Evaluation of technical, pure technical and scale efficiencies of Indian banks: An analysis from cross-sectional perspective

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Abstract: This paper endeavours to measure the extent of technical, pure technical and scale efficiencies of Indian domestic banking industry using the non-parametric technique of data envelopment analysis. The empirical results show that only 9 of the 51 domestic banks operating in the financial year 2006/07 are found to be efficient and, thus, define the *efficient frontier* of the Indian domestic banking industry, with the TE scores range from 0.505 to 1, with an average of 0.792. We note that managerial inefficiency is the main source of overall technical inefficiency in Indian domestic banking industry. The new private sector banks dominate in the formation of the *efficient frontier*. However, the efficiency differences between public and private sector banks are not statistically significant. However, there exists significant differences between large and medium banks appear with regard to scale efficiency. The results pertaining to Tobit analysis reveal that the exposure to off-balance sheet activities and profitability are the most influential determinants of the technical efficiency.

Keywords: Data envelopment analysis (DEA), Tobit analysis, Indian banks, Returns-to-scale

1. Introduction

It has been well documented in the literature that the efficiency of banking system is germane to the performance of the entire economy because only an efficient system guarantees the smooth functioning of nation's payment system and effective implementation of the monetary policy. Rajan and Zingales (1998) asserted that a sound banking system serves as an important channel for achieving economic growth through the mobilization of financial savings, putting them to productive use, and transforming various risks. The efficiency of banking system also bears direct implications for social welfare. Society benefits when a country's banking system becomes more efficient, offering more services at a lower cost (Valverde *et al*., 2003). Owing to aforementioned socio-economic implications of banking efficiency, the analyses of relative efficiency of banks gained a lot of popularity among the policy makers, bank managers, bank investors and academicians. The information obtained from banking efficiency analyses can be used either: (i) to inform government policy by assessing the effects of deregulation, mergers, or market structure on efficiency; (ii) to address research issues by describing the efficiency of an industry, ranking its firms, or checking how measured efficiency may be related to the different efficiency techniques employed; or (iii) to improve managerial performance by identifying 'best practices' and 'worst practices' associated with high and low measured efficiency, respectively, and encouraging the former practices and while discouraging latter (Berger and Humphrey, 1997).

The banking industry has undergone significant transformation all over the world since the early 1980s under the impact of technological advances, deregulation, and globalization (Reserve Bank of India, 2008). The Indian banking sector has not remained insulated from the global trends, and deregulated its banking sector in 1992 by introducing a series of banking reforms measures like dismantling of administrated interest rate structure, reduction in statutory pre-emptions in the form of cash reserve ratio (CRR) and statutory liquidity ratio (SLR), introduction of prudential norms in the line with the international best practices, and liberal entry of *de novo* domestic private and foreign banks, etc. Consequently, the operating environment for the banks has changed significantly, and they are faced with increased competitive pressures and changing customer demands. This has engendered the banks to bring changes in their business strategies, so as to keep their survival intact and maintain a sustainable level of growth. Further, these pressures forced the banks to reduce operating costs while maintaining or improving the quality of their services. As the marketplace continues to evolve at a rapid pace, it has become imperative for banks to remain efficient in production process so that they can withstand the forces of competition and thrive in a changing environment. Against this backdrop, we have carried out this study with the primary objective to measure the magnitude of the technical efficiency in 51 domestic banks operating in India in the financial year 2006/07. Also, we intend to explore the most influential factors causing inter-bank variations in technical efficiency.

To sum up, the aim of this paper is four-fold: i) to obtain a measure of overall technical, pure technical, and scale efficiencies for individual banks; ii) to provide a complete ranking to Indian domestic banks on the basis of *super-efficiency* scores; iii) to examine whether ownership and size matters in Indian domestic banking industry; and iv) to explain the factors determining the OTE of Indian domestic banking industry. To achieve the underlined objectives of the study, we used the non-parametric frontier approach, data envelopment analysis (DEA), to measure the extent of OTE and its components, and to determine the nature of RTS in individual banks using a recent cross-section sample of 51 banks. Further, we made use of Tobit analysis to explain the factors affecting the OTE of Indian domestic banks.

The paper unfolds as follows. Section 2 provides a relevant literature review with special reference to Indian banking industry. Section 3 outlines CCR and BCC models for obtaining efficiency measures corresponding to constant returns-to-scale (CRS) and variable returns-to-scale (VRS) assumptions, respectively. The description of the data and the specification of input and output variables are reported in the Section 4. Section 5 presents the empirical results and discussion. The relevant conclusions and directions for future research are provided in the Section 6.

2. Relevant literature review

In recent years, there has been a proliferation of academic studies on banking efficiency which are primarily confined to the banking system of US and other well-developed European countries (see Berger *et al.*, 1993; Berger and Humphrey, 1997; Berger and Mester, 1997; Ashton and Hardwick, 2000; Casu and Molyneux, 2001; Mokhtar *et al.*, 2006 for an extensive review of literature on the subject matter). In their extensive international literature survey, Berger and Humphrey (1997) pointed out that out of 130 efficiency analyses of financial institutions covering 21 countries, only about 5 percent examined the banking sectors of developing countries. In Indian context, Keshari and Paul (1994) were perhaps the first to estimate the efficiency of banks using the frontier methodology. Since then, some notable attempts have been made by the researchers to analyze: (i) the impact of deregulation and liberalization measures on the efficiency and productivity of Indian banks; (ii) the efficiency differences among banks across different ownership groups; and iii) the efficiency differences among public sector banks.

Sweeping changes in the Indian banking system which occurred with the advent of the era of deregulation and banking reforms in early 1990s motivated the researchers to scrutinize whether the reform measures brought an ascent in efficiency levels of banks across different ownership groups or not. The study of Bhattacharyya *et al.* (1997a) divulged that deregulation has led to an improvement in the overall performance of Indian commercial banks. Bhattacharyya *et al.* (1997b) also reported a positive impact of deregulation on the total factor productivity (TFP) growth of Indian public sector banks. Ataullah *et al. (*2004) reported that overall technical efficiency of the banking industry of India and Pakistan improved following the financial liberalization. Ram Mohan and Ray (2004) found an improvement in the revenue efficiency of Indian banks. Also, they noticed a convergence in performance between public and private sector banks in the post-reforms era. Shanmugam and Das (2004) observed that during deregulation period, the Indian banking industry showed a progress in terms of efficiency of raising non-interest income, investments and credits. Reddy (2004, 2005) noted an ascent in the overall technical efficiency of Indian banks during the period of deregulation. Das *et al.* (2005) found that the efficiency of Indian banks, in general, and of bigger banks, in particular, has improved during the post-reforms period. The methodology and findings of the study of Mahesh and Rajeev (2006) is completely similar to that of Shanmugam and Das (2004). Chatterjee (2006) noticed a declining trend in the cost inefficiency of the banks during the post-reforms era. Sensarma (2006) noted that deregulation in Indian banking industry (especially public sector banks) achieved the aim of reduction in intermediation costs and improving TFP. Zhao *et al.* (2007) noted that, after an initial adjustment phase, the Indian banking industry experienced sustained productivity growth, driven mainly by technological progress. On comparing the effect of deregulation on the productivity growth of banks in Indian sub-continent (including India, Pakistan and Bangladesh), Jaffry *et al.*(2007) concluded that technical efficiency both increased and converged across the Indian sub-continent in response to reforms. Rezvanian *et al*. (2008) reported an ascent in cost efficiency in all ownership groups and industry as a whole. Further, the observed increase in cost efficiency has taken place due to its allocative efficiency improvement rather than technical efficiency gains. Ketkar and Ketkar (2008) noted that the efficiency scores of all banks, in general, have improved regardless of their ownership during the period of reforms. Further, the nationalized banks have registered the strongest gains. These gains in efficiency have shown an improvement in bank profitability. Reserve Bank of India (2008) found that the efficiency has improved across all bank groups during the study period and most of the observed efficiency gains have emanated after few years of reforms i.e., from 1997/98 onwards. Sahoo and Tone (2009) found that competition created after financial sector reforms generated high efficiency growth and reduced excess capacity in Indian banking sector.

Though aforementioned studies reflect a positive effect of deregulation on the efficiency and productivity of Indian banking sector, there are also a few studies which reported an adverse effect of deregulatory environment on the performance of Indian banks. For example, Kumbhakar and Sarkar (2003) concluded that a significant TFP growth has not been observed in Indian banking sector during the deregulatory regime. Galagedera and Edirisuriya (2005) observed that deregulation has brought no significant growth in the productivity of Indian banks. Further, public sector banks have not responded well to the deregulatory measures. Das and Ghosh (2006) found that the period after liberalization did not witness any significant increase in number of efficient banks and some banks have high degree of inefficiency during the period of liberalization. Sensarma (2005, 2008) pointed out that the profit efficiency of Indian banks has shown a declining trend during the period of deregulation.

