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An evaluation of the determinants of total factor productivity growth in Indian information technology industry: an application of DEA-based Malmquist Index

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Abstract:

Aim: This study aims at assessing the Total Factor Productivity Growth (TFPG) and its determinants in the Indian Information Technology (IT) industry.

Design / Research methods: To realize the objectives of the study, firm level data has been collected from the Centre for Monitoring Indian Economy (CMIE) PROWESS database. For empirical analysis, we have applied a two-stage method. In the first-stage, we have used Data Envelopment Analysis (DEA) based Malmquist Productivity Index (MPI) to evaluate the TFPG in the Indian IT industry during the period from 2004-05 to 2014-15. For this purpose, a balanced panel dataset consisting 70 IT firms has been considered. Further, the TFPG has been decomposed into three components, viz. catch-up, frontier-shift, and scale efficiency change (SEC). Consequently, in the second-stage, three random-effects panel regression models are considered to investigate the determinants of TFPG, catch-up, and frontier-shift separately.

Conclusions / findings: During the study period, on an average, the TFPG and frontier-shift has been improved. On the other hand, catch up effect is found to have declined. The variables, such as export intensity, salaries and wages intensity have positive and statistically significant impact on the catch-up and frontier-shift. Export intensity and Salaries and wages have positive impact on TFPG. Age of the firms has positive impact on catch-up and TFPG. On an average, the firms which spent on research and Development (R&D) have experienced improvement in TFPG and frontier-shift. The public limited firms performed better than their private counterparts in terms of catch-up, frontier-shift, and TFPG. The non-group firms have performed better than the group firms in case of catch-up. On the other hand, on an average, the firms exhibiting decreasing Returns to Scale (DRS) are found to have registered deterioration in catch-up and TFPG with respect to the benchmark Constant Returns to Scale (CRS) firms. The firms exhibiting Increasing Returns to Scale (IRS) have shown improvement in catch-up and TFPG over the benchmark CRS firms. The impact of the US subprime crisis has been negative on

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catch-up, frontier-shift, and TFPG. The firms, which have spent on royalty, have experienced improvement in catch-up and TFPG.

Originality / value of the article: So far in our knowledge, we have not found so many empirical studies of this kind pertaining to the IT industry, especially in a developing country like India. Moreover, we have not found any study that covers the span of the dataset considered in this study. In addition to this, the present study has employed a random-effects model to accommodate a number of time-invariant dummy variables which would not be possible in case of a fixed-effects model incorporated by some previous studies of this genre.

Implications of the research (if applicable): The identification of the determinants of TFPG and its components would help the stakeholders and policy makers to formulate appropriate policies which could mitigate the risks faced by the Indian IT industry on one hand, and stimulate the forces that would enhance the growth of this industry on the other. For instance, to mitigate future risks, Indian IT industry should reduce its dependence on the US and UK markets. In other words, it should explore new markets in domestic as well as foreign economies such as the EU, Australia and the emerging economies where the IT markets are seem to be promising. To maintain India's robust global position in the long run, Government of India should play a key role in providing world class infrastructure and telecommunication facilities to its IT industry. In addition to this, Indian Government needs to rationalise and simplify the existing Indian labour law to facilitate the business of IT industry. Various stakeholders along with the Government should put necessary efforts to develop the domestic IT market where ample opportunities are present.

Keywords: Information Technology industry, data envelopment analysis, Malmquist productivity index, random-effects model, total factor productivity, catch-up, frontier-shift, India.

JEL: C23, C61, L86, O47

1. Introduction

The Indian Information Technology and Information Technology-enabled Services (IT-ITeS) industry has been playing an instrumental role in software development globally and providing various IT-enabled back office services since the beginning of the 21st century. As of now, India holds a prestigious position in the world as an off-shoring destination nation. On the other hand, the Indian IT-ITeS sector has occupied a distinguished position in the international market of software and different IT-enabled services. Indian IT companies have been enjoying remarkable position internationally in providing a variety of on-shore as well as off-shore services to their foreign clients. During the last decade, this sector has grown almost six times in terms of its revenue. In the financial year 2016-17, the relative contribution of this sector to India's GDP is estimated to be more than 9.3 percent

(NASSCOM[1] 2017). India's competitive advantage in IT-ITeS industry mainly comes from the abundance of cheap, technically skilled, and English-language proficient workforce. Furthermore, over time, Indian IT sector has become capable of delivering high end quality services in the global sourcing market with supreme reliability and cost-effective manner. During 2016-17, India is able to retain her leading position in IT-ITeS sourcing business globally with a robust share of 55% (NASSCOM 2017).

However, some recent global incidents such as slowdown in the world economic activity followed by U.S. subprime crisis, Britain's exit from the European Union (EU) in 2016, new U.S. administration's policy towards H-1B visa programme in 2017, etc. are likely to have unfavourable impact on the performance of the Indian IT-ITeS sector. In addition to this, the emergence of capital deepening technology (or automation) in IT-ITeS industry may further worsen the situation. There is a perception that increasing automation could diminish job availability in this industry. On the other hand, some internal factors like dearth of quality manpower, inability of the industry to move up the value-chain, underdeveloped domestic market and unpreparedness of the industry for disruptive technologies pose challenges to the growth of this industry in the future (Sharma 2014).

Against this background, maintenance of a steady performance is critical to the sustainability of the Indian IT industry in the future. Therefore, it is pertinent to assess the performance of the Indian IT industry. In this paper, an attempt has been made to measure performance of this industry in terms of total factor productivity change over time. In this context, very few empirical studies are found that investigated the productivity change in Indian IT industry. Moreover, in our knowledge, no study has been conducted so far wherein the productivity change in Indian IT industry is evaluated during 2004-05 to 2014-15. To fill this research gap, this paper aims at exploring the following objectives:

- The trends in total factor productivity growth (TFPG) in the industry over the study period

[1] NASSCOM refers to the National association of Software and Services Companies, which is a premier trade body and the chamber of commerce of the IT-ITeS industry in India.

- The trends in various constituent components of TFPG, viz. catch-up, frontier-shift over the study period
- Decomposition of catch-up effect into pure technical efficiency change (PTEC) and scale efficiency change (SEC)
- To indentify the influence of various environmental variables on TFPG, catch-up, and frontier-shift.

To evaluate the TFPG over time, this study employs Malmquist Productivity Index (MPI) which is based on DEA technique. The TFPG is further decomposed into three components, namely, technical change (innovation), technical efficiency change (catch-up), and scale efficiency change. The TFPG is evaluated on the basis of base period as well as adjacent period. Subsequently, random-effect panel model is used to find out the determinants of TFPG, technical change, and technical efficiency change.

The paper is divided into five sections. Section-1 presents introduction and objectives of the study. Section-2 contains review of literature. Section-3 describes the methodology. Section-4 discusses the data. Section-5 consists of the results and discussion. Finally, Section-6 provides the summary and concluding remarks.

2. Review of Literature

This section summarizes the studies pertaining to the performance analysis in the IT industry. Shao and Shu (2004) evaluate the TFPG in the IT industry across 14 OECD countries during 1978-1990. They employ DEA-based MPI method to estimate TFPG. For this purpose, they collect data from two databases, viz. OECD Stan Database and OECD International Sectoral database. The TFPG is further decomposed into two components, namely, technological change and technical efficiency change. The results of this study reveal that 10 countries experienced TFP growth among the 14 countries during the study period. The technological change is found to be the prime contributor to the TFP growth relative to the technical efficiency change. Furthermore, change in scale efficiency is observed to be played a dampening role in TFP growth.

Shu and Lee (2003) examine productivity and productive efficiency of IT industries of 14 OECD countries during 1998 using stochastic frontier analysis. This study evaluates three types of inefficiency: technical, allocative, and scale. The results reveal that both the technical and scale efficiencies are low among the study countries. The study suggests that a country with low technical efficiency should either provide more high tech job trainings or balance the employment growth in high tech and other industries in order to achieve higher technical efficiency. Furthermore, mergers have been recommended to improve scale efficiency.

Chen and Ali (2004) extend the DEA-based Malmquist index approach by further interpreting its two components viz. technical efficiency change and frontier shift, with managerial implication of each component. In addition to this, they try to identify the strategy shifts of individual DMUs during a particular time period with respect to changes in isoquant. Finally, this new approach is empirically applied to a set of Fortune Global 500 Computer and office Equipment companies.

Mathur (2007a) estimates the technical efficiency of Indian software industry by during 2005-06. Data for 92 software companies is collected from CMIE PROWESS database. An input-oriented DEA model is applied to calculate technical efficiency. Further, the paper investigates the impact ofvarious determinants on technical efficiency of these companies by using Tobit regression model. The average technical efficiency of 92 software companies is found to be 0.69. The regression results show that net export and company size have positive and statistically significant impact on the technical efficiency. On the other hand, total cost has negative and statistically significant impact on the technical efficiency. This study also evaluates the TFPG of Indian software companies during 1996-2006. The TFP and its decomposition results depict that TFP growth mainly occurred due improvement in technological change rather than change in technical efficiencyin the study period.

Mathur (2007b) examines the technical efficiency of the Information and Communication Technology (ICT) sector for selected 12 countries including India by applying DEA. The study found that Taiwan was the most efficient country while India was the least efficient country with technical efficiency scores 1 and 0.72, respectively. This study suggests that India should use its ICT environment and ICT readiness judiciously for higher ICT usage in order to catch up with the efficient countries such as Taiwan, Japan and South Korea.

Chen et al. (2011) estimate overall, managerial, and scale efficiencies in 73 Chinese IT companies during 2005-2007 using DEA technique. This paper also calculates the TFP growth applying Malmquist productivity index. The efficiency results reveal that on an average, the Chinese IT industry was technically and managerially inefficient by 6.8 percent and 5.1 percent, respectively, during the study period. The study does not find any significant progress in productivity during the reference period. The efficiency convergence analysis points out the occurrence of substantial technical diffusion along with a decline in the technical convergence during the study period. The study suggests that the IT-companies may invest in R&D activities and develop intellectual capital to attain competitive advantages and enhancement in performance.

Bhattacharjee (2012) examines the technical efficiency of Kolkata's Software Technology Park (STP)'s IT-ITeS firms using output-oriented DEA model under VRS assumption. For this purpose, data is collected from the STP, Kolkata for the period of 15 years (from 1993-94 to 2007-08). The results illustrate that on an average, the technical efficiency of IT-ITeS firms declines over the study period. The determinants of technical efficiency are assessed by using an OLS regression model. In regression analysis, net foreign exchange earnings and the international orientation (the ratio of foreign exchange outflow to the total cost) are considered as independent variables and the technical efficiency scores as dependent variable. Both the coefficients of the independent variables are observed to be positive and statistically significant. The paper suggests that with rising foreign exchange earnings and the higher the global orientation, the performance of the IT-ITeS industry also improves during the reference period of the study.

Sahoo (2013) evaluates TFP growth in Indian software industry during 1998-2008 using Malmquist productivity index. The study also investigates the determinants of TFP growth applying fixed-effects panel regression model. The results depict that on an average, Indian software industry experiences TFP growth by 0.4 percent during the study period. The older companies are found to be registered higher productivity growth as compared to their newer counterparts. The

Indian-owned companies are observed to be more productive than the group-owned companies. The regression analysis shows that the initial overall technical efficiency has negatively impacted the TFP growth. Finally, the R&D has no statistically significant impact on TFP growth of software industry during the study period.

