# Indian IT Industry: A Firm Level Analysis Using DEA & Malmquist Index

Somesh K. Mathur[1]

## Abstract

The present paper analyzes the performances of the Indian IT industry by working out the technical efficiency of the software and telecommunication firms using the mathematical model of the Data Envelopment Analysis (DEA). The DEA is a non linear programming way of calculating technical efficiency of the decision making units. The study also examines the impact of various determinants on technical efficiency of software firms & net exports across the IT firms and further examines the determinants for new technology adoption by telecommunication industries because the success of the software firms in terms of its exports is intertwined with the performance of telecommunication industry. The study uses a Malmquist index to estimate total factor productivity (TFP) change for common set of software firms existing between 1996 and 2006 using prowess data base. The total factor productivity is decomposed into efficiency change (catching up phenomena) and technical change (innovations) for the common set of software firms existing between 1996 and 2006 in India. At the end the study works out the performance of the Indian ICT sector in comparison with countries which are front runners using the DEA and global information technology report,2006 data base. The study will quantify the changes needed in the relatively good Indian ICT environment and ICT readiness indices to increase its ICT usage among individuals, business and government.

The paper confirms the improvements in productivity, efficiency change and technical change of the Indian Software industry from 1996 to 2006.

------------

Appendix Table IV benchmarks the performance of 92 Indian Software firms (as in 2005- 2006) in terms of input oriented technical efficiency- how judicious are firms in converting inputs into outputs. We have used Data Envelopment Analysis for working out input oriented technical efficiency. Data Envelopment Analysis uses linear programming to calculate technical efficiency of each decision making unit in respect to the 'best practice production frontier'[2]. A score of one means most efficient among the software firms. We have used two outputs namely sales and net exports as outputs and number of employees, years in business and total costs as inputs. We have used data of 2005- 2006 of the Prowess data base published by CMIE.16 firms out of the total are operating at the 'best practice frontier' i.e. are most efficient and have scored one. These include Infosys Technologies, Tata Consultancy Limited, Patni Computers, NIIT( National Institute for Information Technology), HCL, Wipro, Hewlett Packard; among others (see Appendix Table IV). The average technical efficiency of 92 firms works out to be 0.69 as in 2005-2006. The technical efficiency of IT industry has increased since 1990s (an exercise done by the author using prowess database of CMIE-The results are available with author on demand). Joseph and Abraham (2005) using firm level data and an index of claimed technological competence (ICTC) have shown that firms are moving up the value chain and diversifying their services once they reach a threshold level of attainment in terms of revenue and exports.

Technical efficiency of the 92 firms was further regressed on its explanatory

---

[1] Fellow, RIS(www.ris.org.in)..All appendix tables and empirical results are available on demand from the author.

[2] see appendix on the DEA analysis

factors using tobit regression. Tobit regression or censored regression[3] was used as values of technical efficiency are constrained by the upper limit of one.Sales of the firm (proxy for size of firm) and net exports had positive and significant impact on the technical efficiency while total cost had negative and significant impact on technical efficiency. Number of employees and total number of years had insignificant impact on technical efficiency. However, R square could only explain only 20 % of the variation in the dependent variable signifying that rest 80 % variation in the dependent variable is explained by other factors which could not be included in our study. These may be affiliation to the MNC, R& D intensity, SEI-CMM certification (quality), advertising intensity, HR policy, organization climate and culture and technology imports in terms of royalty paid, E- regulations, among others. The results are summarized below in Appendix Table 1.

Regressing net exports on its determinants yielded the following results( see Appendix Table 2). We used tobit regression analysis in this exercise as well. This is because we have some zero net export figures for some software firms. The firms in general have to make two set of decisions-one whether to trade and second if yes then how much.

