incorporating the following restriction into the previous models: $\sum\limits_{k=1}^{K} \lambda^{k,t} = 1$. The scale efficiency in each period is constructed as the quotient obtained by dividing the distance function with constant returns to scale by the distance function which satisfies variable returns to scale. Separately, technical change is calculated in relation to technology with constant returns to scale.

In our case, following expressions in (2.11) and (2.12) we obtain the output distance function for the Mexican states using the production factors labor and capital in the elaboration of the GDP. Incorporating the distance functions in the Malmquist index of expression (2.10) we calculate the Total Factor Productivity (TFP) and disaggregate it into two components: change in efficiency and technical change.

3. Databases and sources of information used

The panel data considered in this paper is from the 1970-2003 period for the Mexican states. The product is represented by GDP in 1993 Mexican pesos (MXN), investment by means of the Gross Fixed Capital Formation in 1993 MXN, and employment is represented by the labor force. The statistical sources from which these databases have been obtained come from the Economic Censuses carried out by the National Institute of Statistics and Geography of Mexico.

The information on the indicator of productive infrastructures utilized corresponds to the categories of transport –referring to roads, ports and airports–, telecommunications and water and electricity supply and sewerage. The years of observation correspond to 1970, 1980, 1988, 1993, 1998 and 2003, from different information sources, which are shown in table 1.

Table 1
Equipment of infrastructures and employed sources

Equipment	*Data sources*
TRANSPORT: Road length (kilometers), Airports and Ports	Statistical Yearbook of the United Mexican States, 1972, 1980, 1991, 1995, INEGI; Statistical Yearbook by State, 2002, INEGI.
Water and electricity supply and sewerage, Household outlets with water, electricity and sewerage	General Censuses of Population and Housing, 1970, 1990, 2000, 2005, INEGI; General Counts of Population and Housing, 1995, 2005, INEGI.
TELECOMMUNICATIONS: Telephone lines	Statistical Yearbook of the United Mexican States, 1972, 1980, 1991, 1995, INEGI; General Direction of Fares and Statistical Integration, COFETEL, 1990-2003.

Source: own elaboration from the consulted sources.

These information sources were combined with a synthetic indicator of productive infrastructures, which was taken from Becerril *et al*. (2009) and that includes all of the equipment mentioned in table 1, standardized and made relative, which were aggregated using the methodology of main components analysis. Hence, they are assigned a weight, which is correlated with the weight extracted from the factorial analysis.[6]

[6] The proposed indicator of infrastructures is calculated by means of a weigh-

The index is calculated by adding factors weighted by the percentage of total variance that explains each of them, as in the following expression:

$$I = \sum_{i=1}^{N} \frac{Var(Y_i)}{N} Y_i \tag{3.1}$$

Where Y_i is the ith factor and $\frac{Var(Y_i)}{N}$ is the percentage of total variance which explains Y_i.

The principal component analysis order factors from largest to smallest variance. Thus, when each factor is multiplied by the above percentage of variance, the amount of information inherent to it is obtained. Defining factors Y_i in terms of observable variables $S_1, S_2, ..., S_N$ yields the following expression:

$$I = \sum_{i=1}^{N} \frac{Var(Y_i)}{N} \sum_{j=1}^{N} t_{ij} Z_j \tag{3.2}$$

Next, we consider the factor structure of the principal component factors. We can define the weights matrix T in terms of the matrix B, which is calculated using a rotation matrix VARIMAX on correlations between the components Y_i and variables S_j, such that:

$$t_{ij} = \frac{b_{ij}}{Var(Y_i)} \tag{3.3}$$

ted sum of the values corresponding to the different categories considered, in physical units, standardized and made relative with respect to the state with the most infrastructure equipment in the initial year, which takes a value of 100. When weighting with respect to the initial year there may be categories that take values above 100, which allows analyzing temporary evolutions; in this case the temporary weight is assigned based on statistical criteria, through the analysis of its main components. Hence, the methodology proposed in the works by Biehl (1986) for the European case, Cutanda and Paricio (1992) and Delgado and Álvarez (2000) in Spain and Fuentes (2007) for the Mexican states is followed. Particularly, in the work by Fernández *et al.* (2003) comparative estimations are performed by introducing one of two variables into the production function: either the indicator of infrastructures calculated in Delgado and Álvarez (2000) following this methodology, or alternatively the stock of public capital in monetary units published by the Valencia Institute of Economic Researches (*Instituto Valenciano de Investigaciones Económicas*, IVIE) through BBVA Foundation, obtaining very similar results.

