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Technical Efficiency in the Mexican Manufacturing Sector: A Stochastic Frontier Approach

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Abstract

This paper analyzes the technical efficiency in the Mexican manufacturing sector in which determinants and changes of the efficiency since NAFTA (North American Free Trade Agreement) are studied using the Panel Data Stochastic Frontier Analysis in its time-invariant and time-variant versions, comparing each other. It was used the Annual Industry Survey (AIS), which panel data information allow us to model the efficiency performance of firms in the period 1994-2001. Our main findings show that Mexican manufacturing firms worked, in average, at almost 23% of its potential product (compared with the best firm performance) and that there was a slight lost of capacity along time (1994-2001). Additionally, could be detected structural change, understood it as the change of firms' ranking observed in the model and the coefficient of the production function. Moreover, could be detected those firms that were consistent, winners or losers in the process of openness. Finally, under the assumption of Cournot duopoly competition, there are studied determinants for R&D investment.

Keywords: Panel Data, Stochastic Frontier, Efficiency, Time-Variant, Time-Invariant.

Resumen

Un supuesto esencial del cual se parte en microeconomía es que las empresas son homogéneas. Esto equivale al supuesto de la competencia perfecta y que todas las empresas operan bajo el mismo nivel de eficiencia. Sin embargo, muchos estudios demuestran que este supuesto no se aplica en todos los casos de la realidad (Caves, 1989), y México no es la excepción. Con la apertura comercial, las empresas mexicanas entraron en una nueva fase competitiva. Este trabajo pretende medir el impacto de la apertura comercial en la eficiencia técnica de las empresas, con base en la metodología de los modelos de Frontera Estocástica con Panel de Datos, de 1994 a 1991. Se encuentra que algunas empresas son consistentes después de la apertura; sin embrago otras pierden eficiencia.

Palabras clave: panel de datos, frontera estocástica, eficiencia, tiempo variable, tiempo invariable.

Technical Efficiency in the Mexican Manufacturing Sector: A Stochastic Frontier Approach

Brasil Acosta-Peña[*]

October 24, 2011

Abstract

This paper analyzes the technical efficiency in the Mexican manufacturing sector in which determinants and changes of the efficiency since NAFTA (North American Free Trade Agreement) are studied using the Panel Data Stochastic Frontier Analysis in its time-invariant and time-variant versions, comparing each other. It was used the Annual Industry Survey (AIS), which panel data information allow us to model the efficiency performance of firms in the period 1994-2001. Our main findings show that Mexican manufacturing firms worked, in average, at almost 23% of its potential product (compared with the best firm performance) and that there was a slight lost of capacity along time (1994-2001). Additionally, could be detected structural change, understood it as the change of firms' ranking observed in the model and the coefficient of the production function. Moreover, could be detected those firms that were consistent, winners or losers in the process of openness. Finally, under the assumption of Cournot duopoly competition, there are studied determinants for R&D investment .

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[*] I would like to thank Professor William Green for his helpful comments; Andres Aradillas-Lopez for his support; and to all those who have contributed to this paper. *Brasil Acosta-Peña*: CIDE. brasil.acosta@cide.edu

1 Introduction

A basic assumption in microeconomic theory is that firms, in general, are homogeneous. Such is represented by the perfect competition framework in which all the firms are assumed to operate at the same level of efficiency. Nonetheless, there are many studies that have shown precisely the contrary (Caves 1989), and Mexico is not the exception to such finding. Moreover, in the last times firms have gradually been exposed to a strong open economy in the worldwide and Mexican firms too. One could expect an improvement in the development of firms which were exposed into the competition environment. In fact, NAFTA (North American Free Trade Agreement), had this as one of its main purposes. But, in practice, what happened? This paper analysis the technical efficiency in the Mexican manufacturing sector in which determinants and changes of the efficiency from the beginning of NAFTA, 1994 to 2001, are measured using the Panel Data Stochastic Frontier Models.

NAFTA transformed Mexico from an inward-looking economy into largely open economy (Calderon and Voicu, 2004). Tariff politics were designed in order to open Manufacturing sector gradually giving it the opportunity to have more competitive firms. A good indicator that could help to measure that impact is the productivity (efficiency) at firm level and its evolution. There are many ways for modeling it. Calderon and Voicu (2004), for example, studied a detailed analysis of performance of Mexican manufacturing firms between 1993 and 2000. They constructed the estimators of individual plant productivity and investigated the relationship between trade reforms and plant performance, using Levinshon and Petrin (2001) methodology instead of Olley and Pakes (1996) which seems to be more restrictive. They found that “access to imported inputs is more significant vehicle for productivity enhancing effects of trade openness, and that investment in technology is, by far, most strongly correlated with plant productivity”.

In this work we used the main information gathered in Annual Industrial Survey (AIS) which allows us modeling efficiency (productivity) using Panel Data Stochastic Frontier technique developed below, in order to show determinants of the poor development observed by Mexican manufacturing sector, in contrast to the optimistic projections that were made. At the same time, we try to explain that the crisis was not the main reason of this poor development, but the lack or lost of efficiency observed. A good survey of

studies realized using the AIS for Mexico, can be found in Calderon and Voicu (2004). However, none of them has used the methodology presented here.
Section 2 presents a survey of the stochastic frontier panel data model, followed by description of data base in Section 3. Empirical results are presented in Section 4 and conclusions in the Section 5.

2 Panel Data Stochastic Frontier Model

The field of the stochastic frontier estimation of technical (and cost) efficiency is enormous and growing (Greene 2002). Most of studies are based on the fixed effects model (Schmidt and Sickles 1984) and random effects model (Pitt and Lee 1981). In both cases time invariant technical efficiency is assumed. This could be questionable, particularly in a long panel. As an alternative approach, the Battese and Coelli's (1992) parametrization of time-effects has been proposed. Following (Kumbahakar and Lovell, 2000, pg. 63-114), I present a brief review of stochastic frontier models in order to estimate the technical efficiency.

2.1 Cross-Sectional Production Frontier Models

It is assumed, in general that cross-sectional data on the quantities of N inputs used to produce a *single output* are available to the econometrist for each of I producers. A production frontier model can be written as

$$y_i = f(x_i; \beta) \cdot TE_i \tag{1}$$

where y_i is the scalar product output of the producer i, $i = 1, ..., I$; x_i is a vector of N inputs used by producer i; β is a vector of technology parameters to be estimated, and $f(x_i; \beta)$ is the production frontier; in other words, $f(\cdot)$ measure the possibility to reach the maximum product given different combinations of inputs and technological parameters, β.

Then, rearranging (1), we have

$$TE_i = \frac{y_i}{f(x_i; \beta)} \tag{2}$$

which defines technical efficiency as the ratio of observed output to maximum feasible output. Indeed, y_i achieves its maximum feasible value of $f(x_i;\beta)$ if, and only if, $TE_i = 1$. Otherwise $TE_i < 1$ provides a measure of the shortfall of observed output from maximum feasible. It is important to notice that $f(x_i;\beta)$ in (1) is *deterministic*, which means that if there is a shortfall in (2) should be attributed, directly, to the inefficiency. This model does not capture some random shocks, that could explain that shortfall in the production process, shocks that are not under producers' control. To incorporate producer-specific random shocks into the analysis requires the specification of a *stochastic production frontier* as follows

$$y_i = f(x_i;\beta) \cdot exp\{v_i\} \cdot TE_i \tag{3}$$

where $[f(x_i;\beta) \cdot exp\{v_i\}]$ is the *stochastic production frontier*, which is defined for two parts: the *deterministic* one, $f(x_i;\beta)$; and, the *stochastic*[1] one: $exp\{v_i\}$. Then, *technical efficiency* can be represented in this way

$$TE_i = \frac{y_i}{f(x_i;\beta) \cdot exp\{v_i\}} \tag{4}$$

here, y_i achieves its maximum feasible output of $[f(x_i;\beta) \cdot exp\{v_i\}]$ if, and only if, $TE_i = 1$. Otherwise $TE_i < 1$ provides a measure of the shortfall of observed output from maximum feasible output in an environment characterized by $exp\{v_i\}$. Technical efficiency can be estimated using either the deterministic production frontier model given by equations (1) and (2), or the stochastic production frontier model given by the equations (3) and (4).

The goal is to estimate the technical parameters, $\beta's$, and the technical efficient measure, TE_i. There is more than one way to achieve this objective. Here, I will mention some estimation techniques in the cross-section case, in order to be deeper in panel data stochastic frontier analysis case, which will be cover with more detail. Then, cross-sectional frontier model can be estimated as follows[2]:

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[1] Note: assumptions about this component will be specified below.

[2] For details, see Kumbhakar and Lovell, 2000. Pg. 66-95.

$$Deterministic\ Production\ Frontier \begin{cases} 1 \quad \text{Goal Programing} \\ \\ 2 \quad \text{Corrected Ordinary Least Squares} \\ \\ 3 \quad \text{Modified Ordinary Least Square} \end{cases}$$

$$Stochastic\ Production\ Frontier \begin{cases} 1 \quad \text{Normal-Half Normal Model} \\ \\ 2 \quad \text{Normal-Exponential Model} \\ \\ 3 \quad \text{Normal-Gamma Model} \\ \\ 4 \quad \text{Method of Moments Approach} \end{cases}$$

2.2 Panel Data Production Frontier Models

Evidently, panel data (repeated observation on each producer, or, the same producer followed in more than one period) contains more information than does a single cross section. Have access to panel data is convenient in more than one sense: First, conventional panel data techniques can be adapted in order to estimate stochastic production frontier models. Second, repeated observations on a sample of producer can serve as a substitute for strong assumptions made in the cross-sectional environment. Finally, since adding more observations on each producer generates information not provided by adding more producers to a cross-section, the technical efficiency of each producer in the sample can be estimated consistently as $T \to \infty$, T being the number of observations on each producer.