We find that size of the Software Company (in terms of sales of the software company), number of employees and total costs (negatively) do matter for net exports. Years in business and technical efficiency are insignificant factors in explaining variation in net exports across the 92 software firms. While net exports have a significant impact on technical efficiency, technical efficiency does not seem to have an impact on net exports. Also, while number of employees statistically worked out to be insignificant factor in explaining variation in technical efficiency across the 92 software firms, the same factor is significantly impacting the net exports of the software firms. R square worked out to be 0.98 signifying that 98 % variability in net exports can be explained by the variation in the explanatory variables

The study also uses a Malmquist index[4] ( as outlined by Fare, et al (1997) to estimate total factor productivity(TFP) changes of common existing software firms( 32) between 1996[5] and 2006 along with TFP decomposition into efficiency change and technical change. Inputs (total cost and years in business) and output data (sales and net exports) for 32 software firms in two time periods -1996 and 2006 are used using CMIE Prowess data base to work out Malmquist index. The Malmquist index as specified in Appendix X will be able to determine levels of change in productivity, efficiency change and technical efficiency changes between 1996 and 2006 for common set of software firms existing between 1996 and 2006. However, the method is non- transitive and so cannot be used to estimate cumulative impacts over time. If the Malmquist index shows a value 1 it implies no change in total factor productivity while a value greater than one implies an improvement while a value less than one implies a decrease in productivity. TFP comprises of two parts-efficiency changes and technical

---

[3] See Appendix XII for details on Tobit Model. See Hermen Briens for working out MLE of the tobit model http://econ.la.psu.edu/~hbierens/EasyRegTours/TOBIT_Tourfiles/TOBIT.PDF

[4] See appendix at the end

[5] 2006 can be said to be a breakpoint as far as services contribution to GDP is concerned. India's services share in GDP rose from around 44% to more than 50 % in this year.

Changes. The efficiency changes relates to how the software firms have performed relative to the production frontier. An efficiency change which is greater than 1 implies that the firms are operating closer to the frontier than in previous period, while if the figure is less than 1, the software firm in question is operating further from the frontier. Technical change means a shift of the frontier. This can be affected by adoption of new ICT technologies like internet, WAP, Wimax, among others which are so much inter-wined with success of the software export of services including ITES exports or also changes in the economic and regulatory environment in India and abroad since 1996. We have used Malmquist output orientation index assuming constant returns to scale.

The results of TFP changes from 1996 to 2006 for 32 software firms are summarized in Appendix Table XI. We find that the maximum TFP changes (more than one) is in Infosys Technology Limited( 3.91, an increase of 291 %) followed by Satyam Computers ( 3.27), then Wipro limited ( 2.39) followed by HP global soft limited (2.15) and Tech Mahindra (2.04). The average TFP changes for 32 firms is greater than one and is 1.27( 27 % increase) implying improvements in productivity of the software firms operating between between 1996 and 2006. This average TFP change is due to average efficiency change ( 1.149-14.9% increase) and average technical change(1.141-14.1% increase) implying movement towards the frontier( efficiency change) and shifting of frontier outwards( technical change) respectively. However, for most of the leading firms mentioned above TFP changes are due to movements of the frontier rather than catching up. One can also model wage increase and prices of products and services based on TFP changes of software firms from 1996 onwards. The wage increase in the IT firms seems to be much more than the increase in total productivity. Maybe that is one of the reasons for taxing the IT industry by the Central Government. However, this substantial wage increase may be partly due to shortage of skilled manpower in the IT Industry. Further there is no evidence of smaller firms catching up with their richer counterparts. This result is due to insignificant regression coefficient of initial level of efficiency in 1996 if one regresses efficiency change, technical change and total factor productivity change independently on initial level of efficiency levels in 1996 for 32 software firms. The fact of the matter is that in case of India most of export of services from India is consumed abroad in the US and the UK( and diversifying) and this has an impact on technical efficiency of the firms. This phenomena is somewhat different from what Porter (1990) had hypothesized about the reasons why firms move up the ladder in terms of its competitiveness. Porter (1990) had argued that local demand conditions, higher intellectual property levels and R&D intensity levels and domestic rivalry promotes innovation and competitiveness of firms. This we find from this study is not evidently clear in case for the Indian export success model.