So, the indicator of productive infrastructures is calculated from the equation:[7]

$$I = \sum_{i=1}^{N} \frac{1}{N} b_{ij} \left(\sum_{j=1}^{N} Z_j \right) = \frac{1}{N} \left(b_{11} + b_{21} + ... + b_{N1} \right) Z_1 \tag{3.4}$$

$$+ ... + \frac{1}{N} \left(b_{1N} + b_{2N} + ... + b_{NN} \right) Z_N$$

Where Z_j are standardized variables, which refer to characteristics that describe information about the qualityof the equipment considered, summarized in table 1:

Z_1: Roads kms
Z_2: Airports
Z_3: Ports
Z_4: Telephone lines
Z_5: Household connections installed with the electric supply
Z_6: Household connections installed with water supply
Z_7: Household connections installed with sewerage service

Together with the global indicator, diverse indicators were calculated for each of the categories considered (transport, communications and household equipment). The transport indicator includes roads, airports and ports, communications is only telephone lines; and household equipment consists of household connections to electricity, water and sewerage.

Figure 1 shows the distribution of the productive infrastructures in the states in 1970 and in 2003. In this figure, the way in which the regions have evolved in terms of infrastructure equipment can be seen, showing divergences overtime; likewise, this equipment is concentrated in the north, center and in the Gulf of Mexico.

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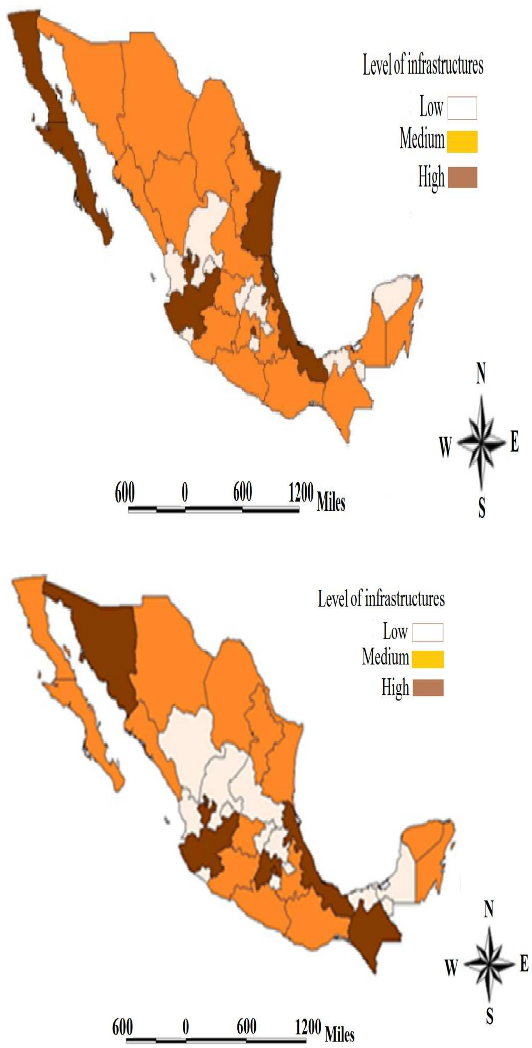
[7] The expression (3.4) shows that the indicator of productive infrastructure is calculated as the weighted sum of standardized equipment variables. Therefore, the weights are determined by principal component analysis and specifically defined as the sum of the vector corresponding to the rotated factor matrix.

Figure 1
Distribution of productive infrastructures in the Mexican states, 1970 and 2003



Source: own elaboration from indicator of infrastructures in table 1.

4. Results

Following the previously described methodology (see Fare *et al.*, we built a frontier of maximum production with the available productive factors (capital and employment) for the Mexican states for the 1970-2003 period. The calculation of the Malmquist productivity index as well as its decomposition into technical change and change in efficiency has been carried out making use of the software DEAP 2.1 (Coelli, 1996), which is based upon the estimation method of multiple stages to solve DEA models described in Coelli (1998).

In table 2 the mean results of each state[8] are summarized for the complete period, 1970-2003, and the sample is also divided into two periods, 1970-1985 and 1988-2003, which correspond to the implementation in Mexico of the last stage of the model of industrialization via import substitution[9] and of export-oriented industrialization,[10] respectively.

Throughout the period, the values corresponding to the Malmquist productivity index show deterioration. This deterioration is due to a reduction, in all of the states, of the component of technical change or optimal productivity of production, which becomes a displacement of the reference frontier. On its own, technical efficiency allows us to identify the states which performed the best in the use of productive factors (as suggested by Krüger, *et al.*, 2000, and Lanteri, 2002, the states which produce in an efficient manner are located at the technological frontier). Most of the states do not show changes in technical efficiency, so their relative productivity remains unaltered, which prevents them from approaching the reference frontier, and

[8] This type of studies is most frequently used for homogeneous geographical units, which might not be available at the local level. For this reason, we focus on states.

