

**ECONOMIC REFORMS AND TECHNICAL EFFICIENCY PERFORMANCE IN
INDIAN MANUFACTURING SECTOR**

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ABSTRACT

This paper estimate and examine the technical efficiencies of Indian manufacturing sector covering 144 three-digit industries for the period of 1973-74 to 1997-98. The main aim of this study is to capture the behavior of technical efficiencies during the pre and post reforms periods. By employing time-varying stochastic frontier production function in the transcendental logarithmic form, this analysis identifies that there is a decreasing trend in the technical efficiency level across industries and across time periods¹. The main finding of this study is that the industry specific inefficiency effects are the main factor affecting the production process in achieving maximum feasible output than the other random factors such as weather, luck, strikes etc. Also, this paper identifies that during the post reforms period, technical efficiency is much lower than that of pre-reform periods.

INTRODUCTION

Changes in the productivity levels are increasingly recognized as a major influence on a host of macro and micro-economies problems. Politicians, industrialists, economists, trade unionists and engineer all emphasis the importance of improving productivity levels. The increasing attention paid to changes in the levels of productivity is probably the results of persistent and high levels of inflation experienced in the past two decades as well as increasingly competitive international market (Abby Ghobadian, 1990). The literature abounds with rival definition of productivity. They range from 'getting work done', 'utilization of resources', 'reduction in cost', 'efficiency of resource allocation' to 'efficiency of production'. In broad terms, the definition of productivity falls into three categories. These are the technological, engineering and economists concepts. The technological concept defines productivity as the ratio of output to inputs expanded in its production. The engineers view efficiency as the relationship between the actual and potential output of the production process, while the economists define productivity as the efficiency of the resource allocation.

An efficient and modern firm/industry is most likely to have lower cost of production, improved quality of products and hence higher profits. Such a firm/industry can only be competitive in the domestic as well as global market. It is well known that Technological change or technical progress brings about production efficiencies, which in turn lead to productivity growth. Production efficiencies may be brought about by technical, allocative (price) or scale economies. Technical inefficiency refers to the failure of the production unit to achieve the maximum possible output for a given level of input vector.

Allocative inefficiency, on the other hand, is associated with the sub-optimal choice of the combination of inputs in the sense that the ratio of any two-factor prices is not equal to the marginal rate of substitution between those two inputs. Scale economies/diseconomies are associated with production carried on at scales either too small or too large to minimize the cost of production. Thus, technological change, technical efficiency and scale economies/diseconomies constitute the three major technological characteristics of a firm / industry.

The industrial and the external sector of the Indian economy witnessed major changes in their policy framework during 1990s when the government of India announced its new industrial policy in June 1991. This industrial policy marked a major departure from the earlier import substituting and regulation oriented industrial policy framework. One of the major reforms in the industrial policy is the abolition of the complex system of industrial licensing, under which new investors setting up new units or existing investors undertaking major expansion had to obtain industrial license from the government. Industrial licensing system was abolished in all the industries except in a small list of strategic and potentially hazardous industries and in a few industries, which are referred for the small-scale sector. The new policy also included many measures to improve the performance of state owned enterprises. Entry of private sector firms into dereserved industries create more competition and is expected to improve the performance of the public sector firms. The incentive to improve performance is also being increased by a conscious policy of phasing out budgetary support to fund losses in loss making enterprises. Foreign Exchange Regulation Act, 1973 (FERA) was substantially

liberalised. All restriction on FERA companies in the matter of borrowing funds or raising deposits in India as well as taking over or creating any interest in Indian companies have been removed. There are number of studies to analysis these policy changes and its impact on productivity, employment level and efficiency in Indian manufacturing sector for various time periods.

Evidence on productivity in India as brought out by number of studies has been varied in the estimation. For the period from 1960 to 1980, Golder's (1986) estimation for Total Factor Productivity Growth (TFPG) turned out to be 1.2 per cent per annum. Ahluwalia (1991), however, in her study observed a decline in total factor productivity at the rate of 0.3 per cent per annum over the period of 1965-66 to 1979-80. Based on the National Accounts Statistics another study done by Goldar(1995) estimated the total factor productivity growth for the organized manufacturing sector at the rate of 1.55 per cent per annum over the period 1970-71 to 1980-81 which rose to 3.85 per cent during 1980-81 to 1985-86 and further to 5.05 per cent during 1985-86 to 1990-91. The studies carried out by the industrial Credit and Investment Corporation of India (ICICI, 1994) for companies for which it provides assistance, estimated the growth rate of TFP at -2.7 per cent per annum in the 1970s, -0.9 per cent per annum for the period from 1982-83 to 1986-87 and 2.1 per cent per annum during 1987-88 to 1991-92. Arup Mitra (1999), in his study estimates technical efficiency for manufacturing industries across Indian states using frontier production framework and observed deceasing trend in the technical efficiency measures during the study period. Firm level study by Parameshwaran (2002) for four major industry groups finds that there is decreasing trend in the efficiency levels

in all the four industries for the period of 1990 to 1997. He also finds that the reform measures are not in favors of improving technical efficiency in Indian manufacturing sector.

In view of these backgrounds, the present study aims at estimating technical efficiency for Indian manufacturing sector at the three-digit level for the period of 1973-74 to 1997-98. Since, for some of the industries the data relating to the WPI, capital and labour inputs were not available for the whole sample period, we have considered 144 three-digit industries for the analysis². This study tries to explore the effects of reform measures on technical efficiency scores during the pre and post liberalization scenario by dividing the whole sample period into three sub periods (1973-74 to 1980-81, 1981-82 to 1990-91 and 1991-92 to 1997-98). Time varying stochastic frontier production function and the estimation process are discussed in the following section. Section-III of this paper briefly explains the data and variable used for this analysis. Section-IV and V presents results and the main findings of the study.

THEORETICAL FRAMEWORK

Technical efficiency is a form of productive efficiency and is concerned with the maximization of output for a given set of resource inputs. The measure of productive and technical efficiency is based on the ‘best practice’ production function proposed by Farrell (1957). Given the one output and two input framework, the efficient frontiers or ‘best practice’ production function can be expressed by the isoquant that shows the

minimum combination of inputs of a given quality given the state of technology that can produce a specific level of output. Thus, in terms of production function, points on the frontier are efficient and those below are inefficient (Chirwa, 2000).