## Technical Efficiency of the ICT Industry: A DEA Analysis

### Technical Efficiency of the ICT Industry in Selected Countries

We have worked out technical efficiency of the ICT sector for selected 12 countries around the globe using Data Envelopment Analysis. We have used two inputs and one output in our model. The two inputs are ICT Environment index(averaged over the variables defining the index and each variable defined on a seven point scale) and ICT Readiness index(averaged over the variables defining the index and each variable defined on a seven point scale).The one output is ICT usage(averaged over the variables defining the index and each variable defined on a seven point scale).For definition of the variables defining each of the three indices please refer to Appendix Table V at the last or the Global Information Technology Report,2006.

Our results show that Taiwan has got a score of one among the 12 countries included in our sample (See Appendix Table 3). Taiwan is the most judicious of all in converting its ICT inputs into ICT output (usage).India has got a score of 0.72 the lowest among all the countries due to its relatively poor telecommunication infrastructure(PCs availability, electricity generation, internet penetration, among others). Also, 0.28(1-0.72) scaling down of inputs (ICT environment and ICT Readiness of India) is required to reach the ‘ best practice frontier”.

Also, ICT technical efficiency and ICT Environment positively and significantly impacts the ICT usage across businesses, individuals and government using simple regression analysis (see Appendix Table 3).

Technical efficiency of the 36 Telecommunication firms using DEA analysis and prowess database of the CMIE shows that seven firms have scored a score of one in year 2004-05(see Appendix Table VI) and are operating at the best practice frontier. We used two inputs and two outputs for our DEA analysis. The two inputs were years in business and total costs while two outputs were sales of firms and net exports. The average technical efficiency of the 36 firms worked out to be 0.643. The companies which were operating at the ‘ best practice frontier’ includes BTA Cellcom Limited, Bharat Sanchar Nigam Limited(Central Government Commercial Enterprises), Bharti Airtel Limited, Bharti Hexacom Limited, India Infoline Limited, Tata Tele Services Limited and VSNL Broadband limited( see Appendix Table V1).

The new technology adopted by the Indian firms like Wimax , Bluetooth, CDMA and GSM to name a few are some of the ways in which the telecommunication industry is moving forward. For this precise reason we in this study wanted to examine the impact of the various determinants on technology adoption by the 36 firms (due to uniformity of data) belonging to the telecommunication industry in 2004-05. We took proxy for technological adoption as royalty know how expenses of telecommunication firms in Rs Millions. The explanatory variables considered were years in business, total cost, sales (for proxy for size of business) and net exports. All the data came from CMIE prowess data base and all of them are expressed in Rs millions except years in business. We used Tobit analysis to run our regression because few firms had zero expenses for technology adoption. Again there are two sets of decisions that the telecommunication firms need to make. One whether to adopt the new technology and second if yes what is the intensity of the adoption. All variables except years in business came out to be significant (see Appendix Table VII). Sales of telecommunication industry came out to be positive and significant determinant of technology adoption signifying that size in terms of sales matter for technology adoption. Total cost was inversely related to technology adoption. Net exports (exports minus imports) also were significantly and inversely related with technology adoption. This happened because most of the telecommunication firms have negative net exports signifying that large import intensity of the present telecommunication firms has a negative impact on adoption of new technology. Indian telecommunication firms can think of providing foreign direct investment in neighboring countries like Sri-Lanka and promote exports of telecommunication hardware as well. Adjusted R square was high signifying the good fit of the tobit model to the telecommunication industry.

## Conclusions

The Data Envelopment Analysis (DEA) model is used to work out technical efficiency of Information and Communication Technology ( ICT) Industry in host of countries which are front runners as far as ICT is concerned. India lags behind the most as far as ICT (not IT) is concerned. India needs to judiciously use its ICT environment and ICT readiness for higher ICT usage to come in concordance with the frontrunners like Japan, Taiwan and South Korea as far as ICT penetration indicators is concerned. .Quantitatively, 0.28( 1-0.72) scaling down of inputs( ICT environment and ICT Usage of India) is required to reach the ' best practice frontier".

