ISSN 1518-3548

BANCO CENTRAL DO BRASIL

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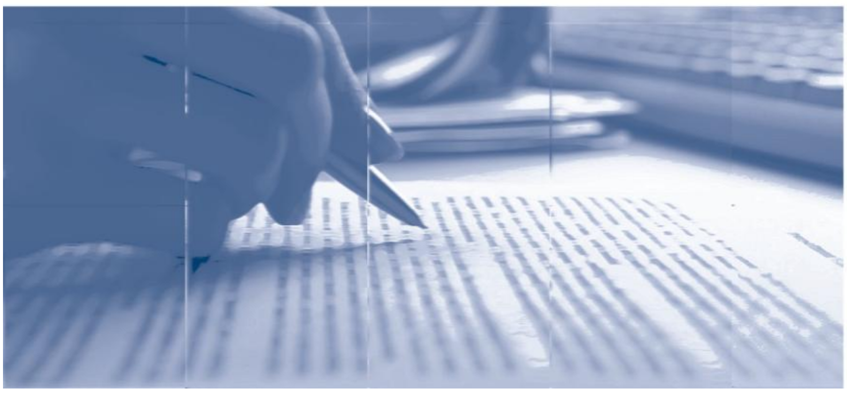
March, 2014

Working Papers



350

ISSN 1518-3548
CGC 00.038.166/0001-05

Working Paper Series	Brasília	n. 350	March	2014	p. 1-19

Working Paper Series

Edited by Research Department (Depep) – E-mail: workingpaper@bcb.gov.br

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The Adequacy of Deterministic and Parametric Frontiers to Analyze the Efficiency of Indian Commercial Banks*

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Abstract

The Working Papers should not be reported as representing the views of the Banco Central do Brasil. The views expressed in the papers are those of the author(s) and not necessarily reflect those of the Banco Central do Brasil.

This study applies data envelopment analysis (DEA) and stochastic frontier approach (SFA) to a sample of Indian commercial banks to discuss the inconsistencies between these models. We find that DEA average efficiency scores are, in general, lower than those from the SFA model. However, both models indicate similar trends on efficiency scores over the years, which we state is more relevant than efficiency levels themselves. We also find that the rank correlation between these efficiency scores is low. This means that the application of only one frontier model may lead to misleading conclusions. We point out that a thorough consideration of the suitability of a deterministic or a parametric frontier to the framework in analysis should guide the choice between the application of parametric or non-parametric methodologies.

Keywords: bank efficiency; stochastic frontier approach; data envelopment analysis.

JEL Classification: G21, G28

*The authors are grateful to financial support from CNPQ foundation.

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1 Introduction

We discuss the adequacy of parametric and non-parametric methodologies in the study of efficiency of financial institutions. To do so, we investigate the consistency between data envelopment analysis (DEA) and stochastic frontier approach (SFA). We apply both methodologies to a sample of Indian banks and point out the inconsistencies between their results.

The comparison of empirical results produced by DEA and SFA is still uncommon in bank efficiency literature. To analyze individual results given by each methodology, we follow Bauer et al. (1998) and compute the rank correlation between their scores. Some studies find inconsistency between DEA and SFA at individual level (Fiorentino et al., 2006; Ferrier and Lovell, 1990). Other studies analyze consistency at industry level and find that the application of these methodologies does lead to similar results (Resti, 1997). Koetter and Meesters (2013) also point out that cost efficiency measures differ depending on the employed technique and suggest the use of multiple benchmarking methods. We investigate to which extent these models are coherent by analyzing their results from individual and general perspectives. We use these results to discuss the adequacy of the theoretical assumptions of these models, more specifically the consideration or not of states of nature in the construction of the frontier, to the context of banking systems.

Studies on the efficiency of Indian banks usually assess the impact of the financial liberalization reform on the performance of these institutions. This reform started in 1991-1992 with the aim of creating a more profitable, efficient and resilient banking system. It did not involve large scale privatization, it only involved the increase in capitalization through diversification of ownership up to 49% to private investors (Ray and Das, 2010). Many of these studies find that state-owned banks are more efficient than private and foreign banks (Bhattacharyya and Pal, 2013; Sharma et al., 2012; Tabak and Tecles, 2010). De (2004) and Debasish (2006) find that foreign banks are actually the most efficient. Some also conclude that the effects of the deregulation reform on efficiency of Indian banks are positive (Ataullah et al., 2004). Other studies, on the other hand, find no clear evidence of improvement on performance after the liberalization reform (Bhattacharyya and Pal, 2013; Ray and Das, 2010). Thus, it is still unclear if this reform brought long lasting efficiency gains to the Indian banking industry. The empirical study of the efficiency of the Indian banking system is not exactly our focus here. It is actually an illustration to the point we aim to make regarding the reliability of efficiency results obtained from the application of only one frontier model.