Sahoo and Nauriyal (2014) analyze the trends in technical efficiency of Indian software companies during 1999-2008. They apply an input-oriented DEA model under VRS assumption to evaluate the technical efficiency. For this purpose, input and output data for a sample of 72 software firms is taken from CMIE PROWESS database. The overall technical efficiency (OTE) is further decomposed in to pure (or managerial) efficiency (PTE) and scale efficiency (SE). The study also investigates the determinants of OTE, PTE and SE of Indian software companies during the study period by using Tobit regression model. The results reveal that the mean OTE is 0.477 during 1999-2008, suggesting thereby on an average, the software industry wastes 52.3% of inputs. Pure technical inefficiency is found to be the main source of overall technical inefficiency. Further, it is found that the number of companies operating on most productive scale size has declined during the study period. The Tobit regression results show that the Indian-owned companies are more efficient that their foreign and group-owned counterparts. The firm size is found to have positive impact on technical efficiency. On the other hand, wages and salaries intensity negatively impacted overall technical efficiency, pure technical efficiency and scale efficiency. Finally, the older companies are found to be more efficient that their younger counterparts.

Chou and Shao (2014) study the TFP growth of IT services industries in 25 OECD countries during 1995-2007 using DEA-based Malmquist productivity index (MPI). MPI is further decomposed into three components, namely, technical change, efficiency change, and scale change. The findings show that technological progress is the major driver of the TFP growth. Efficiency change and scale change have negative effect on TFP growth. On an average, these IT services industries have experienced 1.9% annual TFP growth during the study period.

Das (2017) and Das and Datta (2017) apply a two-stage DEA method to study the trends in and determinants of technical efficiency in Indian IT and ITeS industry, respectively, during 2000-2014. Both the papers estimate the Pareto-Koopmans efficiency along with CCR and BCC[2] efficiency scores to take care of the presence of input and output slacks. These two studies also estimate the input and output specific technical efficiencies.

3. Methodology

3.1. Notion of total factor productivity

According to OECD (2001), productivity can be defined as a ratio of a volume measure of output to a volume measure of inputs. In simple word, productivity implies how efficiently output is produced from a given input combination (Syverson 2011). Moreover, productivity growth can be considered as a major indicator of innovation associated with creation of new production process and product, organizational structure etc. (Jorgenson 2009). The growth of output is often higher than the growth of inputs as a result of innovation. There are two ways to measure productivity: (a) for a single factor of production, and (b) for multi factor of production. Productivity of a single factor of production is also known as partial productivity. The latter is known as total or multi-factor productivity. In our study, we focus on the total factor productivity.

The Total Factor Productivity (TFP) is basically refer to the growth of output which is not explained by the growth in regular factors of production such as labour, capital, raw materials etc. (Comin 2008). Basically, TFP shows how productively the inputs are employed in a production process. Furthermore, differences in TFP show shifts in isoproduct curve which captures variation in output produced from a given input combination (Syverson 2011). There are various methods to measure the TFP. One of the most common techniques is the growth accounting approach introduced by Solow (1957). This approach calculates the TFP by as a residual (popularly known as Solow residual). Since the estimation of productivity growth reflects the changes in output which has not been explained by the changes in the individual inputs, it can be regarded as a residual measure. On the other hand, TFP is

2 CCR and BCC DEA models are developed by Charnes et al. (1978) and Banker et al. (1984), respectively.

also known as a measurement of ignorance as its outcome is unknown to us (Abramovitz 1956). Although this approach allows separating out the effect of technical change on TFP, it does not permit to separate out the changes in technical efficiency from TFP. There are two popular alternative empirical techniques to measures TFP, namely, parametric and non-parametric. Whereas the parametric approach requires an explicit consideration of the production function, the non-parametric approach does not need any prior specification of the production function.

The most popular parametric and non-parametric approaches to measure the TFP are Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA), respectively. The SFA is based on regression method. In contrast, the DEA[3] is based on mathematical programming method. There are two other popular index-based approaches to measure TFP such as Fisher and Tornqvist productivity indexes. Whereas the construction of these two indexes requires a priori price information, DEA[4] does not require any price information of input/ output for estimating TFP index. On the other hand, both Tornqvist and Fisher indexes are descriptive in nature while Malmquist index is a normative one (Ray 2004).

3.2. The Malmquist Productivity Index

This study employs DEA-based Malmquist Productivity Index (MPI) to evaluate the Total Factor Productivity Growth (TFPG) of 70 Indian software firms during 2004-05 to 2014-15. Caves et al. (1982) first introduced the MPI on the basis of Malmquist (1953). The index is further decomposed into two components, namely, technical change (frontier shift) and technical efficiency change (catch up). There are two ways to measure the TFPG on the basis of MPI. One is based on a fixed base period and the other is between two adjacent periods. In the present study, both measures are used to measure TFPG. Following Färe et al. (1994a) and Coelli et al. (1998), we calculate the MPI on the basis of an output-oriented DEA model. The output-oriented MPI is based on four output (Shepherd) distance functions. The

[3] See Cook and Seiford (2009) for a comprehensive review of studies pertain to methodological development in DEA.
[4] See Emrouznejad and Yang (2017), Emrouznejad et al. (2008) for a comprehensive survey and bibliography of studies based on DEA.

output distance function is equivalent to the Farrell measure of technical efficiency[5] and associated with the maximum expansion of the output vector given the input vector. The MPI can be decomposed in the following manner:
Malmquist Index (MI) = Technical Change (TC) x Technical Efficiency Change (TEC)

Technical change is associated with the shift of the production frontier, whereas the technical efficiency change is associated with the movement towards the frontier. The terms 'technical change' and 'technical efficiency change' are also known as frontier-shift and catch-up, respectively. Now, we assume there are 'N' numbers DMUs or firms. Each firm is producing 'm' outputs from 'n' inputs. The production possibility set (S) under CRS can be defined as follows:

$$S = \{(x, y): x \geq \lambda_j x^j,\ y \leq \lambda_j y^j;\ \lambda_j \geq 0, (j = 1, 2\ldots. ,N)\} \quad (1)$$

Where, (x^j, y^j) is the observed input and output bundle of DMU 'j'. To compute the MPI, we need to evaluate four output-oriented distance functions under CRS by solving four linear programming problems (LPP). Among four LPPs, two are for the same period and remaining two are for cross periods.
The four output distance functions are given as:

$$Dot\ (xt\ ,yt) = \min\{\theta : xt\ ,yt\ /\ \theta \in St\}. \quad (2)$$
$$Dot+1\ (xt+1\ ,yt+1) = \min\{\theta : xt+1\ ,yt+1\ /\ \theta \in St+1\} \quad (3)$$
$$Dot\ (xt+1\ ,yt+1) = \min\{\theta : xt+1,yt+1\ /\ \theta \in St\} \quad (4)$$
$$Dot+1\ (xt\ ,yt) = \min\{\theta : xt\ ,yt\ /\ \theta \in St+1\} \quad (5)$$

Equations 2 and 3 represent the same period distance functions for the periods t and t+1, respectively. Equations 4 and 5 represent the cross period distance functions.

5 See Farrell (1957) for more details.

The same period output-oriented distance function for firm 'h' under CRS can be derived by solving the following LPP:

$$\varphi_h^* = \text{Max } \varphi_h$$
$$\text{Subject to}$$
$$\sum_{j=1}^{N} \lambda_j y_j^t \geq \varphi y_h^t \; ;$$
$$\sum_{j=1}^{N} \lambda_j x_j^t \leq x_h^t \; ; \quad (6)$$
$$\lambda_j \geq 0 \; (j = 1, 2, \ldots, N)$$

The optimal value of the distance function $D_o^t (x^t, y^t)$ can be obtained as:

$$D_o^t (x^t, y^t) = \theta_h^* = \frac{1}{\varphi_h^*}$$

The optimal value of the distance function $D_o^{t+1} (x^{t+1}, y^{t+1})$ can also be obtain in similar manner by solving the LPP for period t+1.

Now, the cross period distance function (CRS) $D_o^t (x^{t+1}, y^{t+1})$ for firm 'h' for period t+1 with respect to the t-period's technology can be derived by solving the following LPP:

$$\varphi_h^* = \text{Max } \varphi_h$$
$$\text{Subject to,}$$
$$\sum_{j=1}^{N} \lambda_j y_j^t \geq \varphi y_h^{t+1} \; ;$$
$$\sum_{j=1}^{N} \lambda_j x_j^t \leq x_h^{t+1} \; ; \quad (7)$$
$$\lambda_j \geq 0, \; (j = 1, 2, \ldots, N)$$

The optimal value of the distance function $D_o^t (x^{t+1}, y^{t+1})$ can be obtained as:

$$D_o^t (x^{t+1}, y^{t+1}) = \theta_h^* = \frac{1}{\varphi_h^*}$$

Similarly, the cross period distance function $D_o^{t+1} (x^t, y^t)$ can be estimated by using the LPP stated above after interchanging the superscripts t and t+1.

Here, it may be noted that the value of the distance function and output-oriented technical efficiency are the same.

The MPI for period t can be given as:

$$M_o^t = \frac{D_o^t (x^{t+1}, y^{t+1})}{D_o^t (x^t, y^t)} \quad (8)$$

The MPI for period t+1 can be given as:

$$M_o^{t+1} = \frac{D_o^{t+1} (x^{t+1}, y^{t+1})}{D_o^{t+1} (x^t, y^t)} \quad (9)$$

Now, following Färe et al. (1994a), the output-oriented MPI for period t+1 with respect to period t can be represented as the geometric mean of the two indices:

$$\text{MPI} = M_o^t\,(x^t, y^t, x^{t+1}, y^{t+1}) = \left(M_o^t * M_o^{t+1}\right)^{\frac{1}{2}}$$

$$= \left\{\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\right) * \left(\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)}\right)\right\}^{\frac{1}{2}} \qquad (10)$$

After some algebraic modification, the MPI can be represented as:

$$\text{MPI} = \underbrace{\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\right)}_{\text{Catch-up (C)}} * \underbrace{\left\{\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}\right) * \left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right)\right\}^{\frac{1}{2}}}_{\text{Frontier-shift (F)}} \qquad (11)$$

Therefore, MPI = catch-up (C) * Frontier-shift (F) (12)

When MPI>1, it implies TFP growth or improvement in productivity from period t to t+1. A unitary value of MPI (i.e., MPI =1) indicates no change in TFP from period t to t+1. If the value of MPI<1, it indicates deterioration in TFP from period t to t+1. The catch-up (or technical efficiency change) component of MPI indicates change in overall technical efficiency under CRS technology between periods t and t+1. When C>1, it implies that the firm has been able to transform its inputs to output more efficiently in period t+1 as compared to period t. A unitary value (C=1) of C implies no change in technical efficiency between periods t and t+1. Further, if C<1, it means the firm becomes technically less efficient in period t+1 in comparison to period t. The second component of MPI, i.e., frontier-shift (or technical change) measures change in technology between two time periods t and t+1. If the value of F is greater than one (F>1), it shows technological improvement or innovation from period t to t+1. When F=1, it indicates status quo or no change in technology. Finally, F<1 implies regress in technology from period t to t+1.

To assess the impact of scale size change on TFP, the catch-up effect can further be decomposed into two components, viz. pure technical efficiency change (PTEC) and scale efficiency change (SEC). The decomposition of catch-up (or overall technical efficiency change) can be represented in the following way as proposed by Färe et al. (1994b):

$$\text{Catch-up (C)} = \frac{D_{ov}^{t}(x^{t+1}, y^{t+1})}{D_{ov}^{t}(x^{t}, y^{t})} * \frac{(D_{oc}^{t+1}(x^{t+1}, y^{t+1})/D_{oc}^{t}(x^{t}, y^{t}))}{(D_{ov}^{t+1}(x^{t+1}, y^{t+1})/D_{ov}^{t}(x^{t}, y^{t}))} \qquad (13)$$

PTEC SEC

It is to be mentioned that while distance functions under catch-up are evaluated under CRS technology, the PTEC is estimated under VRS technology. In the real world, a technology exhibiting CRS seldom exists. Further, globally CRS is a restrictive assumption about the underlying technology (Ray 2004). In other words, a technology exhibiting VRS seems to be more realistic. Therefore, in this paper, we have considered the MPI under the VRS framework. The subscripts 'c' and 'v' in distance functions in equation (13) indicate the technical efficiency under CRS and VRS technologies, respectively. If the value of PTEC is found to be greater than unity (PTEC>1), it means the firm reaches nearer to the efficient frontier in period t+1 compared to period t. A unitary value of PTEC (PTEC=1) shows no change in pure (or managerial) technical efficiency between period t and t+1. If PTEC<1, it implies the firm under question further away from the efficient frontier from period t to t+1. Moreover, it can be said that the management of the firm has become less efficient in transforming inputs in output during period t+1 relative to period t.