In the literature on Indian banking, there are also a few studies which have been carried with the main objective to examine the impact of ownership on the efficiency of banks. Keshari and Paul (1994) observed that foreign banks as a group have been found to be less efficient than domestic banks and the standard deviation of technical efficiency of foreign banks was slightly higher than that of domestic banks. However, the efficiency differences were not significant. A few researchers like Bhattacharyya *et al.* (1997a), Mukherjee *et al.* (2002), Sathye (2003), Ram Mohan and Ray (2004), Das and Ghosh (2006), Mahesh and Rajeev (2009) concluded that the banks with public ownership are more efficient than their private counterparts, while others like Khatri (2004), Chakrabarti and Chawla (2005), Chatterjee and Sinha (2006), Mittal and Dhingra (2007) concluded that private sector banks are relatively best-performers. Das (1997b) and Reserve Bank of India (2008) found no significant differences in any of the efficiency measures between public and private sector banks. Srivastava and Jain (2006) and Debasish (2006) found that foreign owned banks are, on an average, more efficient than domestic banks. Singh *et al.* (2008) found that foreign banks are more efficient and showed an efficiency improvement during the study period while nationalized banks observed a fall in efficiency. Gupta *et al.* (2008) noted that SBI and its associates have the highest efficiency, followed by private sector banks, and the other nationalised banks.

A few studies also appear in the literature which exclusively concentrated on the efficiency of public sector banks (PSBs). Noulas and Ketkar (1996) analyzed the technical and scale efficiencies of 18 PSBs and found that majority of the banks were operating under increasing returns-to-scale. Das (1997a, 2000) found that the banks belonging to State Bank of India (SBI) group are more efficient than nationalized banks. Main source of inefficiency was technical in nature, rather than allocative. However, PSBs have improved their allocative efficiency in the post-liberalization period. Saha and Ravisankar (2000) noted that the PSBs have, in general, improved their efficiency scores over the period 1991/92 to 1994/95. Nath *et al*. (2001) generated 5 strategic groups for 27 PSBs using the techniques of DEA and Co-plot. They noted that there is a positive association between efficiency and profitability, and poor performing banks are plagued with over-staffing, low productivity and inefficient training facilities. Kumar and Verma (2003) observed that technical efficiency of PSBs is positively related to higher profitability, larger branch network and higher staff productivity. Mukherjee *et al*. (2003) found that PSBs delivering better services have better transformation of resource to performance using superior service delivery as the medium. Nandy (2007) found that Corporation Bank and Indian Overseas Bank are the star performers among PSBs. Sanjeev (2007) found that there is no conclusive relationship between the efficiency and size of public sector banks. Kumar (2008) analyzed the efficiency-profitability relationship in individual PSBs and found that Andhra Bank and Corporation Bank are ideal benchmarks on both efficiency and profitability dimensions. Kumar and Gulati (2008) noted that the exposure to off-balance sheet activities, staff productivity, market share and size are the major determinants of the technical efficiency of PSBs. Tandon (2008) analyzed the efficiency of 19 PSBs during the period 2003-2006 and found that Corporation Bank is consistently best-performer. Das *et al.* (2009) noticed a considerable variation in the average levels of labour-use efficiency of individual branches of a large public sector banks. Kumar and Gulati (2009) found not only an ascent in technical efficiency of the PSBs during the post-reforms years, but also noticed the presence of convergence phenomenon in the Indian public sector banking industry.

From the deep analysis of existing literature on Indian banking sector, we can draw following inferences. First, an overwhelming majority of studies portraits a positive impact of deregulatory policies on the efficiency and productivity of Indian banks. Second, the ownership effect on the efficiency of Indian banks is inconclusive. It is significant to note that the existing studies particularly aiming at studying the efficiency differences between domestic and foreign banks, assume a common technology, and therefore quantify the relative efficiency of both domestic and foreign banks using a common *efficient frontier*. However, this assumption of common frontier is economically irrational and practicably implausible since both foreign and domestic banks follow different technology and banking practices. Third, the average technical inefficiency across PSBs ranges between 20 and 30 percent.

3 Methodology

3.1 Data envelopment analysis

As already pointed out, the technique of data envelopment analysis (DEA) has been used to assess the relative efficiency of Indian domestic banks. DEA generalizes the Farrell's (1957) technical efficiency measure to the multiple-inputs and multiple-outputs case. DEA involves the use of linear programming methods to construct a non-parametric piecewise surface (frontier) over the data. Efficiency measures are then calculated relative to this surface. Comprehensive review of the methodology is presented in Seiford and Thrall (1990), Charnes *et al.* (1994), Seiford (1996), Zhu (2003), Ray (2004) and Cooper *et al.* (2007). DEA optimizes each individual observation with the objective of calculating a discrete piecewise linear frontier determined by the set of *Pareto-efficient* decision making units (DMUs). Using this frontier, DEA computes a maximal performance measure for each DMU relative to that of all other DMUs. The only restriction is that each DMU lies on the efficient (extremal) frontier or be enveloped within the frontier. The DMUs that lie on the frontier are the best practice units and retain a value of 1; those enveloped by the extremal surface are scaled against a convex combination of the DMUs on the frontier facet closest to it and have values somewhere between 0 and 1.

Several different mathematical programming DEA models have been proposed in the literature. Essentially, these models seek to establish which of n DMUs determine the *envelopment surface* or *best practice frontier* or *efficient frontier*. The geometry of this surface is prescribed by the specific DEA model employed. In the present study, we use the CCR (named after its developers Charnes, Cooper and Rhodes, 1978) and BCC (named after its developers Banker, Charnes and Cooper, 1984) models to obtain efficiency measures corresponding to the assumptions of CRS and VRS, respectively. The efficiency measures obtained from CCR model are popularly known as overall technical efficiency (OTE) scores and are confounded by scale efficiencies. The efficiency measures obtained from BCC model are popularly known as pure technical efficiency (PTE) scores and devoid of scale efficiency effects. Scale efficiency (SE) for each DMU can be obtained by a ratio of OTE score to PTE score (i.e., SE=OTE/PTE).

3.2 CCR model

To illustrate CCR model, consider a set of decision making units (DMUs) $j=1,2,...,n$, utilizing quantities of inputs $X \in R_{+}^{m}$ to produce quantities of outputs $Y \in R_{+}^{s}$. We can denote x_{ij} the amount of the ith input used by the DMU j and y_{rj} the amount of the rth output produced by the DMU j. Assuming constant returns-to-scale (CRS), strong disposability of inputs and outputs, and convexity of the production possibility set, the technical efficiency score for the DMU *k* (denoted by TE^{k}) can be obtained by solving following model (Charnes *et al.*, 1978):

$$
\text{(1)} \quad
\begin{aligned}
&i)\ \min_{\theta_k, \lambda, s_i^-, s_r^+} \quad TE_{CRS}^k = \theta_k - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right) \\
&\text{subject to} \\
&ii)\ \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{rk} \qquad r = 1,2,...,s \\
&iii)\ \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta_k x_{ik} \qquad i = 1,2,....,m \\
&iv)\ s_i^-, s_r^+ \geq 0 \\
&v)\ \lambda_j \geq 0 \qquad j = 1,2,...,n
\end{aligned}
$$

The solution to model (1) is interpreted as the largest contraction in inputs of DMU *k* that can be carried out, given that DMU *k* will stay within the reference technology. The restrictions *ii*) and *iii*) form the convex reference technology. The restriction *iv*) restricts the input slack (s_i^-) and output slack (s_r^+) variables to be non-negative. The restriction *v*) limits the intensity variables to be non-negative. Parameter ε is a non-Archimedean infinitesimal. Since the model measures the efficiency of single DMU (i.e., DMU *k*), it needs to be solved *n* times to obtain efficiency score of each DMU in the sample. The optimal value θ_k^* reflects the OTE score of DMU *k*. OTE measures inefficiencies due to the input/output configuration and as well as the size of operations (Avkiran, 2006). This efficiency score is within a range from zero to one, $0 < \theta_k^* \leq 1$, with a high score implying a higher efficiency. If $\theta_k^* = 1$ and $s_i^{-*} = s_r^{+*} = 0$ then DMU *k* is *Pareto-efficient*. It is worth mentioning here that the model (1) is an input-oriented model since the objective is to utilize minimum level of inputs with the same level of production.

3.3 BCC model

The CCR model detailed above provide the input-oriented constant returns-to-scale(CRS) envelopment surface, and a measure of *overall technical efficiency*(θ_k).Under the assumption of CRS, any scaled-up or scaled-down versions of the input combinations are also included in the production possibility set. However, the constraint over returns-to-scale may be relaxed to allow units to be compared given their scale of operations. To allow returns-to-scale to be variable (i.e., constant, increasing or decreasing), Banker, Charnes and Cooper (1984) added the convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$ to the Model (1). Note that the convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$, essentially ensures that an inefficient DMU is only 'benchmarked' against DMUs of a similar size. The mathematical form of BCC model is as follows:

$$
(2) \quad
\begin{aligned}
& i) \min_{\theta_k, \lambda, s_i^-, s_r^+} \quad TE_{VRS}^k = \pi_k - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right) \\
& \text{subject to} \\
& ii) \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{rk} \qquad r = 1, 2, ..., s \\
& iii) \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta_k x_{ik} \qquad i = 1, 2, ..., m \\
& iv) \sum_{j=1}^{n} \lambda_j = 1 \\
& v) \; s_i^-, s_r^+ \geq 0 \\
& vi) \; \lambda_j \geq 0 \qquad j = 1, 2, ..., n
\end{aligned}
$$

The optimal value of the π_k (i.e., π_k^*) represents pure technical efficiency which is a measure of efficiency without scale efficiency. We should also note that if a DMU is characterized as efficient in the CCR model, it will also be characterized as efficient with the BCC model. However, the converse is not necessarily true.