Thus, our contribution is that we put into discussion the adequacy of parametric and non-parametric models to the determination of efficiency, considering the empirical application to the Indian banking sytem. We introduce this discussion by pointing out the consistencies or inconsistencies between data envelopment analysis and stochastic frontier approach. We study to which extent we can rely on empirical evidence produced by the application of only one of these models. We propose a discussion on the importance (or not) of separating random error from inefficiency in the banking context. This separation is considered a feature of the stochastic frontier model, which disentangles the regression residual into inefficiency and random noise (Berger and Humphrey, 1997). However, it comes with the costs of specifying a specific cost or profit function and a distribution to the inefficiency term.

2 Methodology and Data

Data envelopment analysis and stochastic frontier approach involve the efficiency framework proposed by Farrell (1957) on his seminal paper. He introduced the possibility of inefficiency pointing directly to a frontier production function concept as benchmark, instead of average performance, as previously dominant in literature.

Comparing the empirical results found in the application of these methodologies should not be unusual, since the theoretical framework behind each of them is not equivalent. The DEA model builds a deterministic frontier that outlines the position of the firms ruled out as efficient in a given sample. The frontier built by the SFA model, on the other hand, is not deterministic, and considers the state of nature that as influence over firms' performance at a given period.

The main difference between data envelopment analysis and stochastic frontier approach is that the first is non-parametric, while the latter is a parametric methodology. This implies that DEA does not require prior knowledge on the production function related to the industry in study, neither on the distribution of the inefficiency term. However, this comes with the cost that non-parametric models do not account for random shocks, which is one of the features of the SFA model (Berger and Humphrey, 1997; Seiford and Thrall, 1990; Mester, 1996).

To compare data envelopment analysis and stochastic frontier approach, it is important to ensure that the same efficiency concept is involved (Bauer et al., 1998). For this reason, we refer to economic efficiency to analyze the consistency between these methodologies.

2.1 Data Envelopment Analysis

Data envelopment analysis, which was proposed by Charnes et al. (1978), consists of a specific linear programming model designed for the measurement of efficiency. It builds a non-parametric frontier comprising the practices of the most efficient firms in the sample. In this framework, firms maximize the weighted output-input ratio.

An intuitive way of introducing DEA mathematically is by measuring the inputs over outputs ratio:

$$\frac{u'q_i}{v'x_i} \tag{1}$$

in which υ is a weighting vector of outputs, ν is a weighting vector of inputs, q_i and x_i are output and input vectors, respectively.

The optimal values of υ and ν, after transforming the fractional programming problem into a linear programming one, can be found by the following program:

$$\begin{aligned} & \max_{\upsilon,\nu} \upsilon' q_i \\ \text{s.a} \quad & \nu' x_i = 1 \\ & \upsilon' q_j - \nu' x_j \leq 0 \;\; j = 1, \ldots, m. \\ & \upsilon \geq 0 \\ & \nu \geq 0 \end{aligned} \tag{2}$$

In practice, this problem is easily solved by its dual, which is given by:

$$\begin{aligned} & \min_{\theta,z} \theta \\ \text{s.a} \quad & -q_i + Q\lambda_j \geq 0 \\ & w x_i - X\lambda_j \geq 0 \\ & \lambda_i \geq 0 \end{aligned} \tag{3}$$

in which θ is technical efficiency, λ is a vector of weights and Q and X are output and input matrices, respectively. The program above consists of the original constant returns to scale DEA model proposed by Charnes et al. (1978).

In this study, we estimate the model proposed by Banker et al. (1984), which allows for variable returns to scale. The input-oriented version of the model can be written as:

$$\begin{aligned} & \min_{\phi,z} \phi \\ \text{s.a} \quad & -q_i + Q\lambda_j \geq 0 \\ & \phi x_i - X\lambda_j \geq 0 \\ & \textstyle\sum_{i=1}^{n} \lambda_i = 1 \\ & \lambda_i \geq 0 \end{aligned} \tag{4}$$

in which ϕ is technical inefficiency, q_i are the outputs for firm i, Q and X are matrices of outputs and inputs for all firms, respectively, x_i is the vector of inputs for the i-th firm and λ_i is a vector of weights.