Developments that followed Farrell's approach to measure technical efficiency are grouped into non-parametric frontiers and parametric frontiers. Non-parametric frontier models in measuring technical efficiency do not impose any functional form on the production frontiers and do not make any assumptions about the error term. These use linear programming approaches and the most popular non-parametric approach is Data Envelopment Analysis. Whereas, the parametric approaches impose a functional form on the production function and assumptions are made about the data (Sankho Kim 2003). The most common functional forms include the Cobb-Douglas, Constant Elasticity of Substitution and Transcendental logarithmic production functions. The other distinction in frontier measures is between deterministic and stochastic frontiers. Stochastic frontiers assumes that the deviation from the frontier are due to partly to random events and partly to industry / firm specific inefficiency and deterministic frontiers assumes that all the deviations from the frontier are a results of industry / firm's inefficiency.

The estimation of technical efficiency using econometric models can be categorized according to the type of data employed; i.e., panel data or cross sectional data. Several difficulties noted with the cross sectional stochastic frontier production frontier models in the literature. The main problem is maximum likelihood estimation of stochastic production frontier model, the subsequent separation of technical inefficiency from the

statistical noise, both requires strong distributional assumptions on each error component. Also the robustness of inference to these assumptions is not well documented. Apart from this maximum likelihood estimation also requires an assumption that the technical inefficiency error component be independent of the regressors, although it is easy to imagine that technical inefficiency might correlated with the input vectors producers select (Schmidt and Sickles, 1984). These limitations can be avoided by employing panel data. A panel data contains more information than a single cross-section. Having access to panel data enables us to adopt conventional panel data estimation techniques to the technical efficiency measurement problem. Moreover these techniques are not rest on strong distributional assumptions. Also repeated observations on a sample of producers can serve as a substitute for strong distributional assumptions. Moreover, adding more observations on each producer generates information not provided by adding more producers to a cross section (Kumbhakar 1990).

Two types of estimation techniques are found in the literature while using panel data, in estimating technical efficiencies. The first technique in which, technical efficiency is allowed to vary across producers, but it is assumed to be constant through time for each producers, referred as time-invariant technical efficiency model. In the competitive environment, it is hard to accept the notion that technical efficiency remain constant through vary many time periods. The production frontier model, in which technical efficiency is allowed to vary across producers and through time for each producer, is referred as time-variant technical efficiency model.

Since our study employs 25 years of data for 144 three digit industries, the estimation of technical efficiency in this paper follows time-varying model. The main advantage of this is that, by estimating time-varying technical efficiency, one can test the other alternative models and their suitability for the analysis.

The frontier production function can be expressed as

$$y_{it} = f(x_{it} : \beta)TE \quad \text{-----}(1)$$

where, y_{it} is the scalar output of producer i , $i=1,2,\dots,I$, for the t period, $t=1,2,\dots,T$.

x_{it} is the vector of N inputs used by the producer 'i',

$f(x_{it} : \beta)$ is the production frontier, and β is the vector of technology parameter to be estimated.

The output oriented technical efficiency becomes,

$$TE = \frac{y_{it}}{f(x_{it} : \beta)} \quad \text{-----}(2)$$

which defines technical efficiency as the ratio of observed output to the maximum feasible output. The observed output (y_{it}) achieves its maximum feasible value of $f(x_{it} : \beta)$, if, and only if $TE=1$. Otherwise $TE<1$ provides a measure of the shortfall of observed output from maximum feasible output.

Now we begin by rewriting the equation (1) as,

$$y_{it} = f(x_{it} : \beta)\exp(-u_{it}) \quad \text{-----}(3)$$

Where $TE_i = \exp(-u_{it})$. Since we require that $TE_{it} \leq 1$, we have $u_{it} \geq 0$.

The production function model will usually be linear in the logs of the variables, so the equation (3) becomes,

$$\ln y_{it} = \beta_0 + \sum_n \beta_n \ln x_{nit} - u_{it} \quad \text{-----}(4)$$

where $u_{it} \geq 0$. guarantees that $y_{it} \leq f(x_{it} : \beta)$.

Here $u_{it}=0$ measures the technical efficiency,

$u_{it}>0$ measures the technical inefficiency,

The objective is to obtain the estimates of the parameter vector β , which describes the structure of the production function, and also to obtain estimates of the u_{it} , which can be used to obtain estimates of TE for each producers by means of $TE = \exp(-u_{it})$. Aigner, Lovell and Schmidt (1977), and Meeusen and Van den Broeck(1977) simultaneously introduced stochastic production frontier models. These models allow for technical inefficiency, but they also acknowledge the fact that the random shocks outside the control of producer can affect output. The great virtue of stochastic frontier models is that the impact on outputs shocks due to variation in labour and machinery performance, vagaries of the weather, and just plain luck can a least in principle be separated from the combination of variation in technical efficiency.

If we again assume that $f(x_{it} : \beta)$ takes the log-linear form, then the stochastic production frontier model can be written as

$$\ln y_{it} = \beta_0 + \sum_n \beta_n \ln x_{nit} + v_{it} - u_{it} \quad \text{-----}(5)$$

where v_{it} -is the two-sided ‘noise’ components, and u_{it} is the non-negative technical inefficiency component of the error term. As before, $u_{it}>0$, but v_{it} may take any value. A symmetric distribution, such as the normal distribution is usually assumed for v_{it}

From this equation the measures of the level of technical efficiency of the i^{th} industry in the t^{th} period can be defined as the ratio of observed to the maximum possible output, i.e.

$$TE = e^{(-u_{it})} = \frac{y_{it}}{f(x_{it} : \beta)e^{(v_{it})}} \quad \text{----- (6)}$$

It is rational to argue that the reform policies can influence the industries with varying degree of intensity, and consequently, the level of improvement in technical efficiency in different industry would be different. Therefore, it becomes necessary to model u_{it} accordingly. If u_{it} is remains constant over time, which indicates that there is no improvement in technical efficiency. Alternatively, if u_{it} decrease or increase, indicating that technical efficiency may either improve or deteriorate over time

Following Battese and Coelli (1992), the above characteristics of technical efficiency can be modeled as,

$$u_{it} = u_i \exp(-\eta(t - T)) \quad \text{----- (7)}$$

Where the u_i are independent random variables and η is an unknown parameter, which represents the rate of changes in the technical inefficiency. It is expected that, u_{it} decrease, remain constant or increases as 't' increases depending on whether $\eta > 0$, $\eta = 0$ or $\eta < 0$, respectively. The case in which η is positive implies that, on average, industry improve their level of technical efficiency over time. A negative value of η implies that the industry's efficiency worsens over time. Now the estimates of the industry-specific technical efficiency require the assumption about the distribution of u_i to facilitate the use of maximum likelihood methods. It is assumed that u_i is a non-negative truncation of

the $N(\mu, \sigma_u^2)$. Further, u_{it} and v_{it} are assumed to be distributed independently (Kalirajan 1997).