3.4 Scale efficiency and returns-to-scale

An optimal value of scale efficiency (*SE*) measure for DMU *k* as denoted by μ_k^* can be obtained as: $\mu_k^* = \theta_k^* / \pi_k^*$. Since $\pi_k^* \geq \theta_k^*$ it follows that $\mu_k^* \leq 1$. If $\mu_k^* = 1$ then the DMU *k* is fully scale efficient. If $\mu_k^* < 1$, the DMU is scale inefficient. There are two possible reasons for scale inefficiency. The DMU could be operating under increasing returns-to-scale (IRS) and, therefore, be of sub-optimal scale. Alternatively, the DMU could be operating under decreasing returns-to-scale (DRS) and, therefore, be of supra-optimal scale. To determine whether the DMU is operating in an area of increasing or decreasing returns-to-scale, we run an additional DEA problem with non-increasing returns-to-scale (NIRS) imposed. This is done by altering the BCC model by substituting the $\sum_{j=1}^{n} \lambda_j = 1$ restriction with $\sum_{j=1}^{n} \lambda_j \leq 1$ to provide:

$$
\begin{aligned}
&i)\ \min_{\delta_k,\lambda,s_i^-,s_r^+} \quad TE^k_{NIRS} = \delta_k - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)\\
&\text{subject to}\\
&ii)\ \sum_{j=1}^{n}\lambda_j y_{rj} - s_r^+ = y_{rk} \qquad r = 1,2,...,s\\
(3)\qquad &iii)\ \sum_{j=1}^{n}\lambda_j x_{ij} + s_i^- = \delta_k x_{ik} \qquad i = 1,2,....,m\\
&iv)\ \sum_{j=1}^{n}\lambda_j \le 1\\
&v)\ s_i^-, s_r^+ \ge 0\\
&vi)\ \lambda_j \ge 0 \qquad j = 1,2,...,n
\end{aligned}
$$

Note that the constraint $\sum_{j=1}^{n}\lambda_j \le 1$ ensures that *k*th DMU will not be 'benchmarked' against DMUs which are substantially larger than it, but may be compared with DMUs smaller than it. If $\mu_k^* < 1$ and $\theta_k^* = \delta_k^*$ then scale inefficiency is due to IRS and the DMU is of sub-optimal size. On the other hand, if $\mu_k^* < 1$ and $\theta_k^* < \delta_k^*$ then scale inefficiency is due to DRS and the DMU is of supra-optimal size.

Corresponding to the three measures of efficiency defined above are three measures of inefficiency defined in the obvious way, namely, $1-\theta_k^*$, $1-\pi_k^*$ and $1-\mu_k^*$. In fact, $1-\theta_k^*$ gives the necessary reduction in all inputs of DMU *k* to be rated as fully efficient. Further, overall technical inefficiency, $1-\theta_k^*$, can be thought of as being attributable to pure technical inefficiency, $1-\pi_k^*$, and scale inefficiency, $1-\mu_k^*$, and the former sometimes referred to as *controllable, managerial* or *X-inefficiency* (Alexander and Jaforullah, 2005).

3.5 Andersen and Petersen's Super-efficiency model

It is significant to note that all the efficient DMUs have OTE scores equal to 1 in the CCR model. Therefore, it is impossible to rank or differentiate the efficient DMUs with the CCR model. However, the ability to rank or differentiate the efficient DMUs is of both theoretical and practical importance. Theoretically, the inability to differentiate the efficient DMUs creates a spiked distribution at efficiency scores of 1. This poses analytic difficulties to any post-DEA statistical inference analysis. In practice, further discrimination across the efficient DMUs is also desirable to identify ace performers. For getting strict ranking among the efficient DMUs, Andersen and Petersen (1993) proposed the *super-efficiency* DEA model. The core idea of *super-efficiency* DEA model is to exclude the DMU under evaluation from the *reference set*. The *super-efficiency* score for efficient DMU can, in principle, take any value greater than or equal to 1. This procedure makes the ranking of efficient DMUs possible (i.e., the higher the *super-efficiency* score implies higher rank). However, the inefficient units which are not on the *efficient frontier*, and with an initial DEA score of less than 1, would find their relative efficiency score unaffected by their exclusion from the *reference set* of DMUs.

In the *super-efficiency* DEA model, when the linear program (LP) is run for calculating the efficiency score of DMU *k*, the DMU *k* cannot form part of its reference frontier and hence, if it was a fully-efficient unit in the original standard DEA model (like CCR model in the present study) it may now have efficiency score greater than 1. This LP is required to be run for each of the *n* DMUs in the sample, and in each of these LPs, the *reference set* involves *n*-1 DMUs. In particular, Andersen and Petersen's model for estimating *super-efficiency* score for DMU *k* (denoted by $TE_{CRS}^{k,\text{super}}$) can be outlined as below:

$$
\begin{aligned}
&i) \quad \min_{\theta_k^{\text{super}},\lambda,s_i^-,s_r^+} \quad TE_{CRS}^{k,\text{super}} = \theta_k^{\text{super}} - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)\\
&\text{subject to}\\
&ii) \quad \sum_{j=1, j\neq k}^{n} \lambda_j y_{rj} - s_r^+ = y_{rk} \qquad r = 1,2,...,s\\
(4)\qquad &iii) \quad \sum_{j=1, j\neq k}^{n} \lambda_j x_{ij} + s_i^- = \theta_k^{\text{super}} x_{ik} \qquad i = 1,2,....,m\\
&iv) \quad s_i^-, s_r^+ \geq 0\\
&v) \quad \lambda_j (j \neq k) \geq 0 \qquad j = 1,2,...,n
\end{aligned}
$$

3.6 Tobit analysis

The standard Tobit model can be defined as follows for *i*th observation (bank) is as follows:

$$
\begin{aligned}
y_i^* &= \beta^T x_i + \varepsilon_i\\
y_i &= y_i^* \text{ if } y_i^* > 0, \text{ and}\\
y_i &= 0, \text{ otherwise}
\end{aligned}
$$

where $\varepsilon_i \sim N(0,\sigma^2)$, x_i and β are vectors of explanatory variables and unknown parameters, respectively. '*T*' denotes the matrix transpose operator. y_i^* is a latent variable and y_i is the dependent variable. The likelihood function (*L*) is maximized to solve β and σ based on 51 observations (banks) of y_i and x_i is

$$L = \prod_{y_i=0}\left(1-F_i\right)\prod_{y_i>0}\frac{1}{\left(2\pi\sigma^2\right)^{1/2}}e^{-\frac{1}{2\sigma^2}\left(y_i-\beta^T x_i\right)^2}$$

where, $F_i = \int_{-\infty}^{\beta^T x_i/\sigma}\frac{1}{\left(2\pi\right)^{1/2}}e^{-\frac{t^2}{2}}dt$

The first product is over the observations for which the industrial groups are 100 percent efficient (y = 0) and the second product is over the observations for which industrial groups are inefficient (y > 0). F_i is the distribution function of the standard normal evaluated at $\beta^T x_i/\sigma$. It is possible to estimate the unknown parameter vector β in the Tobit model in several ways.

4. Data and specification of inputs and outputs

In the banking literature, there is a considerable disagreement among researchers about what constitute inputs and outputs of banking industry (Casu, 2002; Sathye, 2003). Two different approaches appear in the literature regarding the measurement of inputs and outputs of a bank.

These approaches are the 'production approach' and 'intermediation approach' (Humphrey, 1985). The intermediation approach views the banks as using deposits together with purchased inputs to produce various categories of bank assets. Outputs are measured in monetary values and total costs include all operating and interest expenses (see Sealey and Lindley, 1977 for a discussion). In contrast, the production approach view banks as using purchased inputs to produce deposits and various categories of bank assets. Both loans and deposits are, therefore, treated as outputs and measured in terms of the number of accounts. This approach considers only operating costs and excludes the interest expenses paid on deposits since deposits are viewed as outputs. Although the intermediation approach is most commonly used in the empirical studies, neither approach is completely satisfactory, largely because the deposits have both input and output characteristics which are not easily disaggregated empirically.