[9] This economic model for the case of Mexico was valid from 1950 to 1985, however according to Fuentes (2007) during the last fifteen years of the strategy of the model of industrialization via import substitution, the Mexican government supported the process of industrialization through a dynamic policy of investment in public capital.

[10] Likewise, following Fuentes (2007), the exhaustion of the model of industrialization via import substitution, which led to the 1982 economic crisis, forced the Mexican government to abandon this model. From 1986 Mexico started a program that combined fiscal incentives and trade liberalization, among others. Separately, as a part of the program of fiscal austerity implemented in 1986, the government reduced its current and capital expenditures, and stimulated the formation of private capital.

thus from approaching the maximum productivity obtained by the states that reach optimal productivity.

In the states of Colima and Nayarit this index surpasses 1, during the complete period of study, which indicates that in these states the best use of inputs is being obtained, helping to expand their outputs, which implies that they approach the efficient frontier; the opposite case occurs in Aguascalientes, Baja California Sur, Campeche, Queretaro and Quintana Roo.

The importance of the change in the economic paradigm in Mexico by the end of the 1980s, derived from the exhaustion of the model of industrialization via import substitution and from the implementation of the model of export-oriented industrialization, due to the insertion of Mexico into the global economy in 1986, as it joined the General Agreement on Tariffs and Trade (GATT), motivates us to analyze both paradigms and to contrast whether the effect of government intervention in economic activity contributed to improve TFP and its components in the Mexican economy and in that of the states. The Malmquist productivity index, which measures growth in TFP, was below 1 in both periods, which shows that TFP did not improve, or equivalently, that it has been negative, due mainly to growth in technical change, which was positive in the first period and close to 1 in the second.

The results indicate that during the period when the first economic model was applied, states such as Aguascalientes, Baja California Sur and Colima improved their efficiency, and that efficiency decreased during the period when the model of industrialization oriented to exports was applied. Only the state of Nayarit reflects an improvement over the period of both models; efficiency in the rest of the states remains unchanged in both periods. Then the abovementioned group of states improves their efficiency during the period of trade liberalization. Following the articles of Sanchez-Reaza and Rodriguez-Pose (2002) and Rodriguez-Pose and Sanchez-Reaza (2003), this result suggests that trade liberalization and economic integration have led to regional divergences, because this process has affected to the states in different ways. So, to explain the improvement in efficiency in these states it is necessary to take into account recent regional economic development patterns in Mexico. In economic literature articles, such as for example Rodriguez-Oreggia and Rodriguez-Pose (2004), show that there is no evidence that the distribution of public investment funds distribution affects regional growth, because it was not efficient.

Table 2

Total factor productivity decomposition

Federal State	*Total factor productivity change*			*Technical change*			*Efficiency change*		
	1975-2003	*1975-1985*	*1988-2003*	*1975-2003*	*1975-1985*	*1988-2003*	*1975-2003*	*1975-1985*	*1988-2003*
Aguascalientes	.755	.645	.634	.763	.642	.647	.990	1.004	.979
Baja California	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Baja California Sur	.782	.713	.718	.787	.615	.775	.993	1.160	.927
Campeche	.738	.620	.638	.748	.640	.638	.987	.970	1.000
Coahuila	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Colima	.779	.660	.754	.776	.621	.765	1.004	1.063	.986
Chiapas	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Chihuahua	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Federal District	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Durango	.744	.633	.636	.744	.633	.636	1.000	1.000	1.000
Guanajuato	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Guerrero	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Hidalgo	.744	.632	.633	.744	.632	.633	1.000	1.000	1.000
Jalisco	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Mexico	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Michoacan	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Morelos	.745	.635	.633	.745	.635	.633	1.000	1.000	1.000

Table 2
(continued)