Allocative efficiency measures the adequacy of the mix of inputs chosen by the firm to produce outputs. It can be measured by a cost minimization problem that determines the optimal levels of inputs to be used given their prices (w_i):

$$\min_{w_i,\chi} w_i'\chi_i$$
$$\text{s.a} \quad \sum_j \lambda_j y_j - y_i \geq 0$$
$$\chi_i - \sum \lambda_j x_j \geq 0$$
$$\lambda_j \geq 0 \tag{5}$$
$$\sum_i \lambda_i = 1 \tag{6}$$

Economic efficiency (EE) analyzes both technical and allocative efficiencies (Bauer et al., 1998) and will be determined by the following ratio:

$$EE_i = \frac{w_i\chi_i}{w_i'x_i} \tag{7}$$

2.2 Stochastic Frontier Approach

The stochastic frontier approach was proposed by Meeusen and Van den Broek (1977) and Aigner et al. (1977). It designs a parametric frontier from a standard cost or profit function. This frontier represents the best possible practices achievable by the firms in the sample. We use a cost function, since it is a more common application in bank efficiency literature (Berger and Mester, 1997).

Our application of the SFA model consists of the estimation of a translog cost function, which has the feature of being a flexible functional form (Berger et al., 2009; Lozano-Vivas and Pasiouras, 2010). The inefficiency term υ_{it} follows a truncated-normal distribution, while random error ν_{it} follows a normal distribution.

The fixed effects cost function is written as follows:

$$\begin{aligned} ln(CT/w_2z) = \quad & \delta_0 \quad + \sum_j \delta_j ln(y_j/z)_{it} + \frac{1}{2}\sum_j\sum_k \delta_{jk} ln(y_j/z)_{it} ln(y_k/z)_{it} \\ + \quad & \beta_1 ln(w_1/w_2)_{it} + \frac{1}{2}\beta_{11} ln(w_1/w_2)_{it} ln(w_1/w_2)_{it} \\ + \quad & \sum_j \theta_j ln(y_j/z)_{it} ln(w_1/w_2)_{it} \\ + \quad & ln\upsilon_{it} + ln\nu_{it}. \end{aligned} \tag{8}$$

in which CT is the firm's total costs. i and t stand for bank and time, respectively. In the true fixed effects model, the inefficiency term, υ_{it}, is composed by a set of dummy variables, which determine its behavior across time. This study considers three outputs and two inputs. Thus, w_1 and w_2 are the prices of the two inputs used to produce the three outputs, y_j. The normalization by the price of the last input (w_2) guarantees price homogeneity and the normalization by bank's total assets reduces heteroscedasticity (Berger et al., 2009).

Besides controlling for heteroscedasticity, we are also interested in controlling for unobserved heterogeneity across firms. Farsi et al. (2006) point out the influence unobserved heterogeneity may have over the results obtained from efficiency estimation. They find inconsistencies from efficiency measures produced by frontier models that do not consider unobserved heterogeneity and those that do. Therefore, we estimate the 'true' fixed effects model from Greene (2005), which, besides being a model designed to account for unobserved heterogeneity, has the features of allowing for the inefficiency term to vary freely over time and for the heterogeneity term to be correlated with the included variables.

2.3 Data

The sample we use consists of an unbalanced panel with 622 observations from 60 Indian commercial banks. These observations refer to the period 1998-2012 and the data source is Bankscope. We follow the intermediation approach on the choice of inputs and outputs, which states that banks use funds, capital and labor to offer loans and other assets (Sealey and Lindley, 1977). Therefore, we use deposits, loans and liquid assets as outputs. We specify input quantities as total interest expenses and total non-interest expenses. Input prices are the ratios total interest expenses over deposits and total non-interest expenses over total assets. We report descriptive statistics of these variables on Table 1.

3 Results

Bank efficiency in India does not show signs of improvement over the years. This indicates that, if the interest is on the behavior of efficiency scores, the application of only one frontier model should not lead to misleading results. However, if the intention is to determine the size of the efficiency gap firms face or to compare the performance of individual firms, the analysis should be considered with care.

Tables 2 and 3 show the yearly average efficiency scores for the Indian banking system in the period 1998-2012. At first sight, these scores seem to point out that this market has experienced periods of efficiency gains and others of drawbacks. However, figures 1 and 2 show that a closer look into average scores and their volatility indicates that the variation of these scores are inconclusive, since they are not statistically significant. This