However, information and Communication technology industry has brought revolution in India because of at least three reasons. First, it has reduced intermediation in business and society, second- provided solutions across sectors

and ICT technologies are increasingly becoming an important tool for national development. Also, progressively Indian telecommunication industry is expanding its business through adopting new technology and competitively pricing their products. The other South Asian countries can use the services of the

Indian telecommunication firms to provide BPO services to other nations.

DEA is also applied to benchmark the performance of the 92 Indian software companies for 2005- 2006. 16 Software companies turn out to be most efficient among the total. The average technical efficiency of 92 software firms works out to be 0.69 and has increased over the years particularly since 1990s. Malmquist analysis is used to measure changes in total factor productivity for common set of software firms existing between 1996 and 2006[6]. The average TFP for 1996-2006 is greater than one implying improvements in productivity due to more or less equal decomposition of total factor productivity change into efficiency changes (movement of firms towards the frontier- catching up phenomena) and technical changes (movement of the frontier). However for most of the leading software firms TFP changes are due to improvements in technical change rather than catching up. It is up to future research to work out whether the wage and price increase of products and their services offered by software firms commensurate with changes in TFP of firms as calculated in this study. This is also important to seek answers to the recent budget announcements of 2007-08 by the government on taxing the high growth ITES and IT sector[7] .From preliminary exercise it seems that wage increase in IT firms is much more than the increase in total factor productivity of the IT firms. However, the hike in wages and salaries may be due to shortage of skilled manpower in the IT industry.

The impact of various determinants of technical efficiency of the Indian software firms is also worked out using tobit regression. Sales of the firm (proxy for size of firm) and net exports had positive and significant impact on the technical efficiency of the software firms while total cost had negative and significant impact on technical efficiency( all at 10% level of significance). Smookler, J. (1966) study emphasized the importance of market size and sales on innovation and efficiency of firms. Number of employees and total number of years had insignificant impact on technical efficiency. However most of the changes in technical efficiency cannot be explained by the determinants taken up in this study. It is up to future research to study HR policies and regulations existing in IT software firms more closely to determine variations in technical efficiency across firms. We also find that size of the software company (in terms of sales of the software company), number of employees and total costs do matter

[6] Sample of firms that exists in 1996 and 2006 may not be representative of the overall industry due to survival bias. Those firms that existed in both periods are probably the more efficient firms; lesser performers would have dropped out of the sample

[7] In the budget 2007-08, Finance Minister had announced taxes on the IT sector- Fringe benefit taxes will be imposed on employees stock option( these may induce employees to demand higher wages.), tax on dividend distribution and venture capital and reduced exemptions on operating in the software technology parks. Taxes on venture capital may affect competitiveness of small companies. Also domestic venture capitalist would be in a disadvantage position as opposed to foreign venture capitalist who are routing their funds through Mauritius route( no taxes).

for net exports. Years in business and technical efficiency are insignificant factors in explaining variation in net exports across the 92 software firms. Seven telecommunication firms including one central government commercial enterprise out of 36 firms in India were operating on best practice frontier in 2004-05 and the average score of 36 firms worked out to be 0.643- a figure lower than that was estimated for software firms. Tobit regression analysis for the telecommunication industry depicts that sales of firms (positive), net exports (negative impact on new technology adoption because net exports are negative for most of the telecommunication firms) and total cost (negative) have a significant impact on adoption of new technology by such firms. It is interesting to find that size is important for exports but not for technical efficiency (weak relationship) signifying the importance of human resource management, organization skills and judicious regulation for the Indian software firms.

In summary it is interesting to find that size is important for exports but not for technical efficiency. Number of years in business is not statistically significant for explaining variation in technical efficiency and net exports .Net exports impacts technical efficiency (it seems through learning of new managerial practices, innovative ideas, among others) but technical efficiency has no significant impact on net exports for software firms. Even endogenous growth literature (Mathur,2005) emphasize the importance of trade openness on technology levels. Number of employees has a significant impact on net exports but not significant impact on technical efficiency of software firms. Total cost negatively impacts technical efficiency and Net exports.