However, neither u_{it} nor v_{it} can be obtained from the estimation and what is obtained is the residual ε , which is the sum of u_{it} and v_{it} . According to the statistical theory the best predictor of an unknown random variable (u_{it}), given the value of the combined random variable (u_{it} and v_{it}), is the minimum mean-square error predictor obtained from the conditional expectation of u_{it} (Kalirajan and Shand 1999).

Following Battese and Coelli (1992)³, the logarithm of the likelihood function for the sample observation is represented as

$$\begin{aligned} L^*(\theta^*; y) = & -\frac{1}{2} \left[\sum_{i=1}^N T_i \right] \ln(2\pi) - \frac{1}{2} \sum_{i=1}^N (T_i - 1) \ln(\sigma_v^2) - \frac{1}{2} \sum_{i=1}^N \ln(\sigma_v^2 + \eta_i' \eta_i \sigma^2) \\ & - N \ln[1 - \Phi(-\mu/\sigma)] + \sum_{i=1}^N \ln[1 - \Phi(-\mu_i^*/\sigma_i^*)] \quad \text{----(8)} \\ & - \frac{1}{2} \sum_{i=1}^N \left[(y_i - x_i \beta)' (y_i - x_i \beta) / \sigma_v^2 \right] - \frac{1}{2} \sum_{i=1}^N N(\mu/\sigma)^2 + \frac{1}{2} \sum_{i=1}^N N(\mu_i^*/\sigma_i^*)^2 \end{aligned}$$

where $\theta^* \equiv (\beta', \sigma_v^2, \sigma^2, \mu, \eta)'$

Using the re-parameterization, where $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$, the logarithm of the likelihood function is expressed by

$$\begin{aligned} L^*(\theta; y) = & -\frac{1}{2} \left[\sum_{i=1}^N T_i \right] \{ \ln(2\pi) + \ln(\sigma^2) \} - \frac{1}{2} \sum_{i=1}^N (T_i - 1) \ln(1 - \gamma) \\ & - \frac{1}{2} \sum_{i=1}^N \ln[1 + (\eta_i' \eta_i - 1)\gamma] - N \ln[1 - \Phi(-z)] - \frac{1}{2} N z^2 + \sum_{i=1}^N \ln[1 - \Phi(-z_i^*)] \text{-----(9)} \\ & + \frac{1}{2} N z_i^{*2} - \frac{1}{2} \sum_{i=1}^N \left[(y_i - x_i \beta)' (y_i - x_i \beta) / (1 - \gamma) \sigma^2 \right] \end{aligned}$$

where $\theta \equiv (\beta', \sigma^2, \gamma, \mu, \eta)$, $z \equiv \mu/(\gamma\sigma^2)^{1/2}$ and

$$z_i^* = \frac{\mu(1-\gamma) - \gamma\eta_i'(y_i - x_i\beta)}{\{\gamma(1-\gamma)\sigma^2[1 + (\eta_i'\eta_i - 1)\gamma]\}^{1/2}}$$

The minimum mean square error predictor of the technical efficiency of the i^{th} firm at the t^{th} period $TE_{it} = \exp(-u_{it})$ is estimated as:

$$E[\exp(u_{it}/\varepsilon_i)] = \left(\frac{1 - \Phi[\eta_{it}\sigma_i^* - \mu_i^*/\sigma_i^*]}{1 - \Phi(-\mu_i^*/\sigma_i^*)} \right) \exp\left(-\eta_{it}\mu_i^* + \sqrt{\eta_{it}^2\sigma_i^{*2}}\right) \text{-----}(10)$$

where ε_i represent the $(T_i \times 1)$ vector of η_{it} 's associated with the time periods observed from the i^{th} industry, and

$$\mu_i^* = \frac{\mu\sigma_v^2 - \eta_i'\varepsilon_i\sigma_u^2}{\sigma_v^2 + \eta_i'\eta_i\sigma_u^2}, \quad \sigma_i^{*2} = \frac{\sigma_v^2\sigma_u^2}{\sigma_v^2 + \eta_i'\eta_i\sigma_u^2}$$

Where η_i represents the $(T_i \times 1)$ vector of η_{it} 's associated with time periods observed for the i^{th} industry, and is the standard normal distribution function (Schmidt and C A Knox Lovell (1980).

The mean technical efficiency of industry at the t^{th} period given by

$$TE_t = \left(\frac{1 - \Phi[\eta_t\sigma - \mu/\sigma_u]}{1 - \Phi(-\mu/\sigma_u)} \right) \exp\left(-\eta_t\mu + \sqrt{\eta_t^2\sigma_u^2}\right) \text{-----} (11)$$

If the industry effects are time invariant, then the mean technical efficiency is obtained from the equation (11) by substituting $\eta_i = 1$.

Thus the time-varying stochastic frontier approach explained above offers a better methodology consistent with production theory to examine the pattern of technical efficiency over period of time.

DATA AND METHODOLOGY

Two basic sources of production data are the Index of Industrial production (IIP) and Annual Survey of Industries (ASI). The index deals with only selected products and selected firms. ASI collects and provides industry wise data on value added, wages, output, capital stock, depreciation etc, at current prices for the factory registered under the Indian Factory Act 1945, i.e., those which use power and employ at least 10 workers and those which do not use power and employ at least 20 workers.

To estimate technical efficiency level, annual data on value added, fixed capital, number of workers etc., are collected for the organized manufacturing sector from the Annual Survey of Industries for the period of 25 years from 1973-74 to 1997-98 for 144 three digit industries. Data on value added and capital stock are on gross basis inclusive of depreciation. Since the major changes in the classification of industries was introduced in the year 1973-74, we choose this year as initial year for this analysis (Pushpa Triveti 2000).