The SEC captures the impact of change in scale of production on TFP. If the value of SEC is greater than one (SEC>1), it reflects improvement in scale efficiency during period t+1 compared to period t. if SEC=1, it indicates status quo in scale efficiency between periods t and t+1. Finally, SEC<1 implies decline in scale efficiency in period t+1 than period t.

Finally, the MPI can be represented as:

$$\text{MPI} = = \frac{D_{ov}^{t+1}(x^{t+1}, y^{t+1})}{D_{ov}^{t}(x^{t}, y^{t})} * \frac{(D_{oc}^{t+1}(x^{t+1}, y^{t+1})/D_{oc}^{t}(x^{t}, y^{t}))}{(D_{ov}^{t+1}(x^{t+1}, y^{t+1})/D_{ov}^{t}(x^{t}, y^{t}))} * \left\{\left(\frac{D_{oc}^{t}(x^{t+1}, y^{t+1})}{D_{oc}^{t+1}(x^{t+1}, y^{t+1})}\right) * \left(\frac{D_{oc}^{t}(x^{t}, y^{t})}{D_{oc}^{t+1}(x^{t}, y^{t})}\right)\right\}^{\frac{1}{2}} \qquad (14)$$

Where, $D_{ov}^{t+1}(x^{t+1}, y^{t+1})$ and $D_{ov}^{t}(x^{t}, y^{t})$ denote the same period distance functions under VRS technology.

Therefore, MPI = PTEC * SEC * TC (15)

3.3. Econometric Methodology

Now, we discuss the econometric method employed to investigate the determinants of catch-up and frontier-shift, TFPG. In this regard, we use panel data regression to explore the environmental factors that influence the productivity change of Indian IT industry over the study period. Catch-up, frontier shift and Malmquist index are considered as dependent variables. Therefore, we have to estimate three regression equations as follows:

I. Catch $up_{it} = \alpha + \beta$ (explanatory variable) $+ u_{it}$
II. Frontier $shift_{it} = \gamma + \delta$ (explanatory variable) $+ v_{it}$
III. $MPI_{it} = \varepsilon + \eta$ (explanatory variable) $+ w_{it}$

Where the subscripts ‘i’ and ‘t’ denote the cross-sectional and time series dimensions, respectively, such that i = 1, 2, ….,70 and t = 1, 2, ….,10.

Now, we are going to conduct some relevant model selection tests to determine the most appropriate model for our regression analysis. The details of these tests are described below.

3.3.1. Poolability Test

This test indicates whether the pooled OLS model or fixed-effects panel model provides more reliable estimates of the parameters of the regression model. We assume the OLS and fixed-effects panel models as follows:

OLS model: $y_{it} = a + bX_{it} + u_{it}$ (a)

Fixed-effects model: $y_{it} = a + bX_{it} + \mu_i + u_{it}$ (b)

Where μ_i captures the firm-specific effects and u_{it} denotes the idiosyncratic error.
The corresponding null and alternative hypotheses are given by

H_0: pooled OLS model is appropriate
H_1: fixed-effects panel model is appropriate

Basically, under the null hypothesis (H_0), the firm-specific individual effects are assumed to be zero. The F statistic of poolability test can be constructed as

$$F = \frac{(RSS_R - RSS_U) / (N-1)}{RSS_U / [(T-1)N-K]}$$

Where RSS refers to the residual sum of squares, the subscripts ‘R’ and ‘U’ denote restricted and unrestricted models, respectively. N, K and T stand for number of firms, number of regressors and total time period (year), respectively. The aforementioned test statistic follows F distribution with [(N-1), {(T-1)N-K}] degrees of freedom.

3.3.2. Breusch and Pagan LM Test

Breusch and Pagan (1980) developed a Lagrange Multiplier (LM) test to find out the most suitable model between pooled OLS model and random effect panel model. The null and alternative hypotheses are as follows:

H_0: pooled OLS model is appropriate
H_1: random-effects model is appropriate

The corresponding test statistic is:

$$LM = \frac{NT}{2(T-1)}\left\{1 - \frac{\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\tilde{u}_{it}\right)^2}{\sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{u}_{it}^2}\right\}^2$$

Where, ũ refers to the residuals from pooled OLS model. The test statistic follows χ^2 distribution with one degree of freedom.

3.3.3. Housman Test

Housman test, developed by Hausman (1978), is another crucial model selection test that indicates whether the random-effects panel model or the fixed-effects panel model is suitable for analyzing the dataset. Generally, the Housman test can be performed to those hypotheses testing problems where two estimators from different regression models are available (Greene 2008). To explain this test under present scenario, we assume $\hat{b}$ and $\tilde{b}$ are the vectors of estimated slope parameters obtained from the fixed-effects and random-effects panel models, respectively. In this context, the null and alternative hypotheses can be given as:

H_0: random-effects model is appropriate
H_1: fixed-effects model is appropriate

Under the null hypothesis, $\hat{b}$ is considered to be efficient, while inconsistent under alternative hypothesis. On the other hand, the other estimator $\tilde{b}$ is inefficient under both hypotheses whereas consistent under both hypotheses. The corresponding test statistic is:

$$M = q'(\text{var}q)^{-1} q,$$

where $q = (\hat{b} - \tilde{b})$ and $\text{var}q = (\text{var}\hat{b} - \text{var}\tilde{b})$. The test statistic 'M' follows χ^2 distribution.

3.3.4. Unit root Test

To examine the presence of unit root in regression variables, we incorporate Fisher-type unit root test applicable for panel dataset. This unit root test was first proposed by R. A. Fisher and latter further discussed and developed by Choi (2001). This test consists of the following steps:

A. Initially, this test performs either Augmented Dickey-Fuller (ADF) test or Phillips-Perron (PP) test (depending on the researcher's choice) on each panel's series separately.

B. Thereafter, it combines the P-values obtained from each panel-specific unit root test to construct an overall test statistic for the entire panel series to check whether variable under consideration is stationary or not.

There are four alternative methods to transform the individual P-values into the overall test statistic as proposed by Choi (2001). These methods are: inverse χ^2

method, inverse normal method, inverse logit method, and modified inverse χ^2 method. The corresponding null and alternative hypotheses are as follows:

H_0: all panels are having a unit root
H_1: at least one panel is stationary

Now, we briefly discuss the four alternative test statistics in Fisher-type test given by Choi (2001) below:
The inverse chi-squared test statistic (P) can be given as

$$P = -2\sum_{i=1}^{N} \ln(p_i)$$

Where, p_i denotes the p-value of the unit root test on the i^{th} panel. N denotes the number of firms. The test statistic P follows the chi-square distribution with 2N degrees of freedom.

The test statistic (Z) of inverse normal distribution is given as:

$$Z = \frac{1}{\sqrt{N}}\sum_{i=1}^{N} \phi^{-1}(p_i)$$

Where, ϕ^{-1} refers to the inverse of the standard normal cumulative distribution function.
The corresponding test statistic of inverse logit t can be presented as

$$L^* = \sqrt{k}L$$

Where, $L = \sum_{i=1}^{N} \ln(\frac{p_i}{1-p_i})$ and $k = \frac{3(5N+4)}{\Pi^2 N(5N+2)}$. L^* consists of (5N + 4) degrees of freedom.
Finally, the modified inverse chi-squared test statistic is given as

$$P_m = \frac{1}{\sqrt{N}}\sum_{i=1}^{N}\{\ln(p_i) + 1\}$$

Where, P_m follows standard normal distribution.

3.3.5. Fixed-effects vs. Random-effects Panel Models

There are various linear models available for panel data analysis. Among these models, the primary difference occurs between random-effects and fixed-effects models. In regression model presented in equation (b), the component μ_i captures the firm-specific heterogeneity. Now, in fixed effects model, μ_i is assumed to be correlated with the explanatory variables. On the other hand, μ_i is assumed to be purely random and uncorrelated with the regressors in random effects model. The error component u_i is assumed to be uncorrelated with regressors in both the models. Apart from the Housman test, the choice between random effect and fixed effect models depends on the relative size difference between time (T) and individual (N) dimensions. For instance, if the individual (here, firm) dimension is relatively larger than that of time (i.e., N>T), one would choose random effect model. On the other hand, fixed effect model would be more attractive if the time dimension is relatively higher than the number of firms (i.e., T>N). Moreover, a fixed effects model cannot estimate the effect of any time-invariant variables (such as time invariant dummies), unlike a random effects model (Baltagi 2001).

4. Data

4.1. Variables for First stage TFPG (MI) estimation

For the measurement of total factor productivity growth based on Malmquist Productivity Index, we have considered three input variables, viz. salaries and wages, net fixed assets and operating expenses and one output variable, viz. sales. The inputs and output data is collected from the Centre for Monitoring Indian Economy (CMIE) PROWESS online database for the financial year[6] 2004 to 2014. All the inputs and output data collected from the CMIE PROWESS database are reported in rupees millions. The selection of the salaries and wages as one of the input variables is based on some previous studies (Das 2017; Das et al. 2017;

[6] In this paper, the dataset is collected for each financial year. For instance, any data for the financial year (FY) 2004 implies the data belongs to the period during April 2004 to March 2005. For notational simplicity, we have used 2004 instead of 2004-05 to denote the FY. The same explanation is applicable for the other FYs.

Mahajan et al. 2014). Since the firm-level data on number of employees is not frequently reported in the CMIE PROWESS database, salaries and wages data is considered as a measure of labour input of the firm. Salaries and wages refer to the total annual expenses incurred by an IT firm on its all employees. A significant number of previous studies have used either net fixed assets or gross fixed assets as one of the input variables in performance evaluation by applying DEA in different industries (Ahuja, Majumdar 1995; Subramanyam, Reddy 2008; Mogha et al. 2012; Zhang et al. 2012). In our study, we have considered the net fixed assets as input variable instead of the gross fixed assets to take care of the depreciation of fixed assets. Net fixed assets of an IT firm comprise of buildings, computer equipment, software, furniture, land, machinery etc. less the accumulated depreciation. We have considered operating expenses as another input variable as a measure of capital input of the firm in line with the existing studies of this genre (Cinca et al. 2005; Chen et al. 2011). Operating expenses of an IT firm generally consist of salaries and wages, rent, official supplies, utilities, marketing, taxes, insurance, R&D expenses, inventory cost etc. Since we have considered salaries and wages as an input variable, we have excluded the salaries and wages during the calculation of operating expenses. Sales revenue is considered as the output variable on the basis of the previous studies (Sahoo 2011; Sahoo, Nauriyal 2014; Bhattachrjee 2012; Mathur 2007a). The output and input variables are deflated by GDP deflator to mitigate the impact of price change.

The year-wise summary statistics of input and output variables are reported in the following Table 1.