Panel data can be *balanced* (each producer is observed T times) and *unbalanced* (producer i is observed $T_i \leq T$). In this study we use a balanced panel. Again, we assume that there is *more than one inputs* (multiple inputs) that are combined using certain technology (represented by the production function), which result is a *single output*. There are *two main assumptions* to be done having in hand a panel data: Can be allowed that technical efficiency vary across producer, but is assumed to be constant through time for each producer, this model is known as *time invariant technical efficiency*; this assumption could be implausible in long panels. That is why we include the assumption of *time variant technical efficiency* which allows that technical efficiency vary across producer and through time for each producer.

2.2.1 Time-Invariant Technical Efficiency

Set up of the model: we assumed to have I producers ($i = 1, ..., I$), followed in T periods ($t = 1, ...T$). A Cobb-Douglas production frontier with *time-invariant* technical efficiency:

$$lny_{it} = \beta_0 + \sum_n \beta_n lnx_{nit} + v_{it} - u_i \tag{5}$$

where:

y_{it}: is the output of the producer i at time t,

β_0: is the intercept,

β_n: are the "technological parameters",

x_{nit}: is the vector of inputs of the production function of producer i at time t,

v_{it}: two-sided "noise" component. Production can be affected by random shocks out side the control of producers.

u_i: shocks attributed to the technical efficiency.

Then, v_{it} represents random statistical noise and $u_i \geq 0$ represents technical inefficiency[3]. Notice that technical change is not allowed, since u_i does not vary over the time, but vary over producers. This model is very similar to a conventional panel data model with producer effects but without time effects, the only difference is that producer effects are required to be non-negative. Again, parameters of the model, and technical efficiency can be estimated in a number of ways.

The Fixed-Effects Model: Assumptions:

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[3] Notices that: $lny_{it} - (\beta_0 + \sum_n \beta_n lnx_{nit} + v_{it}) = -u_i$, but $lny_{it} \leq (\beta_0 + \sum_n \beta_n lnx_{nit} + v_{it})$, which implies that u_i must be positive.

1. $u_i \geq 0$
2. v_{it} are iid $(0, \sigma_v^2)$
3. We make no distributional assumptions on the u_i
4. We allowed u_i to be correlated with regressors or with the v_{it}.

Given that u_i does not vary in time, it is treated as fixed (nonrandom) effects, then, can be considered as *specific intercept parameters*, which can be estimated along with the $\beta_n s$. Consequently, the model can be estimated by applying OLS to:

$$lny_{it} = \beta_{0i} + \sum_n \beta_n lnx_{nit} + v_{it} \tag{6}$$

where $\beta_{0i} = \beta_0 - u_i$ are producer specific intercepts. After the estimation we can employ the normalization

$$\hat{\beta_0} = max_i\{\hat{\beta_{0i}}\} \tag{7}$$

then, u_i are estimated using

$$\hat{u_i} = \hat{\beta_0} - \hat{\beta_{0i}} \tag{8}$$

notice that this ensures the assumption that $u_i \geq 0$. Producer-specific estimates of technical efficiency are then given by

$$TE_i = exp\{-\hat{u_i}\} \tag{9}$$

we can observe that in this model at least one producer is assumed to be 100% technical efficient, and the rest of producers measure their efficiency relatively to this "*benchmark*" producer(s).

Fixed-effect model is quite simple to be calculated, and has nice consistency properties, and provides consistent estimates of producer-specific technical efficiency. Nonetheless, fixed-effects model have some potentially drawback: u_i not necessarily capture only the time-invariant technical efficiency, capture *all* phenomena (such as the regulatory environment, as an example). Then, the econometrist can confound variation with technical efficiency with variation in other effects. That is why in the literature was proposed the next model.

The Random-Effects Model: In this framework we assumed that u_i is randomly distributed with constant media and variance, but uncorrelated with the regressors and the error term v_{it}. There is no another assumption to be done about u_i, only that it should hold the nonnegative requirement. Again, it is assumed that v_{it} have zero expectation and constant variance. Under this assumptions we are able to include *time-invariant* regressors in the model.

$$\begin{aligned} \ln y_{it} &= [\beta_0 - E(u_i)] + \sum_n \beta_n \ln x_{nit} + v_{it} - [u_i - E(u_i)] \\ &= \beta_0^* + \sum_n \beta_n \ln x_{nit} + v_{it} - u_i^* \end{aligned} \tag{10}$$

This random-effects model fits exactly into the one-way error components model in the panel data literature (see Baltagi 2005 pg. 107-8), then can be estimated by the standard two-step Generalized Least Squares (GLS) method. In the first step all parameters are estimated using OLS. The two variance components are estimated by any of several methods. In the second step β_0^* and the $\beta_n s$ are reestimated using feasible GLS. There is only one intercept term to be estimated because β_0^* does not depend on i, because by assumption $E(u_i)$ is a constant. Once β_0^* and $\beta_n s$ have been estimated using feasible GLS, the u_i^* can be estimated from the residuals by means of

$$\hat{u}_i^* = \frac{1}{T} \sum_t \left[\ln y_{it} - \hat{\beta}_0^* - \sum_n \hat{\beta}_n \ln x_{nit} \right] \tag{11}$$

And finally, the estimations of u_i are obtained by means of the normalization:

$$\hat{u}_i = max_i\{\hat{u}_i^*\} - \hat{u}_i^* \tag{12}$$

These estimates are consistent as both $I \to \infty$ and $T \to \infty$. Estimates of producer-specific technical efficiency can be obtained by substituting $\hat{u}_i$ in (9). There is more than one ways of estimates u_i, for example, using best linear unbiased predictor (BLUP), (see Kumbahakar and Lovell, 2000, pg. 101).

Finally, in the time-invariant framework we can assume certain distributions of the errors and estimate parameters and technical efficiency using *maximum likelihood.*

Maximum Likelihood: This technique is widely used in empirical analysis. In this work was used. The general setup of the model is:

(i) $v_{it} \sim iid\ N(0, \sigma_v^2)$

(ii) $u_i \sim iid\ N^+(0, \sigma_u^2)$

(iii) v_{it} and u_i are distributed independently of each other, and of the regressors.

Pit and Lee (1981) used this assumptions to estimate technical efficiency using panel data. We will use this parametric specification of the *random effects* model which adds the normality and half-normality assumptions[4], considering the inefficiency as *time-invariant.* The density of u is given by

$$f(u) = \frac{2}{\sqrt{2\pi}\sigma_u} exp\Big\{ - \frac{u^2}{2\sigma_u^2} \Big\} \tag{13}$$

the density function of $\mathbf{v} = (v_1, ..., v_T)'$, which depends on time, is

$$f(\mathbf{v}) = \frac{1}{(2\pi)^{T/2}\sigma_v^T} \cdot exp\Big\{ \frac{-\mathbf{v'v}}{2\sigma_v^2} \Big\} \tag{14}$$

then, given the independence assumption the joint density function of u and $\mathbf{v}$ is

$$f(u, \mathbf{v}) = \frac{2}{(2\pi)^{(T+1)/2}\sigma_u\sigma_v^T} \cdot exp\Big\{ - \frac{u^2}{2\sigma_u^2} - \frac{\mathbf{v'v}}{2\sigma_v^2} \Big\} \tag{15}$$

the joint density of u and $\boldsymbol{\varepsilon} = (v_1 - u, ..., v_T - u)'$ is

$$f(u, \boldsymbol{\varepsilon}) = \frac{2}{(2\pi)^{(T+1)/2}\sigma_u\sigma_v^T} \cdot exp\Big\{ - \frac{(u - \mu_*)^2}{2\sigma_*^2} - \frac{\boldsymbol{\varepsilon}'\boldsymbol{\varepsilon}}{2\sigma_v^2} + \frac{\mu_*^2}{2\sigma_*^2} \Big\} \tag{16}$$

where

$$\mu_* = -\frac{T\sigma_u^2\bar{\boldsymbol{\varepsilon}}}{\sigma_v^2 + T\sigma_u^2}$$

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[4] N^+ represents the normal distribution when the support of the error term u_i is positive.

$$\sigma_*^2 = \frac{\sigma_u^2 \sigma_v^2}{\sigma_v^2 + T\sigma_u^2}$$

$$\overline{\boldsymbol{\varepsilon}} = \frac{1}{T}\sum_t \boldsymbol{\varepsilon}_{it}$$

consequently, the marginal density function of $\boldsymbol{\varepsilon}$ is

$$\begin{aligned} f(\boldsymbol{\varepsilon}) &= \int_0^\infty f(u,\boldsymbol{\varepsilon})du & (17)\\ &= \frac{2[1-\boldsymbol{\Phi}(-\mu_*/\sigma_*)]}{(2\pi)^{T/2}\sigma_v^{(T-1)}(\sigma_v^2+T\sigma_u^2)^{1/2}} \cdot exp\Big\{-\frac{\boldsymbol{\varepsilon}'\boldsymbol{\varepsilon}}{2\sigma_v^2}+\frac{\mu_*^2}{2\sigma_*^2}\Big\} & (18)\end{aligned}$$

where $\boldsymbol{\Phi}(\cdot)$ is the standard normal cumulative distribution. Then, we assumed that the econometrist have in hand sample of I producer, each observed at for T periods of time, so the likelihood function is

$$\begin{aligned} \ln L &= constant - \frac{I(T-1)}{2}\ln\sigma_v^2 - \frac{I}{2}\ln(\sigma_v^2+T\sigma_u^2)\\ &+ \sum_i \ln\Big[1-\boldsymbol{\Phi}\Big(-\frac{\mu_{*i}}{\sigma_*}\Big)\Big] - \frac{\sum_i \boldsymbol{\varepsilon}_i'\boldsymbol{\varepsilon}_i}{2\sigma_v^2} + \frac{1}{2}\sum_i\Big(\frac{\mu_{*i}}{\sigma_*}\Big)^2 & (19)\end{aligned}$$