***References***


Banker, R.D., Charnes, A.W. and Cooper, W.W(1984)," Some models for estimating technical and scale inefficiencies in Data Envelopment Analysis", Management Science, Volume .30, No 9, pp 1078- 1092

Coelli, T.,D.P. Rao, and G. Batteese (1998). An introduction to efficiency and productivity analysis. London, Kluwer Academic Publishers. 1998.

Caves, Doglas., Christensen, Laurits R. and Diewert , W Erwin(1982 a), "Multilateral Comparisons of Output, Input and Productivity Using Superlative Index Numbers", Economic Journal, March, 92(365), pp73

Caves, Doglas., Christensen, Laurits R. and Diewert , W Erwin (1982b), "The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity", Econometrica, November,50(6), page 1393- 1414

Charnes, A., Cooper, W.W(1962) ,"Programming with Linear Fractional Functions", Naval Research Logistic Quarterly, vol. 9,no. 304,pp 181-186

Charnes, A., Cooper, W.W., and Rhodes, E(1978) ," Measuring the Efficiency of Decision Making Units", European Journal of Operational Research, volume 2, no 2, pp 429-444

Cooper, W W., K.S.Park and J.T.Pastor(1999)," RAM : Arrange adjusted measure of efficiency", Journal of Productivity Analysis, Volume 11, page 42-50

Farell, M.J (1957) ,"The measurement of production efficiency ", Journal of the Royal Statistical Society, series A, Volume 120, no. 3, pp 253-90

Fare, R., S. Grosskopf, and C.A.K. Lovell (1994). Production frontiers. New York, Cambridge University Press. 1994

Fare, R., Grosskopf S Grifell-Tatje, and C .A. Knox –Lovell(1997), " Biased Technical Change and the Malmquist Productivity Index", Scandinavian Journal of Economics 99:1, 119-127

Global Information Technology Report (2006), World Economic Forum, Geneva

Joseph, K.J and V. Abraham (2005), " Moving Up or Lagging Behind? An Index of Technological Competence in India's ICT Sector", in A.Saith and M.Vijayabaskar (eds), ICT s and Indian Economic Development (New Delhi: Sage Publications)

Mathur, Somesh K(2007) Perspective of Economic Growth and Convergence in Selected South Asian and East Asian Economies, E-Book published by ideaindia.com( www.ideaindia.com), London.

Mathur, Somesh .K.(2005),"Economic Growth and Conditional Convergence "Its Speed for Selected Countries for 1961-2001", Indian Economic Review, Delhi School of Economics, June-December Issue.

Malmquist, Sten(1953), " Index numbers and Indifference Curves", Trabajos de Estatistica, 4 (1),pp 209-42

Porter (1990), The Competitive Advantage of Nations, The Free Press, New York

Stavarek, Daniel (2005) , Efficiency of Banks in Regions at Different Stage of European Integration Process, Economics Working Paper Archive Econ WPA

Smookler, J. (1966), Invention and economic growth. Cambridge, Mass.: Harvard University Press.

Ruggiero, J (2001) ," Determining the base cost of education: An Analysis of Ohio School Districts", Contemporary Economic Policy, 19, 268-279

Ruggiero , J(2004)," Performance Evaluation in Education: Modeling Educational Production, Chapter 12, Handook on DEA, Kluwer Academic Publishers: Boston/ Dordrecht/ London.

Rouuatt, S.,(2003), " Two stage evaluation of bank branch efficiency using DEA", MaSc dissertation, Centre for Management of Technology and Entrepreneurship

Schware, R(1987),"Software Industry in the Third World: Policy Guidelines, Institutional Options and Constraints" ,World Development, Volume 15,No 10/11,pp 1249-1267

Schware, R.( 1992). "Software Industry Entry Strategies for Developing Countries: A Walking on Two Legs' Proposition. In *World Development*, Vol. 20, No. 2, pp. 143-164.

