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REGULATORY REFORM AND PRODUCTIVITY CHANGE IN INDIAN BANKING

Barbara Casu[a], Alessandra Ferrari[b*], Tianshu Zhao[c]

Abstract - This paper examines the impact of regulatory reform on productivity growth and its components for Indian banks in 1992-2009. We estimate parametric and non-parametric efficiency frontiers, followed by Divisia and Malmquist indexes of Total Factor Productivity respectively. To account for technology heterogeneity among ownership types we utilise a metafrontier approach. Results are consistent across methodologies and show sustained productivity growth, driven mainly by technological progress. Furthermore, results indicate that different ownership types react differently to changes in the operating environment. The position of foreign banks becomes increasingly dominant and their production technology becomes the best practice in the industry.

Key words: Deregulation; Productivity Change; Ownership; DEA; SFA, Metafrontier.

JEL Classification: G21; G28; G32; D24; C16; C23

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[a] Cass Business School, City University, London, UK; [b] Department of Economics, University of Reading, UK; [c] Department of Economics, Stirling University, UK.

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I. Introduction

The past two decades have witnessed deregulatory policy reforms in banking industries around the world. These reforms have aimed to increase competition in order to promote productive financial systems, which would ultimately foster the development of the real economy. Deregulation is usually expected to stimulate productivity growth via the general advancement of production technology and the efficiency improvements of individual banks.[1] Re-regulation, on the other hand, is often expected to work as a constraint on the activity of banks with the aim of long term stability. Empirical evidence to support these aforementioned assertions is mixed, with some studies reporting improvements in productivity following financial reforms, while others suggest little, no, or even negative productivity growth.[2] Differences in empirical findings are likely to arise from: differences in the applied modelling techniques utilised; difficulties in disentangling the sources of productivity growth (arising from technological progress, scale or efficiency improvements); and complex relationships between ownership structure and efficiency and productivity changes. [3]

It is against this background that we seek to extend previous research by presenting an assessment of the effects of regulatory reforms on productivity growth, its sources, and on the relationship between bank performance and ownership types for Indian banks over the period 1992 to 2009. The Indian case is particularly suited to our research questions since it is a representative illustration of a gradualist approach to reform a banking system that was characterised by financial repression. The reforms started in 1992 and were guided by two Narasimham Committee reports, in 1991 and 1998 respectively. The period 1992-1997 saw the introduction of policy instruments aimed at promoting competition (deregulation), whereas from 1998 onwards the policy focus shifted towards the long run stability of the banking system (prudential re-regulation). [4] The whole reform process can thus be divided, at

least in theory, in two stages with the year 1997 as the watershed. Moreover, the Indian Government introduced a uniform regulatory framework to the different ownership types, which gives us an opportunity to investigate the impact of regulatory reform on the ownership-performance relationship in a market with a level playing field.[5]

Methodologically, we utilise two complementary approaches: a non-parametric metafrontier sequential Malmquist TFP index and a parametric metafrontier Divisia index. To our knowledge, this is the first study to perform an analysis of productivity change and its components within a metafrontier framework, both in a parametric and non-parametric setting. To test whether different approaches lead to similar policy conclusions, both share a common framework in terms of dataset, variables definition and behavioural assumptions. Having estimated technology gaps between ownership specific frontiers and metafrontier, a natural extension is to analyse them more closely and then test for convergence, that is the attainment of productivity equality in the long run. We do this by using the augmented Dickey-Fuller (ADF) test.

To anticipate our main results, we find that the reforms have fostered sustained TFP growth, driven mainly by technological progress. Results also indicate that state-owned, private and foreign banks reacted differently to changes in the operating environment. Specifically, regulatory changes generated a very favourable environment for foreign banks, which enabled them to use the best available technology in the industry and engage in cost technology innovation. On the other hand, the increasing technological gap between the best practice and the private and state banks frontiers indicates a lack of significant technological spillovers between different types of bank.

The remainder of the paper is structured as follows: Section 2 provides a review of the relevant literature. Section 3 describes the data set and the variables used in the construction

of the estimable models, while Section 4 presents a detailed exposition of the methodology utilised. Section 5 discusses the empirical findings and finally Section 6 concludes.