Table 1. Year-wise summary statistics of output and input variables. (at constant prices, 2004 = 100)

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Sales revenue											
Mean	5373	7130.1	9271.7	10901.5	12212.0	11520.5	12447.9	14178.1	15068.6	17672.6	18998.6
Median	1076	1393.0	1589.7	2175.6	2730.1	2339.8	1656.9	1880.5	1650.9	1809.8	1739.3
Std. Dev.	15370	20419	26219.2	30616.0	34712.5	33801.4	37493.3	43302.0	47682.4	57450.2	61843.6
Skewness	4.1	4.1	4.0	4.0	4.1	4.3	4.3	4.4	4.5	4.5	4.7
Kurtosis	16.5	16.4	15.9	15.7	16.5	17.6	18.0	18.7	20.3	21.5	23.1
Minimum	129.9	134.1	116.7	74.1	40.8	22.1	11.5	5.3	4.8	4.5	4.3
Maximum	80545	107862	134757	155558	175748	170342	198892	239209	281897	354609	393082
Count	70	70	70	70	70	70	70	70	70	70	70
Salaries and wages											
Mean	2239	2973.9	3864.7	4673.5	5262.1	4852.1	5368.0	6213.5	6832.4	7849.5	8307.3
Median	309.7	359.1	462.8	486.5	589.7	555.2	616.6	717.7	636.8	595.8	606.0
Std. Dev.	6798	8870.0	11525.3	13935.1	15924.5	14822.7	16645.9	19346.2	22639.1	26533.4	28429.6
Skewness	4.0	4.0	4.0	4.0	4.1	4.3	4.3	4.4	4.5	4.5	4.7
Kurtosis	15.8	15.2	15.7	15.6	16.3	17.8	18.5	19.2	20.1	20.9	23.0
Minimum	9.6	16.1	7.6	8.6	6.4	3.5	3.3	5.1	2.6	2.9	2.8
Maximum	35619	45011	60202.9	73538.9	84113.8	79477.2	91150.5	108345	127386	155364	176214
Count	70	70	70	70	70	70	70	70	70	70	70

Table 1. Continuation

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Operating expenses											
Mean	1657	2012.9	2593.3	3087.4	3433.7	3204.0	3642.1	3970.2	4270.5	4835.0	5548.4
Median	452.9	492.7	546.8	655.1	715.2	648.4	834.0	551.4	616.8	587.8	576.1
Std. Dev.	4177	5434.9	6838.8	8337.3	8932.4	9056.9	9902.0	11657.5	12406.1	14211.1	17006.0
Skewness	4.3	4.6	4.4	4.7	4.6	5.0	4.7	4.8	4.4	4.2	4.4
Kurtosis	18.6	21.9	21.2	24.7	23.8	28.8	24.5	24.7	20.2	18.0	20.4
Minimum	57.8	33.0	51.1	24.1	22.5	10.0	83.6	4.0	6.2	5.6	5.3
Maximum	23964	33512	43003.6	55142.9	58674.5	62530.7	65103.3	75958.6	70844.5	81688.0	104801
Count	70	70	70	70	70	70	70	70	70	70	70
Net fixed assets											
Mean	922.5	1121.0	1372.0	1653.6	2097.3	2028.4	2083.7	2344.7	2452.1	2539.6	2833.7
Median	237.0	278.8	370.9	534.7	607.5	521.9	462.0	514.6	452.5	414.4	360.8
Std. Dev.	2072	2581.3	3283.3	4020.3	5237.5	5272.1	5606.3	5840.2	6168.8	6462.1	7920.3
Skewness	4.0	4.0	4.2	4.2	4.2	4.1	3.9	3.7	3.5	3.6	3.9
Kurtosis	16.4	16.9	18.4	17.8	17.7	16.6	15.3	12.8	11.4	12.7	15.7
Minimum	8.7	14.0	11.6	11.6	9.6	10.3	4.1	3.8	2.9	2.6	2.3
Maximum	11770	14990	19386.8	22712.6	29796.1	27930.5	28784.0	29189.0	29710.6	32506.5	42715.2
Count	70	70	70	70	70	70	70	70	70	70	70

Source: Author's calculations based on CMIE PROWESS database.
Note: All the variables are reported in rupees millions.

4.2. Variables for second stage Regression analysis

In our study, we would like to investigate the determinants of technical change (frontier shift), technical efficiency change (catch up) and total factor productivity growth (MI). According to Caves (1992), the determinants of industrial efficiency and productivity can be classified into five categories, viz. 1) organizational features, 2) structural heterogeneity, 3) competitive conditions, 4) dynamic disturbances, and finally 5) regulation.

Organizational features of an industry consist of firm's age, location of the firm, size of firm, organization type, extent of foreign investment, multi-plant operation, diversification, structure of labour force such as use of part-time workers and degree of unionization. *Structural heterogeneity* includes capital vintage, intensity of capital, diversity of product, regional dispersion, fuel intensity, diversity of plant scale etc. *Competitive conditions* consist of those factors related to export intensity, import competition and market structure such as concentration. The factors pertain to the competitive conditions are generally external to the firm. Dynamic disturbances are primarily responsible for deviations from the long run equilibrium condition. Factors such as rate of productivity growth, rate of output growth, variability of output growth, expenditures pertaining to research and development (R & D), imported technology and receipt for exported technology are considered as *dynamic disturbances*. The occurrence of dynamic disturbances is mainly due to either change in demand pattern for the product or the extent of technical innovation in the long term. Finally, the *regulatory environment* of the State reflected in tariff protection policy, entry regulation etc. also have significant influence on industrial efficiency. Since stringent governmental intervention may discourage competition, entry of new firms and desire to innovate; the regulatory environment should be considered as one of the important determinants of efficiency. Ownership of the firm does also matter for efficiency. For instance, public and private limited firms may have different efficiency levels.

It should be noted that all the determinants of efficiency and productivity discussed above may not be pertinent to the IT industry as this industry is relatively more human capital (or skill) intensive unlike the manufacturing industry which is either relatively physical capital intensive or labour intensive. On the basis of the above discussion, the following explanatory variables are considered to explain TFPG (or MPI), technical efficiency change (or catch up) and technical change (or frontier shift) in Indian IT industry. In IT industry, the market is mostly dominated by the export-oriented firms. Hence, to assess the impact of the extent of openness or external competition on productivity change, we have considered *export intensity* as one of the independent variables. It is measured as the ratio of total export to sales. On the other hand, we consider *market concentration*, which captures the extent of internal competition in the software industry, as another independent variable. Market concentration is measured by Hirschman-Herfindahl index.

To analyze the influence of various organizational factors on efficiency and productivity, we have considered firm's age, size, wages and salaries intensity, and plant size as independent variables. Age of firms is measured as the natural logarithm of years in business. Firm size is assessed in terms of the natural logarithm of real sales. The wages and salaries intensity is measured as the ratio of wages and salaries to operating expenses. Plant size is considered as the indicator of structural heterogeneity. Plant size is incorporated as dummy variable. On the basis of returns to scale, plant size is measured in terms of increasing returns to scale (IRS), constant returns to scale (CRS) and decreasing returns to scale (DRS). Dynamic disturbances are incorporated by considering two factors, viz. R&D expenditure and royalty payments. R&D expenditure is considered as proxy for innovation. The R&D and non R&D software firms have been segregated by using dummy variable. On the other hand, Royalty payment consists of expenditure towards imported technologies, viz. drawings, blueprints, designs of software products. In regression analysis, the royalty paying and non paying firms are distinguished by incorporating dummy variable approach. Lastly, the ownership dummies have been introduced to investigate the differences in efficiency and productivity between: (1) public limited and private limited firms and (2) Group and non-group firms. Since the variables, namely, export intensity, wages and salaries intensity, plant scale, R&D expenditure and royalty payments are less likely to influence catch-up, frontier-shift and TFP instantaneously; these five variables are considered with one-year lag for regression analysis. Table 2 summarizes the variables discussed above for regression analysis.

Now, we have three regression models corresponding to three dependent variables, viz. catch up, frontier shift and Malmquist Productivity Index (MPI). The functional relationship of these variables can be represented in the following way:

Catch up = f (export intensity, market concentration, age, size, salaries and wages intensity, plant scale dummy, R&D dummy, royalty dummy, ownership dummy, group dummy, US subprime crisis dummy)

Frontier shift = g (export intensity, market concentration, age, size, salaries and wages intensity, plant scale dummy, R&D dummy, royalty dummy, ownership dummy, group dummy, US subprime crisis dummy)

MI = h (export intensity, market concentration, age, size, salaries and wages intensity, plant scale dummy, R&D dummy, royalty dummy, ownership dummy, group dummy, US subprime crisis dummy)

Table 2. Variable measurement for regression analysis

Variable	**Construction**
Dependent variables: Catch up, frontier shift and Malmquist index (MI)	
Independent variables	
1. Export intensity	Total exports/sales
2. Market concentration	Hirshman-Herfindahl index
3. Age	Natural log of years in business
4. Size	Natural log of real sales
5. Wages and salaries intensity	Ratio of wages and salaries to operating expenses
6. Plant scale dummy	Returns to scale (RTS) dummies. a) CRS dummy =1, if the firm exhibits CRS =0, otherwise b) DRS dummy =1, if the firm exhibits IRS =0, otherwise
7. Research and Development (R&D) dummy	R&D dummy =1, if the firm spends on R&D =0, if the firm does not spend on R&D
8. Royalty dummy	Royalty dummy =1, if the firm pays for royalty =0, if the firm does not pay for royalty
9. Ownership dummy	=1, for public limited company =0, for private limited company
10. Group dummy	=1, if the firm belongs to a group of companies =0, otherwise
11. US subprime crisis dummy	=1, for the years 2008 to 2014 =0, otherwise

Source: Author's own elaboration.

5. Results and Discussion

5.1. Results Pertaining to the Productivity Analysis

In this section, we intend to analyze the trend in Malmquist productivity index for 70 Indian IT firms during 2004-05 to 2014-15. The TFPG is calculated on the basis of two methods. One is based on the base period and another is based on adjacent period. In base period method, the year 2004 is considered as the benchmark. The MPI and its three components on the basis of the base period frontier are represented in Table 3 below.

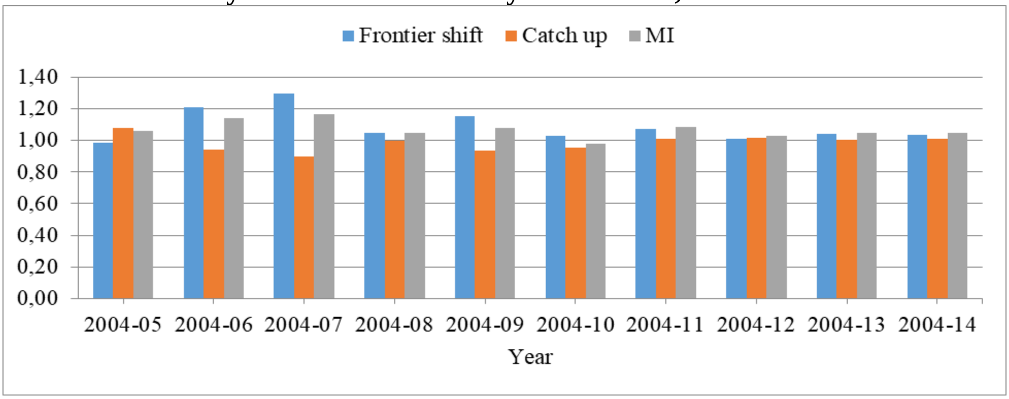
Table 3. Year-wise average Frontier shift, Catch up, Pure Technical Efficiency Change (PTEC), Scale Efficiency Change (SEC) and Malmquist Index (MI) in Indian IT industry on the basis of base-year frontier, 2004

Year	Frontier shift	Catch up	PTEC	SEC	MI
2004-05	0.984	1.079	1.062	1.016	1.062
2004-06	1.211	0.941	0.991	0.949	1.139
2004-07	1.294	0.901	0.988	0.911	1.166
2004-08	1.050	0.999	1.013	0.985	1.048
2004-09	1.155	0.933	0.986	0.946	1.077
2004-10	1.026	0.952	0.988	0.964	0.977
2004-11	1.075	1.009	1.002	1.007	1.085
2004-12	1.011	1.015	1.002	1.013	1.026
2004-13	1.043	1.003	0.990	1.014	1.047
2004-14	1.035	1.011	0.980	1.031	1.046
Average	**1.085**	**0.983**	**1.000**	**0.983**	**1.066**

Source: Author’s calculations based on CMIE PROWESS database.