Our estimation on gross value added function is based on single deflation method. The WPI for the years 1973-74 to 1980-81 was given at the base 1970-71, whereas, rest of the period the base year is 1980-81. The price index corresponding to the years 1973-74 to 1980-81 have therefore, converted into the 1980-81 base year before deflating the value added series. Perpetual Inventory Method (PIM) is used to derive the measure of capital input series. According to this method, capital stock for a given period is traced by

adding the previous investment starting from a benchmark year, converting to constant value by a price index for capital asset. Following Benerji (1975), Goldar (1986) and Balakrishnan and Pushpangadan (1994), double of the book value of the fixed capital is taken as a measure of capital stock for the benchmark year.

Capital stock for the benchmark year is,

$$K_0 = 2(B_t) \quad \text{where } t = 1973-74.$$

For the subsequent years, gross real investment has taken as a measure of capital stock.

The gross real investment for the year 't' is obtained by,

$$I_t = (B_t - B_{t-1} + D_t) / P_t \quad \text{-----}(12)$$

where B_t is the book value of the fixed capital in the year 't'.

B_{t-1} is the depreciation in the year 't'.

P_t is the index for machinery and machine tools for the t^{th} year with base year 1980-81.

The capital input, gross capital stock at the constant prices (1980-81) at the year 't' derived as,

$$K_t = K_0 + \sum_{i=0}^t I_{t-i} \quad \text{-----}(13)$$

The labor input is used for the analysis is that the total employees including wage earners and the salaried classes.

The more flexible functional form of production function, transcendental logarithmic form has been used to estimate coefficients of production variables. The two inputs stochastic frontier production function in the translog form is expressed as,

$$\ln VA_{it} = \alpha_0 + \beta_K \ln KA_{it} + \beta_L \ln LA_{it} + \beta_T T + \frac{1}{2} \beta_{KK} (\ln KA_{it})^2 + \frac{1}{2} \beta_{LL} (\ln LA_{it})^2 + \beta_{KL} (\ln KA_{it})(\ln LA_{it}) + \beta_{KT} (\ln KA_{it})T + \beta_{LT} (\ln LA_{it})T + \frac{1}{2} \beta_{TT} T^2 + v_{it} - u_{it} \quad \text{----(14)}$$

where VA-Real value added at 1980-81 prices.

KA-capital stock at 1980-81 prices.

LA-number of workers.

T-time period., $t=1,2,3,\dots,25$ (1973-74 to 1997-98)

$i=1,2,3,\dots,144$.

v is the stochastic error term affecting the production process..

u is the measure of technical inefficiency.

RESULTS AND DISCUSSION

The data used in this paper are an unbalanced panel consisting of annual-time series for 144 Indian manufacturing industries at 3-digit level during the period of 1973-74 to 1997-98, with a total of 3451 observations. The summary statistics for variables used in the stochastic frontier production function in estimating technical efficiency are presented in the table-1. The mean values presented in the table are the logarithmic value of value added, capital and labour used in the actual estimation. The estimation has been carried out in four periods including three sub-periods to capture the changes in the technical efficiency. The second column of the table-1 shows the summary statistics for the whole sample period (1973-74 to 1997-98). The other three columns presented in the table shows the summary statistics for the variables used in the analysis for three sub periods via.1973-74 to 1980-81, 1981-82 to 1990-91 and 1991-92 to 1997-98.

Table-1
Summery statistics for variables in the stochastic frontier production function for
Indian manufacturing industry

Variables	1973-74 to 1997-98	1973-74 to 1980-81	1981-82 to 1990-91	1991-92 to 1997-98
Value added	8.3270 (1.8701)	7.7696 (1.7813)	8.3196 (1.8323)	9.0169 (1.8030)
Capital	8.0430 (1.9266)	7.6850 (1.9297)	8.0301 (1.8970)	8.4982 (1.8729)
Labour	9.4752 (1.5446)	9.2721 (1.5683)	9.4949 (1.5419)	9.6934 (1.4883)
Total observations	3451	1138	1379	934
Number of industries	144	144	144	144

Note: figures in parenthesis are standard deviations.

Hypothesis Test

The transcendental logarithmic production function, used in the estimation of technical efficiency, allows us testing various hypotheses. The stochastic frontier production function in the translog form, defined by equation (14), contains 10 β parameters and four additional parameters associated with the distribution of v_{it} and u_{it} -random variables. Maximum likelihood estimates for these parameters were obtained by using the computer programme, developed by Tim Coelli (1996), FRONTIER 4.1. We estimated five basic models using the frontier production function defined in equation (14).

1. Model-1 assumes that there is no technical inefficiency effect in the production

$$\text{function, i.e., } H_0 : \gamma = \mu = \eta = 0$$

2. Model-2 assumes that technical inefficiency is time-invariant, $H_0 : \eta = 0$.

3. Model-3 assumes that there is no technical change in the production function,

$$H_0 : \beta_T = \beta_{TT} = \beta_{TK} = \beta_{TL} = 0$$

4. Model-4 assumes that technical progress is neutral, $H_0 : \beta_{TK} = \beta_{TL} = 0$

5. Model-5 assumes that the production function is Cobb-Douglas form,

$$H_0 : \beta_{KK} = \beta_{LL} = \beta_{TK} = \beta_{TL} = 0$$

The likelihood ratio test, a statistical test of goodness of fit between two models, used to test null-hypothesis. It is defined that more complex models must differ from the simple models only if the addition of one or more parameters. Adding additional parameters will always results in higher likelihood scores. To determine, whether the difference in likelihood scores among the two models is statistically significant, the degree of freedom should be considered. In the LR test, the degree of freedom equals to the number of more additional parameters in the more complex model. In general, the LR test statistics approximately follows the chi-square distribution.

The likelihood ratio (LR) test statistics is given by

$$\lambda = -2[L(H_0) - L(H_1)] \quad \text{-----(15)}$$

Where

$L(H_0)$ - value of log-likelihood function under the null hypothesis.

$L(H_1)$ - value of log-likelihood function under the alternative hypothesis.

if the null hypothesis is true, then the LR test statistics has approximately a chi-square distribution with the degrees of freedom equals to the number of restrictions.