II. Literature review

There is a vast literature investigating bank efficiency, its components and its determinants using both parametric and non parametric approaches.[6] Most studies have measured technical and cost efficiency and, to a lesser extent, revenue and profit efficiency and productivity change. While early studies investigate mainly the US and EU banking markets, in recent years the number of studies focusing on developing countries has increased, mainly due to the unprecedented economic reforms implemented in those countries. Indian banking is no exception and starting from the mid-1990s the outcomes of the Indian reform process have been extensively analysed. Bhattacharyya *et al.* (1997) investigated the productivity growth of Indian public sector banks in the pre-reform period (1970 - 1992) and found that nationalisation curtailed bank productivity growth. Kumbahakar and Sarkar (2003)'s sample included both public sector and private banks in the period 1985-1996 and found that reforms did not deliver the expected TFP growth. The empirical literature on developing nations generally finds relatively low efficiency of state-owned institutions. In India, though, a number of studies, using competing methodologies and different time periods, seem to provide convincing evidence of higher average cost (and profit) efficiency of public sector banks (Sathye, 2003; Bhaumik and Dimova, 2004; Sensarma, 2006; Das and Ghos, 2006; 2009; Zhao *et al*., 2010; Ray and Das, 2010, among others). Das and Ghosh (2006) posit that public banks might be more efficient as government ownership may have facilitated recapitalisation at the onset of reforms. The literature seems also to agree on the poor performance of smaller private banks and on the considerable differences among banks both in terms of efficiency and productivity change.

The fact that the three ownership types co-exist and, to a certain extent, compete on the Indian banking market does not imply that they form a homogenous group. State, private and foreign ownership entail different organisational forms and incentive structures, which are likely to result in different operational behaviour. At the macro level, Bhaumik *et al.* (2011) find evidence that different ownership types react differently to monetary policy initiatives of the Reserve Bank of India. These varying reactions might be driven by differences in the structure of their balance sheet, particularly in terms of asset composition (Stein, 1998). Theory suggests a number of reasons as to why different types of banks lend to different types of firms, mostly based on information asymmetries. For example, Stein (2002) suggests that foreign banks may be less able to process "soft" information about local firms and therefore may prefer to lend to more "transparent" larger firms. Foreign banks might also have a comparative advantage in granting large loans. In contrast, state-owned banks often have to lend to "priority sectors" such as small and medium size enterprises, state-owned firms and firms in rural areas. Based on Indian data, Berger *et al.* (2008) find evidence of these different lending relationships.

These significant differences are often overlooked by the existing bank efficiency literature; however the importance of properly accounting for heterogeneity has been highlighted in a handful of recent studies (Bos and Schmiedel, 2007; Kontolaimou and Tsekouras, 2010). The assumption underlying the estimation of efficiency against a common frontier is that all banks in the industry are homogenous and utilise the same technology. If this assumption is not correct it will result in biased estimators and efficiency measures. Koetter and Poghosyan (2009) identify two main types of systematic differences across and within national banking markets: the first type of heterogeneity pertains to the environment in which banks operate and is exogenous to managers, although it affects their choice of available technology. The second type pertains to managerial choices and therefore affects efficiency, that is the ability

to attain the optimum benchmark rather than the shape of the efficient frontier. Our study builds upon this recent strand of literature by employing the metafrontier approach (Battese *et al*., 2004; O'Donnell *et al*., 2008) to account for the possibility of technological differences among ownership types.

III. Data and variables definition

A. Data

The data were collected from the Reserve Bank of India and cover all commercial banks (foreign, domestic private and state owned) operating in India from 1992 until 2009.

With the guide of homogeneity criteria and in line with previous literature, we excluded regional rural banks and foreign banks that consistently had less than two branches over the entire sample period. In both cases, their lines of business are very different from the nation-wide operations of other commercial banks. The resulting sample is an unbalanced panel data set of a total of 1230 observations. Table 1 gives a snapshot of the relative weight of the three ownership categories and of how the sample relates to the total market (proportion of total assets). All data were deflated using the GDP deflator using 1994 as base year.

< Insert Table 1>

B. Variable definition

To identify the inputs and outputs variables we follow the intermediation approach (Sealey and Lindley, 1977) and employ a two-input, three-output specification. The three chosen outputs are performing loans (y_1), other earning assets (y_2) and fee-based income (y_3).[7] The revenues with respect to these three outputs are given by interest income on loans, interest income on total other earning assets and non-interest income respectively. [8] The two chosen

inputs are total loanable funds (the sum of deposits and money market funding) and non-interest operating cost (which includes both the cost of the labour input and of physical capital). The price for total loanable funds (w_1) is calculated as the ratio of total interest expenditure to total loanable funds, and the price for non-interest operating cost (w_2) is given by the ratio between non-interest operating cost and total assets. The number of branches is also introduced separately to proxy for size. Summary statistics for outputs and inputs are given in Table 2.