Sherman, H.D (1984) ," Hospital Efficiency measurement and evaluation", Medical Care, 22, no 10, 922-928

Vassiloglou, M and Giokas,D.,(1990) ," A Study of the relative efficiency of the bak branches: An application of Data Envelopment Analysis", Journal of Operational Research Society, Volume 41,no 7, pp 591-597

Zenios, CV., Zenios , S.A., Agathocleous K. and Soterioou, A.C., (1999) ," Benchmarks of the efficiency of bank branches", Interfaces, volume 29, no 3, pp 37-51

***Appendix IX: DEA Analysis***

The DEA technique permits an assessment of the performance or TE of an existing technology relative to an ideal, "best-practice", or frontier technology (Coelli et al 1998). The frontier or best-practice technology is a reference technology or production frontier that depicts the most technically efficient combination of inputs and outputs (i.e., output is as large as possible given the technology and input levels, or input levels are as small as possible given the output levels). The frontier technology is formed as a non-parametric, piece-wise, linear combination of observed "best-practice" activities. Data points are enveloped with linear segments, and TE scores are calculated relative to the frontier technology.

DEA is a non parametric non linear mathematical programming approach for construction of production frontiers and the measurement of technical efficiency relative to best practice production frontiers. DEA model is used to evaluate the relative efficiency of a decision making units ( in this study for software firms and telecommunication firms) in their use of multiple inputs to produce multiple outputs where the form of production is neither known nor specified .However DEA model cannot handle data noise which models like Stochastic Frontier are better equipped to do. Another criticism of the DEA is that the best -practice frontier-a lower bound on the frontier under the assumption of constant returns-fails to identify the 'true' but unknown frontier, especially at low capital labor ratios

The seminal work was done by Farrell (1957) who used one output and many input model for working out technical efficiency. Charnes Cooper and Rhodes (1978) and Banker, Charnes and Cooper( BCC) are now the most applied models as they can take care of multiple inputs and multiple outputs along with the latter taking into account variable returns to scale. The BCC model eliminates the scale part of efficiency from the analysis and therefore the CCR efficiency score for each DMU( Decision Making Units) will not exceed the BCC efficiency score, which is intuitively clear since the BCC model analyses each DMU locally, i.e. compared to the subset of DMUs that operate in the same region of returns to scale, rather than globally. Thus, the BCC efficiency scores are also called pure technical efficiency scores.

Charnes et. Al(1978) developed DEA to evaluate the efficiency of public sector non-profit organizations. DEA aims to measure how efficiently a DMU uses the resource available to generate a set of outputs and DMUs can include manufacturing units, departments of universities, research organizations, schools, banks, hospitals, airports, power plants, police stations, among others including DMUs who do not price their products and services. The best performing DMU is assigned an efficiency score of unity or 100% and the performance of other DMUs ranges between 0 and 100 percent relative to this best performance. For inefficient DMU (Efficiency <100%), DEA measures the slacks in each of the input and output variables and also derive a reference group of efficient units with which they can be directly compared (Cooper et a1. 1999). DEA result also helps to improve the productivity of these relatively inefficient units without reducing quality of service and while maintaining or even increasing the volume of services provided by DMUs. Ruggiero (2001, 2004) discussed the application of DEA in education sector, Vassiloglon et a1. (1990), Zenios et. al(1999), Rouatt (2002) discussed various application of DEA in banking sector to improve the performance; Sherman (1984) used DEA in hospital sector, Lewin et a1. (1982) used DEA in court system.. Mathur (2007) works out technical efficiency levels of 29 countries consisting of some selected South Asian, East Asian and EU countries using data envelopment analysis from 1966 onwards till 2000. He also decompose labor productivity growth into components attributable to technological changes (shifts in the overall production frontier), technological catch up or efficiency changes (movement towards or away from the frontier), capital accumulation (movement along the frontier) and human capital accumulation (proxied by life expectancy). The overall production frontier is constructed using deterministic methods requiring no specification of functional form for the technology nor any assumption about market structure or the absence of market imperfections. Growth accounting results tend to convey that for the East Asian and the South Asian countries efficiency changes (technological catch up) have contributed the most, while for the European countries it is the technical changes which has contributed more to labour productivity changes between 1966-2000. Mathur (2007) study also works out technical efficiency levels of the Indian States and Union Territories using Data Envelopment Analysis from 1980-81 to 1997-98. He also analyzes the evolution of cross states net value added distribution for the 22 Indian states and union territories from 1980-81 to 1997-98 using Kernel densities. The efficiency factor accounted for 5.07 % only,technological change accounted for 11.66 % while the contribution of capital deepening is relatively higher at 17.82% while the point to point productivity change is of 11.66%. The Solovian model seems to work in the case of industrial sector in India The overall averages provide evidence of productivity improvements of 173.29 over 1980-81 (base) to 1997-98 (current year) period. The efficiency factor accounted for -10.63% % only,technological change accounted for 173.20 while the contribution of capital deepening is 42.52% to account for 173.20% overall productivity change (not point to point).