Table-2 presents the test results of various hypotheses for the total sample period and also for the other three sub-periods. The estimated log-likelihood function value, calculated LR test statistics and critical value to accept or reject the test statistics are presented in the

table for the different sample periods. In the case of whole sample period all the null-hypothesis are rejected at 1 % significant level. The null hypothesis that there is no technical inefficiency is rejected at 1% level for period-I, period-II and Period-III.

Table-2
Test of hypothesis for parameters of the distribution of technical efficiency

Null Hypothesis	Log-likelihood Function	LR-Test Statistics	Critical Value	Decision
Whole sample period (1973-74 to 1997-98)				
$H_0 : \gamma = \mu = \eta = 0$	-2905.844	2712.2452	10.50	Reject
$H_0 : \eta = 0$	-1634.060	169.3421	6.63	Reject
$H_0 : \alpha_T = \beta_{TT} = \beta_{TL} = \beta_{TK} = 0$	-1673.085	247.3839	13.28	Reject
$H_0 : \beta_{TL} = \beta_{TK} = 0$	-1598.031	48.6423	9.21	Reject
$H_0 : \beta_{LL} = \beta_{KK} = \beta_{LK} = \beta_{TT} = 0$	-1667.956	118.5672	13.28	Reject
Period-I (1973-74 to 1980-81)				
$H_0 : \gamma = \mu = \eta = 0$	-780.6721	1013.0041	10.50	Reject
$H_0 : \eta = 0$	-274.4909	0.6414	6.63	Accept
$H_0 : \alpha_T = \beta_{TT} = \beta_{TL} = \beta_{TK} = 0$	-294.9299	41.5194	13.28	Reject
$H_0 : \beta_{TL} = \beta_{TK} = 0$	-274.5816	0.8228	9.21	Accept
$H_0 : \beta_{LL} = \beta_{KK} = \beta_{LK} = \beta_{TT} = 0$	-331.8111	115.2818	13.28	Reject
Period-II (1981-82 to 1990-91)				
$H_0 : \gamma = \mu = \eta = 0$	-1073.951	980.5456	10.50	Reject
$H_0 : \eta = 0$	-585.7958	4.2348	6.63	Accept
$H_0 : \alpha_T = \beta_{TT} = \beta_{TL} = \beta_{TK} = 0$	-613.4231	59.4894	13.28	Reject
$H_0 : \beta_{TL} = \beta_{TK} = 0$	-585.3672	3.3774	9.21	Accept
$H_0 : \beta_{LL} = \beta_{KK} = \beta_{LK} = \beta_{TT} = 0$	-626.0284	84.7004	13.28	Reject
Period-III (1991-92 to 1997-98)				
$H_0 : \gamma = \mu = \eta = 0$	-965.9869	967.0924	10.50	Reject
$H_0 : \eta = 0$	-483.3579	1.8342	6.63	Accept
$H_0 : \alpha_T = \beta_{TT} = \beta_{TL} = \beta_{TK} = 0$	-526.1003	87.3192	13.28	Reject
$H_0 : \beta_{TL} = \beta_{TK} = 0$	-484.0757	3.2698	9.21	Accept
$H_0 : \beta_{LL} = \beta_{KK} = \beta_{LK} = \beta_{TT} = 0$	-497.3846	29.8876	13.28	Reject

Note: These models are estimated using Frontier 4.1 computer program.

Based on the critical value it is accepted that there is a technical inefficiency levels, which are affecting the production process in order to achieve the maximum feasible output in Indian manufacturing sector during the whole sample period and also during other three sub-periods. The second null-hypothesis is that, the technical inefficiency is time-invariant is rejected during the period of 1973-74 to 1997-98, thereby accepting that technical inefficiency is varying across time periods. In the case of other three sub-periods, this null hypothesis is accepted, indicating that technical inefficiency is constant across periods, given the time-varying specification of the stochastic frontier production function. The third null hypothesis that there is no technical progress in Indian manufacturing industry is rejected at 1 % significant level and accepting that the existence of technical change in the production process during all the sample periods considered for the analysis.

The fourth hypothesis, technical progress is neutral is rejected at the whole sample period study, whereas it is accepted at the other three sub-periods. It is evident from the results that during three study period, the technical progress is found to be non-neutral in Indian manufacturing sector. The last hypothesis is that, the technology in Indian manufacturing sector is a Cobb-Douglas for, is rejected for the whole sample period and also for the other three sub-periods. Thus, the Cobb-Douglas production function is not an adequate specification for the Indian manufacturing sector, given the assumptions of the translog production function.

Estimates of frontier production function

The maximum likelihood estimates of frontier production function in the transcendental logarithmic specification for the period of 1973-73 to 1997-98 are presented in the table-3. In the table we have reported only two models out of five models estimated and also the full model represents the estimation of all the parameters. The estimated model-I is similar to that of OLS, since there is no technical inefficiency effects are considered for the analysis. The model-I shows that the estimates of average production function, in which the parameters μ , η and γ are restricted to be zero, indicating that there is no technical inefficiency effects in the production function. Model-II represents the technical inefficiency is time-invariant, indicating that there is no change in the technical inefficiency levels across time periods in the industries. Full Model represents the full frontier production function, expressing the existence of technical inefficiency, technological progress and the time-varying effects of technical inefficiency in the given stochastic frontier production function of transcendental logarithmic specification. Based on the log-likelihood ratio test, the column 5 of the table-3 (full model) indicates the existence of the time-varying technical inefficiency in Indian manufacturing industry over the period of 1973-74 to 1997-98. From the table it is evident that all the coefficients are significant at 1 % level. The significance of variance parameter σ^2 and the ratio variance parameter γ implies that the realized output differ from potential output significantly and the difference are mainly due to the differences in the industry-specific technical inefficiency effects and not to any random change factors.