Table 1: Descriptive statistics on variables used for efficiency measurement

Year		Loans	Deposits	Liquid Assets	Total Assets	Total Expenses	Total interest expenses	Total non-interest expenses	w_1*	w_2**
1998	Mean	650769	1351325	242513.4	1665855	133948.6	97956.16	35992.44	0.085	0.026
	SD	571756.5	1239737	250903.9	1443803	107814.9	77228.34	34062.63	0.028	0.030
	N	25	25	25	25	25	25	25	25	25
1999	Mean	818789	1667869	258229	2109009	191875.6	139282.4	52593.18	0.087	0.033
	SD	658234.4	1412535	236852.2	1680550	153198.7	109861.5	46261.43	0.012	0.052
	N	28	28	28	28	28	28	28	28	28
2000	Mean	847504.8	1639574	264310.1	2133643	182172	129190.8	52981.23	0.084	0.038
	SD	764756.1	1530549	230461.8	1819913	170096.6	120279.3	52479.08	0.032	0.064
	N	30	30	30	30	30	30	30	30	30
2001	Mean	2427420	4265546	734514.1	5918660	444796.3	326985.9	117810.4	0.118	0.034
	SD	5758001	1.13E+07	2508889	1.54E+07	1224666	896279.8	329902.9	0.167	0.055
	N	36	36	36	36	36	36	36	36	36
2002	Mean	3319840	5843508	659654.8	7645210	570814.4	406798.3	164016.1	0.079	0.021
	SD	6478905	1.24E+07	1742010	1.65E+07	1274549	918601.2	358115.3	0.092	0.009
	N	41	41	41	41	41	41	41	41	41
2003	Mean	3967592	6906220	794260.6	9021723	577368.9	382465.8	194903.1	0.091	0.026
	SD	7945888	1.46E+07	1829597	1.92E+07	1342483	897319.4	449424	0.156	0.039
	N	45	45	45	45	45	45	45	45	45
2004	Mean	5664008	8929046	983152	1.16E+07	673539.7	441248.1	232291.6	0.060	0.024
	SD	1.07E+07	1.78E+07	1883700	2.31E+07	1461150	913141.1	565917.7	0.082	0.027
	N	40	40	40	40	40	40	40	40	40
2005	Mean	6692139	9392462	1121870	1.23E+07	708513.1	437152	271361.2	0.062	0.020
	SD	1.32E+07	1.82E+07	2093853	2.44E+07	1615757	975195.8	659183.8	0.084	0.008
	N	46	46	46	46	46	46	46	46	46
2006	Mean	8692163	1.14E+07	1476371	1.52E+07	950417.5	583796.2	366621.3	0.052	0.022
	SD	1.72E+07	2.16E+07	2713313	2.92E+07	2068062	1240276	855273.5	0.025	0.012
	N	49	49	49	49	49	49	49	49	49
2007	Mean	1.17E+07	1.51E+07	1636922	2.05E+07	1394988	927708.3	467279.3	0.082	0.019
	SD	2.26E+07	2.80E+07	2016927	3.91E+07	3049754	1891553	1235543	0.133	0.015
	N	51	51	51	51	51	51	51	51	51
2008	Mean	1.13E+07	1.46E+07	1491941	1.96E+07	1317241	978999	338241.6	0.104	0.017
	SD	2.18E+07	2.80E+07	2038309	3.78E+07	2614185	1848971	790019.4	0.146	0.014
	N	51	51	51	51	51	51	51	51	51
2009	Mean	1.52E+07	1.95E+07	1918486	2.62E+07	1678954	1164263	514690.4	0.068	0.016
	SD	2.85E+07	3.55E+07	2467776	4.81E+07	3523019	2192605	1362611	0.061	0.015
	N	49	49	49	49	49	49	49	49	49
2010	Mean	1.91E+07	2.39E+07	2926984	3.22E+07	1942604	1292251	650353	0.075	0.022
	SD	3.40E+07	4.14E+07	5393783	5.62E+07	3794491	2303492	1521013	0.108	0.025
	N	48	48	48	48	48	48	48	48	48
2011	Mean	2.05E+07	2.49E+07	2253210	3.39E+07	2305974	1678988	626986.3	0.066	0.017
	SD	3.50E+07	4.15E+07	2869978	5.58E+07	4060833	2725071	1375482	0.025	0.009
	N	46	46	46	46	46	46	46	46	46
2012	Mean	2.68E+07	3.19E+07	2850180	4.33E+07	3094995	2309571	785424.7	0.076	0.016
	SD	4.24E+07	4.84E+07	3673042	6.61E+07	4867736	3268083	1642194	0.018	0.010
	N	37	37	37	37	37	37	37	37	37