Berger and Humphrey (1997) suggested that the intermediation approach is best suited for analyzing bank level efficiency, whereas the production approach is well suited for measuring branch level efficiency. This is because, at the bank level, management will aim to reduce total costs and not just non-interest expenses, while at the branch level a large number of customer service processing take place and bank funding and investment decisions are mostly not under the control of branches. Also, in practice, the availability of flow data required by the production approach is usually exceptional rather than in common. Therefore, following Berger and Humphrey (1997), we have selected a modified version of intermediation approach as opposed to the production approach for selecting input and output variables in the present study.

The data on input and output variables have been culled out from two annual publications of Indian Banks' Association entitled, 'Performance Highlights of Public Sector Banks: 2006/07' and 'Performance Highlights of Private Sector Banks: 2006/07'. The study is confined to 51 public and private sector banks operating in the financial year 2006/07[3]. In this study, the inputs used for computing various efficiency scores are i) physical capital[4], ii) labour[5], and iii) loanable funds[6]. The output vector contains two output variables: i) net-interest income[7], and ii) non-interest income[8]. The variable 'net-interest income' connotes net income received by the banks from their traditional activities like advancing of loans and investments in the government and other approved securities. The output variable 'non-interest income' accounts for income from off-balance sheet items such as commission, exchange and brokerage, etc. The inclusion of 'non-interest income' enables us to capture the recent changes in the production of services as Indian banks are increasingly engaging in non-traditional banking activities. As pointed out by Siems and Clark (1997), the failure to incorporate these types of activities may seriously understate bank output and this is likely to have statistical and economic effects on estimated efficiency.

It is worth noting here that the choice of output variables is consistent with the managerial objectives that are being pursued by the Indian banks. In the post-reforms years, intense competition in the Indian banking sector has forced the banks to reduce all the input costs to the minimum and to earn maximum revenue with less of less inputs. Further, the inclusion of deposits and loans in the output vector as reported in the studies of Mukherjee *et al.* (2002) and Chakrabarti and Chawla (2005) is not in consonance of policy objectives of the Indian banks and, thus, seems irrational in the efficiency analysis of Indian banks that confined to the post-reforms period. In this context, Ram Mohan and Ray (2004) rightly remarked that:

> "Using deposits and loans as outputs would have been appropriate in the nationalized era when maximizing these was indeed the objective of a bank but they are, perhaps, less appropriate in the reforms era. Banks are not simply maximizing deposits and loans; they are in the business of maximizing profits. If inputs are treated as pre-determined, this amounts to maximizing revenue."

5. Empirical results

In this section, we provide and discuss the contents of OTE, PTE and SE scores that are obtained by executing the two most generic DEA models, namely, CCR and BCC models. Further, the results pertaining to RTS are also provided herewith. The results of the DEA modeling are derived from the computer program DEA Excel Solver developed by Zhu (2003). Table 1 presents OTE, PTE and SE scores along with nature of RTS for individual banks. The subsequent discussion is based on the summary tables prepared from Table 1.

The perusal of table gives that out of 51 sample banks, only 9 banks have been found to be overall technically efficient with OTE score equal to 1. These efficient banks together define the *efficient frontier* of Indian domestic banking industry and, thus, form the *reference set* for inefficient banks. The level of overall technical inefficiency (OTIE)[9] in the remaining 42 inefficient banks can be gauged as the radial distance from this frontier. The frontier banks are State Bank of Bikaner and Jaipur, Andhra Bank, Nainital Bank, Tamilnad Mercantile Bank, Centurion Bank of Punjab, HDFC Bank, ICICI Bank, Kotak Mahindra Bank, and Yes Bank. Note that a total of 5 out of 9 overall technically efficient banks are *de nova* private sector banks which were established after 1996. Thus, the *de nova* private sector banks armed with state-of-the-art banking technology and business practices dominate in the formation of *efficient frontier* for Indian domestic banking industry. It is noteworthy here that the process of resource utilization in the aforementioned frontier banks is functioning well, and featuring no waste of resources. In the spirit of DEA terminology, these banks can be termed as *global leaders* (or globally efficient banks) and set the idyllic benchmarks of best operating practices in the Indian domestic banking industry. Further, the inefficient banks identified in the sample could move towards the *efficient frontier* by emulating the best practices of these efficient banks. That is, the ultimate destination for all inefficient banks in their drive to achieve high level of performance is to follow the input-output combinations that are being used by the *global leaders*.

Table 1 **OTE, PTE, SE and returns-to-scale in Indian domestic banks**

Bank code	Public Sector Banks	OTE	PTE	SE	RTS	Bank code	Private Sector Banks	OTE	PTE	SE	RTS
B1	State Bank of India	0.892	1.000	0.892	DRS	B29	City Union Bank	0.770	0.829	0.929	IRS
B2	State Bank of Bikaner and Jaipur	1.000	1.000	1.000	CRS	B30	Development Credit Bank	0.895	0.960	0.932	IRS
B3	State Bank of Hyderabad	0.924	0.926	0.998	DRS	B31	ING Vysya Bank	0.639	0.653	0.979	IRS
B4	State Bank of Indore	0.881	0.888	0.993	IRS	B32	Karnataka Bank	0.801	0.804	0.996	IRS
B5	State Bank of Mysore	0.948	0.968	0.979	DRS	B33	Nainital Bank	1.000	1.000	1.000	CRS
B6	State Bank of Patiala	0.935	0.939	0.995	DRS	B34	SBI Commercial & Int. Bank	0.653	1.000	0.653	IRS
B7	State Bank of Saurashtra	0.540	0.542	0.997	IRS	B35	Tamilnad Mercantile Bank	1.000	1.000	1.000	CRS
B8	State Bank of Travancore	0.902	0.980	0.920	DRS	B36	Bank of Rajasthan	0.567	0.608	0.934	IRS
B9	Allahabad Bank	0.561	0.563	0.997	IRS	B37	Catholic Syrian Bank	0.672	0.701	0.958	IRS
B10	Andhra Bank	1.000	1.000	1.000	CRS	B38	Dhanalakshmi Bank	0.600	0.656	0.915	IRS
B11	Bank of Baroda	0.690	0.775	0.89	DRS	B39	Federal Bank	0.873	0.874	0.998	DRS
B12	Bank of India	0.838	0.994	0.843	DRS	B40	Jammu & Kashmir Bank	0.797	0.831	0.959	DRS
B13	Bank of Maharashtra	0.732	0.821	0.892	DRS	B41	Karur Vysya Bank	0.741	0.756	0.980	IRS
B14	Canara Bank	0.536	0.566	0.947	DRS	B42	Lakshmi Vilas Bank	0.625	0.686	0.910	IRS
B15	Central Bank of India	0.600	0.678	0.885	DRS	B43	Ratnakar Bank	0.810	1.000	0.810	IRS
B16	Corporation Bank	0.988	1.000	0.988	DRS	B44	South Indian Bank	0.706	0.717	0.984	DRS
B17	Dena Bank	0.638	0.645	0.988	IRS	B45	Centurion Bank of Punjab	1.000	1.000	1.000	CRS
B18	Indian Bank	0.791	0.794	0.996	DRS	B46	HDFC Bank	1.000	1.000	1.000	CRS
B19	Indian Overseas Bank	0.819	0.948	0.864	DRS	B47	ICICI Bank	1.000	1.000	1.000	CRS
B20	Oriental Bank of Commerce	0.874	0.882	0.991	DRS	B48	IndusInd Bank	0.632	0.650	0.972	IRS
B21	Punjab & Sind Bank	0.759	0.761	0.997	IRS	B49	Kotak Mahindra Bank	1.000	1.000	1.000	CRS
B22	Punjab National Bank	0.818	1.000	0.818	DRS	B50	UTI Bank	0.936	0.938	0.998	IRS
B23	Sydicate Bank	0.591	0.618	0.956	DRS	B51	Yes Bank	1.000	1.000	1.000	CRS
B24	UCO Bank	0.505	0.552	0.916	DRS						
B25	Union Bank of India	0.692	0.746	0.927	DRS						
B26	United Bank of India	0.601	0.604	0.995	IRS						
B27	Vijaya Bank	0.849	0.896	0.948	DRS						
B28	IDBI Bank	0.772	0.780	0.989	IRS						

Note: RTS= Returns-to-scale, IRS=Increasing returns-to-scale, DRS=Decreasing returns-to-scale, and CRS= Constant returns-to-scale

Source: Authors' calculations

Table 2: Frequency distribution and descriptive statistics of OTE, PTE and SE scores			
Efficiency Scores	**OTE**	**PTE**	**SE**
E < 0.5	0 (0.00)	0 (0.00)	0 (0.00)
0.5 ≤ E < 0.6	6 (11.77)	4 (7.84)	0 (0.00)
0.6 ≤ E < 0.7	11(21.57)	9 (17.65)	1 (1.96)
0.7 ≤ E < 0.8	8 (15.69)	8 (15.69)	0 (0.00)
0.8 ≤ E < 0.9	11 (21.57)	8 (15.69)	8 (15.68)
0.9 ≤ E < 1.0	6 (11.77)	8 (15.69)	33 (64.71)
E=1.0	9 (17.6)	14 (27.45)	9 (17.65)
Descriptive Statistics			
No. of Banks	51	51	51
Mean	0.792	0.834	0.951
Median	0.801	0.874	0.980
Standard Deviation	0.155	0.155	0.066
Q_1	0.646	0.694	0.924
Q_3	0.930	1.000	0.997
Minimum	0.505	0.542	0.653
Maximum	1.000	1.000	1.000
Notes: (i) Q_1 =First Quartile and Q_3 =Third Quartile; and (ii) Figures in parenthesis are the percentage of banks.			
Source: Authors' calculations			