Table-3
ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION FUNCTION USING
MAXIMUM LIKELIHOOD METHOD (1973-74 to 1997-98)

Sl.No	Variables	Parameters	Model-I (OLS)	Model-II (MLE)	Full Model (MLE)
1	Constant	α_0	-5.2081 (19.20)	-1.0137 (3.06)	-1.8178 (5.83)
2	Capital	β_K	0.2004 (3.94)	0.2478 (4.99)	0.3668 (7.54)
3	Labour	β_L	1.7483 (21.72)	1.0759 (12.92)	1.0487 (12.17)
4	Capital*capital	β_{KK}	0.1037 (13.03)	0.0436 (4.93)	0.0491 (6.03)
5	Labour*labour	β_{LL}	-0.1109 (9.62)	-0.0041 (0.29)	-0.0120 (0.82)
6	Kapital*labour	β_{KL}	-0.0436 (5.75)	-0.0405 (4.12)	-0.0425 (4.56)
7	Time	β_T	-0.0259 (2.65)	-0.0035 (0.53)	0.0224 (3.16)
8	Time*capital	β_{TK}	-0.0082 (7.13)	-0.0013 (1.66)	-0.0098 (10.26)
9	Time*labour	β_{TL}	0.0111 (7.83)	0.0032 (3.29)	0.0095 (8.69)
10	Time*time	β_{TT}	0.0016 (3.88)	0.0021 (7.14)	0.0035 (11.09)
11	$\sigma^2 = \sigma_v^2 + \sigma_u^2$		0.3165	0.5511 (17.55)	0.8333 (23.21)
12	$\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$		0	0.7758 (69.14)	0.8529 (85.10)
13	μ		0	1.3077 (16.37)	1.6862 (14.38)
14	η		0	0	-0.0272 (14.53)
15	Log-Likelihood Function		-2905.84	-1675.79	-1590.18

Note: figures in parenthesis are 't' statistics. The parameters are estimated using computer programme FRONTIER 4.1

However, the asymptotic t-test on the estimated μ value found to be 14.38, which is significant at 1 % level, indicating that the mean of technical inefficiency is significantly differ from zero. The result implies that the inclusion of 'u' in the production function

equation is valid, and the assumption that 'u' follows a truncated normal distribution with $N(\mu, \sigma_u^2)$, and 'u' does not follow the normal distribution $N(0, \sigma_u^2)$. The time varying technical (in)efficiency parameter η is found to be negative to the tune of 0.0272, which is significant at 1 % level indicating that the technical efficiency is decreasing over the sample period in Indian manufacturing industry. It implies that the rate of growth of technical efficiency in Indian manufacturing sector during 1973-74 to 1997-98 found to be decreasing to the extent of 2.72 per cent.

Given the specification of full model in which technical efficiency is found to be time-varying with truncated distribution, the technical efficiencies of the individual industries are calculated using minimum mean square predictor explained in equation (12). We have estimated technical efficiencies for all the 144 three-digit industries for each time period covering from 1973-74 to 1997-98 and reported only the average technical efficiency levels in the table-4.

Since, the technical efficiency coefficient is found to be negative; the decreasing trends in the estimated technical efficiencies scores are observed in the table. It is clear from the analysis that overall average level of technical efficiency is found to be 31.61 % in Indian manufacturing sector, implies that around 68 % of industry specific inefficiency effects are affecting the production process in achieving the maximum feasible output. Also, the causes for inefficiency levels in the manufacturing industry in India is mainly due to the industry specific effects, but not the other stochastic effects such as, luck, whether, strikes and lock-outs.

Table-4
Predicted average technical efficiencies of manufacturing industry in India

year	TE	Year	TE	year	TE
1973-74	0.4218	1982-83	0.3401	1991-92	0.2626
1974-75	0.4118	1983-84	0.3257	1992-93	0.2502
1975-76	0.4016	1984-85	0.3216	1993-94	0.2448
1976-77	0.3941	1985-86	0.3194	1994-95	0.2438
1977-78	0.3852	1986-87	0.3059	1995-96	0.2323
1978-79	0.3775	1987-88	0.2999	1996-97	0.2268
1979-80	0.3679	1988-89	0.2899	1997-98	0.2233
1980-81	0.3548	1989-90	0.2819	Average TE	0.3161
1981-82	0.3485	1990-91	0.2703		

Note: the estimates are computed using the computer programme FRONTIER 4.1, and these results are only the average TE of 144 three-digit industries for each period mentioned above.

In order to capture the effects of reform policies on technical efficiency levels, we estimated the parameters of the stochastic frontier production function in the transcendental logarithmic form for three sub-periods, covering from 1973-74 to 1980-81, 1981-82 to 1990-91 and 1991-92 to 1997-98. The results were presented in the appendix-I, II, and III. From the results it is found that the technical efficiency is time-invariant in all the three sub-periods, implying that there are no changes in the technical efficiency scores during the three study periods. As we discussed earlier, in the time-invariant model, the technical efficiency vary only across industries but it is not allowed to vary over time periods. Hence, using the equation (11) we estimated mean technical efficiency for each industry for the three different periods and reported the average of this mean technical efficiency. It is evident from the results that technical efficiency is found to be 28.84 % during 1973-74 to 1980-81, implies that around 71 % of inefficiency effects are affecting the production process in Indian manufacturing industries. During 1981-82 to 1990-91, the level of technical efficiency is estimated as 30.05 %, implies that there is increase in the TE compare with the earlier periods. In the post liberalization

period, 1991-92 to 1997-98, the estimated technical efficiency is 21.45 %, which is less compare with the other two sub-periods. From the estimated results for the three different sub-periods, the technical efficiency during the post reforms periods is much less than the other two periods, implies that the reforms policies are not influencing in increasing technical efficiency in Indian manufacturing industries.

CONCLUDING REMARKS

This paper estimates the technical (in)efficiency levels of the Indian manufacturing sector using a sample of 144 three-digit industries for the period of 1973-74 to 1997-98 by employing time-varying stochastic frontier production function of transcendental logarithmic form. The estimates of technical efficiencies are found to be time-varying across industries and across time periods, for the whole sample period study. The study reveals that there is a decreasing trend in the technical efficiency levels in Indian manufacturing sector during the entire sample period. The empirical results of this study suggest that the realized output differ from the potential output significantly in Indian manufacturing sector and the differences are mainly due to the difference in the industry-specific technical inefficiency effects than the other stochastic random factors. The estimates for the three time periods (1973-74 to 1980-81, 1981-82 to 1990-91 and 1991-92 to 1997-98), reveals that technical efficiency scores are constant across sample periods, implies that there is no significant changes in the levels of technical efficiencies. The estimated average mean technical efficiency is found to be lower during the period 1991-92 to 1997-98 as compare with the other two periods. Also, the study finds that

there exist of neutral technical progress during all three time periods in Indian manufacturing sector. In concluding, the post reform period has negative impact on Indian manufacturing sector with respect of its technical efficiency performance.