*Ratio total interest expenses over deposits

**Ratio total non-interest expenses over total assets

Table 2: DEA economic efficiency scores

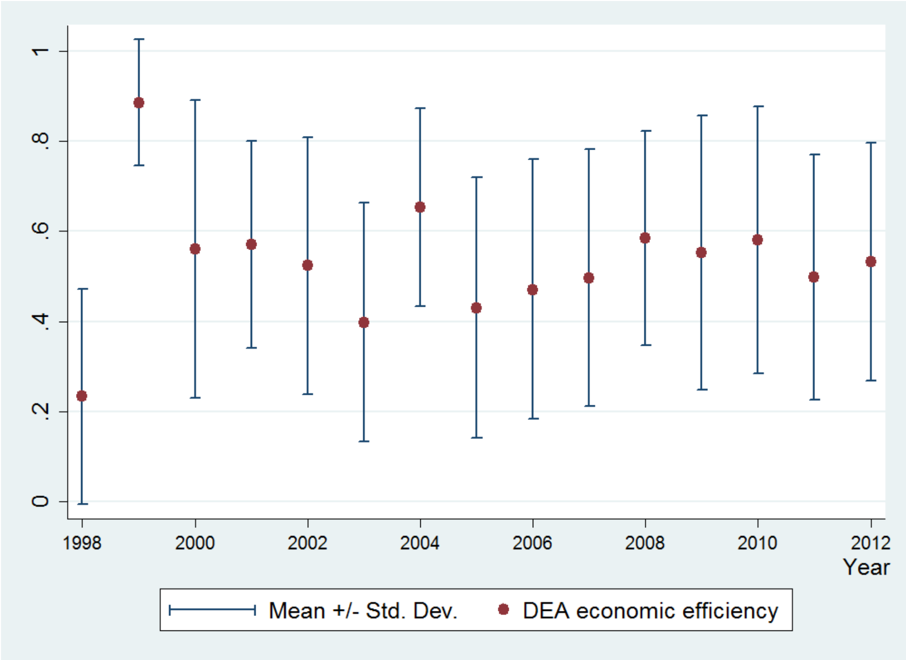
Year	Obs.	Mean	Std. Dev.	Min	Max
1998	25	0.2328255	0.2389044	0.0903041	1
1999	28	0.8854527	0.1396717	0.313264	1
2000	30	0.560	0.330	0.109	1
2001	36	0.570	0.230	0.112	1
2002	41	0.523	0.285	0.039	1
2003	45	0.397434	0.2652112	0.0228417	1
2004	40	0.6532004	0.2200286	0.0647184	1
2005	46	0.4302451	0.2899446	0.0166588	1
2006	49	0.4705817	0.2883156	0.113266	1
2007	51	0.4963352	0.28522	0.116857	1
2008	51	0.5843869	0.2380966	0.153541	1
2009	49	0.5519723	0.3042412	0.0701847	1
2010	48	0.5812726	0.2963175	0.09215	1
2011	46	0.4979057	0.2724351	0.0694541	1
2012	37	0.5320542	0.2646806	0.0396014	1

means that results produced by both data envelopment analysis and stochastic frontier approach suggest Indian banks have operated in the same level of economic efficiency over the period we consider. This is consistent with the findings of Fujii et al. (2014), who report that there is no confirmation of a trend of efficiency gains over the period 2000-2010. Some studies find that financial liberalization reforms had a positive initial impact on bank efficiency with a posterior drawback on performance (Bhattacharyya and Pal, 2013; Das et al., 2005; Zhao et al., 2010). Bhattacharyya and Pal (2013), for instance, find that this drawback takes place on the period 1998-2009, which is in part the period considered here. Since this drawback is relative to the pre-reform period, these findings do not necessarily contradict the results we report in this paper. Thus, our evidence indicate that, even though financial reforms may have had effects on bank efficiency, these effects dissipated before the period we analyze in this paper.

Table 3: SFA cost efficiency scores

Year	Obs.	Mean	Std. Dev.	Min	Max
1998	25	0.949	0.068	0.808	1
1999	28	0.982	0.020	0.924	1
2000	30	0.972	0.039	0.822	1
2001	36	0.954	0.085	0.562	1
2002	41	0.928	0.112	0.556	1
2003	45	0.946	0.081	0.729	1
2004	40	0.943	0.110	0.516	1
2005	46	0.945	0.122	0.508	1
2006	49	0.961	0.073	0.672	1
2007	51	0.949	0.059	0.814	1
2008	51	0.954	0.047	0.811	1
2009	49	0.946	0.071	0.654	1
2010	48	0.967	0.057	0.678	1
2011	46	0.937	0.084	0.561	1
2012	37	0.930	0.084	0.551	1