This log likelihood function can be maximized with respect to the parameters to obtain maximum likelihood[5] estimates of β, σ_v^2 and σ_u^2. Next step is to obtain estimates of *producer-specific time-invariant technical efficiency.* We start deriving the conditional distribution $(u|\boldsymbol{\varepsilon})$, using its definition:

$$\begin{aligned} f(u|\boldsymbol{\varepsilon}) &= \frac{f(u,\boldsymbol{\varepsilon})}{f(\boldsymbol{\varepsilon})}\\ &= \frac{1}{(2\pi)^{1/2}\sigma_*[1-\boldsymbol{\Phi}(-\mu_*/\sigma_*)]}\cdot exp\Bigg\{-\frac{(u-\mu_*)^2}{2\sigma_*^2}\Bigg\} & (20)\end{aligned}$$

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[5] Remember that we are in the "second step" in which we have already estimated u and v, then "observable" variables in this likelihood function are estimation errors that come from observable data (x and y), ε.

which is the density function of a variable distributed as $N^+(\mu_*, \sigma_*^2)$, where N^+ indicates that is positive normal distribution. Then, the mean (or the mode) of this distribution can be used as a point estimator of technical efficiency, then we have:

$$\hat{u}_i = E(u_i|\boldsymbol{\varepsilon}_i) = \mu_{*i} + \sigma_* \left[\frac{\boldsymbol{\phi}(-\mu_{*i}/\sigma_*)}{1 - \boldsymbol{\Phi}(-\mu_{*i}/\sigma_*)} \right] \tag{21}$$

The estimators of u_i are consistent as $T \to \infty$. And, again, $\hat{u}_i$ can be substituted in the equation (9) in order to obtain the producer-specific estimates of time-invariant technical efficiency.

2.2.2 Time-Variant Technical Efficiency

If the econometrist have access to a long panel, it is plausible to think that technical efficiency is not constant. Particularly in a competitive environment. Then, we expect that technical inefficiency changes over time. Then, we are able to relax the assumptions that the producer-specific technical efficiency is *time-variant.* As in time-invariant model, the estimation of a time-varying technical efficiency model can be reach using fixed or random effects and maximum likelihood approach.

Fixed-Effects Models and Random-Effects Models: Cornwell, Schmidt, and Sickles (1990), and Kumbhakar (1990) were the first to propose a stochastic production frontier panel data model with time-varying technical efficiency.

$$\begin{aligned} \ln y_{it} &= \beta_{0t} + \sum_n \beta_n \ln x_{nit} + v_{it} - u_{it} \\ &= \beta_{it} + \sum_n \beta_n \ln x_{nit} + v_{it} \end{aligned} \tag{22}$$

where β_{0t} is the production frontier intercept common to all producers in period t, $\beta_{it} = \beta_{0t} - u_{it}$ is the intercept for producer i in period t, an all other variables are as previously defined. The objective is to obtain the estimates of the parameters describing the structure of production technology, and the second objective is to obtain producer-specific estimates of technical efficiency. The main problem is the identification of the intercept, in order to reduce the amount of $I \cdot T$ intercepts to another amount handle, Cornwell, Schmidt, and Sickles (1990) addressed this problem by specifying

$$\beta_{it} = \Omega_{i1} + \Omega_{i2}t + \Omega_{i3}t^2 \tag{23}$$

which reduces the number of intercept parameters to I*3. But, most importantly is that this specification allows technical efficiency to vary through time, and in a different manner for each producer. We can delete u_{it} from (22), estimate the $\beta_n s$, from the residuals, and regress the residuals on a constant t and t^2 to obtain estimations of $(\Omega_{i1}, \Omega_{i2}, \Omega_{i3})$ for each producer. Then we can estimate β_{it} and can be defined $\hat{\beta}_{0t} = max_i\{\hat{\beta}_{it}\}$ as the estimated intercept of the production frontier in the period t. The technical efficiency of each producer in period t is then estimated as $TE_{it} = exp\{-\hat{u}_{it}\}$, where $\hat{u}_{it} = (\hat{\beta}_{0t} - \hat{\beta}_{it})$. Thus, similar that in the time-invariant case, in each period at least one producer is consider to be 100% technical efficiency, but it can change through time.

Maximum Likelihood: This procedure is too similar to the time-invariant, then we arrive to the next likelihood function[6]:

$$\begin{aligned} \ln L &= constant - \frac{I}{2}\ln\sigma_*^2 - \frac{1}{2}\sum_i a_{*i} - \frac{I \cdot T}{2}\ln\sigma_v^2 \\ &- \frac{I}{2}\ln\sigma_u^2 + \sum_i \ln\left[1 - \mathbf{\Phi}\Big(-\frac{\mu_{*i}}{\sigma_*}\Big)\right] \end{aligned} \tag{24}$$

where:

$$\mu_{*i} = \frac{(\sum_t \beta_t \boldsymbol{\varepsilon}_{it})\sigma_v^2}{(\sigma_v^2 + \sigma_u^2 \sum_t \beta_t^2)}$$

$$\sigma_* = \frac{\sigma_v^2 \sigma_u^2}{\sigma_v^2 + \sigma_u^2 \sum_t \beta_t^2}$$

$$a_{*i} = \frac{1}{\sigma_v^2}\left[\sum_t \boldsymbol{\varepsilon}_{it}^2 - \frac{\sigma_u^2(\sum_t \beta_t \cdot \boldsymbol{\varepsilon}_{it})^2}{\sigma_v^2 + \sigma_u^2 \sum_t \beta_t^2}\right]$$

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[6] For details see Kumbahakar and Lovell, 2000, pg. 110-113.

maximizing the log-likelihood function, ln L, we can estimate β, β_t, σ_v^2 and σ_u^2. Analogously, we can derive $u_i|\boldsymbol{\varepsilon}_i \sim N^+(\mu_{*i}, \sigma_*^2)$, and an estimator of u_i can be obtained from the mean (or the mode) of $u_i|\boldsymbol{\varepsilon}_i$.

$$\hat{u}_i = E(u_i|\boldsymbol{\varepsilon}_i) = \mu_{*i} + \sigma_* \left[\frac{\boldsymbol{\phi}(-\mu_{*i}/\sigma_*)}{1 - \boldsymbol{\Phi}(-\mu_{*i}/\sigma_*)} \right] \tag{25}$$

Finally, an alternative time-varying technical efficiency models was proposed by Battese and Coelli (1992), the model is based in next equations:

$$\begin{aligned} \ln y_{it} &= \beta_{0t} + \sum_n \beta_n \ln x_{nit} + v_{it} - u_{it} \\ &= \beta_{it} + \sum_n \beta_n \ln x_{nit} + v_{it} \end{aligned} \tag{26}$$

where

$$u_{it} = \beta(t) \cdot u_t \tag{27}$$

more than one author have proposed a particular functional[7] to $\beta(t)$, but in this work we followed the specification proposed by Battese and Coelli (1992):

$$\beta(t) = \exp\{-\gamma(t - T)\} \tag{28}$$

which has another parameter that should be estimated, γ. The function $\beta(t)$ satisfies the properties: (i) $\beta(t) \geq 0$ and $\beta(t)$ decreases at an increasing rate if $\gamma > 0$, and increases at a decreasing rate if $\gamma < 0$, or remains constant if $\gamma = 0$. Distributional assumptions are normal for v_{it} and truncated normal for u_i, and is used maximum likelihood to obtain estimates of all parameters in the model. The log-likelihood and its partial derivatives are in their paper, they showed that $(u_i|\boldsymbol{\varepsilon}_i) \sim iid\ N^+(\mu_{**i}, \sigma_*^2)$, where $\boldsymbol{\varepsilon}_i = \mathbf{v}_i - \beta \cdot u_i$ and

$$\mu_{**i} = \frac{\mu\sigma_v^2 - \beta'\boldsymbol{\varepsilon}_i\sigma_u^2}{\sigma_v^2 + \beta'\beta\sigma_u^2}$$

$$\sigma_*^2 = \frac{\sigma_u^2\sigma_v^2}{\sigma_v^2 + \beta'\beta\sigma_u^2}$$

---

[7] Lee and Schmidt (1993).

$$\beta' = (\beta(1), ..., \beta(T))$$

if $\gamma = 0$ which implies that $\beta(t) = 1$, and $\beta'\beta = T$, technical efficiency is *time invariant* and μ_{**i} and σ_*^2 collapses to their time invariant version described in (16).

The minimum square error predictor of technical efficiency is

$$\begin{aligned} E(\exp\{-u_{it}\}|\boldsymbol{\varepsilon}_i) &= E(\exp\{\beta(t) \cdot u_t\}|\boldsymbol{\varepsilon}_i) \\ &= \frac{1 - \mathbf{\Phi}(\beta(t)\sigma_* - \mu_{*i}/\sigma_*)}{1 - \mathbf{\Phi}(-\mu_{*i}/\sigma_*)} \\ &\cdot \exp\Big\{ - \beta(t)\mu_{*i} + \frac{1}{2}\beta(t)^2\sigma_*^2\Big\} \qquad (29) \end{aligned}$$

In this paper we will compare both: Pit and Lee (1981), and Battese and Coelli's (1992) approaches. Results from two models will be compared. In the two specifications alike, we will use maximum likelihood estimator instead of least squares; the standard errors where corrected using bootstrap techniques[8], with 1000 replications.

2.3 The Model

The functional form in this work, for the sake of parsimony, will be Cobb-Douglas as was described in the last section[9]; despite its simplicity, it has proved to be a surprisingly good description of technology (Hayashi, 2000. Pg. 63). Then the model is:

Production Function

$$y_{it} = f(l_{it}, k_{it}, o_{it}) + v_{it} - u_{it} \qquad (30)$$

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[8] For bootstrapping techniques, a useful guide is Handbook of Econometrics, 4, *Methodology and theory for the bootstrap* P. Hall (1994).