It is revealed from Table 3 that the MPI is greater than one for most of the study periods except the year 2010. The average MI is found to be 1.066 for the entire study period. It implies that on an average, the total factor productivity of Indian IT industry has improved during the study period. The technical change (TC) or frontier shift component of MPI is found to be greater than one for most of the study years except 2005. The average TC for the overall study period is found to be 1.085, which implies improvement in TC during the study period. The change in technical efficiency component (or catch up) of MPI is found to be greater than one for the years 2006, 2007, 2008, 2009 and 2010, implying improvement of TEC. For the years 2007, 2010, 2012 and 2014; it is found to be less than one, indicating deterioration of TEC. The TEC for the entire study period is found to be less than one (0.983) which indicates a decline in average TEC over the study period. The PTEC is observed to be regressing during 2006, 2007, 2009, 2010, 2013 and 2014. On the other hand, PTEC is found to be improved during 2005, 2008, 2011 and 2012. PTEC is 1.00 during the entire study period, suggesting thereby on an average, neither regress nor progress in managerial efficiency. Finally, scale efficiency deteriorated during the years 2006, 2007, 2008, 2009 and 2010. On the other hand, it improved during the years 2005, 2011, 2012, 2013 and 2014. Overall, SEC is found to be less than one (0.983) during the study period implying deterioration of scale efficiency during the entire study period.

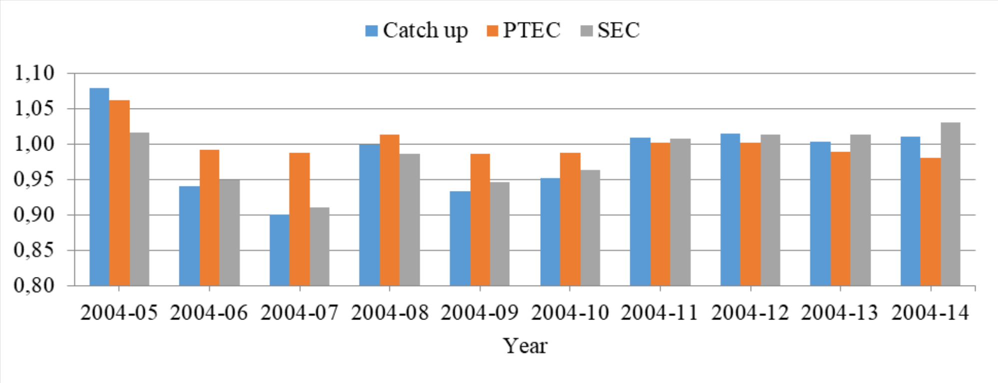
Figure 1. Year-wise average Frontier shift, Catch up and Malmquist Index in Indian IT Industry on the Basis of Base-year Frontier, 2004



Source: Author’s own elaboration.

Figure 1 depicts the year-wise average MI and its components (frontier shift and catch up) as illustrated in Table 3. It can be seen that the frontier shift (TC) is highest during 2007 (1.294), with a growth rate of 29.4 percent. On the other hand, TC is lowest during 2005 (0.984) with a negative growth rate of -1.6 percent. The catch up (or TEC) is found to be highest during 2005 (1.079) with a growth rate of 7.9 percent. The catch up effect is lowest (0.901) during 2007 with a negative growth rate of -9.9 percent.

Figure 2. Year-wise average Catch up, Pure Technical Efficiency Change (PTEC) and Scale Efficiency Change (SEC) in Indian IT Industry on the Basis of Base-year Frontier, 2004



Source: Author's own elaboration.

Figure 2 shows the year-wise average catch up and its two components (PTEC and SEC) as presented in Table 3.The PTEC is found to be highest (1.062) and lowest (0.980) with growth rate of 6.2 percent and -2.0 percent during 2005 and 2014, respectively. The SEC is highest during 2014 (1.031) with a growth rate of 3.1 percent. The SEC is lowest during 2007 (0.911) with a negative growth rate of -8.9 percent. The TFPG (or MI) is highest during 2007 (1.166) with a growth rate of 16.6 percent and lowest (0.977) during 2010 with a growth rate of -2.3 percent. For the entire study period, the growth rate of frontier shift, catch up, SEC and MI is found to be 8.5 percent, -1.7 percent, -1.7 percent and 6.6 percent, respectively. PTEC has shown no change during the overall study period. From this discussion, it can be inferred that on an average, the TFPG of Indian software industry has improved. However, the decomposition analysis of MI shows deterioration in scale efficiency. On the other hand, the frontier shift effect (or technical change) has improved during the overall study period.

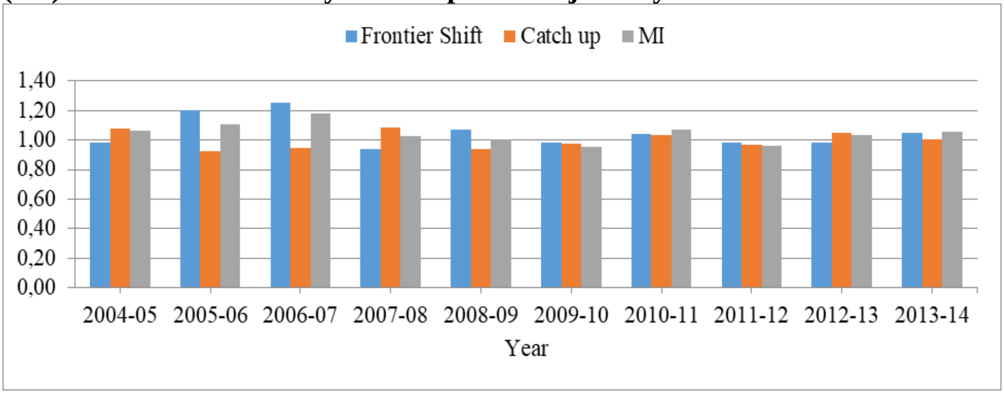
Table 4 illustrates the MI and its components on the basis of adjacent year frontier. It is revealed from Table 4 that TFPG (MI) is greater than one (or shown improvement) during most of the study periods except for the years 2010 and 2012. The frontier shift (TC) effect is greater than one for the years 2006, 2007, 2009, 2011 and 2014. It is less than one for the remaining years. The catch up is greater than one for the years 2005, 2008, 2011, 2013 and 2014. For the remaining years, it is less than one. PTEC is found to be improving during 2005, 2011 and 2013 and deteriorating for the remaining years. The SEC is greater than one for the years 2005, 2008, 2010, 2011 and 2014. It is less than one for the remaining study periods.

Table 4: Year-wise average Frontier shift, Catch up, Pure Technical Efficiency Change (TEC), Scale Efficiency Change (SEC) and Malmquist Index (MI) in Indian IT Industry on the basis of adjacent year frontier

Year	Frontier Shift	Catch up	PTEC	SEC	MI
2004-05	0.984	1.079	1.062	1.016	1.062
2005-06	1.199	0.925	0.972	0.952	1.109
2006-07	1.251	0.944	0.989	0.954	1.180
2007-08	0.943	1.087	0.989	1.099	1.025
2008-09	1.069	0.943	0.973	0.969	1.008
2009-10	0.981	0.975	0.958	1.018	0.957
2010-11	1.042	1.031	1.008	1.023	1.074
2011-12	0.986	0.972	0.975	0.997	0.958
2012-13	0.982	1.050	1.074	0.978	1.032
2013-14	1.049	1.004	0.985	1.019	1.053
Average	**1.045**	**0.999**	**0.998**	**1.002**	**1.044**

Source: Author's calculations based on CMIE PROWESS database.

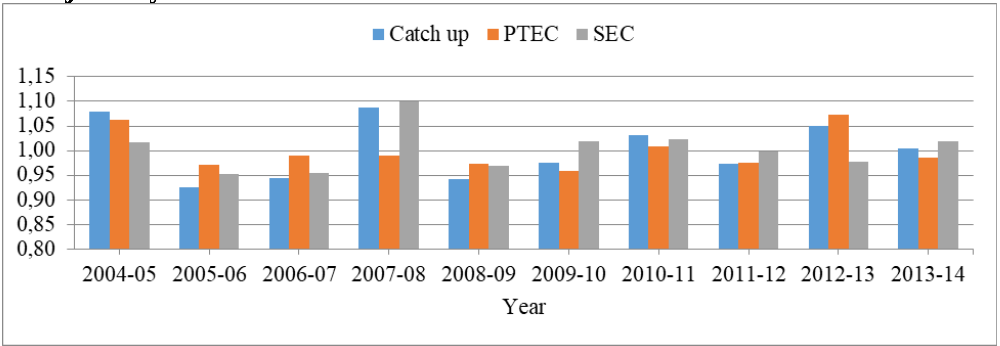
Figure 3. Year-wise average Frontier shift, Catch up and Malmquist Index (MI) in Indian IT Industry with respect to adjacent year frontier



Source: Author's own elaboration.

Figure 3 shows the year-wise average frontier shift, catch up and MI with respect to adjacent year frontier. The MI attained maximum (1.180) with a growth rate of 18 percent during the year 2007 and minimum (0.957) with a negative growth rate of -4.3 percent during the year 2010. The frontier shift (TC) is highest (1.251) with a growth rate of 25.1 percent during 2007 and lowest (0.943) with a negative growth rate of -5.7 percent during 2008. The catch up effect is highest (1.087) with a growth rate of 8.7 percent during 2008 and lowest (0.925) with a negative growth rate of -7.5 percent during 2006.

Figure 4. Year-wise average Catch up, Pure Technical Efficiency Change (PTEC) and Scale Efficiency Change (SEC) in Indian IT Industry on the basis of adjacent year frontier



Source: Author's own elaboration.

Figure 4 presents the year-wise average catch up and its components (PTEC and SEC) on the basis of adjacent year frontier. PTEC is found to be highest (1.074) with a growth rate of 7.4 percent during 2013 and lowest (0.958) with a growth rate of 4.2 percent during 2010. The SEC is maximum (1.099) during 2008 with a growth rate of 9.9 percent and minimum (0.952) during 2006 with a negative growth rate of -4.8 percent. The average MI, frontier shift, catch up, PTEC and SEC for the entire study period are worked out to be 1.044, 1.045, 0.999, 0.998, 1.002 respectively. The corresponding growth rates are 4.4 percent, 4.5 percent, -0.1 percent, -0.2 percent and 0.2 percent, respectively.

It is evident from the above discussion that, on an average, technical change has experienced improvement during the entire study period. On the other hand, catch up has experienced deterioration over the study period. The average PTEC shows negative growth (i.e., regress) during the overall study period. The average scale efficiency has been found to be improving during the study period. It can be inferred from this analysis that on an average, MI and frontier shift have improved in Indian IT industry on the basis of base year (2004) as well as adjacent year frontiers during the study period. In case of average overall technical efficiency (or catch up), it shows regress with respect to base year (2004) as well as adjacent year frontiers during the study period. While PTEC shows deterioration under base year (2004) frontier, it shows improvement under adjacent year frontier analysis. Finally, the average scale efficiency has improved with respect to base year (2004) frontier but deteriorated under adjacent year frontier.