The mathematical formulation of DEA model is presented in the following section as given by Stavarek (2005). The Primal Problem

$$\max_{u,v} h_0 \ (u,v) = \frac{\sum_{y=1} u_r y_{r2}}{\sum_{t=1} v_t x_{fr}} \qquad (1)$$

Subject to:

$$\frac{\sum_{r=1}^{s} U_r y_{r3}}{\sum_{t=1}^{M} v_t x_{fr}} \leq 1 \; j = 1,2,\ldots j.., n \qquad (2)$$

$u_r \geq 0$, r=1,2…,s (3)

$v_y \geq 0$, I=1,2…,m (4)

where h0 is the technical efficiency of DMU0 to be estimated, ur and vi are optimal weights to be determined, yrj is the observed amount of output of the r th type for the j th DMU, xij is the observed amount of input of the i th type for the j th DMU, r indicates the s different outputs, I denotes the m different inputs, and j indicates the n different DMUs. The weights ur and vi in the objective function are chosen to maximize the value of the DMU's efficiency ratio subject to the less than unity constrains. These constrains ensure that the optimal weights for DMU0 in the objective function does not imply an efficiency score greater than unity, either for itself or for any of the other DMUs.

The DEA model mentioned above is a fractional linear program in which the numerator has to be maximized and the denominator would be minimized simultaneously. To solve this kind of model, it is converted into linear form by following a transformation developed by Charnes and Cooper (1962) for fractional programming. It allows the introduction of a constant which is given in Equation 5

$$\sum_{t-1}^{m} V_1 X_t = 1 \quad (5)$$

This means the sum of all inputs is set to equal one. The obtained linear programming problem that is equivalent to the linear fractional programming problem (Equation 1 to 4) for DMU s can be written as:

$$\max_x z_0 = \sum_{r=1}^{s} u_r y_{r2}$$

$$\sum_{r=1}^{s} u_r y_{r2} - \sum_{r=1}^{m} v_r x_{rs} \leq o, j = 1,2,....,n$$

$$\sum_{t-1}^{s} v_1 x_t = 1$$

$u_r \geq 0$, r=1,2…,s

$v_y \geq 0$, i=1,2…,m

The input-oriented VRS for the DMU0( dual of the primal problem)

$$\min_{\lambda} z_0 = \Theta_0$$

$$\sum_{f-1}^{n} \lambda_j y_{rj} \geq y_{ro}, r = 1,2,......, s$$

$$\Theta_0 x_{fo} - \sum_{j=1}^{n} \lambda_j\, x_{tj} \geq 0, i = 1,2,......, n$$

$\lambda j \geq 0$, j= 1, 2, …….,n

where the technical efficiency of DMU0 is denoted by $\Theta_o$. and $\lambda j$ indicates weight of the j th DMU. Moreover, $\lambda=(\lambda_{1,} \lambda_{2, \ldots,} \lambda_n)$ $\lambda$ 0 0, is the vector of weights obtained by individual DMUs which can determine the peer group identified by particular DMU for emulation. The DMU with technical efficiency $\Theta$ j < 1 is considered as inefficient, the efficiency $\Theta$ j = 1 shows the efficient DMU placed on the efficiency frontier.