[9] The analysis could be done using a deterministic transcendental logarithmic (translog) production function (Greene 1997):

$$lny_{it} = ln\alpha_i + \lambda_t + \sum \beta_k ln_{kit} + \sum \beta_{2k}(lnx_{kit})^2 + \tfrac{1}{2}\Sigma_{q\neq w}\gamma_{qw}(lnx_{qit})(lnx_{wit}) + \varepsilon_{it}$$
$$where, k = 1, ..., p; i = 1, ..., N; t = 1, ..., t_i \; and \; q = 1, ..., p; w = 1, ..., p, q \neq w$$

$$i = 1, 2, ..., 4348;$$

$$t = 1, 2, ..., 8, (1994, ..., 2001)$$

Where[10],

$$f(l_{it}, k_{it}, o_{it}) = a + \beta_1 l_{it} + \beta_1 k_{it} + \beta_1 o_{it} \tag{31}$$

y is log of net value of total sales; l, log of value of the labor force; k, log of value of the net capital stock; o, log of value of other inputs, including value of the electrical consumption (see Section 3 below). It is important to recall that the error term u will be: u_i, in the *time invariant* model, and u_{it}, in the *time varying* one.

Inefficiency Analysis

In order to identify the sources of inefficiency, as a second step, u_{it} (estimated) is modeled using OLS. Explanatory variables are the following ones: 3 dummy variables and 2 decision variables.

$$\hat{u}_{it} = g(h_{it}) + W_{it} \tag{32}$$

$$h_{it} = (Export_{it}, RD_{it}, Publicity_{it}, ER_{it}, \pi_{it}) \tag{33}$$

Assuming $g(\bullet)$ *linear*, then,

$$\hat{u}_{it} = \delta_0 + \delta_1 Export_{it} + \delta_2 RD_{it} + \delta_3 Publicity_{it} + \delta_4 ER_{it} + \delta_5 \pi_{it} + W_{it} \tag{34}$$

Where *dummy variables* are: $Export_{it}$, 1 if firm i exports at time t, 0 otherwise; RD_{it}, 1 if firm i invests in Research and Development at time t, 0 otherwise and $Publicity_{it}$, 1 if firm i invests in publicity at time t, 0 otherwise. On the other hand, *decision variables* are: ER_{it}, which represents exchange rate (Mexican pesos per dollar), and π_{it}, which represents the annual inflation rate (based in Producer Price Index). W_{it} is the OLS error

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[10] $F(L, K, O) = AL^{\beta_1} K^{\beta_2} O^{\beta_3},\ such\ that\ \beta_1 + \beta_2 + \beta_3 = 1; then,\ lnF(\bullet) = f(l, k, o) = lnA + \beta_1 lnL + \beta_2 lnK + \beta_3 lnO = \alpha + \beta_1 l + \beta_2 k + \beta_3 o,\ where\ \alpha = lnA, l = lnL, k = lnK,\ and\ o = lnO$

term, which must satisfied the classical assumptions.

The first three dummy variables include those qualitative aspects that could have influence in the efficiency of the firms. For example, one could expect that those export oriented firms being more efficient than those whose behavior is inward looking. Similar analysis can be made in the R&D case. At the same time, publicity was included in order to capture behavior of those firms related with the competition, and how this kind of investments affect, or not, the efficiency; we expect that the more aggressive in publicity investment, the more efficiency the firm would have; this is not necessarily true, but could be understood as a signal of efficiency: a poor firm will not invest in publicity. Finally, exchange rate and inflation rate were included in order to capture their influence in the efficiency as indicator of "external influences" in the internal decisions of the firms.

3 The Mexican Manufacturing Sector Data Set

The data set used here has been obtained from the Annual Industrial Survey (AIS) applied to the Mexican manufacturing sector (sample). The full data set observes 6867 firms; nonetheless, we discarded those data which were uncompleted and unable to be analyzed because of the lack of information. Thus, we have in hand a panel-data sample with 4348 manufacturing firms followed 8 periods (1994-2001), and distributed in 9 subsectors (See appendix). Descriptive statistics for the data used in this study are given in Table 1:

Table 1. Descriptive Statistics

Variables	Means	Standard Deviation	Description
Production (Y)	218699.00	1132205.00	Thousands of Mexican Pesos
Labor (L)	21978.23	60315.36	Thousands of Mexican Pesos
Capital (K)	46482.96	219831.00	Thousands of Mexican Pesos
Other Inputs (O)	152382.20	816043.80	Thousands of Mexican Pesos
Export			1 if exports 0 otherwise
RD			1 if firm spend in R&D 0 otherwise
Publicity			1 if firm spend in Publicity 0 otherwise
Exchange Rate (ER)	7.968588	2.01293	Mexican Pesos / Dollars
Inflation ()	17.72844	12.62997	% (From Price Productor Index)

* Lowercase: y, l, k and o, are logs of its corresponding uppercase.

Behavior of the manufacturing sector, export oriented, shows three different stages as could be seen in Figure 1: first, the number of exporting firms raised 56 percent since NAFTA, 1994 to 1997 (crisis period). The second period shows an important failure (-10 percent) only in one year (1997-1998). Since then, the number of export manufacturing firms has been relatively constant (1998-2001). Additionally, Figure 2, shows that the exporting sector share of total production value at 1994 was 57 percent and grew gradually until 1997 when achieved its maximum value: 77 percent. Since then, there have not had significant changes and its share on total production value is around 74 percent.

Figure 1: Manufacturing Export Sector Evolution (1994-2001)

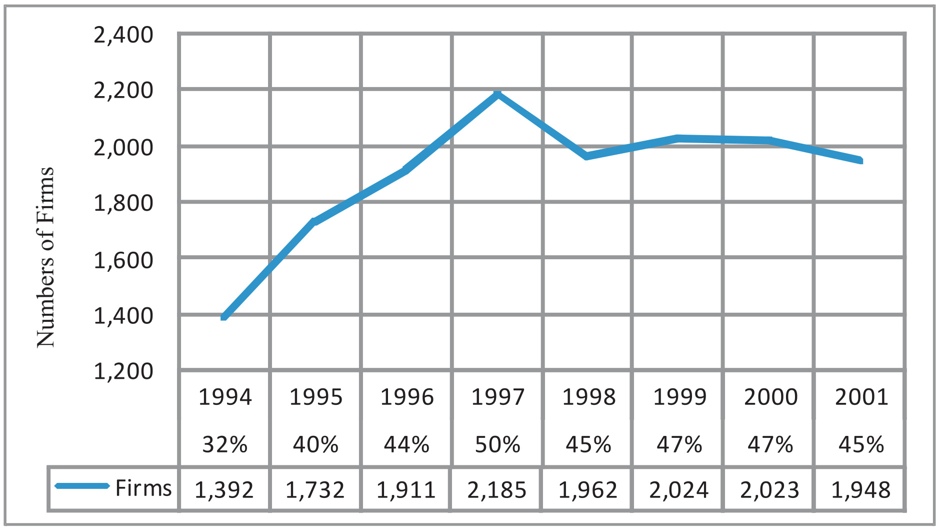
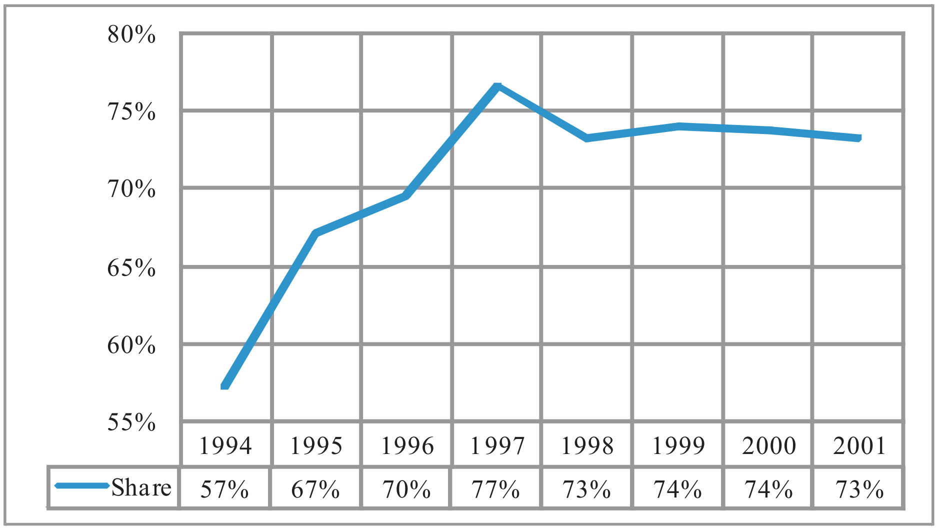


Figure 2:
Total Production Value Manufacturing Export Share (1994-2001)



In order to capture these changes, the empirical strategy will be the next: 1) we will study the whole period: 1994-2001, additionally, as the manufacturing sector seems to have had a structural change, we will try to capture it dividing main period in two parts: 2) 1994-1997 (Mexican Crisis period); 3) 1998-2001 (Transitional period).

4 Empirical Results

The stochastic frontier panel data model was estimated, as was mentioned, using the maximum likelihood method which standard errors were corrected using bootstrap techniques (1000 replications). The estimated coefficients of Equation (31) in its two models, time-invariant and time varying, are presented in Table 2.