APPENDIX

Table-A.1
ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION FUNCTION USING
MAXIMUM LIKELIHOOD METHOD (1973-74 to 1979-80)

Sl.No	Variables	Parameters	Model-I (OLS)	Model-II (MLE)	Full Model (MLE)
1	Constant	α_0	-3.8867 (10.09)	-1.4454 (3.08)	-1.7975 (4.01)
2	Capital	β_K	0.2586 (3.38)	0.2385 (2.71)	0.2637 (2.81)
3	Labour	β_L	1.4453 (12.13)	1.1764 (9.94)	1.2289 (9.89)
4	Capital*capital	β_{KK}	0.1001 (7.59)	0.0815 (5.77)	0.0987 (7.08)
5	Labour*labour	β_{LL}	-0.0828 (4.46)	-0.0082 (0.33)	0.0039 (0.15)
6	Kapital*labour	β_{KL}	-0.0448 (3.55)	-0.0608 (3.34)	-0.0812 (4.34)
7	Time	β_T	-0.0853 (1.79)	-0.0134 (0.49)	0.0123 (0.44)
8	Time*capital	β_{TK}	-0.0126 (2.14)	-0.0022 (0.61)	-0.0006 (0.17)
9	Time*labour	β_{TL}	0.0226 (3.09)	0.0087 (1.98)	0.0059 (1.36)
10	Time*time	β_{TT}	-0.0019 (0.31)	-0.0069 (1.89)	-0.0079 (2.17)
11	$\sigma^2 = \sigma_v^2 + \sigma_u^2$		0.2329	0.4438 (11.53)	0.4311 (10.89)
12	$\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$		0	0.8713 (104.85)	0.8691 (101.56)
13	μ		0	1.2437 (13.07)	1.2242 (12.69)
14	η		0	0	-0.0063 (0.95)
15	Log-Likelihood Function		-780.67	-274.49	-274.17
Average mean technical efficiency				0.2884	

Note: figures in parenthesis are 't' statistics. The parameters are estimated using computer programme FRONTIER 4.1

Table-A.2
ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION FUNCTION USING
MAXIMUM LIKELIHOOD METHOD (1980-81 to 1989-90)

Sl.No	Variables	Parameters	Model-I (OLS)	Model-II (MLE)	Full Model (MLE)
1	Constant	α_0	-6.0443 (14.23)	-2.5666 (4.43)	-3.5982 (6.61)
2	Capital	β_K	0.2764 (2.68)	0.3739 (3.92)	0.4997 (4.86)
3	Labour	β_L	1.8262 (12.39)	1.3415 (8.78)	1.4351 (9.33)
4	Capital*capital	β_{KK}	0.1185 (9.38)	0.1082 (8.63)	0.1083 (8.71)
5	Labour*labour	β_{LL}	-0.1021 (5.53)	0.0148 (0.61)	0.0033 (0.13)
6	Kapital*labour	β_{KL}	-0.0591 (4.81)	-0.1031 (6.86)	-0.1065 (6.85)
7	Time	β_T	0.0376 (0.97)	0.0488 (2.07)	0.1108 (4.64)
8	Time*capital	β_{TK}	-0.0108 (2.34)	-0.0024 (0.78)	-0.0096 (2.84)
9	Time*labour	β_{TL}	0.0082 (1.43)	0.0014 (0.38)	0.0047 (1.27)
10	Time*time	β_{TT}	0.0034 (0.88)	0.0027 (1.07)	0.0011 (0.44)
11	$\sigma^2 = \sigma_v^2 + \sigma_u^2$		0.2799	0.4782 (12.81)	0.5775 (10.01)
12	$\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$		0	0.8108 (66.42)	0.8402 (59.54)
13	μ		0	1.2451 (13.43)	1.3932 (10.61)
14	η		0	0	-0.0212 (4.43)
15	Log-Likelihood Function		-1073.95	-585.796	-583.678
Average mean technical efficiency				0.3005	

Note: figures in parenthesis are 't' statistics. The parameters are estimated
using computer programme FRONTIER 4.1

Table-A.3
ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION FUNCTION USING
MAXIMUM LIKELIHOOD METHOD (1990-91 to 1997-98)

Sl.No	Variables	Parameters	Model-I (OLS)	Model-II (MLE)	Model-III (MLE)
1	Constant	α_0	-6.3654 (9.19)	-2.6372 (2.88)	-3.1816 (3.65)
2	Capital	β_K	0.2022 (0.88)	-0.1273 (1.11)	0.0144 (0.11)
3	Labour	β_L	1.9366 (6.32)	1.9782 (8.42)	1.9557 (8.46)
4	Capital*capital	β_{KK}	0.0954 (5.93)	0.0219 (1.72)	0.0224 (1.76)
5	Labour*labour	β_{LL}	-0.1553 (6.46)	-0.1019 (3.51)	-0.1123 (4.11)
6	Kapital*labour	β_{KL}	-0.0308 (2.04)	-0.0162 (1.13)	-0.0126 (0.88)
7	Time	β_T	-0.0678 (0.77)	0.0215 (0.55)	0.0785 (1.76)
8	Time*capital	β_{TK}	-0.0113 (1.25)	0.0103 (2.35)	0.0024 (0.45)
9	Time*labour	β_{TL}	0.0169 (1.49)	-0.0057 (1.08)	-0.0014 (0.25)
10	Time*time	β_{TT}	0.0124 (0.95)	0.0023 (0.36)	0.0039 (0.61)
11	$\sigma^2 = \sigma_v^2 + \sigma_u^2$		0.4683	0.7844 (9.79)	0.8274 (11.14)
12	$\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$		0	0.8898 (105.59)	0.8928 (113.19)
13	μ		0	1.6708 (13.87)	1.7191 (14.94)
14	η		0	0	-0.0216 (2.77)
15	Log-Likelihood Function		-965.99	-483.36	-482.44
Average mean technical efficiency				0.2145	

Note: figures in parenthesis are 't' statistics. The parameters are estimated using computer programme FRONTIER 4.1

NOTES

1. This study is the part of the first author's Ph.D work. The analysis in this study is only for the whole sample covering all the 144 three-digit industries.
2. Out of 181 three-digit industries, reported in the Annual Survey of Industries, we have chosen 144 industries based on the availability of information regarding the data for the whole study period.
3. The detailed information regarding the derivation of equations relating to the log-likelihood function are found in Battese and Coelli (1992).