Table 2 provides the frequency distribution of OTE, PTE and SE scores and their descriptive statistics. From the table, we observe that OTE scores range between 0.505 and 1, and their mean and standard deviation (SD) are 0.792 and 0.155, respectively. Thus, the average level of OTIE in Indian domestic banking industry is to the tune of about 21.8 percent. It can, therefore, be concluded that the same level of outputs in Indian domestic banking sector could be produced with 21.8 percent lesser inputs. Further, we note the presence of significant variations in OTIE at the level of individual banks. The highest and lowest levels of OTIE have been noted for UCO Bank (49.5 percent) and Corporation Bank (1.2 percent), respectively (see Table 1 for OTE scores of these banks). The analysis of frequency distribution of OTE scores reveals that about 49 percent of banks have efficiency score below 0.8 and, thus, have OTIE more than 20 percent.

As noted above, OTE can be decomposed into two mutually exclusive and non-additive components, namely, pure technical efficiency (PTE) and scale efficiency (SE). It is significant to note that like OTE measure, the PTE measure also indicates the underutilization of inputs. However, in contrast to the OTE measure, the PTE measure is devoid of scale effects. Table 2 also provides the frequency distribution of PTE scores along with their relevant descriptive statistics. The mean value of PTE scores has been observed to be 0.834 (with SD of 0.155), and PTE scores range from the lowest figure of 0.542 to the highest of 1. Thus, the extent of pure technical inefficiency (PTIE)[10] in Indian domestic banking industry has been observed to be 16.6 percent. The results delineate that 16.6 percentage points of 21.8 percent of OTIE identified above in the Indian domestic banking industry is due to inappropriate management practices that are being followed by banks' managers in organizing inputs in banking operations. The remaining part of OTIE is due to the banks operating at sub-optimal scale size. This implies that in Indian domestic banking industry, PTIE is a more dominant source of OTIE, and scale inefficiency (SIE)[11] is a relatively diminutive one. Further, 14 banks have been identified as relatively efficient under VRS assumption since they have attained PTE score equal to 1. Out of these 14 banks, 9 banks were also relatively efficient under CRS assumption with OTE score equal to 1. Thus, in only 5 banks, the OTIE is caused entirely by SIE rather than PTIE. In other words, the OTIE in these banks is completely due to inappropriate choice of the scale size instead of managerial incapability to organize the resources in the production process. These 5 banks are State Bank of India, Corporation Bank, Punjab National Bank, SBI Commercial & Int. Bank, and Ratnakar Bank. We further note that in 40.9 percent banks, the extent of PTIE is more than 20 percent.

As mentioned earlier, SE score for each bank can be obtained by taking a ratio of OTE score to PTE score. The value of SE equal to 1 implies that the bank is operating at most productive scale size (MPSS) which corresponds to constant returns-to-scale. At MPSS, the bank operates at minimum point of its long-run average cost curve. Further, SE<1 indicates that the bank is experiencing OTIE because it is not operating at its optimal scale size. An inspection of Table 2 reveals that mean SE for Indian domestic banking industry as a whole is quite high being 0.951 (with SD equal to 0.066), and SE scores range from a minimum of 0.653 to maximum of 1. The connotation of this finding is that average level of SIE in the Indian domestic banking sector is to the tune of about 4.9 percent. This finding reiterates our earlier findings that SIE is a scant source of OTIE relative to that of PTIE in Indian domestic banking industry. Further, only 9 banks attained SE score equal to 1 and are, thus, operating at most productive scale size (MPSS). The remaining 42 banks are operating with some degree of SIE and have either DRS or IRS. In addition, the majority of banks are operating with scale efficiency above 80 percent.

5.1 Discrimination of efficient banks: super-efficiency DEA model

The Anderson and Peterson's *super-efficiency* scores obtained for the efficient banks and their ranks are reported in Table 3. We note that among the efficient banks, ICICI Bank dominates the whole sample with the *super-efficiency* score equal to 1.66 and, thus, ranked at the top position among the 51 banks under consideration. Another private sector bank, Yes Bank occupied the second place with *super-efficiency* score equal to 1.413. Further, HDFC Bank, Nainital Bank, Centurion Bank of Punjab have occupied third, fourth and fifth place, respectively. Two more private sector banks, namely, Tamilnad Mercantile Bank and Kotak Mahindra Bank acquired seventh and ninth place, respectively, among the efficient banks of Indian domestic banking industry. However, only two public sector banks, namely, State Bank of Bikaner and Jaipur, and Andhra Bank attained the status of efficient banks and ranked at sixth and eighth positions, respectively.

Table 3 Andersen and Petersen's *super-efficiency* scores and ranks of efficient banks

Bank	Andersen and Petersen's *super-efficiency* scores	Rank
ICICI Bank	1.660	1
Yes Bank	1.413	2
HDFC Bank	1.288	3
Nainital Bank	1.225	4
Centurian Bank of Punjab	1.201	5
State Bank of Bikaner and Jaipur	1.090	6
Tamilnad Mercantile Bank	1.083	7
Andhra Bank	1.034	8
Kotak Mahindra Bank	1.021	9

Source: Authors' calculations

5.2 Discrimination of inefficient banks

In order to get a deep insight into the behaviour of inefficient banks, we made an attempt to classify 42 inefficient banks into four broad categories. The values for first quartile (Q_1), median, and third quartile (Q_3) of OTE scores have been selected as three cut-off points to discriminate the inefficient banks. Table 4 provides the classification of inefficient banks into four distinct categories.

Table 4 Discrimination of Inefficient Banks

Category I (Below Q_1)	**Category II** (Q_1 <OTE<Median)	**Category III** (Median<OTE< Q_3)	**Category IV** (Q_3 <OTE<1)
UCO Bank (51)	SBI Commercial & Int. Bank(38)	Ratnakar Bank (25)	State Bank of Patiala (13)
Canara Bank (50)	Catholic Syrian Bank (37)	Punjab National Bank (24)	UTI Bank (12)
State Bank of Saurashtra (49)	Bank of Baroda (36)	Indian Overseas Bank (23)	State Bank of Mysore (11)
Allahabad Bank (48)	Union Bank of India (35)	Bank of India (22)	Corporation Bank (10)
Bank of Rajasthan (47)	South Indian Bank (34)	Vijaya Bank (21)	
Sydicate Bank (46)	Bank of Maharashtra (33)	Oriental Bank of Commerce (20)	
Central Bank of India (45)	Karur Vysya Bank (32)	Federal Bank (19)	
Dhanalakshmi Bank (44)	Punjab & Sind Bank (31)	State Bank of Indore (18)	
United Bank of India (43)	City Union Bank (30)	State Bank of India (17)	
Lakshmi Vilas Bank (42)	IDBI Bank (29)	Development Credit Bank (16)	
IndusInd Bank (41)	Indian Bank (28)	State Bank of Travancore (15)	
Dena Bank (40)	Jammu & Kashmir Bank (27)	State Bank of Hyderabad (14)	
ING Vysya Bank (39)	Karnataka Bank (26)		

Note: The figures in parentheses are respective ranks of inefficient banks.

Source: Authors' elaboration

Some discussion on the banks in the categories I and IV is warranted here. This is worth mentioning here that the banks in category IV are operating with a high level of OTE and, thus, can be categorized as *marginally inefficient* banks. These banks can attain the status of globally efficient banks by bringing little improvement in their resource allocation process. Putting it differently, we can say that although these banks are not fully technically efficient yet they are the perspective candidates for the status of global leaders because of their vitality in the terms of input utilization. To achieve high level of total factor productivity (TFP) growth, these banks need to rely more upon the technological change because the resource utilization process of these banks is up to the mark and, thus, efficiency change would be negligible in these banks and would not contribute much to TFP growth. On the other hand, the banks in category I are the *worst performers* in the sample. These banks need to concentrate more upon minimizing the waste of resources given the existing technology rather than the deepening of technology so as to achieve high level of TFP growth in the future[12].