4.1 Period 1994-2001: Production Function Results

Table 2. Production Function Estimated Coefficients

(1994-2001)

	Time Invariant Model		Time Variant Model	
	Coeff.	t-value	Coeff.	t-value
Cosntant	2.4273	0.43	1.9855	32.48
l=ln(L)	0.1136	41.15	0.1255	44.31
k=ln(K)	0.0194	10.63	0.0224	12.31
o=ln(O)	0.8603	360.46	0.8623	362.63

This is the calculation of the Cobb-Douglas coefficient. Then, the constant term in a Cobb-Douglas function represents the *total factor productivity*, and is a variable which accounts for effects in total output not caused by inputs. In time invariant model, the constant term was no significant, this means that the the effects in total output depends only of the inputs. On the contrary, in time variant model the constant term was significant, which means that there is effects in total output driven by other reasons and not caused by inputs, which make sense since we allowed technical efficiency changes in each period (time-varying model).

All coefficient inputs (time invariant and time variant models) are positive and statistically significant at 1-percent level; results are very similar between two models.

Eventhough constant term in the time invariant model was no significant, we can estimate u_i using the steps described in section 2. Then, having in hand estimated inefficiencies for both models, u_i and u_{it}, we can compare them. The correspondence between both sets of estimation draws attention:

Table 3 shows that pairwise correlation is near to 1 (0.9148).

Table 3. Analysis of Estimated Technical Inefficiencies

	Time Invariant	Time Variant
Mean	1.7310	1.5080
Standar Dev.	0.2063	0.1907
Correlation	0.9148	

We can rank, in terms of inefficiency[11], producers of the Mexican manufacturing sector using both models: time-invariant and time-variant. We observe that time-invariant model reproduces, in more than one case, the ranking of time-variant model as can be seen in Figure 3. However, distribution of inefficiency is different between time-invariant and time-variant models as can be seen in inefficiency kernel[12] estimated distribution (Figure 4). For instance, mean and standard deviation is greater in time-invariant case, $\hat{u}_i$, compared with time-variant $\hat{u}_{it}$ case[13]. This implies less variability in time-variant model of inefficiency. Eventhough this difference between models exists, the ranking made for both models is almost the same as it will be seen below.

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[11] Which is analogous if we express it in terms of efficiency, because we use a monotone transformation of error terms $(\hat{TE_i}) = exp(-\hat{u}_i)$. The scatter plot of $(\hat{TE_i}) = exp(-\hat{u}_i)$ versus $(\hat{TE_i}) = exp(-\hat{u}_{it})$ is very similar to Figure 3.

[12] We use Epanechnikov kernel function:

$$\hat{f} = \hat{f}(x) = \frac{1}{nh}\sum_{i=1}^{n} K\Big(\frac{x_i - x}{h}\Big)$$

where

$$K(u) = \frac{3}{4}(1 - u^2)\mathbf{1}_{\{|u|\leq 1\}},$$

where $\mathbf{1}_{\{A\}} = 1$ if A holds; 0, otherwise. Optimal bandwidth was used. See Pagan and Ullah (1999), pg 28.

[13] *Time-invariant* mean and standard deviation were 1.73 and 0.21 respectively; *time-variant* mean and standard deviation were in turn 1.51 and 0.19.

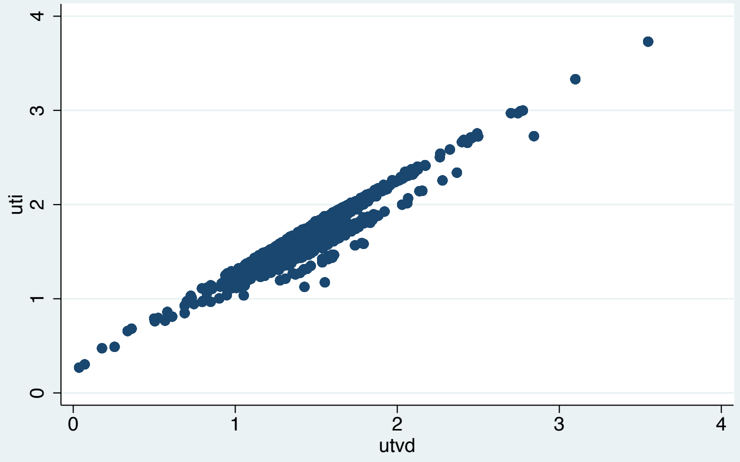

Figure 3. Inefficiencies
Time Invariant (uti) vs. Time Variant Models (utvd)

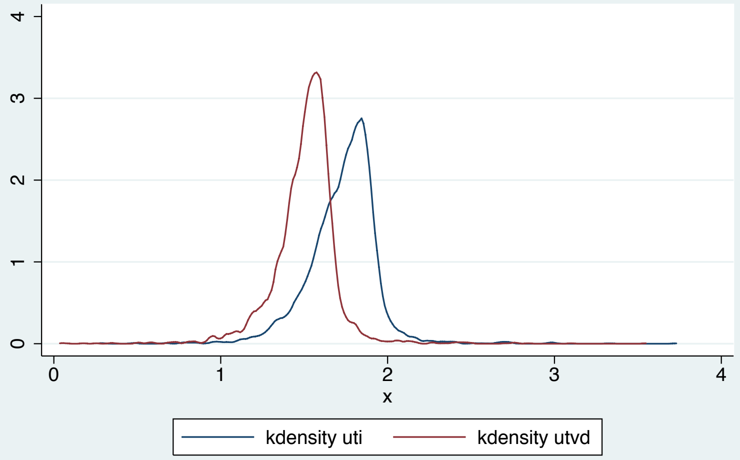

Figure 4. Inefficiencies, Kernel Density Estimation of
Time Invariant (uti) vs. Time Variant Models (utvd)

4.2 Period 1994-2001: Sources of Inefficiency

Table 4 presents a second step analysis in order to identify sources of inefficiencies from the two models. Since u_i is given in proportional terms, the absolute magnitudes of the coefficients give the proportional impacts (Greene, 2002). Results in both models, suggest that exports and publicity are significant in explaining variation in efficiency. Exports impulse the efficiency (negative sign)[14], and publicity reduces it (positive sign), maybe because of its impact in the costs. In particular, R&D has ambiguous results: in the expected direction, time invariant model shows that R&D is a source of efficiency (negative sign and significant). On the contrary, in time variant model, R&D is not significant. Figure 1A in appendix could help us to explain the problem: it shows us the number of firms that invested on R&D. It should be noticed that from 1994 to 1997, the percentage of total number of firms that invested in R&D grew from 9 to 23%; since then, this percentage felt until it reached 16 percent and stayed. It seems that time-variant model capture this behavior which explains that R&D was not statistically significant. Finally, neither exchange rate nor inflation[15] has statistic significance. It means that inefficiency depends on firm's internal structure and decisions rather than external influences such as prices or exchange rate.

Table 4. Second Step Regression Results

	Time Invariant		Time Variant	
	Coeff.	t-value*	Coeff.	t-value*
Constant	1.7343	774.78	1.5046	732.34
Export	-0.0195	-9.03	-0.0088	-4.2
R&D	-0.0147	-4.76	-0.0032	-1.14
Publicity	0.0115	4.87	0.0118	5.47
ER	0.0005	0.95	0.0001	0.27
π_i	0.00001	0.938	0.00001	0.07

*Standard Errors Bootstrap Corrected.

4.3 Period 1994-2001: Firms Performance

Using $\hat{TE}_i$ in both models, time-invariant and time-variant, we can compare performance between firms, in terms of the "benchmark" explained in section 2. Table 5, shows the ten most efficient firms in the manufacturing sector and their levels of technical efficiency over the period 1994-2001 using both models: time-invariant and time-variant.

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[14] Increases in u_i imply lower efficiency (Greene, 2002).

[15] Producer Price Index percentage change is used in this case as a measure of inflation rate.

Table 5. Firms Rank Based on Stochastic Frontier Model with Time-Invariant and Time-Variant assumptions

#Id	Time Invariant	Time Varying	SIC Classif.	Description
1654	1	1	351214	Industrial Gas Manufacturer
376	2	2	314002	Cigarette Manufacture
1510	3	3	351214	Industrial Gas Manufacturer
775	4	4	351214	Industrial Gas Manufacturer
1434	5	5	351214	Industrial Gas Manufacturer
1362	6	6	351214	Industrial Gas Manufacturer
477	7	8	314002	Cigarette Manufacture
1067	8	10	351214	Industrial Gas Manufacturer
3704	9	7	355003	Natural or Synthetic Pieces or Articles Rubber Manufacture
1536	10	9	382106	Joint and Repairer of Machinery and Equipment for other Specific Industries

In general, the two models fit very well and almost coincide; in fact, the first six firms have the same rank in both models; on what remains, they have minimum differences. Interestingly, six firms of the top ten, including the first one, were classified as 351214 (Industrial gas manufacture) and the total number of firms in this classification represents, surprisingly, only 0.34% of the whole manufacturing sector.

Those that are ranked as 2nd and 7th (2nd and 8th, respectively, considering time-variant model), were classified as 314002 (Cigarettes manufacture). The 9th (or 7th in time-variant case) was classified as 355003 (Natural or synthetic pieces or rubber manufacture articles) and, finally, 10th (or 9th in time-variant model) was classified as 382106 (Manufacture, joint and repair of machinery and equipment for other specific industries).

It seems that time-invariant model underestimate potential efficiency of the firms because of the contrast that can be seen between models. For example, the most efficient firm (1654) worked at 76% of its potential output in the time-invariant model, whereas worked near to 97% of its potential output in time-variant model (see Table 5.1). Although this happened, the important thing is that the ranking fitted well between models as was said before.