Figure 1: DEA efficiency scores over the years

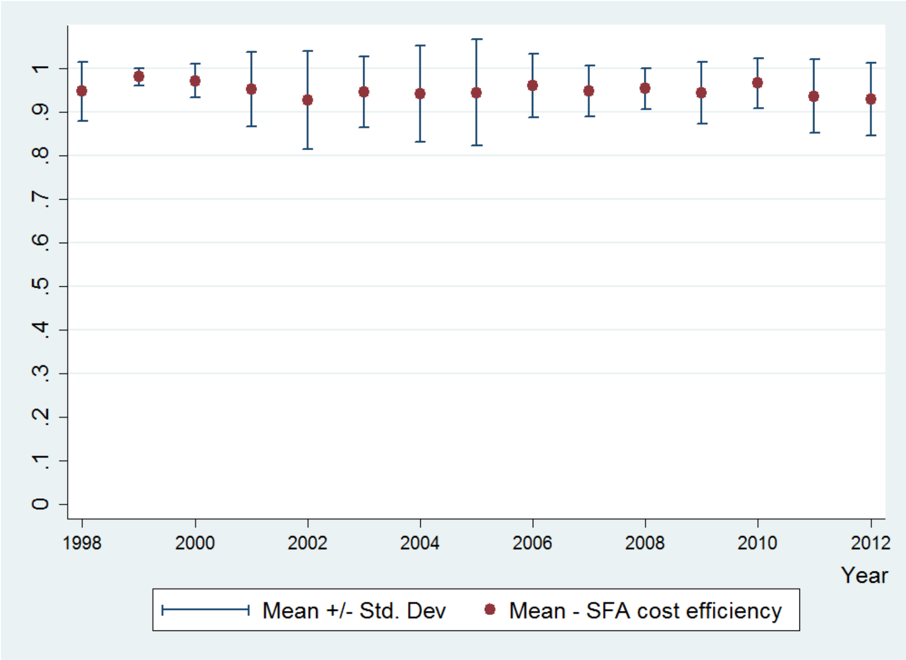


With respect to efficiency levels, we expect that the application of data envelopment analysis yields to lower average efficiency and higher volatility, since it does not separate inefficiency from random error (Berger and Mester, 1997). This is exactly the case here. Figure 3 shows that there is a difference in DEA and SFA efficiency levels, even when considering their volatility. However, this does not rule out their consistency from a general perspective, regarding the efficiency of the market as a whole. We point out that the efficiency levels themselves are not enough to rule these methodologies as inconsistent, since they yield to the same conclusion, that efficiency of Indian banks does not show signs of improvement over the years.

Rankings of firms are also inconsistent. We compute a rank correlation of 19.78% between DEA and SFA efficiency scores, which is statistically significant, but low. This is in line with the findings of Ferrier and Lovell (1990) and Fiorentino et al. (2006), who report insignificant and low rank correlations of 1.4% and 20%, respectively. Chen (2002) and Bauer et al. (1998) also find evidence of inconsistencies between parametric and non-parametric methodologies. Berger and Humphrey (1997) point out that the first task in evaluating performance is separating firms in those that perform well and those that perform poorly according to some standard. Given this, our results indicate that parametric and non-parametric models are not coherent even in this first step of efficiency analysis.

It should not be surprising that DEA and SFA have inconsistent results in some cases. The frontier built by data envelopment analysis is deterministic, while the frontier obtained from the stochastic frontier model is parametric and the possibility of separating

Figure 2: SFA efficiency scores over the years



the inefficiency term from the random component is often pointed as the main feature of this model (Berger and Humphrey, 1997).

Depending on the framework considered, the estimation of a deterministic frontier may not seem unreasonable. In a very controlled environment, it may seem unreasonable to actually consider that the objects of analysis are affected differently by random factors. This is the case of an agricultural experiment run in an area of 100 m^2, for example. However, if this agricultural experiment goes from this small area to different places in a country, random shocks may turn out to have a relevant role in the determination of the efficiency frontier and in the measured distances from it. We want to shed light to the question of whether the assumption of a deterministic frontier is suitable for financial systems. If DEA and SFA produce consistent results for a given market, this discussion is irrelevant. However, this is clearly not the case here. When these models are ruled as inconsistent, which one should we choose?

At first, it does not sound realistic to think that a deterministic frontier is appropriate for measuring the efficiency of financial institutions. After all, they are affected at least by economic shocks. At the same time, DEA is the most applied methodology in the measurement of bank efficiency (Staub et al., 2008). The non-parametric features of data envelopment analysis, which clear researchers from assumptions regarding production functions and the distribution of inefficiency terms, are usually listed as reasons why it seems the right choice of methodology. Nevertheless, a thorough consideration of why separating the effects of management decisions and random shocks are not decisive in the framework in question is harder to find. We want to point out the necessity of comparing

Figure 3: Comparison of the behavior of DEA and SFA efficiency scores, considering their volatility.

both methodologies to be sure that a robust result is found. After all, it is not simple to know *a priori* which of these models suits the framework of financial institutions better. In some cases, the cost of assuming that the framework of analysis is deterministic may be higher than the possibility of misspecification of the production function or the distribution of the inefficiency term, which both yield to biased efficiency estimates. In other cases, the exact opposite may occur. Therefore, even with a thorough consideration of the hypothesis involved in each methodology, results derived from the application of only one frontier model should be handled with care.