The non increasing-returns-to scale (NIRS) technology is constructed by restricting the process operation levels as satisfy $0 \leq z^j \leq 1$ for all j, so that observed process can be radially contracted but not expanded. The variable-returns-to-scale (VRS) technology is constructed by adding the restriction $\sum_j z^j \leq 1$, resulting in increasing returns as scale at low levels of input. By construction, efficiency indexes calculated under the assumption of constant returns to scale are no higher than those calculated under the assumption of NIRS, which in turn are no greater than those constructed under the assumption of VRS (see Fare et al. [1994] for details).

***Appendix X: Malmquist Approach***

In this study productivity change is measured as the geometric mean of two Malmquist indexes. The Malmquist index was introduced by Caves et. al (1982 a,b) who dubbed it the ( output based) Malmquist index after Sten Malmquist , who earlier proposed constructing quantity indexes as ratios of distance functions( see Malmquist 1953).The Malmquist index discussed above is calculated as follows [(as outlined in Fare, et.al. (1997)]

$$m(u_t, x_t, u_{t+1}, x_{t+1}) = \left[\frac{d_0^t(u_{t+1}, x_{t+1})}{d_0^t(u_t, x_t)} x \frac{d_0^{t+1}(u_{t+1}, x_{t+1})}{d_0^{t+1}(u_t, x_t)}\right]^{1/2} \ldots\ldots\ldots\ldots\ldots(1)$$

This formula can be further decomposed into efficiency and technical change as follows

$$m(u_t, x_t, u_{t+1}, x_{t+1}) = \frac{d_0^{t+1}(u_{t+1}, x_{t+1})}{d_0^t(u_t, x_t)} \left[ \frac{d_0^t(u_{t+1}, x_{t+1})}{d_0^{t+1}(u_{t+1}, x_{t+1})} x \frac{d_0^t(u_t, x_t)}{d_0^{t+1}(u_t, x_t)} \right]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

Where the first phase of the equation (that which lies outside of the parenthesis) represents efficiency change and the second part (contained within the parenthesis) represents technical change.

The Malmquist index can be estimated as a function of a set of distance functions( which are reciprocals of the technical efficiency measures), which, in turn, can be estimated using DEA. This is a methodology proposed, again, by Fare, *et at.* (1997). The index requires 4 DEA models to be estimated, which respectively specify efficiency in the current time *period,* $d^t_o$ $(u_t , x_t)$ efficiency in the next time *period,* $d_o{}^{t+1}(u_{t+1} , x_{t+1})$; efficiency of a firm operating in this time period relative to firms operating in the next time period, $d_o{}^{t+1}$ $(u_t , x_t)$; and the efficiency of firms operating in the next time period relative to the frontier in this time period, $d_o{}^t(u_{t+1} , x_{t+1})$ The TFP index is then calculated using Equation (1), above.

We have used Malmquist output orientation index. for this study, an alterative approach is to use an input orientation where the frontier is the minimum set of inputs required for a given level of output. However if one assumes constant returns to scale input oriented Malmquist measure is a reciprocal of the output oriented Malmquist measure of TFP changes.

***Appendix XII: Tobit Model***

The Tobit model is based on the following latent variable model:

$$Y^* = b'X + U,$$

where $X$ is a $k$-vector of regressors, possibly including 1's for the intercept, and the error term $U$ is $N(0,s^2)$ distributed, conditionally on $X$.

The latent variable $Y^*$ is only observed if $Y^* > 0$. In particular, the actual dependent variable is:

$$Y = \max(0, Y^*)$$

The appropriate method to estimate the Tobit model is maximum likelihood method