Table 5.1. Firms Performance Indices Based on Stochastic

Frontier Model with Time-Invariant and Time-Variant Assumptions

#Id	Time Invariant	Time Varying
1654	0.7646	0.9664
376	0.7402	0.9355
1510	0.6237	0.8450
775	0.6141	0.7845
1434	0.5190	0.7261
1362	0.5061	0.7088
477	0.4680	0.6178
1067	0.4650	0.5812
3704	0.4547	0.6199
1536	0.4518	0.6055

Finally, following the time-invariant model, in average, manufacturing sector, as a whole, is working at 18 percent of its potential product (1994-2001); on the other hand, considering the time-variant version of our model, which includes certain dynamic behavior, we observed a falling in efficiency. Indeed, should be highlight that in 1994 the manufacturing sector as a whole was working at almost 24 percent of its potential product; on the contrary, in 2001 was working at 22 percent (see Figure 4A in Appendix).

4.4 Period 1994-1997 vs. 1998-2001: Production Function

Now, in order to capture structural change, if there exists, analysis will be done by dividing the whole period in two parts: 1994-1997 (Crisis) and 1998-2001 (Transition). Considering the length of both symmetric periods, 4 years each, we are able to use time-invariant assumption, explained in Section 2 above, for modeling technical efficiency.

Table 6. Production Function Coefficients

	1994-1997		1998-2001	
	Coeff.	t-value	Coeff.	t-value
Cosntant	2.4794	0.25	2.4886	0.33
l=ln(L)	0.1464	39.83	0.0978	25.76
k=ln(K)	0.0287	11.70	0.0222	8.49
o=ln(O)	0.8329	274.70	0.8832	265.08

Given the time invariant assumption, in both cases the constant was no significant. In both periods, capital (k) and other inputs (o) are relatively similar: 0.0287 vs. 0.222 and 0.8329 vs. 0.8832 respectively; but, that is not the case of the labor force which was 0.1464 in the first four years and 0.0978 in the next period.

Taking account the fact that our model was expressed in logs, then, coefficients of the production function can be understood as elasticities. The relevant one is β_1: the elasticity of the production with respect to the labor force. Indeed, this coefficient felt from 1994–1997 to 1998–2001, i.e., in the first period, *ceteris paribus*, a 1% increment in labor would lead approximately 0.14% increase in output; in the second period, the same increase in labor (1%), would lead only 0.09% increase in output, less than in the first period. It means that productivity of the labor decayed between periods.

Inefficiency measure, u_i, is notably different between two periods as can be seen in Figure 5. There is not a clear pattern in the scatter plot which means that inefficiency changed in time, eventhough the distribution of inefficiency in both periods was relatively similar (see Figure 6). Another component that gives us information about the existence of structural change is the relatively low pairwise correlation coefficient between inefficiency estimated in both periods: 0.4685.

Table 7. Analysis of Estimated Technical Inefficiencies

	1994-1997	1998-2001
Mean	0.9927	1.0264
Standar Dev.	0.1291	0.1197
Correlation	0.4685	

Figure 5. Inefficiencies

Time Invariant Model (1994–1997) vs. (1997–2001)

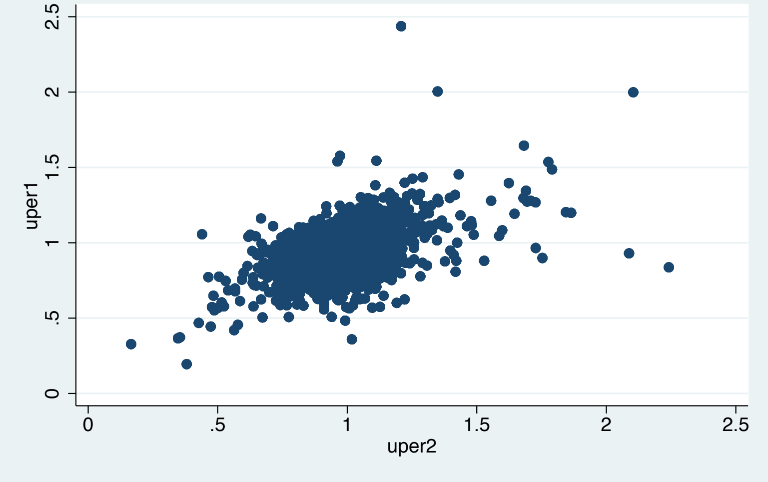
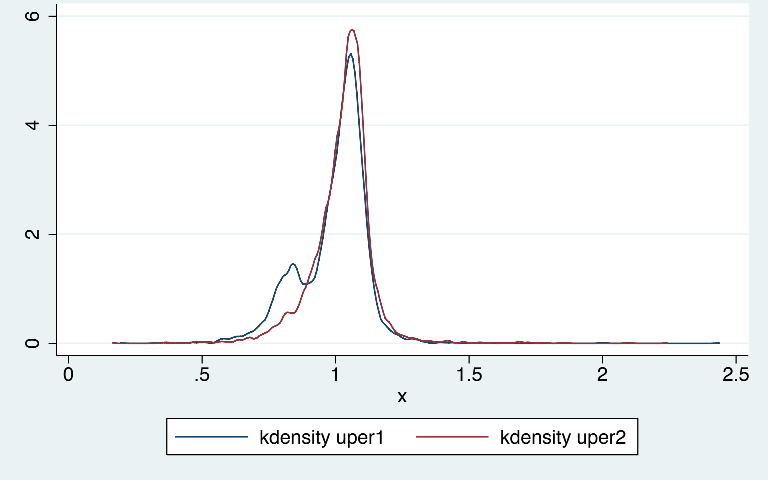


Figure 6. Inefficiencies, Kernel Density Estimation

Time Invariant Model (1994–1997) vs. (1997–2001)



4.5 Period 1994-1997 vs. 1998-2001: Sources of Inefficiency

Results are shown in Table 8.

Table 8. Second Step Regression Results

	1994-1997		1998-2001	
	Coeff.	t-value*	Coeff.	t-value*
Constant	0.9884	552.79	1.0267	520.87
Export	-0.0075	-3.84	-0.0080	-4.34
R&D	-0.0135	-4.5	0.0024	0.95
Publicity	0.0147	7.46	0.0045	2.18
ER	0.0006	0.6	-0.0003	-0.03
π_i	-0.00004	-0.33	0.000005	0.01

*Standard Errors Bootstrap Corrected.

In both periods the constant term is positive and significant. In both cases, export is a source of efficiency (negative sign). On the other hand, as was seen above, spending on publicity reduces the efficiency of the firm in both periods. As in the whole period, neither exchange rate (ER) nor inflation rate (π), as decision variables, were significant. Figure 2A and 3A in the appendix, could help to understand why: in the first one, exchange rate (ER) shows only one important change (1994/12-1995/01) which is the crisis period; since then, eventhough ER rises, monetary policy in Mexico seems to have been efficient and ER was stabilized. In the second one, the inflation rate was drawn. In the first period (1994-1997), inflation rate dramatically arouse, even more than 50 percent; since then, fall gradually until certain stabilization. Then, instability of those variables in the first period could have been the reason because of what firms did not take account them as a decision variables.

Finally, the main source that could explain the structural change is R&D variable. Indeed, in the period 1994-1997 R&D, as expected, was negative and significant which means that a major efficiency was observed. But in period 1998-2001 was not significant which means that firms lost the confidence in R&D as a source of efficiency (see Figure 1A in the appendix).

4.6 Period 1994-1997 vs. 1998-2001: Firms Performance

Table 9, shows firms ranking comparison between periods.

Table 9 Firms Rank and Performance Indices Based on the Stochastic Frontier Model (1994-1997 vs. 1998-2001)

iid	Rank 1994-1997	Efficiency	Rank 1998-2001	Efficiency	subsector
376	1	0.8247	4	0.6846	31
1654	2	0.7217	1	0.8484	35
2298	3	0.6994	1705	0.3618	31
1510	4	0.6943	2	0.7080	35
775	5	0.6900	3	0.7026	35
1067	6	0.6582	18	0.5701	35
1362	7	0.6423	8	0.6238	35
477	8	0.6347	21	0.5619	31
1434	9	0.6275	5	0.6535	35
162	10	0.6177	1280	0.3712	32
3704	20	0.5644	9	0.6210	35
2361	256	0.4626	7	0.6298	35
2310	2310	0.5237	10	0.6174	35
3645	2885	0.3483	6	0.6451	33

In general, the top ten firms of the first period (1994-1997) worked at 68 percent of their capability (in average); in the second period, 1998-2001, there is a slight losing of technical efficiency because, in average, the firms worked at 67 percent of their capability.

Behavior of firms in terms of efficiency measure, reveals that some enterprises have been consistent, but, at the same time, it is possible to detect some winners and some losers. Then, we can define as “consistent” firms those that belong to top ten in the first period and in the second period too (eventhough, they were not in the same ranking); we can define as “winners” those firms that do not belong to top ten in first period but in the second one they are; and, finally, we defined: “losers” to those firms that were in top ten in the first period and were not in the second one.

Taking account this classification, we have 6 “consistent” firms which, surprisingly, are the same first six firms ranked in the Table 5 of both models that were seen before, including 5 firms (the first one too) that are classified as 351214 (Industrial gas manufacture) and, ranking in 2nd place, classified as 314002 (Cigarettes manufacture). The most efficient firm worked at 82 percent of its potential output[16]. “Winners” are 4, but the relevant one is identified as 3645 (see first column of Table 9) which in the first period was placed in 2885th; in the second period, this firm was ranked in the 6th place and is classified as 332001 (Manufacture and repair of furniture, wood mainly). This firm worked at 35 percent in the first period and at 65 percent at the second period. Finally, there are 4 “losers”, but the relevant one is the firm number 2298 (see Table 9) which is classified as 312200 (Food preparation and mixture for animals) that felt from 3rd place to 1705th place; moreover, this firm worked at 70% of its potential output in the first period and at 36%, in the second one.

The manufacturing sector, as a whole, in the first period (1994-1997), according with this model (time-invariant), was working at 37 percent of its capacity; in the second period (1998-2001) felt and worked at 36% of its potential output.