Directing the discussion to the role random error plays in the banking context is our goal here. Its relevance comes precisely from the inconsistencies between parametric and non-parametric methodologies, which may lead to misleading conclusions and policy decisions. The extensive application of only one frontier method to measure the efficiency of financial institutions shows that the issue is not as simple as it may seem. Meanwhile, results and conclusions should be carefully considered, especially when policy decisions are to be guided by them.

4 Conclusion

We discuss the adequacy of parametric and non-parametric methodologies to assess the performance of financial institutions. To do so, we use empirical results from the application of data envelopment analysis and stochastic frontier approach to a sample of

Indian commercial banks and determine to which extent they are consistent. We find evidence of relevant inconsistencies between them. We point out that determining the suitability of deterministic and parametric frontiers to the banking context is at least one factor to be taken under consideration when applying only one of these models.

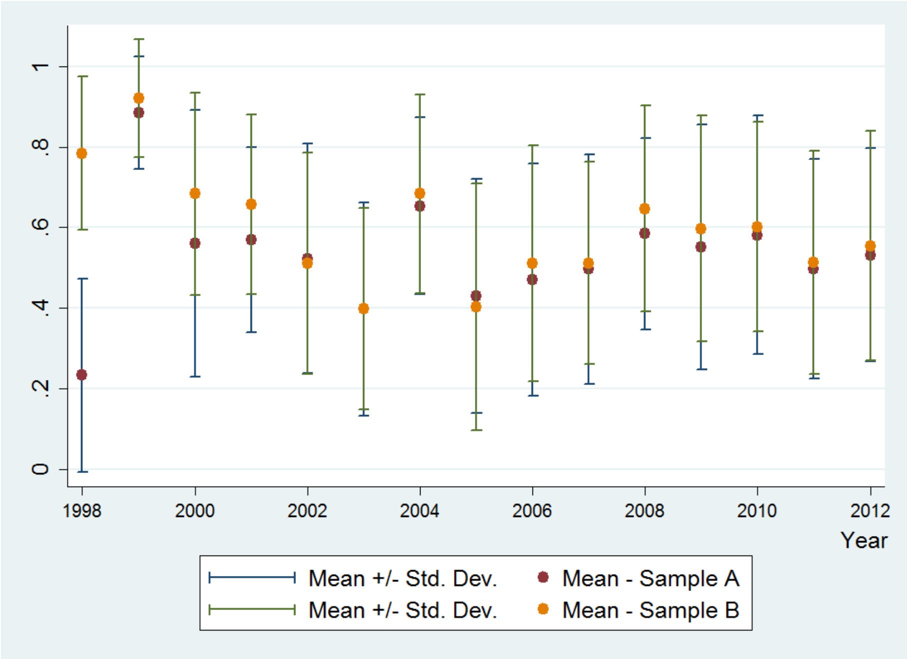
Our findings indicate that the application of data envelopment analysis yields to lower average efficiency scores and higher volatility. This is in line with what we expect in theory, since this methodology does not separate inefficiency from random error (Berger and Mester, 1997). However, we also find that both methodologies yield to similar trends on efficiency scores. We state that this is more relevant to rule these models as coherent from a general perspective than efficiency levels themselves. We also compute the rank correlation between efficiency scores from DEA and SFA and find that they are statistically significant, but low. This means that the individual diagnosis of performance may change depending on the methodology considered. This shows the relevance of the discussion we propose. The measurement of efficiency may guide policy or management decisions, which makes it important to ensure that empirical results are reliable. We point out that conclusions obtained from the application of a single frontier method should be carefully handled.

The main conclusion of our discussion is that the choice of a parametric or a non-parametric frontier model should come with a thorough consideration of the framework in analysis. Deterministic frontiers are appropriate for controlled environments, in which it is unlikely for firms to be affected differently by given factors. In the same way, parametric frontiers are suitable for contexts in which random shocks are likely and may change the position of firms in reference to the efficient frontier. However, there is another aspect to be considered other than the parametric or deterministic choice of the frontier. The specification of parametric frontiers involve assumptions regarding the production function of firms, the distribution of the inefficiency term and even the distribution of the random noise term. Different specifications also yield to incoherent results. Therefore, choosing one methodology over another is not simple. The application of more than one frontier model may guarantee the robustness of results and conclusions or point out the issue of considering only one of these models.

A Appendix

We run two robustness checks on our results. First, we remove all banks that are economically efficient on the application of data envelopment analysis to verify if sample heterogeneity is not leading to erroneous conclusions. Results are reported on Figure 4, which shows that our results for data envelopment analysis are robust to sample specification. We do not repeat this procedure with results from the SFA model because our estimation of the parametric frontier controls for unobserved heterogeneity.