5.3 Returns-to-scale

One of the most significant features of DEA is its capacity to determine whether a DMU is operating in the region of CRS, IRS, or DRS. A DMU exhibiting CRS have optimum or most productive scale size (MPSS), and operates at flatter portion of long-run average cost curve. On the other hand, a DMU exhibits DRS when a percentage increase in inputs produces a less than proportional expansion of outputs. The DMUs experiencing DRS lie above the optimal scale of operations (i.e., at the rising portion of long-run average cost curve) and would improve their efficiency by downsizing their scale of operations (e.g., by splitting into two or more production units that operate under CRS). Further, a DMU exhibits IRS when a percentage increase in inputs produces a more than proportional expansion of outputs. The DMUs experiencing IRS lies below the optimal scale of operations (i.e., at the declining portion of long-run average cost curve) and would improve their efficiency by expanding the size of their scale of operations. As noted above, the existence of increasing or decreasing returns-to-scale can be identified by the equality or inequality of the efficiency scores under CRS, VRS and NIRS assumptions. Table 1 also provides the nature of RTS for individual banks. We note here that 20 (i.e., 39.2 percent) banks in the sample are operating at below their optimal scale size and, thus, experiencing IRS. These banks have sub-optimal scale size and increase in average productivity in these banks would require an expansion in terms of size. In contrast, 22 (i.e., 43.1 percent) banks experience DRS. These banks have supra-optimal scale size and downsizing is needed for achieving efficiency gains. Further, only 9 (i.e., 17.6 percent) banks are found to be operating at MPSS and experiencing CRS.

5.4 Ownership and efficiency differences

Table 5 provides the descriptive statistics of OTE, PTE and SE scores for both public and private sector banks. It has been observed that mean OTE for 28 PSBs is equal to 0.774, whereas the same for 23 private sector banks is 0.814. This indicates that the private sector banks, on an average, are 4 percent more technically efficient in utilizing inputs than the public sector banks. Further, the variability in OTE has been observed to be almost same in both segments of Indian domestic banking industry. The perusal of the table further gives that, on an average, the extent of managerial efficiency as reflected by PTE score, is more in private sector banks relative to public sector banks. This is manifested from the fact that the values of mean PTE have been observed to be 0.817 and 0.855 for public and private sector banks, respectively. The results further provide that, on an average, both public and private sector banks have almost identical levels of scale efficiency.

Table 5 Descriptive statistics of efficiency measures in Indian banking industry by ownership groups and size classes

Statistics	Public Sector Banks	Private Sector Banks	Small banks	Medium banks	Large banks
Overall Technical Efficiency (OTE)					
No. of Banks	28	23	24	13	14
Mean	0.774	0.814	0.793	0.825	0.759
Median	0.805	0.801	0.786	0.849	0.795
Standard Deviation	0.152	0.157	0.156	0.153	0.161
Q_1	0.629	0.653	0.643	0.685	0.598
Q_3	0.895	1.000	0.945	0.961	0.878
Minimum	0.505	0.567	0.540	0.561	0.505
Maximum	1.000	1.000	1.000	1.000	1.000
Pure Technical Efficiency (PTE)					
No. of Banks	28	23	24	13	14
Mean	0.817	0.855	0.833	0.846	0.824
Median	0.852	0.874	0.852	0.896	0.831
Standard Deviation	0.161	0.147	0.154	0.155	0.172
Q_1	0.670	0.701	0.690	0.719	0.663
Q_3	0.971	1.000	1.000	0.990	1.000
Minimum	0.542	0.608	0.542	0.563	0.552
Maximum	1.000	1.000	1.000	1.000	1.000
Scale Efficiency (SE)					

No. of Banks	28	23	24	13	14
Mean	0.950	0.953	0.955	0.975	0.923
Median	0.984	0.980	0.982	0.995	0.922
Standard Deviation	0.054	0.080	0.078	0.035	0.060
Q_1	0.910	0.933	0.933	0.953	0.879
Q_3	0.995	1.000	0.998	0.997	0.989
Minimum	0.818	0.653	0.653	0.892	0.818
Maximum	1.000	1.000	1.000	1.000	1.000
Note: Q_1 =First Quartile and Q_3 =Third Quartile					
Source: Authors' calculations					

To test whether the efficiency differences between public and private sector banks are statistically significant or not, we applied four statistical tests, namely, Analysis of Variance (ANOVA), Wilcoxon Mann-Whitney test, Kruskal-Wallis test and Kolmogorov-Simrnov test. The ANOVA test is parametric in nature and assumes that the underlying distribution is normal and compares public and private sector banks on the basis of mean efficiency measures. Other tests are non-parametric in nature in which normality assumption is not invoked. The Mann-Whitney test compares the two sample distributions of efficiency on the basis of their central tendency, as measured by the median. The remaining two tests compare the entire structures of the distribution, not just the central tendency. The results pertaining to these tests are presented in Table 6.

Table 6 Hypothesis testing: efficiency differences between public and private sector banks

		Parametric test	**Non-parametric tests**		
Individual Tests		**ANOVA test**	**Wilcoxon Mann-Whitney test**	**Kruskal-Wallis test**	**Kolmogorov-Simrnov test**
H_o		$\text{Mean}_{\text{Public}} = \text{Mean}_{\text{Private}}$	$\text{Median}_{\text{Public}} = \text{Median}_{\text{Private}}$	$\text{Distribution}_{\text{Public}} = \text{Distribution}_{\text{Private}}$	
Efficiency Measures	**OTE**	0.482 (0.072)	1.200 (0.262)	1.477 (0.224)	0.284 (0.186)
	PTE	1.244 (0.606)	1.12 (0.230)	1.295 (0.255)	0.213 (0.500)
	SE	0.982 (0.954)	0.97 (0.327)	0.993 (0.319)	0.233 (0.417)
Decision		Accept H_o	Accept H_o	Accept H_o	Accept H_o

Notes: 1) The figures in parentheses are the *p*-values associated with the relative test, and 2) The test statistics for ANOVA , Wilcoxon Mann-Whitney, Kruskal Wallis, and Kolmogorov Simrnov Test are F, z, χ^2 and D.

Source: Authors' calculations

As can be seen from the table, the test statistics indicate that for all the efficiency measures, the respective null hypothesis cannot be rejected. This implies that the differences in distribution of efficiency measures between public and private sector banks are not significant. Thus, there are insignificant differences in mean levels of OTE, PTE and SE between public and private sector banking segments of Indian domestic banking industry. Accordingly, a weak ownership effect on the performance of banks exists in the Indian domestic banking industry. This could be attributable to the fact that there has been a change in the orientation of PSBs from social objectives towards an ascent in profitability, particularly given that some of these banks have been listed on the stock exchange and, thus, a stake of private investors is involved. Another factor that seems to have played a role is that PSBs enjoy a huge first-mover advantage in terms of scale of operations over private sector banks and these advantages perhaps offset any inefficiency that could be ascribed to the government ownership (Ram Mohan, 2005).

5.5 Size and efficiency differences

In order to get an answer of the question "Does size matter in Indian domestic banking industry?", we analyzed the efficiency differences among banks belonging to different size classes and their efficiency scores. We divided the entire sample of 51 banks into three distinct size classes depending upon the value of their total assets (TAs): (i) small banks, (ii) medium banks, and (iii) large banks. Small banks are defined as those banks whose TAs are less than the value of first quartile (Q_1) of TAs of the sample. Large banks have TAs greater than the value of third quartile (Q_3) of TAs of the sample. The remaining banks that are not classified as either large or small banks are defined as the medium banks. Table 5 also provides the descriptive statistics of various efficiency measures for the different size classes.

The perusal of table gives that the medium banks are technically more efficient than the small and large banks. This is evident from the fact that mean OTE score for medium banks is 0.825, for small banks is 0.793 and for large banks is 0.759. Further, the extent of managerial efficiency in medium banks is larger than those of small and large banks. The mean PTE score is equal to 0.846 for medium banks against 0.833 for small banks and 0.824 for large banks, bears a testimony of this fact. Further, the medium banks are more scale efficient than those of small and large banks. This is well reflected by the fact that mean SE score for the medium banks is 0.975 which is larger than 0.955 for small banks and 0.923 for large banks. On the whole, it seems that medium banks are more efficient than small and large banks in the Indian domestic banking industry.

To test whether the observed efficiency differences between banks belonging to different size classes are statistically significant or not, we again apply aforementioned parametric and non-parametric tests. Pair-wise comparisons of different efficiency measures are made and results are presented in Table 7. We noted that the efficiency differences in OTE and PTE scores are statistically insignificant among the banks belonging to different size classes. However, as far as SE measure is concerned, the differences seem to be significant, especially in case of large and medium banks. Further, the difference between large and small banks, and small and medium banks appears in a weak form.