Then, the 1995’s Mexican crisis was not itself the main cause of lacking development of the manufacturing sector, but the absence of R&D investments; weak capability of adaptation for “fighting” successfully against the foreign firms; and lacking development of efficiency in the new scenario. Despite this facts, there were some firms that “survived” to the openness and were “consistent”; whereas other firms were “winners” and other firms were “losers” in the process.

5 R&D Strategic Interaction

In the context of NAFTA, we would expect that interaction between firms have had place. Considering, for example, the survivor analysis, we expect that firms increase its investment in R&D, taking account that they believe

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[16] Should be remembered that time-invariant model seems to underestimate the potential efficiency of the firms. And we should remember that this efficiency is related to the “benchmark” firm(s).

that other firms like them would do the same thing. In order to capture interaction behavioral between firms, in particular strategic interaction between the two most important firms of each six digit manufacturing sector in R&D decisions[17], we assume that this two firms interact under a Cournot competition; in other words, each firm should decide the quantity given the expected action to the other firm and the demand structure.

In the simplest model of Cournot competition, we assume that the demand structure is given and unknown by the econometrician. Then, each firm maximize its profits, and price is a commonly known decreasing function of total output. We assume that each firm has a cost function $c(q_i)$, which is a "marginal constant function". This function is an increasing function of the q_i. Market price is set at a level such that demand being equal to the quantity produced by two firms (duopoly). Assuming Nash equilibrium, we can conclude that $q_1 = q_1(q_2)$. Symmetric result is obtained for q_2. Given the equilibrium quantity, firms observe their equilibrium profits, Π_i^*.

5.1 Assumptions

A1. Each of two firm in six digit level produce an homogeneous product. Firms do not cooperate, and because of its size have market power, and compete in quantities, choosing quantities simultaneously. The econometrician does not observe this quantities, neither firm's equilibrium profits Π_i^* (latent variable). Player 1 and player 2 are distinguished each other for the size (which is determined by its sales share): player 1 is the largest firm in each couple of players.

A2. It is assumed that Π_i^*, derived from Nash equilibrium, can be expressed as follows:

$$\Pi_i^* = \boldsymbol{\beta}'\mathbf{X}_i + \varepsilon_i \tag{35}$$

for *i=1,2*.

Following Aradillas-Lopez, (2003),

A3. $\mathbf{X}_1 \in \mathbb{R}^k$ and $\mathbf{X}_2 \in \mathbb{R}^k$ are independent draws from the same distribution with (joint) cdf given by *F(**x**)*, and corresponding pdf given by *dF(**x**)*

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[17] By "most important" we understand those firms whose market share set them in the first and second place of all this six digit industry.

A4. $\varepsilon_1 \in \mathbb{R}$ and $\varepsilon_2 \in \mathbb{R}$ are independent draws from the same distribution with cdf given by $G(\epsilon)$.

A5. ε_i is independent from $\mathbf{X}_i$ for $i \in \{1, 2\}$

A6. *At the time the game is played*, the realizations of $(\mathbf{X}_1, \varepsilon_1)$ and $(\mathbf{X}_2, \varepsilon_2)$ are privately known by players 1 and 2 respectively.

A7. Distributions $(F(\boldsymbol{x}), G(\epsilon))$ are known by both players.

Now, suppose that some time after the game was played, the econometrician have access to M outcomes of the players and the following is true:

B1.-Assumptions (A1-A7) were satisfied when the game was played by each of the N pairs of players.

B2.-The realizations of $\{\mathbf{X}_{1,i}, \mathbf{X}_{2,i}\}_{i=1}^{M}$ are now available to the econometrician.

B3.-The realizations of $\{\varepsilon_{1,i}, \varepsilon_{2,i}\}_{i=1}^{M}$ are *not* available to the econometrician.

B4.-The distribution $G(\epsilon)$ is assumed to be known -up to a finite number of parameters- to the econometrician.

B5.-No particular functional form is assumed for the distribution of $F(\boldsymbol{x})$. We only assume that this distribution does not depend on any of the payoff parameters, beliefs or the unknown parameters of $G(\epsilon)$.

5.2 Decision rule

Now, let us define decision rule. There are two kind of actions that players can choose in this model: "to be aggressive" or "not" in the investment of R&D sense. A firm will be "aggressive" ($y_i = 1$) if $\mathbf{1}[\Pi_i^* > 0]$, where $\mathbf{1}[A]$ is the indicator function: equal to 1 if the event A is true, zero, otherwise.

5.3 The Model

Under this criteria, we are trying to determine the probability of being aggressive ($y_i = 1$), given the characteristics of the firms, i.e., $Pr(y_i = 1|\mathbf{x})$.

5.3.1 ε-distribution

As was said, we assumed that ε_i is orthogonal to $\mathbf{X}_i$. In order to be parsimonious and without losing of generality, we suppose that ε_i adopt a logistic distribution.

$$\Lambda(\epsilon) \equiv \frac{e^{\epsilon}}{1+e^{\epsilon}} \tag{36}$$

Then, following Wooldridge (2001) pg. 457-469,

$$\begin{aligned} Pr(y_i = 1|\mathbf{x}) &= Pr(\Pi_i^* = \boldsymbol{\beta}'\mathbf{X}_i + \varepsilon_i > 0|\mathbf{x}) \\ &= Pr(\varepsilon_i > -\boldsymbol{\beta}'\mathbf{X}_i|\mathbf{x}) \\ &= \Lambda(\boldsymbol{\beta}'\mathbf{X}_i) \end{aligned} \tag{37}$$

Solving (37) by maximum likelihood methods, we can find the betas.

5.4 Empirical application

Let be $y_i = 1$ if there is a positive increment of R&D investment between period t and t+1, $y_i = 0$ otherwise. Periods taken account in this model were $t \in \{94, 96, 98\}$. The difference between years was made in order to mitigate the time influence. M=235, which means that there were 470 firms. That is why were used Standard Errors corrected by bootstrap (1000 replications).

5.4.1 Variables

Dependent variable: this is a dichotomous variable y_i, which values are 1, if $i's$ firm is aggressive, i.e., if $i's$ firm increase its R&D investment between t and t+1; zero otherwise. The firm taken account in this case was the smallest one of the two firms considered here, in each six digit industry.

Other firm's actions: there is a dichotomous variable too, y_{-i}, which criteria is the same that was taken in the dependent variable. These are the biggest firms, according with the size criteria, which was constructed using the market share in each sector.

Herfindhal index: market structure could have influence in the competence between the two most important firms in each six digit manufacturing sector. Then, the concentration of the industry influence in the decisions of the firms is capture by Herfindhal index[18], H_i.

Price producer index: evidently, changes in the prices affronted by the producer could affect his R&D investment decisions. We expect a negative influence between price producer index, P_i, and R&D investment decisions.

$$\mathbf{X}_i = \{y_{-i}, H_i, P_i\}_{i=1}^{M} \tag{38}$$

where M=235.

5.5 Results

Solving (37), and using (38), we have:

Table 1. Estimation Results

(Standard Errors[19] in parentheses)

y_{-i}	1.8049*
	(0.4609)
H_i	2.6404*
	(1.3866)
P_i	-0.0153*
	(0.0021)

(∗) Statistically significant at a 5% level.

This result shows, that the decision made by the largest firm, i.e., if there it is aggressive in the R&D investment sense, impulses the smaller one to be aggressive, and this can be seen in the sign of the coefficient which is positive and statistically significant. On the other hand, the more concentrated the industry is, the more aggressive the smaller one tends to be; this can be explained evoking the survivor analysis. In a competitive context (perfect competition), firms can survive with higher probability, without necessity of being aggressive in the R&D investment; on the contrary, in a concentrated industry firms need to invest in R&D in order to compete and survive, that is why the coefficient sign is positive and statistically significant. Finally, as

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[18] In general, manufacturing sector is not concentrated. On average, Herfindhal index reach the value of 0.13.

[19] Bootstrap corrected using 1000 replications

was expected, an increase of the general level of prices that producers affront, tends to restrain the R&D investment impulse of the smaller firm: this can be seen in the negative sign of the coefficient, which is statistically significant too.

Considering the structure of the model, "logit model", we can calculate marginal effects ($\partial y_i / \partial \mathbf{X}_i$) which are presented in table 2.

Table 2. Marginal Effects

(Standard Errors in parentheses)

y_{-i}	0.2472*
	(0.1011)
H_i	0.2208*
	(0.1127)
P_i	-.0013*
	(0.0002)

(∗) Statistically significant at a 5% level.

Sign of marginal effects have been inherited of the coefficients signs. The probability of smaller firm tending to be aggressive is 0.25. In other words, for each large firm that increase its R&D investment, 1/4 of firms will increase its R&D investment too. Similar analysis can be made with the other coefficients.

6 Conclusions

Manufacturing sector in Mexico is not homogenous. This assertion is confirmed by the models presented in this paper: each firm observes different level of efficiency. For instance, the worst firm in *time-invariant* model (1994-2001) was working at 2.4 percent of its capacity (2.8 percent in *time-variant* model), compared with the "benchmark" firm[20]; the best one (which is the same in two models), classified as 351214 (Industrial gas manufacture), was working at 76 percent of its capacity (97 percent in time-variant model). In average, manufacturing sector was working at 18 percent of its potential

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[20] The worst firm is the same in these two models and is classified as 311301 (Preparation and packaging of fruits and vegetables).

product (23 percent in the time-variant case), understanding "potential product" in comparison with the best firm(s) performance to the manufacturing sector. At the same time, should be highlight that in 1994 the manufacturing sector as a whole was working at almost 24 percent of its potential product but in 2001 at 22 percent, which means a loss of its capacity.