Figure 4: Sample heterogeneity robustness check on DEA efficiency scores.



Sample A comprises the original sample.
Sample B is obtained by removing economic efficient banks from sample A.

The second robustness check consists on changing the specification of outputs variables. More specifically, we remove one of the original outputs and apply both models again to analyze the results and repeat this procedure removing two of the original outputs. Results are reported on figures 5 and 6. We conclude that our results are not sensitive to variable specification.

Figure 5: Variable specification robustness check on DEA efficiency scores

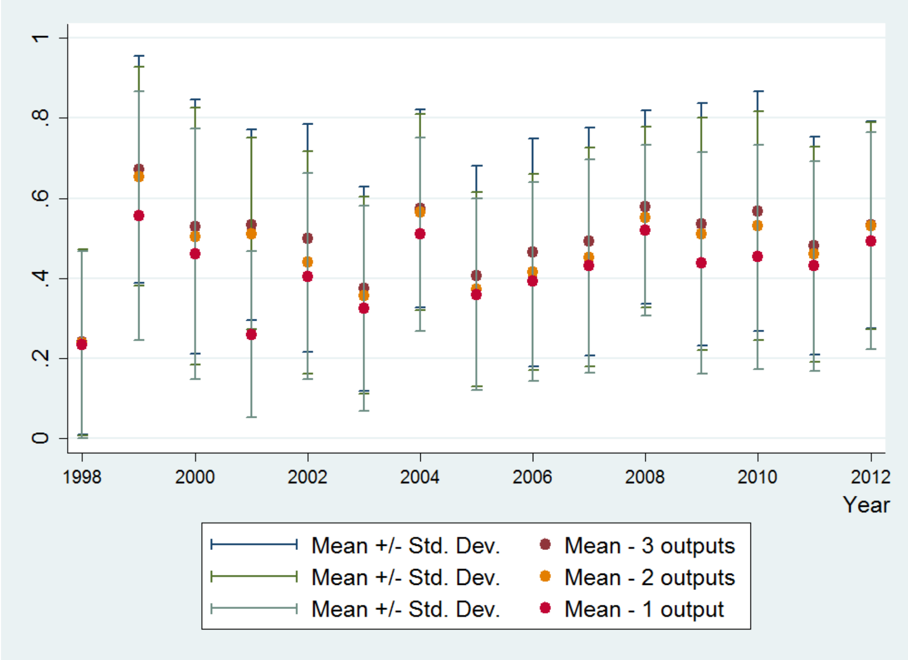
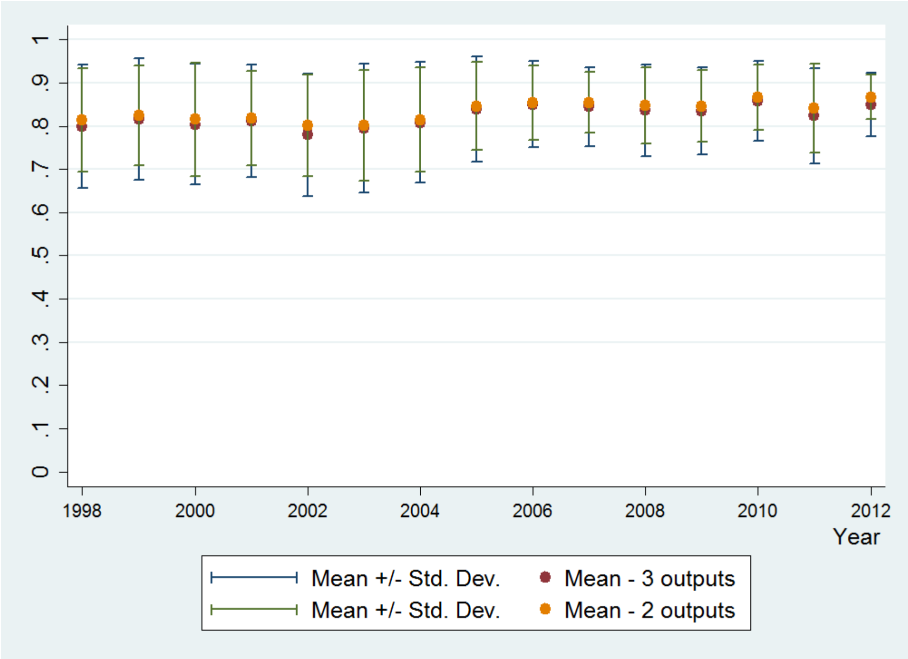


Figure 6: Variable specification robustness check on SFA efficiency scores



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