Table 7 Hypothesis testing: efficiency differences across different size classes				
Pair-wise comparisons	**Test**	**OTE**	**PTE**	**SE**
Large vs. Small Banks	ANOVA test $\left(H_o\text{:Mean}_{Large}=\text{Mean}_{Small}\right)$	1.066 (0.861)[A]	1.26 (0.607)[A]	0.589 (0.324)[A]
	Wilcoxon Mann-Whitney test $\left(H_o\text{:Median}_{Large}=\text{Median}_{Small}\right)$	0.57 (0.54)[A]	0.11 (0.915)[A]	1.97 (0.05)[A]
	Kruskal Wallis test $\left(H_o\text{:Distribution}_{Large}=\text{Distribution}_{Small}\right)$	0.350 (0.554)[A]	0.015 (0.902)[A]	3.894 (0.048)[R]
	Kolmogorov Simrnov test $\left(H_o\text{:Distribution}_{Large}=\text{Distribution}_{Small}\right)$	0.19 (0.817)[A]	0.131 (0.976)[A]	0.423 (0.06)[A]
Large vs. Medium Banks	ANOVA test $\left(H_o\text{:Mean}_{Large}=\text{Mean}_{Medium}\right)$	1.106 (0.867)[A]	1.233 (0.724)[A]	0.34 (0.071)[A]
	Wilcoxon Mann-Whitney test $\left(H_o\text{:Median}_{Large}=\text{Median}_{Medium}\right)$	1.08 (0.273)[A]	0.22 (0.828)[A]	2.26 (0.023)[R]
	Kruskal Wallis test $\left(H_o\text{:Distribution}_{Large}=\text{Distribution}_{Medium}\right)$	1.249 (0.264)[A]	0.060 (0.807)[A]	5.112 (0.024)[R]
	Kolmogorov Simrnov test $\left(H_o\text{:Distribution}_{Large}=\text{Distribution}_{Medium}\right)$	0.319 (0.424)[A]	0.269 (0.548)[A]	0.489 (0.049)[R]
Small vs. Medium Banks	ANOVA test $\left(H_o\text{:Mean}_{Small}=\text{Mean}_{Medium}\right)$	1.037 (0.985)[A]	0.978 (0.923)[A]	4.989 (0.006)[R]
	Wilcoxon Mann-Whitney test $\left(H_o\text{:Median}_{Small}=\text{Median}_{Medium}\right)$	0.39 (0.69)[A]	0.06 (0.949)[A]	0.03 (0.762)[A]
	Kruskal Wallis test $\left(H_o\text{:Distribution}_{Small}=\text{Distribution}_{Medium}\right)$	0.172 (0.678)[A]	0.006 (0.936)[A]	0.102 (0.749)[A]
	Kolmogorov Simrnov test $\left(H_o\text{:Distribution}_{Small}=\text{Distribution}_{Medium}\right)$	0.192 (0.814)[A]	0.186 (0.819)[A]	0.234 (0.586)[A]

Notes: 1) The figures in the parentheses are the *p*-values associated with the respective test, 2) The test statistics for ANOVA , Wilcoxon Mann-Whitney, Kruskal Wallis, and Kolmogorov Simrnov Test are F, z, χ^2 and D, 3) The super-subscript 'A' implies that null hypothesis is accepted, 4) The super-subscript 'R' implies that null hypothesis is rejected.

Source: Authors' calculations

5.6 Sensitivity analysis

With the purpose to check the robustness of the efficiency results and the presence of extreme observations (outliers) in the sample, a post-DEA sensitivity analysis as put into operation by Kirjavainen and Loikkanen (1998), Kumar and Verma (2003), Mostafa (2007a, 2007b) and Kumar and Gulati (2008) has been conducted. The purpose of our DEA analysis is twofold, first to compute the efficiency scores for individual banks so as to quantify the potential for efficiency improvement and second, to identify those banks that define the *efficient frontier*. For this double-purpose, the simplest and probably most reasonable sensitivity analysis is to remove all the efficient banks one by one and study the effect of their removal on the mean OTE of the remaining 50 banks. An efficient bank may be considered as an outlier if its removal from the *efficient frontier* drastically changes the mean OTE of banking industry as a whole. Table 8 presents the results of sensitivity analysis.

Table 8 Results of sensitivity analysis

Bank removed from the analysis	Average of OTE scores	Number of efficient banks	New bank in the reference set
State Bank of Bikaner and Jaipur	0.791	9	State Bank of Mysore
Andhra Bank	0.790	8	None
Nainital Bank	0.791	8	None
Tamilnad Mercantile Bank	0.795	8	None
Centurian Bank of Punjab	0.789	8	None
HDFC Bank	0.815	8	None
ICICI Bank	0.800	10	UTI Bank, IDBI Bank
Kotak Mahindra Bank	0.789	8	None
Yes Bank	0.790	9	State Bank of Mysore

Source: Authors' calculations

Recall that 9 banks defined the *efficient frontier* and the mean OTE of the 51 sampled banks turned out to be 0.792 (see Table 2). Our sensitivity analysis gives 9 distinct cases which emerged by removing the efficient banks one by one from the sample. From these cases, we observed that none of the bank on the *efficient frontier* is extreme in the sense that its exclusion from the analysis did not bring any significant and drastic change in the mean OTE of Indian domestic banking industry. This is evident from the fact that the values of mean OTE obtained by removing the efficient banks one by one from the sample ranged between 0.789 and 0.815, and are very close to 0.792 (the mean OTE value of the original DEA analysis). Further, in 6 cases, we note no change in the reference set for inefficient banks. Thus, it can be safely inferred that the results of the present study are quite robust to discriminate between efficient and inefficient banks belonging to Indian domestic banking sector.

5.7 Determinants of overall technical efficiency

Finally, in order to investigate the possible determinants of OTE, we carried out a post-DEA regression analysis. As stressed by Mester (1996), the findings of this analysis are intended mainly to indicate where banks might look for clues towards increasing their efficiency. In the present study, our post-DEA regression analysis aims to explain the variations in calculated OTE scores to a set of explanatory variables like bank's size, market share, loan quality, profitability, staff productivity, ownership, etc. For this purpose, we utilized the multivariate Tobit analysis to explain the determinants of OTE scores (see Appendix 1 for details on Tobit analysis). Note that this is an appropriate method since the dependent variable, the calculated OTE score from the CCR model, falls between the interval 0 and 1 (i.e., $0<\text{OTE}\leq 1$) and, thus, censored at 1. It is significant to note that a simple application of OLS estimation procedure may produce biased estimates if there is a significant position of the observations equal to 1 (Resende, 2000). Some of the notable studies that applied the Tobit analysis for explaining the inter-bank variations in efficiency include Jackson and Fethi (2000), Kumar and Verma (2003), Grigorian and Manole (2006), Hu *et al.*(2006), Pasiouras *et al*. (2007), Sufian and Majid (2007), Pasiouras (2008), among others. Table 9 provides the description and expected signs of the predictors included in the regression analysis.

Table 9 Description and expected sign of the predictors			
Predictor	**Symbol**	**Description**	**Expected Sign**
1) Size	*SIZE*	log(Total Assets)	±
2) Profitability	*ROA*	$\frac{\text{Net Profit}}{\text{Total Assets}}$	+
3) Market Share in Deposits	*MS*	$\frac{\text{Deposit of } i\text{-th Bank}}{\text{Total Deposits of 27 PSBs}} \times 100$	+
4) Loan Quality	*LQ*	$\frac{\text{Net NPA}}{\text{Net Advances}}$	–
5) Staff Productivity	*SP*	$\frac{\text{Business (i.e., Deposits + Advances)}}{\text{Staff}}$	+
6) Exposures to Off- balance Sheet Activities	*OFFBALANCE*	$\frac{\text{Non-interest Income}}{\text{Total Assets}} \times 100$	+
7) Advances to Priority Sector	*PRIORITY*	$\frac{\text{Priority Sector Advances}}{\text{Total Advances}} \times 100$	–
8) Capital Adequacy	*CRAR*	$\frac{\text{Tier I Capital + Tier II Capital}}{\text{Risk Weighted Assets}} \times 100$	±
9) Ownership	*OWNER*	Dummy variable taking value 1 for PSBs and 0 for private banks	±
Source: Authors' elaboration			

In the present context, we estimated the following left-censored Tobit regression:

$$OTIE_i = (1 - OTE_i) = \beta_0 + \beta_1 SIZE_i + \beta_2 ROA_i + \beta_3 MS_i + \beta_4 LQ_i + \beta_5 SP_i + \beta_6 OFFBALANCE_i + \beta_7 PRIORITY_i + \beta_8 CRAR_i + \beta_9 OWNER_i + \varepsilon_i$$

It is important to note that dependent variable in above model is the overall technical inefficiency (OTIE) which was obtained by transforming DEA efficiency scores. This is exactly what has been done by Kirjavainen and Loikkanen(1998), Loikkanen and Susiluoto (2002), and Kamruzzaman *et al*.(2006). Therefore, we explain 'inefficiency' rather than efficiency in above model. Thus, the sign of the regression coefficients are required to be reversed for explaining efficiency- a *positive* coefficient implies an *inefficiency* increase whereas a *negative* coefficient means an association with *inefficiency* decline or increased efficiency. In this paper, we use the econometric software package Eviews Version 5.1 to estimate the parameters of the above regression equation by the method of maximum likelihood.

The preliminary estimates of the model suggest that the results are quite sensitive to the inclusion and exclusion of the specific explanatory variables. This is not surprising in the light of the high degree of correlation between many of the regressors to be included. Although there has been a considerable attention given to pre-testing procedures in applied econometrics, no clear guidelines exist with respect to selecting variables for inclusion in a 'final' model. Accordingly, separate versions of the model are reported to avoid some of the difficulties associated with a potentially severe multi-collinearity problem. It should be emphasized that the final model has been selected on the basis of a two considerations: i) the statistical significance of regression coefficients, and ii) an agreement of signs of regression coefficients with *a priori* expectations.