Table 5. Company-wise annual average Frontier shift, Catch up, Scale Efficiency Change (SEC) and Malmquist Index (MI) with respect to base year (2004) frontier

Sl. No.	Company Name	Frontier shift	Catch up	PTEC	SEC	MI
1	3D P L M Software Solutions Ltd.	1.092	0.919	0.946	0.971	1.004
2	3I Infotech Ltd.	1.155	0.903	0.965	0.937	1.044
3	Accel Transmatic Ltd.	1.036	0.918	0.945	0.972	0.951
4	Accelya Kale Solutions Ltd.	0.961	1.131	1.139	0.994	1.087
5	Aftek Ltd.	1.008	0.919	0.962	0.955	0.926
6	Agnite Education Ltd.	0.990	0.938	0.967	0.970	0.928
7	Birlasoft (India) Ltd.	1.014	1.163	1.226	0.949	1.179
8	Blue Star Infotech Ltd.	1.012	0.929	0.961	0.967	0.940
9	Bristlecone India Ltd.	0.957	1.274	1.307	0.975	1.220
10	California Software Co. Ltd.	1.113	0.958	0.975	0.982	1.066
11	Compucom Software Ltd.	0.944	1.125	1.215	0.925	1.062
12	Cranes Software Intl. Ltd.	1.238	0.922	0.944	0.977	1.141
13	Datamatics Global Services Ltd.	1.121	0.921	0.942	0.978	1.033
14	F C S Software Solutions Ltd.	1.023	0.917	0.937	0.979	0.938
15	Four Soft Ltd.	1.009	0.926	0.921	1.006	0.935
16	Genesys International Corpn. Ltd.	1.018	1.440	1.349	1.067	1.466
17	Geodesic Ltd.	1.060	1.000	1.000	1.000	1.060

Table 5. Continuation

Sl. No.	Company Name	Frontier shift	Catch up	PTEC	SEC	MI
18	Geometric Ltd.	1.056	0.993	1.017	0.977	1.049
19	Glodyne Technoserve Ltd.	0.985	0.951	0.965	0.985	0.937
20	Goldstone Technologies Ltd.	1.046	0.928	0.956	0.970	0.970
21	Green Fire Agri Commodities Ltd.	1.091	0.918	0.954	0.962	1.002
22	H C L Technologies Ltd.	1.065	1.064	0.978	1.087	1.132
23	Hexaware Technologies Ltd.	1.063	1.013	1.080	0.939	1.077
24	I C S A (India) Ltd.	0.933	1.377	0.932	1.478	1.285
25	I T C Infotech India Ltd.	0.979	1.295	1.323	0.979	1.268
26	Infosys Ltd.	1.114	0.916	1.000	0.917	1.021
27	Infotech Enterprises Ltd.	1.002	0.928	0.970	0.957	0.930
28	K P I T Technologies Ltd.	1.034	1.088	1.161	0.937	1.125
29	Larsen & Toubro Infotech Ltd.	1.045	1.096	1.171	0.936	1.146
30	Mascon Global Ltd.	1.049	1.330	0.989	1.345	1.395
31	Mastek Ltd.	1.023	0.922	0.926	0.995	0.942
32	Megasoft Ltd.	1.134	0.940	1.000	0.940	1.066
33	Mphasis Ltd.	0.943	1.102	0.948	1.162	1.039
34	N I I T Gis Ltd.	0.983	0.958	0.984	0.974	0.942
35	N I I T Ltd.	1.087	0.917	0.914	1.004	0.997
36	N I I T Technologies Ltd.	1.098	0.991	1.006	0.985	1.088
37	Nucleus Software Exports Ltd.	1.104	0.968	1.001	0.967	1.068
38	Ontrack Systems Ltd.	0.925	1.109	1.067	1.040	1.027
39	Onward Technologies Ltd.	0.992	1.113	1.164	0.956	1.104
40	Oracle Financial Services Software Ltd.	1.095	1.020	1.044	0.976	1.117
41	Patni Computer Systems Ltd.	1.067	0.928	0.972	0.955	0.991
42	Pentamedia Graphics Ltd.	1.030	0.924	1.001	0.923	0.951
43	Persistent Systems Ltd.	1.070	0.978	1.028	0.951	1.046
44	Polaris Financial Technology Ltd.	1.015	1.122	0.996	1.127	1.138
45	Quintegra Solutions Ltd.	1.023	0.917	0.947	0.969	0.938
46	R S Software (India) Ltd.	1.085	0.973	1.017	0.956	1.056
47	R Systems International Ltd.	1.032	1.158	1.207	0.960	1.195

Table 5. Continuation

Sl. No.	Company Name	Frontier shift	Catch up	PTEC	SEC	MI
48	Rolta India Ltd.	1.014	1.005	1.024	0.981	1.019
49	S Q L Star International Ltd.	1.050	0.933	0.997	0.936	0.980
50	Sankhya Infotech Ltd.	1.029	1.021	0.921	1.108	1.050
51	Sasken Communication Technologies Ltd.	1.059	1.088	1.114	0.977	1.152
52	Satyam Computer Services Ltd.	1.022	0.921	0.974	0.945	0.941
53	Software Technology Group International Ltd.	1.053	0.925	0.954	0.970	0.974
54	Sonata Software Ltd.	1.058	1.116	1.163	0.959	1.181
55	Steria (India) Ltd.	1.060	1.049	1.018	1.030	1.111
56	Subex Ltd.	1.012	1.204	1.201	1.002	1.218
57	Syntel Ltd.	1.078	0.944	0.979	0.964	1.017
58	Take Solutions Ltd.	1.029	0.987	0.932	1.059	1.016
59	Tata Consultancy Services Ltd.	1.121	0.936	1.000	0.936	1.048
60	Tata Elxsi Ltd.	1.027	0.923	0.940	0.982	0.948
61	Tata Industries Ltd.	1.113	0.916	0.942	0.972	1.019
62	Tata Technologies Ltd.	1.058	1.104	1.150	0.959	1.168
63	Tech Mahindra Ltd.	1.088	1.015	1.046	0.971	1.105
64	Tera Software Ltd.	0.998	1.109	0.948	1.169	1.106
65	V J I L Consulting Ltd.	1.080	0.911	0.972	0.937	0.984
66	Vakrangee Ltd.	0.935	1.475	1.465	1.007	1.379
67	Wipro Ltd.	1.043	1.003	0.988	1.015	1.046
68	Xchanging Solutions Ltd.	0.995	1.105	0.947	1.166	1.100
69	Zensar Technologies Ltd.	1.036	1.162	1.168	0.995	1.204
70	Zylog Systems Ltd.	1.012	0.967	0.992	0.975	0.979
	Mean	**1.040**	**1.022**	**1.026**	**0.996**	**1.062**
	Median	**1.036**	**0.982**	**0.990**	**0.974**	**1.049**
	Std. Dev.	**0.056**	**0.133**	**0.117**	**0.091**	**0.115**

Source: Author's calculations based on CMIE PROWESS database.

Table 5 reveals that among 70 software companies, on an average 56 companies experienced improvement in technology (i.e., TC>1) and the remaining 14 companies exhibited technological regress (i.e., TC<1) over the study period. On the other hand, on an average, 32 companies were found to have experienced improvement in technical efficiency and the remaining 38 firms were exhibiting deterioration in technical efficiency during the study period. It has also been observed from Table 4 that on an average, 32 firms have recorded growth in managerial efficiency (or PTEC) and the remaining 38 firms experienced regress in PTEC. 17 firms registered enhancement in scale efficiency, one firm (Geodesic Ltd.) experienced status quo in scale efficiency and the remaining 52 firms experienced deterioration in scale efficiency over the study period. Lastly, it is observed that on an average, 49 companies registered improvement in TFPG, whereas 21 companies experienced decline in TFPG during the study period.

From Table 5, it can be seen that on an average, 56 firms registered improvement in technology (or innovation) during the study period. Among these 56 firms, 38 firms were found to have experienced improvement in total factor productivity (measured by MI). It indicates that the remaining 18 firms were exhibiting deterioration in TFP despite the growth in technology (or frontier shift). This phenomenon clearly depicts that for the 18 firms, on an average, the magnitude of the fall in TEC or SEC or both was much severe than that of the increase in TC, as a result, the MI showed decline in TFPG during the study period. Moreover, out of these 56 companies, on an average, only 21 companies were found to have registered rise in overall technical efficiency (catch up), 25 companies have exhibited improvement in PTEC and 12 companies have recorded improvement in scale efficiency during the study period.

Table 4 also reveals that among 70 companies, on an average, 32 companies experienced improvement in overall technical efficiency (or catch up) over the study period. Out of these 32 companies, TFP of all those 32 companies was found to be improving. On the other hand, out of these 32 companies, on an average, TC of 21 companies was found to be improving and SEC of 15 companies was found to be improving during the study period. Hence, it can be inferred that on an average, both the frontier shift (TC) and catch up had been moving towards the same direction (i.e., improved) for 21 companies that attributed to improvement in TFP despite regress in SEC for 12 companies among those 21 companies. Finally, it can be said that improvement in frontier shift (or TC) is the primary contributor to the TFPG followed by catch up effect (or TEC) and SEC. During the overall study period, the average TFPG, frontier shift, catch up, PTEC and SEC are found o be 1.062, 1.040, 1.022, 1.026, and 0.996 with growth rates of 6.2 percent, 4 percent, 2.2 percent and 0.4 percent, respectively.

Table 6. Company-wise annual average Frontier shift, Catch up, Pure Technical Efficiency Change (PTEC) Scale Efficiency Change (SEC) and Malmquist Index (MI) in Indian IT Industry with Respect to adjacent year frontier

Sl. No.	Company Name	Frontier shift	Catch up	PTEC	SEC	MI
1	3D P L M Software Solutions Ltd.	1.023	1.015	1.015	1.000	1.038
2	3I Infotech Ltd.	1.056	0.987	0.966	1.023	1.043
3	Accel Transmatic Ltd.	1.088	0.923	0.978	0.943	1.004
4	Accelya Kale Solutions Ltd.	1.066	1.128	1.074	1.051	1.202
5	Aftek Ltd.	1.070	1.012	1.000	1.012	1.083
6	Agnite Education Ltd.	0.999	0.947	0.959	0.988	0.946
7	Birlasoft (India) Ltd.	1.045	1.084	1.047	1.036	1.133
8	Blue Star Infotech Ltd.	1.054	0.983	0.963	1.021	1.036
9	Bristlecone India Ltd.	1.011	1.035	1.037	0.999	1.046
10	California Software Co. Ltd.	1.062	0.950	0.931	1.021	1.009
11	Compucom Software Ltd.	1.078	1.045	1.025	1.019	1.126
12	Cranes Software Intl. Ltd.	1.075	0.883	0.889	0.993	0.949
13	Datamatics Global Services Ltd.	1.065	1.030	1.001	1.029	1.097
14	F C S Software Solutions Ltd.	0.973	0.996	0.999	0.997	0.969
15	Four Soft Ltd.	1.049	0.950	0.918	1.034	0.996
16	Genesys International Corpn. Ltd.	1.028	1.023	1.007	1.016	1.051
17	Geodesic Ltd.	0.993	1.000	1.000	1.000	0.993
18	Geometric Ltd.	1.072	1.026	0.974	1.053	1.100
19	Glodyne Technoserve Ltd.	0.977	0.944	0.954	0.989	0.922
20	Goldstone Technologies Ltd.	1.045	0.933	0.924	1.010	0.976
21	Green Fire Agri Commodities Ltd.	1.067	1.007	1.000	1.007	1.075
22	H C L Technologies Ltd.	1.044	1.065	1.010	1.055	1.112
23	Hexaware Technologies Ltd.	1.048	0.975	1.017	0.959	1.022
24	I C S A (India) Ltd.	0.990	0.966	0.931	1.038	0.957