Federal State	*Total factor productivity change*			*Technical change*			*Efficiency change*		
	1975-2003	*1975-1985*	*1988-2003*	*1975-2003*	*1975-1985*	*1988-2003*	*1975-2003*	*1975-1985*	*1988-2003*
Nayarit	.774	.648	.743	.764	.644	.731	1.013	1.007	1.017
Nuevo Leon	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Oaxaca	.743	.630	.631	.743	.630	.631	1.000	1.000	1.000
Puebla	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Queretaro	.744	.633	.634	.748	.640	.634	.995	.989	1.000
Quintana Roo	.706	.578	.629	.740	.579	.643	.954	.999	.979
San Luis Potosi	.743	.631	.630	.743	.631	.630	1.000	1.000	1.000
Sinaloa	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Sonora	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Tabasco	.743	.630	.636	.743	.630	.636	1.000	1.000	1.000
Tamaulipas	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Tlaxcala	.774	.634	.769	.774	.634	.769	1.000	1.000	1.000
Veracruz	.743	.630	.630	.743	.630	.630	1.000	1.000	1.000
Yucatan	.744	.632	.636	.744	.632	.636	1.000	1.000	1.000
Zacatecas	.755	.641	.669	.755	.641	.669	1.000	1.000	1.000
Mean	.747	.633	.646	.748	.630	.648	.998	1.006	.996

Source: own elaboration.

In line with these works, we observe that, given a randomly distributed initial infrastructure investment concentrated on the north, center and on the Gulf of Mexico, the north benefits from trade liberalization due to its proximity to United States; central states such as Aguascalientes depend upon internal markets; and Nayarit is located on the Pacific Coast, where maritime infrastructure facilitates the transport of goods and international relations.

The deterioration in productivity during the period of the study and in both sub-periods is due to reductions in technical change or changes in optimal production productivity (due to a lack of innovation and technical incorporation, which hinder outward displacement of the frontier of production–. On the other side, efficiency change or relative productivity remains almost unaltered since its value remained close to 1 in most of the states during the entire period. Nonetheless, during the time of validity of the model of industrialization via import substitution, efficiency change is positive due to gains in relative productivity in some states, which is shown by their approaching the technological frontier.

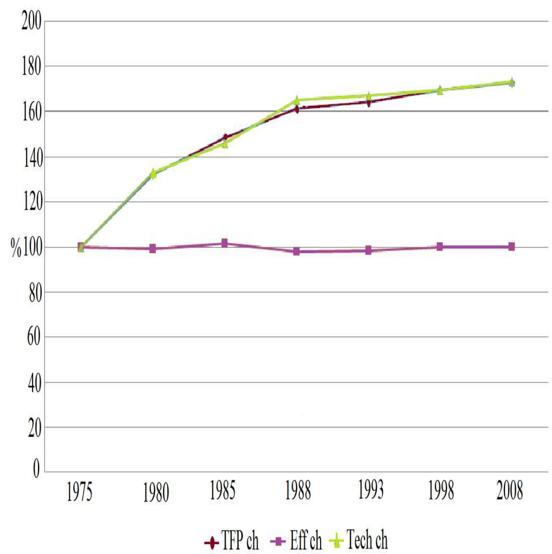
Graph 1 shows the accumulated Malmquist index as well as its components: technical change and efficiency change, which are shown as *TFP ch*, *Tech ch* and *Eff ch*, respectively. This graph shows their evolution throughout the period taking 1975 as a base year for each of them. Note that this graph shows clearly that technical innovation or change is highly correlated to TFP, whereas change in technical efficiency, in spite of showing an evolution in the same sense, has a looser degree of association. This allows us to infer that the incorporation of technical improvements would have a high influence on the displacement of the technological frontier of Mexico.

Finally, by means of panel data analysis techniques,[11] the role played by the infrastructures in the evolution of change in total factor productivity and its components is determined. In table 3 we present the results; in the first place we verified whether it is necessary to control for the specific effects of each state. To do so, the F contrast of individual effects is carried out. In all of the cases, it allows us to reject the null hypothesis of equal effects on the individual effects, so we decided to estimate the equation by means of panel data techniques. Since, the Hausman (1978) test verifies the existence of correlation between individual effects and regressors, the "intra-groups" estimator is applied, since it is a model of fixed effects,

[11] For a detailed description on the techniques of panel data employed, see Baltagi (2008).

except for the case where the dependent variable is represented by the component of change in technical efficiency, which has been estimated by random effects. All the models are jointly significant. In addition, the residual standard errors are robust for heteroscedasticity.

Graph 1
Individual evolution of TFP and its components
((1975=100)



Source: own elaboration.

The results show that the indicator of infrastructures, which incorporates transport equipment (roads, ports and airports), telecommunications and household equipment (water and electricity supply and sewerage) has a positive effect on the growth of private productive factors and also on the component of technical change, whilst in the case of the change in technical efficiency, the associated coefficient is not significant. The positive effect of infrastructures on technical productivity growth and on the component of technical change is preserved when the indicator of infrastructures is disaggregated in the different categories.