Various specifications of the model were tested because of the likelihood of multi-collinearity (see Table 10). The following observations have been made (i) the coefficients of non-binary explanatory variables *SIZE*, *MS*, *SP* and *CRAR* were statistically insignificant in all the regression equations in which they were included. However, the variable *PRIORITY* was observed to be statistically significant in only one instance, (ii) the binary variable *OWNER* which takes value equal to 1 for public sector banks and 0 otherwise has statistically insignificant coefficients in the specifications 1.10, 1.11 and 1.13. This suggests that, in the current environment of Indian banking industry, the commercial banks whether public or private operate on a commercial basis rather than on the basis of non-economical and political objectives. This confirms our earlier findings that ownership does not have a strong link with the efficiency of banks in the Indian domestic banking industry.

The most influential determinant of OTE has noted to be *OFFBALANCE*. It has statistically significant coefficient and sign in consonance with *a priori* expectations in all the cases in which it has been included. This suggests that the banks with extensive exposure to off-balance sheet activities are more efficient. Out of 14 model specifications, we considered the specification 1.14 as the most preferred specification because the coefficient of the explanatory variables in this specification have expected signs and are also statistically significant. This specification includes *ROA* and *OFFBALANCE* as most influential factors explaining the overall technical efficiency of Indian domestic banks.

Table 10 Results of Tobit analysis

Dependent variable: *OTIE score*

	Independent variables										
Model Specification	**Constant**	*SIZE*	*ROA*	*MS*	*LQ*	*SP*	*OFFBALANCE*	*PRIORITY*	*CRAR*	*OWNER*	**Log-likelihood function**	**R^2**
1.1	0.2652 (1.586)	-0.0056 (-0.345)	×	×	×	×	×	×	×	×	23.13	0.002
1.2	0.4343* (6.36)	×	-0.2557* (-3.707)	×	×	×	×	×	×	×	8.47	0.229
1.3	0.1978* (6.226)	×		-0.0032 (-0.342)	×	×	×	×	×	×	2.26	0.003
1.4	0.094** (1.987)	×	×	×	0.0998* (2.431)	×	×	×	×	×	5.02	0.113
1.5	0.2407* (3.575)	×	×	×	×	-9.69E-05 (-0.788)	×	×	×	×	2.51	0.015
1.6	0.4278* (7.193)	×	×	×	×	×	-0.2223* (-4.106)	×	×	×	11.03	0.214
1.7	0.3459* (2.425)	×	×	×	×	×	×	-0.0043 (-1.097)	×	×	2.80	0.014
1.8	0.2301* (2.358)	×	×	×	×	×	×	×	-0.0029 (-0.409)	×	2.28	0.003
1.9	0.7616** (2.465)	0.0156 (0.614)	-0.0846 (-0.934)	-0.0120 (-1.086)	0.0616 (1.270)	-0.0001 (-1.126)	-0.2053* (-4.011)	-0.0077** (-1.974)	-0.0094 (-1.486)	×	18.82	0.441
1.10	0.7493** (2.124)	0.0174 (0.489)	-0.0861 (-0.924)	-0.0123 (-1.058)	0.061 (1.206)	-0.00015 (-1.104)	-0.2065* (-3.805)	-0.0077 (-1.958)	-0.0093 (-1.437)	-0.0048 (-0.071)	18.82	0.440
1.11	0.4814* (3.617)	×	-0.1374 (-1.495)	×	0.0413 (0.815)	×	-0.1891* (-3.558)	×	×	0.0032 (0.075)	15.65	0.362
1.12	0.4853* (3.971)	×	-0.1379 (-1.505)	×	0.0407 (0.813)	×	-0.1901* (-3.699)	×	×	×	15.65	0.362
1.13	0.5683* (7.006)	×	-0.1924* (-3.039)	×	×	×	-0.1811* (-3.483)	×	×	-0.00182 (-0.042)	15.32	0.350
1.14	0.5667* (7.874)	×	-0.1926* (-3.045)	×	×	×	-0.1805* (-3.628)	×	×		15.32	0.351

Notes: (i) *, **, and *** indicates that value is statistically significant at 1 percent, 5 percent and 10 percent level of significance, respectively; and (ii) '×' shows that the explanatory variable is not considered in the particular specification.

Source: Authors' calculations

6 Conclusions and future research

The objective of this paper is to evaluate the extent of technical (in)efficiency and its determinants in Indian domestic banking industry. Also, the strict ranking of the efficient domestic banks, on the basis of *super-efficiency* scores, is sought. The overall technical efficiency (OTE), pure technical efficiency (PTE), and scale efficiency (SE) scores for 51 domestic banks operating in the financial year 2006/07 have been computed by using two generic DEA models, namely, CCR and BCC models. The results show that OTE scores range between 0.505 and 1, with an average of 0.792. Thus, the level of overall technical inefficiency (OTIE) in Indian domestic banking industry is to the tune of about 21.8 percent. Out of the 9 efficient banks defining the *efficient frontier* of Indian domestic banking industry, 5 banks are *de nova* private sector banks. This highlights that *de nova* private sector banks armed with the state-of-the-art banking technology dominates in the formation of *efficient frontier* of Indian domestic banking industry. Further, managerial inefficiency (as reflected by pure technical inefficiency (PTIE)) is a more dominant source of OTIE, and scale inefficiency (SIE) is a diminutive one. The analysis of *super-efficiency* scores highlights that ICICI Bank is numero uno bank of Indian domestic banking industry, which followed closely by Yes Bank and HDFC Bank.

The results relating to returns-to-scale indicate that 39.2 percent banks in the sample are operating at below their optimal scale size and, thus, experiencing increasing returns-to-scale. These banks have sub-optimal scale size, and an increase in average productivity in these banks would require an expansion in terms of size. In contrast, 43.1 percent banks experience decreasing returns-to-scale. These banks have supra-optimal scale size, and a downsizing is needed for achieving efficiency gains. Further, only 17.6 percent banks are found to be operating at most productive scale size and experiencing constant returns-to-scale.

Our study reports a weak ownership effect on the performance of banks since the efficiency differences between public and private sector banks are not statistically significant. A change in the orientation of PSBs from social objectives towards an ascent on profitability may be the main cause of observed weak ownership effect. We also note that the differences in overall technical and pure technical efficiencies are statistically insignificant among the banks belonging to different size classes. However, some statistically significant differences among large and medium banks, with regard to scale efficiency, have been noted. The results of Tobit analysis reveal that (i) the exposure to off-balance sheet activities is the most influential determinant of overall technical efficiency; and (ii) the profitability has a strong link with the overall technical efficiency of banks.

The future research could extend our work in various directions which are not considered in this study. Using data over a longer period, one may analyze the inter-temporal variations in technical efficiency of individual banks, and one could measure the total factor productivity (TFP) growth in Indian domestic banking industry and decompose it into technical efficiency change and technological progress components using DEA-based Malmquist Productivity Index (MPI). We can also explore efficiency differences between domestic and foreign banks using meta-frontier approach. This would enrich the existing literature on the efficiency of Indian banking industry since all the existing studies estimated a common frontier for obtaining the efficiency estimates for domestic and foreign banks. Nevertheless, the assumption of common frontier is economically irrational and absurd one given that the banks in both segments of Indian banking industry operate under different technological and business environments.

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Notes

1. In the entire study, the terms 'technical efficiency' and 'overall technical efficiency' have been used interchangeably.
2. DMUs are usually defined as entities responsible for turning input(s) into output(s), such as firms and production units. In the present study, DMUs refer to the banks. A DMU must, as the name indicates, have at least some degree of freedom in setting behavioural goals and choosing how to achieve them.
3. Given that DEA is an efficient frontier technique where outliers can substantially influence the scores of other banks, we follow Avkiran's (2006) rule of thumb where bank(s) with *super-efficiency* score of 2 or above is (are) treated as potential outlier(s). We dropped two private sector banks from our initial sample of 53 banks because they emerged as outliers with super efficiency scores above 2.
4. The input variable 'physical capital' represents the book value of premises and fixed assets net of depreciation.
5. The input variable 'labour' is measured as full-time staff in the categories of officers, clerks and sub-ordinates.
6. The input variable loanable funds is obtained by adding both deposits and borrowings.
7. The output variable 'net-interest income' is also known as 'interest spread' and is computed by subtracting 'interest expenses' from 'interest income'.
8. The output variable 'non-interest income' accounts for income from off-balance sheet items such as commission, exchange and brokerage, etc.

9. OTIE= (1-TE)×100
10. PTIE=(1-PTE)×100
11. SIE=(1-SE)×100
12. The contemporary literature on measurement of TFP growth recognizes that TFP growth stems from two mutually exclusive sources, namely, technical efficiency change and technological progress. For more details, please refer the work of Fare *et al.* (1994) and Mahadevan (2004).