Table 6. Continuation

Sl. No.	Company Name	Frontier shift	Catch up	PTEC	SEC	MI
25	I T C Infotech India Ltd.	1.024	1.027	1.031	0.997	1.052
26	Infosys Ltd.	1.045	0.999	1.000	0.999	1.044
27	Infotech Enterprises Ltd.	1.067	1.056	0.997	1.058	1.126
28	K P I T Technologies Ltd.	1.044	1.047	1.043	1.003	1.093
29	Larsen & Toubro Infotech Ltd.	1.023	0.993	0.999	0.994	1.016
30	Mascon Global Ltd.	1.034	1.031	1.000	1.031	1.066
31	Mastek Ltd.	1.033	1.004	0.980	1.024	1.037
32	Megasoft Ltd.	1.087	0.999	0.966	1.034	1.086
33	Mphasis Ltd.	1.038	1.037	0.992	1.046	1.076
34	N I I T Gis Ltd.	0.993	0.977	0.981	0.996	0.970
35	N I I T Ltd.	1.042	0.997	0.969	1.028	1.039
36	N I I T Technologies Ltd.	1.021	0.958	0.991	0.967	0.978
37	Nucleus Software Exports Ltd.	1.062	0.960	0.993	0.967	1.019
38	Ontrack Systems Ltd.	1.025	1.053	1.031	1.021	1.080
39	Onward Technologies Ltd.	1.084	1.043	1.069	0.976	1.130
40	Oracle Financial Services Software Ltd.	1.022	1.012	1.005	1.007	1.033
41	Patni Computer Systems Ltd.	1.069	1.056	1.052	1.004	1.129
42	Pentamedia Graphics Ltd.	1.046	1.010	1.010	1.000	1.057
43	Persistent Systems Ltd.	1.037	1.004	0.959	1.048	1.041
44	Polaris Financial Technology Ltd.	0.994	1.039	1.001	1.038	1.033
45	Quintegra Solutions Ltd.	1.079	1.058	1.153	0.917	1.141
46	R S Software (India) Ltd.	1.045	1.013	1.001	1.013	1.059
47	R Systems International Ltd.	1.011	0.981	0.993	0.988	0.992
48	Rolta India Ltd.	1.078	0.984	1.000	0.984	1.061
49	S Q L Star International Ltd.	1.033	0.924	1.021	0.905	0.955
50	Sankhya Infotech Ltd.	1.042	1.093	1.036	1.056	1.139
51	Sasken Communication Technologies Ltd.	1.081	0.973	1.001	0.972	1.052
52	Satyam Computer Services Ltd.	1.073	1.032	1.039	0.993	1.107
53	Software Technology Group International Ltd.	1.070	0.914	0.996	0.917	0.978
54	Sonata Software Ltd.	1.057	1.010	1.039	0.971	1.067

Table 6. Continuation

Sl. No.	Company Name	Frontier shift	Catch up	PTEC	SEC	MI
55	Steria (India) Ltd.	1.054	1.007	1.005	1.002	1.061
56	Subex Ltd.	1.033	1.023	0.997	1.026	1.057
57	Syntel Ltd.	1.088	1.058	1.030	1.026	1.151
58	Take Solutions Ltd.	1.025	1.063	1.038	1.024	1.090
59	Tata Consultancy Services Ltd.	1.019	1.042	1.000	1.042	1.061
60	Tata Elxsi Ltd.	1.126	0.993	1.000	0.993	1.118
61	Tata Industries Ltd.	1.047	0.941	0.939	1.002	0.986
62	Tata Technologies Ltd.	1.115	1.085	1.047	1.037	1.210
63	Tech Mahindra Ltd.	1.025	0.983	1.016	0.967	1.008
64	Tera Software Ltd.	1.027	1.051	1.024	1.026	1.079
65	V J I L Consulting Ltd.	1.072	0.906	0.935	0.969	0.971
66	Vakrangee Ltd.	1.042	1.069	1.066	1.003	1.114
67	Wipro Ltd.	1.089	0.988	1.000	0.988	1.076
68	Xchanging Solutions Ltd.	1.069	0.957	0.939	1.019	1.023
69	Zensar Technologies Ltd.	1.048	0.974	1.013	0.962	1.021
70	Zylog Systems Ltd.	1.031	0.929	0.926	1.002	0.958
	Mean	**1.046**	**1.003**	**0.998**	**1.004**	**1.049**
	Median	**1.045**	**1.005**	**1.000**	**1.004**	**1.052**
	Std. Dev.	**0.031**	**0.049**	**0.042**	**0.033**	**0.062**

Source: Author's calculations based on CMIE PROWESS database.

A perusal of Table 6 shows that on an average, 63 software firms have experienced technical progress (or innovation), implying that these firms experienced an upward shift in the production frontier, and remaining 7 firms have experienced technical regress, suggesting that these firms experienced a downward shift in the production frontier. Out of these 63 firms, on an average, 36 firms are found to have exhibited improvement in overall technical efficiency (catch up), 38 firms are found to be experiencing progress in scale efficiency, and 53 firms are found to have attained growth in TFP during the overall study period.

As far as the relative significance of the three components of MI in TFPG is concerned, it has been found from Tables that frontier-shift effect has the highest contribution to the MI (TFPG) followed by scale efficiency change and catch-up in the Indian IT companies during the overall study period. From this discussion, it can be inferred that innovation played a pivotal role in improving total factor productivity of IT companies during the study period. One of the prime reasons behind this robust frontier shift effect in the Indian IT-companies could be the necessity to maintain their position in volatile and competitive global environment.

5.2 Analysis of Regression Results

To investigate the determinants of TFPG, catch-up and frontier shift, we have employed panel data regression technique. Before going to discuss the regression results, we would like to introduce the results of pre-regression diagnostic tests, which have been theoretically discussed earlier in this paper.

5.2.1. Results of Pre-regression Diagnosis Tests

At first, we apply poolability test on our data. This test helps the researchers to choose between OLS and Fixed-Effect (FE) models. The corresponding values of F-test statistic for three regression models have been reported in the following Table 7. It is found that the F-statistics for all the three regression models are statistically significant at 1% level. This implies that there exists firm-specific heterogeneity across all these models and simple pooled OLS model would produce misleading conclusions. Therefore, according to poolability test, the FE panel regression method would be suitable for estimating these three models.

Table 7. Summary results of poolability test pertaining to the regression models

Regression Equation no.	Dependent Variable	Value of F-test statistic	P-value
1.	Catch-up	35.55***	0.0001
2.	Frontier-shift	29.84***	0.0010
3.	Malmquist Index	31.16***	0.0004

Source: Author's Calculations based on CMIE PROWESS database.
*** => Significant at 1%level.

Now, we apply the Breusch and Pagan LM test to examine whether pooled OLS model or Random Effect (RE) model is appropriate for our empirical analysis. The chi-square test statistic pertaining to the LM test is found to be statistically significant at 1% level for all three models as depicted in Table 8. This result clearly indicates rejection of null hypothesis, which considers that the pooled OLS model is suitable. On the other hand, it is established from this test that the RE panel model is suitable for all the regression models we intend to estimate.

Table 8. Summary results of LM test pertaining to the regression models

Regression Equation no.	Dependent Variable	Value of χ^2-test statistic	P-value
1.	Catch-up	124.47***	0.0001
2.	Frontier-shift	102.63***	0.0001
3.	Malmquist Index	93.05***	0.0003

Source: Author's Calculations based on CMIE PROWESS database.
*** => Significant at 1%level

To examine whether FE or RE model is suitable for our study, we apply Housman test. Table 9 summarizes the results of this test for three regression models. It can be seen that the value of the test statistic is statistically insignificant across all these models. This implies that the RE panel regression model would be appropriate to analyze our dataset.

Table 9. Summary results of Housman test pertaining to three regression models

Regression Equation no.	Dependent Variable	Value of χ^2-test statistic	P-value
1.	Catch-up	18.66	0.8561
2.	Frontier-shift	16.54	0.2291
3.	Malmquist Index	17.69	0.4637

Source: Author's Calculations based on CMIE PROWESS database.

Now, we apply the Fisher-type unit root test on four independent variables, viz. export intensity, age, size, and salaries and wages intensity separately to test whether these variables are stationary or not. Here, the Fisher-type test is based on the ADF test. The test results are summarized in the following Table 10.

All the four tests reported in Table 10 are based on ADF unit root test. It is observed that all the test statistics are significant at 1% level, indicating thereby rejection of the null hypothesis and acceptance of the alternative hypothesis. Alternatively, it can be said that there exists at least one panel series in every variable without having any unit root. Moreover, on the basis of the Fisher-type tests, it can be inferred that all the four variables are stationary at the level. Hence, these variables can be used as independent variable in the RE-panel regression model at their level without any transformation. Finally, we have examined the partial correlation coefficients between various independent variables by constructing a correlation matrix to check the presence of multicollinearity problem. However, the correlation matrix does not show any presence of severe correlation between the independent variables, suggesting thereby the absence of multicollinearity among independent variables.

Table 10. Summary results of Fisher-type unit root tests

	Export intensity		**Age**		**Size**		**Salaries and wages intensity**	
Method	Statistic	P-value	Statistic	P-value	Statistic	P-value	Statistic	P-value
Inverse Chi-squared (P)	426.43***	0.000	265.31***	0.000	218.58***	0.000	194.61***	0.000
Inverse normal (Z)	-13.80***	0.000	-10.21***	0.000	-9.14***	0.002	-9.05***	0.000
Inverse logit t (L^*)	-14.69***	0.000	-11.02***	0.003	-9.76***	0.007	-9.62***	0.000
Modified inv. Chi-squared (P_m)	31.17***	0.000	23.87***	0.000	12.05***	0.000	10.18***	0.000

Source: Author's Calculations based on CMIE PROWESS database.
*** => Significant at 1% level.

On the basis of the results of the diagnostic tests discussed above, it is quite clear that random-effects panel regression model would be the most suitable for our present study. It is to mention that all the data analysis pertains to various diagnostic tests and RE-panel regression are carried out in the statistical software package *Stata*. All these regression results are obtained under the clustered robust specification in *Stata*. The summary results of regression analysis are reported in Table 11.

Table 11. Summary results of three random-effects Generalized Least Square (GLS) regression models

Indepen-dent variables	Regression 1 (R1) Dependent variable: Catch-up		Regression 2 (R2) Dependent variable: Frontier-shift		Regression 3 (R3) Dependent variable: Malmquist Index	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Export intensity	0.614**	0.042	0.849*	0.072	0.701***	0.002
Market concentrati on	0.053***	0.001	0.036	0.267	0.064**	0.033
Age	0.018**	0.012	0.004	0.106	0.009*	0.069
Size	0.007**	0.048	0.004	0.283	0.002	0.109
Salaries and wages intensity	0.795***	0.000	0.443**	0.046	0.656**	0.018
IRS dummy	0.011**	0.030	0.005	0.198	0.012*	0.058
DRS dummy	-0.007*	0.084	0.004	0.526	-0.005*	0.067
R&D dummy	0.001	0.127	0.009**	0.028	0.004*	0.085
royalty dummy	0.012**	0.028	0.002	0.194	0.008**	0.029
Ownership dummy	0.004***	0.000	0.008*	0.059	0.010*	0.061
Group dummy	-0.005**	0.066	0.005	0.331	0.015	0.482
US subprime crisis dummy	-0.091*	0.091	-0.061**	0.020	-0.059**	0.043
Constant	1.415***	0.000	0.826***	0.000	1.583***	0.000
Wald χ^2-statistic	387.21***	0.000	331.24***	0.000	459.85***	0.000
R Squared	Within=0.201 Between=0.566 Overall=0.171		Within=0.244 Between=0.622 Overall=0.216		Within=0.398 Between=0.70 Overall=0.282	
Number of observation s	700		700		700	
sigma_u sigma_e rho	0.3691 0.2201 0.7376		0.4710 0.3315 0.6687		0.2778 0.1484 0.7779	

Source: Author’s calculations based on CMIE PROWESS database.
*, **, *** =>Significant at 10%, 5%, and 1% level, respectively.

It can be seen that the value of Wald chi-square statistic is statistically significant at 1% level in three regression models, implying that all the models are overall significant. Table 11 also reports the values of rho (ρ). Mathematically, the rho can be given as follows:

$$\rho = \frac{\sigma_u^2}{(\sigma_u^2 + \sigma_e^2)}$$

Where, σ_u^2 and σ_e^2 denote the variance of the error components u and e, respectively. In Table 11, sigma_u and sigma_e refer to the standard deviations of u and e, respectively. It is found the value of rho is not equal to zero across all models. On the other hand, it indicates that the variance of the panel-level error component is not zero, which is also evident from Table 11. Therefore, it is established that the panel estimator is different from the pooled estimator. Furthermore, it can also be said that there exists firm specific heterogeneity in our dataset. This also supports the selection of RE-panel regression model for our study.