REFERENCES

1. Abby Ghobadian and Tom Husband (1990), "Measuring total productivity using production function", *International Journal of Productivity Research*, Vol: 28(8).
2. Abid A Burki (1998), "Measuring Production efficiency in small firms in Pakistan, *World Development*, Vol: 26, No: 1, Pp: 155-169.
3. Afriat S. N (1972), "Efficiency estimation of production function", *International Economic Review*, Vol: 13 (3).
4. Agarwal R N (2001), "Technical efficiency and productivity growth in the Central Public Sector Enterprises in India during 1990s", Working Paper, *Institute of Economic Growth*, New Delhi, India.
5. Aigner D J and S.F Chu (1968), "On estimating industry production function", *American Economic Review*, Vol: 58 (4), Pp: 826-839.
6. Allison Green, C Harris and David Mayes (1991), "Estimation of technical inefficiency in manufacturing industry", *Applied Economics*, Vol: 23.

7. Ana Martin-Marcos and Christina Suarez-Galvez (2000), “Technical efficiency of Spanish manufacturing firms: a panel data approach”, *Applied Economics*, Vol: 32.
8. Arup Mitra (1999), “Total factor productivity and technical efficiency in Indian industries”, *Economic and Political Weekly*, July 31.
9. Christopher Cornwell, Peter Schmidt and Robin C Sickles (1990), “Production frontiers with cross-sectional and time-variation in efficiency levels”, *Journal of Econometrics*, Vol: 46, Pp: 185-200.
10. Donald M Waldman (1984), “Properties of technical efficiency estimators in the stochastic frontier model”, *Journal of Econometrics*, Vol: 25, Pp: 353-364.
11. Finn R Forsund and Lennart Hjalmarsson (1974), “On the measurement of productive efficiency”, *Scandinavian Journal of Economics*.
12. Finn R Forsund, Peter Schmidt and C A Knox Lovell (1980), “A survey of frontier production function and of their relationship to efficiency measurement”, *Journal of Econometrics*, Vol: 13, Pp: 5-25.
13. George E Battese and Tim J Coelli (1988), “Prediction of firm-level technical efficiencies with generalized frontier production function and panel data”, *Journal of Econometrics*, Vol: 38, Pp: 387-399.
14. George E Battese and Tim J Coelli (1995), “A model for technical efficiency effects in a stochastic frontier production function for panel data”, *Empirical Economics*, Vol: 20.
15. Gopinath Pradhan and Kaustuva Barik (1999) “Total factor productivity in developing economies; A study of selected industries in India”, *Economic and Political Weekly*, July 31.

16. Gorti V L Narasimham, P A V B Swamy and R C Reed (1988), "Productivity analysis of U.S manufacturing using a stochastic coefficient production function", *Journal of Business and Economic Statistics*, Vol: 6 (3).
17. Hans Bjurek, Lennart Hjalmarsson and Finn R Forsund (1990), "Deterministic parametric and nonparametric estimation of efficiency in service production", *Journal of Econometrics*, Vol: 46, Pp: 213-227.
18. James Jondrow, C A Knox Lovell, Ivan S Mathrov and Peter Schmidt (1982), "On the estimation of technical inefficiency in the stochastic frontier production functional model", *Journal of Econometrics*, Vol: 19, Pp: 233-238.
19. Julien van den Broek, Finn R Forsund, Lennart Hjalmarsson and Wim Meeusen (1980), "On the estimation of deterministic and stochastic frontier production functions- A comparison", *Journal of Econometrics*, Vol: 13, Pp: 117-138.
20. Kalirajan K P and M B Obwona (1994), "Frontier production function: The Stochastic coefficient approach", *Oxford Bulletin of Economics and Statistics*, Vol: 56 (1).
21. Kalirajan K P and R T Shand (1989), "A Generalized measured of technical efficiency", *Applied Economics*, Vol: 21.
22. Kalirajan K P and R T Shand (1999), "Frontier production function and technical efficiency measures", *Journal Economic Surveys*, Vol: 13 (2).
23. Patricia E Beeson and Steven Husted (1989), "Pattern and determinants of productive efficiency in State manufacturing", *Journal of Regional Science*, Vol: 29 (1).
24. Paul Stoneman and Nathan Francis (1994), "Double deflation and the measurement of output and productivity in UK manufacturing 1979-89", *International Journal of the Economics of Business*, Vol: 1 (3).

25. Paul W Bauer (1990), “Recent Developments in the Econometric Estimation of Frontiers”, *Journal of Econometrics*, Vol: 46, Pp: 39-56.
26. Peter Schmidt and C A Knox Lovell (1980), “ Estimating stochastic production and cost frontiers when technical efficiency and allocative efficiency are correlated”, *Journal of Econometrics*, Vol: 13, Pp: 83-100.
27. Peter Schmidt and Robin C Sickles (1984), “Production frontier and panel data”, *Journal of Business and Economic Statistics*, Vol: 2 (4).
28. Pravin Krishna, Devashish Mitra (1998), “Trade liberalization, Market Discipline and Productivity Growth: New evidence from India”, *Journal of Development Economics*, Vol: 56, Pp: 447-462.
29. Rafik B and Mokhtar Kouki (2003), “Stochastic production frontiers and technical inefficiency: A sensitivity analysis”, *Econometrics Review*, Vol: 22 (1).
30. Sankho Kim (2003), “Identifying and estimating source of technical efficiency in Korean manufacturing industry”, *Contemporary Economic policy*, Vol: 21 (1).
31. Subal C Kumbhakar(1990), “Production frontiers, panel data, and time-varying technical inefficiency”, *Journal of Econometrics*, Vol: 46, Pp: 201-211.
32. Wim Meeusen and Julien van den Broek. Antwerpen (1977), “Technical Efficiency and the dimension of the firms: Some results on the use of frontier production functions”, *Empirical Economics*, Vol: 2 (2).
33. Xiao-Guang Zhang and Siqi Zhang (2001), “Technical efficiency in China’s Iron and Steel industry: Evidence from new census data”, *International Review of Applied economics*, Vol: 15 (2).