Table 3

Determinants of TFP, 1970-2005

Federal	*I. Malmquist*		*Technical change*		*Efficiency change****	
Constant	-1.727 (-7.09)**	-1.573 (-9.98)**	-1.768 (-7.23)**	-1.674 (-10.62)**	0.004 (0.32)	0.002 (0.07)
Indust. infrastructure	0.439 (6.07)**		0.453 (6.23)**		-0.002 (-0.44)	
Transport		0.085 (2.33)**		0.082 (2.32)**		-0.003 (-0.52)
Telecommu-nications		0.292 (3.78)**		0.249 (3.41)**		0.000 (0.02)
Household equipment		0.154 (1.64)*		0.216 (2.39)**		0.002 (0.11)
Joint Sig. test	F(1,191)=36.84	F(3,189)=96.70	F(1,191)=38.76	F(3,189)=87.67	χ^2 (2)=0.51	χ^2 (4)=4.43
Indiv. effects F test	F(31,191)=1.24	F(31,189)=14.97	F(31,191)=1.22	F(31,189)=13.74	F(31,191)=0.30	F(31,189)=0.39
Hausman test	χ^2 (1)=36.62	χ^2 (3)=634.62	χ^2 (1)=36.70	χ^2 (3)=564.05	χ^2 (1)=0.42	χ^2 (3)=4.76
Rho	0.682	0.948	0.682	0.944	0	0

*parameter significant at 90%, **parameter significant at 95%, ***model of random effects, estimated by generalized least squares. Source: own elaboration.

In relation to these results, the positive influence exercised by public-sector investment on transport, telecommunication and household equipment infrastructures on the growth of productivity of the private productive factors is evident, so investment enhances productivity. On its own, technical change is also positively related to infrastructures because of the weight of this component on productivity change, which allows us to verify the positive effect of infrastructures on innovation. The empirical evidence we produce in favor of investment in public capital is similar to that of other studies that use the same methodology. That is the case by Alvarez, *et al.* (in press), who obtained similar results in sectors and for the countries of the European Union using the same methodology of nonparametric frontier decomposition of total factor productivity.

Finally, the improvement in efficiency, which provides evidence on the "catching up" toward the frontier, is not influenced by changes in the equipment of infrastructures. By contrast, in Alvarez, *et al.* (in press) increases in public capital affect technical efficiency positively, indicating that investments by Mexicos states in its transport infrastructure, communications and household equipment do not influence the efficiency of private production factors. So, they contribute to moving the technological frontier, but not the approach to it. The empirical evidence for the influence of the productive infrastructure of technical efficiency in the states in Mexico is similar to that obtained in Becerril, *et al.* (2010), who concluded that infrastructure does not promote convergence in technical efficiency, except for communications infrastructure.

Therefore, infrastructures contribute to improve the productivity of private factors and empower the acquisition power and assimilation of innovation in the private sector. Nevertheless, they do not influence the growth of efficiency in the use of private factors, so they do not generate convergence towards the technological frontier, which is the most production attainable with the available productive factors. The principal reason would be that the distribution of public investment funds does not follow efficiency criteria, as has been illustrated by Rodriguez-Oreggia and Rodriguez-Pose (2004).

5. Conclusions

The availability of information on production, investment, employment and infrastructures of the Mexican states allowed us to carry out an analysis on TFP, and its components: technical change and efficiency change. The use of the nonparametric frontier techniques of Data Envelopment Analysis has given us the opportunity to build a Malmquist productivity index and obtain its components. Also, the use of the econometric technique of panel data has contributed with information to identify the role played by infrastructures on the evolution of TFP. The results reflect the weight technical change has on this evolution; while efficiency change was not found to have an important influence. In the light of these results it is possible to express the need to incorporate innovations in the productive processes, although considerations related to a better use of the inputs in order to expand the output of the states and that of the country itself must not be put aside.

Likewise the incorporation of infrastructures as a variable that conditions improvements in TFP provides interesting results. Among them, was the result that infrastructures positively affect private productive factors and the components of technical change.

The positive influence exercised by public sector investment in transport, telecommunication and household equipment infrastructures on the growth of productivity of private productive factors is shown. Technical change, on its own, is also related in a positive manner to infrastructures because of the weight this component has on productivity change, which allows us to verify the favorable effect infrastructures exercise on innovation. Finally, we found that improvements in efficiency, which help firms to "catch up" to the frontier, are not influenced by the changes in the equipment of infrastructures.

The analysis of the economic paradigms adopted in Mexico during the period of this study shows that there are no important differences between the two as far as their effect on changes in TFP an its components is concerned. Only three states showed improvements in their efficiency during the period in which the model of industrialization via import substitution was being implemented in Mexico, which does not permit us to generalize the hypothesis that under this model, better results were obtained for TFP.

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