Now, we are going to discuss the coefficients of the regression models as reported in Table 11. The coefficient of export intensity is observed to be positive and statistically significant in all the three models. The coefficients of export intensity are found to be 0.614, 0.849, and 0.701 in R1, R2, and R3, respectively. We can say that on an average, technical efficiency (or catch-up), technology (or frontier-shift), and TFP of IT firms would improve by 61.4%, 84.9%, and 70.1%, respectively, due to 100% increase in export intensity during the study period. The coefficients of market concentration (MC) and age are positive across three models but statistically significant in R1 and R3. In R1, the coefficient (0.053) of MC implies that on an average, a 100% rise in MC would result 5.3% increase in technical efficiency during the study period. Similarly, in R3, the coefficient (0.064) of MC indicates that on an average, there would be 6.4% improvement in TFP due to 100% increase in MC during the study period. The coefficients of age in R1 and R3 are found to be 0.018 and 0.009, respectively.

The coefficient of size is positive in all the models but statistically significant in R1 only. The coefficient of size is 0.007 in R1, implying that on an average, there would be 0.7% progress in catch-up for 100% increase in size of the industry during the study period. The positive and statistically significant coefficient of salaries and wages intensity (SWI) across three models indicates that SWI plays a key role in promoting technical efficiency, technology, and TFP growth during the study period. In particular, the coefficients of SWI are observed to be 0.795, 0.443, and 0.656 in R1, R2, and R3, respectively. This implies that on an average, there would be 79.5% improvement in technical efficiency, 44.3% progress in technology, and 65.6% enhancement in TFP due to 100% increase in SWI during the study period.

Both IRS and DRS dummies are found to be statistically significant in R1 and R3. The sign of the coefficient of the IRS dummy is found to be positive, whereas that of the DRS dummy is found to be negative in R1 and R3. This indicates that on an average, the firms exhibiting IRS technology experienced better improvement in technical efficiency and TFP compared to the benchmark CRS firms. On the other hand, the DRS firms are found to have registered lesser progress in technical efficiency and TFP than the firms exhibiting benchmark CRS technology during the study period. R&D dummy is positive across all models but found significant only in R2 and R3. The coefficients of R&D dummy in R2 and R3 indicate that on an average, the IT firms which spent on R&D have experienced higher growth in technology (or frontier-shift) and TFP than those which did not spend on R&D (i.e., the reference firms) during the study period. On the other hand, the relation between change in technical efficiency and expenditure on R&D has not been established as we have not found any statistically significant relation between R&D dummy and catch-up during the study period.

Now, the coefficients of royalty dummy are positive in all models but statistically significant at 5 % level in only R1 and R3. It can be inferred that on an average, the IT firms, which paid royalty for importing blueprints, designs of software from abroad, were shown relatively higher improvement in catch-up and TFP than those IT firms which did not incur any expenditure on royalty during the study period. The coefficients of ownership dummy are positive and statistically significant across all three models. It means that on an average, the public limited IT firms were experienced comparatively better improvement in technical efficiency, technology, and TFP than the benchmark private limited IT firms during the study period.

The coefficient of group dummy is negative and statistically significant in R1, implying that on an average, the non-group IT companies (i.e., the reference companies) had experienced more improvement in technical efficiency than the group owned IT companies during the study period. On the other hand, the coefficients of group dummy are found to be positive but statistically insignificant in R2 and R3. Hence, it can be said that there is no significant difference between group and non-group IT firms as far as improvement in technology and TFP are concerned during the study period. Finally, the last but not the least, the coefficient of crisis dummy is observed to be negative and statistically significant in all three models. This indicates that on an average, the technical efficiency, technology, and TFP of Indian IT industry had been deteriorated during the post subprime crisis period (2008 onwards) as compared to the pre-crisis period.

6. Summary and Concluding Remarks

This paper attempted to evaluate the total factor productivity of Indian Information technology industry during the period from FY 2004-05 to FY 2014-15. For this purpose, a DEA-based Malmquist Productivity Index is applied to calculate TFPG over the study period. The TFPG is decomposed into three components, viz. technical efficiency change (or catch-up), technological change (or frontier-shift), and scale efficiency change. The Malmquist index is evaluated on the basis of output-oriented DEA approach, where the goal is to examine whether the firm under consideration is able to produce maximum output with given input combinations. The Malmquist productivity index is evaluated on the basis of the base period frontier as well as adjacent period frontier. Furthermore, to investigate the determinants of catch-up, frontier-shift, and TFP growth; three separate regression models are estimated by applying random-effects panel regression method. For the regression analysis, we have used a balanced panel dataset consists of 70 Indian IT firms for the period from FY 2005 to FY 2014.

The productivity analysis suggests that the technological progress is the major source of productivity growth in Indian IT industry during the study period. On the other hand, catch up has played a dampening role in productivity growth during the study period. On an average, the TFP shows improvement during the study period, thereby implying that the positive impact of innovation has compensated the adverse impact of catch up effect during the reference period. Moreover, it can be inferred that although Indian IT industry performs well in innovation front, the technical efficiency needs to be improved in the future. On the other hand, the inefficient IT companies should improve their managerial efficiency to catch up with the efficient IT companies over time.

The regression results reveal that export intensity and salaries and wages intensity have positive impact on catch up, frontier shift, and TFPG. This suggests that on an average, the companies with higher export-orientation and salaries and wages intensity have experienced improvement in productivity. The result suggests a positive relationship between market concentration and TFPG. R&D is found have positive impact on innovation and productivity in IT industry. Therefore, policy should be formulated to encourage more investment in R&D in IT industry in the future. Royalty payment is observed to have positive impact on catch up and TFPG. Hence, royalty expenditure towards importing designs, blueprints of proprietary software technologies etc. should be encouraged for achieving higher productivity.

The impact of the US subprime crisis is found to be negative on frontier shift and TFPG. This result indicates that during the years after the US subprime crisis, the productivity of Indian IT industry has deteriorated as compared to the pre crisis years. Since a significant portion of revenue comes from export, income of the Indian IT firms is highly susceptible to various global adversities. In view of this, the Indian IT industry should explore new business in domestic as well as foreign markets such as the European Union, Australia and the emerging economies such as Africa and Latin America where the IT markets are in nascent stage and opportunities are plenty. Further, various stakeholders of this industry require to develop relevant strategies towards innovation, infrastructure and diversification to keep pace with the evolving technological and business environment in the future. In addition to this, the Government of India should play a pivotal role in simplifying the existing Indian labour law and providing world class infrastructure and telecommunication to facilitate the IT industry in the long run.

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Ocena determinant wzrostu całkowitej produktywności czynników produkcji w indyjskim przemyśle technologii informacyjnych: zastosowanie indeksu Malmquista opartego na metodzie DEA

Streszczenie

Cel: Niniejsze badanie ma na celu ocenę wzrostu całkowitej produktywności czynników produkcji (ang. Total Factor Productivity Growth (TFPG)) i jego determinant w indyjskim przemysle technologii informacyjnych (ang. Information Technology (IT)).

Metodyka badań: Aby zrealizować cel badań, zgromadzono dane na poziomie firm z bazy danych PROWESS z Centrum Monitoringu Indyjskiej Gospodarki (ang. Centre for Monitoring Indian Economy (CMIE)). W analizie empirycznej wykorzystano metodę dwuetapową. W pierwszym etapie zastosowano Indeks Produktywności Malmquista (ang. Malmquist Productivity Index (MPI)) oparty na Metodzie Obwiedni Danych (ang.: Data Envelopment Analysis (DEA)), aby ocenić TFPG w indyjskim przemyśle IT w okresie od 2004-05 do 2014-15. W tym celu uwzględniono zrównoważony panel 70 firm z branży IT. Następnie dokonano rozkładu TFPG na trzy komponenty, mianowicie catch-up , frontier-shift oraz zmiana efektywności skali (ang. scale efficiency change (SEC)). W drugim etapie rozważono trzy modele regresji dotyczące efektów losowych paneli, aby zbadać oddzielnie determinanty TFPG, catch-up i frontier-shift.

Wnioski: W okresie badawczym, poprawił się średnio TFPG i frontier-shift. Z drugiej strony zmalał efekt catch-up. Zmienne, takie jak intensywność eksportu czy intensywność wynagrodzeń miały pozytywny i statystycznie znaczący wpływ na catch-up i frontier-shift. Intensywność eksportu oraz wynagrodzenia pozytywnie oddziaływały na TFPG. Wiek przedsiębiorstw pozytywnie wpływał na catch-up i TFPG. Średnio, firmy, które dokonały wydatków na badania i rozwój (ang. Research and Development (R&D)), doświadczyły poprawy TFPG i frontier-shift. Publiczne przedsiębiorstwa z ograniczoną odpowiedzialnością radziły sobie lepiej niż ich prywatni odpowiednicy pod względem catch-up, frontier-shift i TFPG. Niezgrupowane firmy miały lepsze osiągnięcia z punktu widzenia catch-up aniżeli firmy zgrupowane. Z drugiej strony, przeciętnie, firmy osiągające malejące efekty skali (ang. decreasing Returns to Scale (DRS)) odnotowały pogorszenie w catch-up i TFPG w porównaniu do wyznacznika, jakim są firmy o stałych efektach skali (ang. Constant Returns to Scale (CRS)). Przedsiębiorstwa osiągające rosnące efekty skali (ang.: Increasing Returns to Scale (IRS)) uzyskały poprawę w zakresie catch-up i TFPG w większym stopniu niż będące wyznacznikiem firmy CRS. Kryzys na amerykańskim rynku kredytów hipotecznych negatywnie odbił się na catch-up, frontier-shift i TFPG. Przedsiębiorstwa, które poniosły wydatki na należności, doświadczyły poprawy catch-up i TFPG.

Wartość artykułu: Autorzy dotychczas nie spotkali tak licznych badań empirycznych tego typu odnoszących się do przemysłu IT, zwłaszcza w krajach rozwijających się, jak Indie. Co więcej, autorzy nie doszukali się żadnych badań obejmujących tak dużą rozpiętość danych, jaką uwzględniono w niniejszym artykule. W dodatku w niniejszym badaniu zastosowano model efektów losowych, aby dostosować pewne niezmienne w czasie zmienne, co nie byłoby możliwe w przypadku modelu stałych efektów, który wykorzystywano w niektórych wcześniejszych badaniach tego rodzaju.

Implikacje: Identyfikacja determinant TFPG i jego komponentów mogłaby pomóc interesariuszom i decydentom w sformułowaniu odpowiedniej polityki, co pozwoliłoby z jednej strony zmniejszyć ryzyko, którego doświadcza indyjski przemysł IT, a z drugiej pobudzić siły, które mogłyby przyczynić się do rozwoju tego przemysłu. Na przykład, aby ograniczyć przyszłe ryzyko, indyjski przemysł IT powinien zmniejszyć swoją zależność od rynku Stanów Zjednoczonych i Wielkiej Brytanii. Innymi słowy, powinien poszukiwać nowych rynków zarówno krajowych, jak też zagranicznych, np. w Unii

Europejskiej, Australii i w gospodarkach wschodzących, gdzie rynki IT wydają się być obiecujące. Aby utrzymać indyjską solidną pozycję globalną w długim okresie, rząd indyjski powinien odgrywać kluczową rolę w zapewnianiu światowej klasy infrastruktury i urządzeń telekomunikacyjnych w przemyśle IT. Co więcej, rząd indyjski musi zracjonalizować i uprościć istniejące indyjskie prawo pracy, aby ułatwić aktywność ekonomiczną w przemyśle IT. Przeróżni interesariusze wraz z rządem powinni włożyć niezbędny wysiłek w rozwój krajowego rynku IT, które jest pełen możliwości.

Słowa kluczowe: przemysł technologii informacyjnych, metoda obwiedni danych, indeks produktywności Malmquista, model efektów losowych, całkowita produktywność czynników produkcji, catch-up, frontier-shift, Indie

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