On the other hand, the second part of this paper shows the existence of structural change. Indeed, the model in which a partition of the whole period was made: 1994-1997 and 1998-2001, shows how some firms were "consistent" keeping its performance in top ten ranking; how an other firms were "winners" remaining in top ten ranking in the second lapse; and finally, how some firms were "losers", i.e., those firms that in the first period were in top ten and not in the second one. Then, eventhough the crisis period (1995), the second lapse (1998-2001) shows certain stability, however, there was a lost of the potential capabilities of the manufacturing sector, maybe because of the openness and the entrance of foreign manufacturing products since NAFTA.

Finally, calls the attention that "industrial gas manufacture" had 6 firms in the top ten ranking (in both models) which means that NAFTA seems have not had an important effect in another manufacturing subsectors; on the contrary, seems that had a harmful effect in whole manufacturing sector given the loss of competence observed.

It seems that manufacturing sector was resistent to the openness in those cases in which natural resources give some advantages (gas resources, tobacco (natural conditions), etc.); but, its not the case of those firms in which was necessary to compete ("fight", in the IO jargon). This firms should have been more efficient.

In terms of R&D decisions we can say that, under a Cournot competition equilibrium, firms care about other actions, in particular, smaller firms tend to be aggressive if the biggest one of the six digit manufacture sector, is aggressive. Actually, the probability that small firms would tend to be aggressive is 0.25. NAFTA created competence between the two most important firms in each six digit manufacturing sector.

Appendix

Table 1A. Manufacturing Sector Classification

31 - Manufacture of Food, Beverages and Tobacco

32 - Textile, Wearing Apparel and Leather Industries

33 - Manufacture of Wood and Wood Products, Including Furniture

34 - Manufacture of Paper and Paper Products, Printing and Publishing

35 - Manufacture of Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products

36 - Manufacture of Non-Metallic Mineral Products, except Products of Petroleum and Coal

37 - Basic Metal Industries

38 - Manufacture of Fabricated Metal Products, Machinery and Equipment

39 - Other Manufacturing Industries

It was used the Mexican Classification of Activities and Products (MCAP) in its 1994 version, which is compatible with Uniform International Industrial Classification (UIIC) at four digit level.

Table 2A.Firms in each manufacturing subsector		
Subsector	**Firms**	**%**
31	819	18.84
32	664	15.27
33	160	3.68
34	357	8.21
35	901	20.72
36	285	6.55
37	101	2.32
38	1,010	23.23
39	51	1.17
Total	4,348	100

Figure 1A. Percentage of Total of Firms that Invested in R&D (1994-2001)

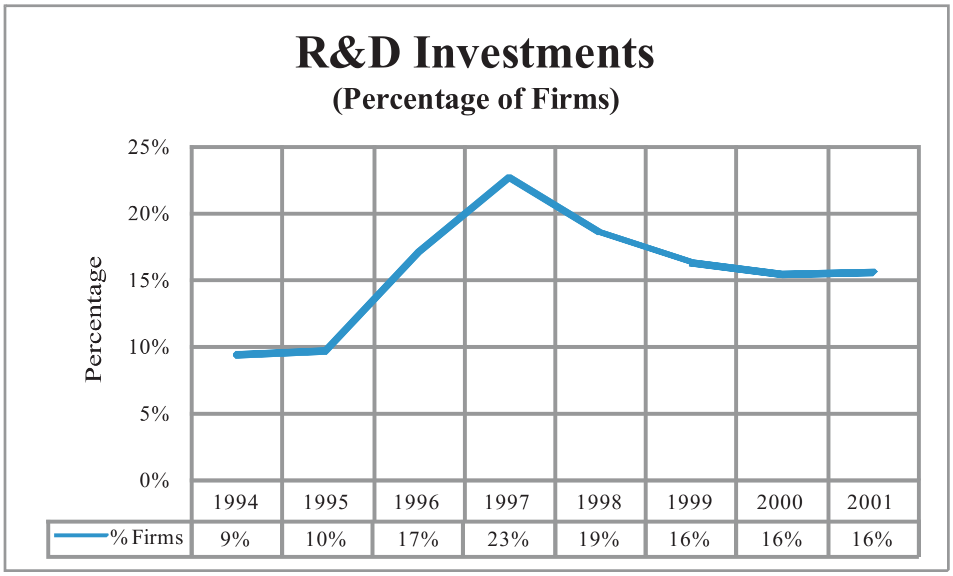


Figure 2A

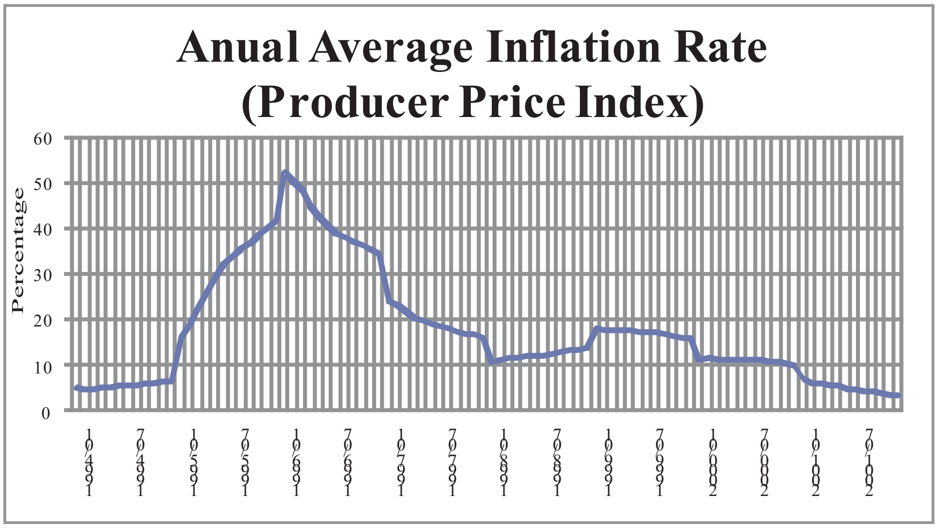


Figure 3A

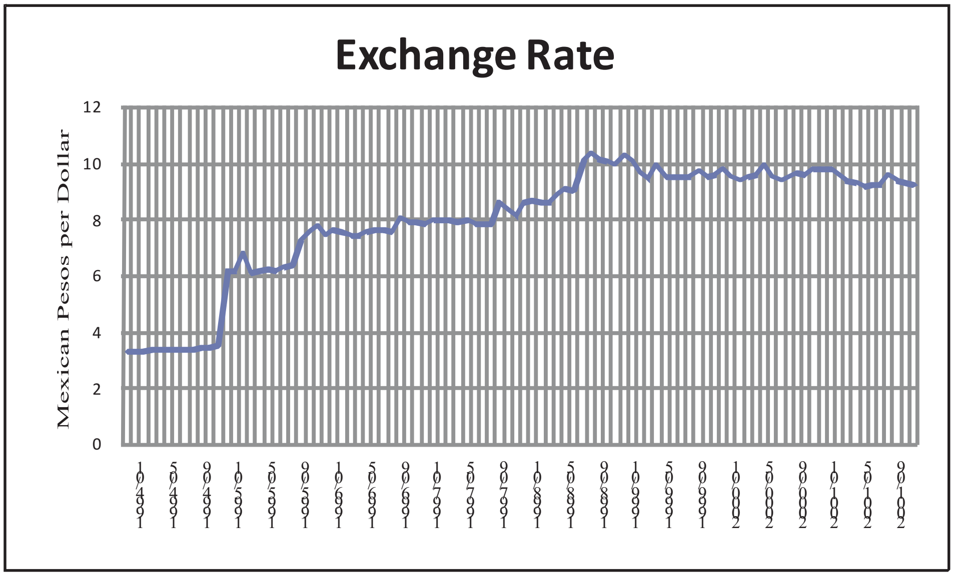
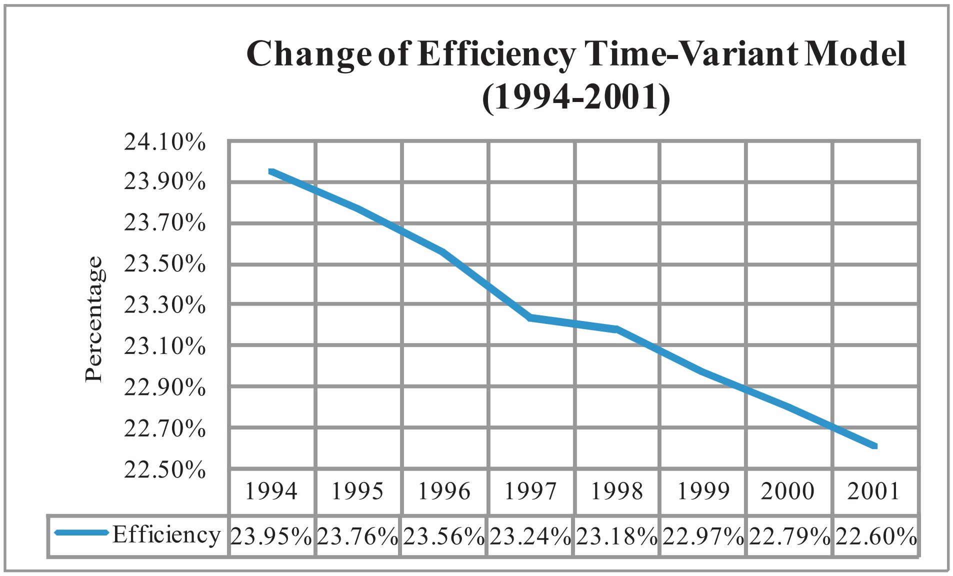


Figure 4A



Change of Efficiency Time-Variant Model
(1994-2001)
Percentage
24.10%
23.90%
23.70%
23.50%
23.30%
23.10%
22.90%
22.70%
22.50%
1994
1995
1996
1997
1998
1999
2000
2001
Efficiency
23.95%
23.76%
23.56%
23.24%
23.18%
22.97%
22.79%
22.60%

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