To account for the macroeconomic environment and prevent bias especially in the estimation of technical change we also include the cash reserve ratio (CRR), the statutory liquidity ratio (SLR) and a measure of the reliance of the economy upon the banking sector as opposed to other sources of finance (Mac). Finally in the econometric specification we also specify a dummy variable R to capture the period before and after re-regulation (before and after 1997).

<Insert Table 2>

IV. Methodology

A. Empirical framework

The measurement of total factor productivity change (TFP) and its components can be performed via the estimation of efficiency frontiers, either using Stochastic Frontier Analysis (SFA) or Data Envelopment Analysis (DEA), which lead respectively to the calculation of a Divisia index and of a Malmquist index of TFP change (Malmquist, 1953).[9] In this paper we make a number of methodological contributions to the literature: firstly, we use both parametric and non-parametric techniques as they have well known complementary properties and consistency in their results strengthens the analysis and is particularly useful for regulators and other decision makers (Bauer *et al.*, 1998; Casu *et al.*, 2004). To improve comparability, we implement a sequential DEA approach (Tulken and Vanden Eeckaut,

1995) which leads to the estimation of a sequential Malmquist TFP index. In addition, unlike most of the literature, for the decomposition of the Malmquist index we do not follow Färe *et al.* (1994), since their method, albeit very popular, is actually valid only under the assumption of constant returns to scale. We follow instead the method proposed by Ray and Desli (1997), which is valid under variable returns to scale and allows the proper separation of scale effects from the rest. Finally, we recognise the heterogeneous nature of our data across ownership types, and therefore we address this issue in the context of a metafrontier framework (Battese *et al*, 2004; O'Donnell *et al*, 2008). We then estimate both a non-parametric sequential metafrontier Malmquist TFP index and a parametric metafrontier Divisia index to assess productivity change.

B. Group-specific frontiers: SFA, DEA and Divisia and Malmquist indexes

In an input minimization perspective, an efficiency frontier is defined as the minimum level of input(s) for a given level of output(s), and the efficiency of a firm can be measured by means of a "distance function" *D* (Shephard 1953, 1970): this is a *radial* measure of the distance of that firm from the frontier such that D = 1 when the firm is fully efficient and D>1 otherwise.

Data Envelopment Analysis constructs a piece-wise linear convex frontier from the linear combination of the best practices among the observations (Charnes *et al*., 1978, 1981). In the case of $i = 1 \ldots N$ firms that produce $m = 1, \ldots, M$ outputs using $j = 1 \ldots, J$ inputs at time t and with variable returns to scale, the efficiency of each firm is calculated by solving the following linear programming problem (once for each firm).

$$\{D^t{}_o(x_{it}, y_{it})\}^{-1} = \min_{\theta,\lambda} \theta_o$$

$$s.t. \quad \sum_{i=1}^{N} y_{im}^t \lambda^t{}_i \geq y_{om}^t$$

$$\sum_{i=1}^{N} x_{ij}^t \lambda^t{}_i \leq \theta_o x_{oj}^t \tag{1}$$

$$\lambda^t{}_i \geq 0, \sum_{i}^{N} \lambda_i^t = 1$$

Where $\theta_o = 1/D_o^t$ so that $\theta_o \leq 1$.

For the calculation of TFP we follow Ray and Desli (1997) and we define the Malmquist index for the *k-th* ownership between any two times *t* and *t+1* and with variable returns to scale as:

$$M^k(X_{t+1}, Y_{t+1}, X_t, Y_t) = \left[\frac{D_{v,t}^k(X_t, Y_t)}{D_{v,t+1}^k(X_{t+1}, Y_{t+1})}\right] * \left[\frac{D_{v,t+1}^k(X_t, Y_t)}{D_{v,t}^k(X_t, Y_t)} \frac{D_{v,t+1}^k(X_{t+1}, Y_{t+1})}{D_{v,t}^k(X_{t+1}, Y_{t+1})}\right]^{1/2} *$$

$$* \left[\frac{D_{c,t+1}^k(X_t, Y_t)}{D_{v,t+1}^k(X_t, Y_t)} \frac{D_{v,t+1}^k(X_{t+1}, Y_{t+1})}{D_{c,t+1}^k(X_{t+1}, Y_{t+1})} \frac{D_{c,t}^k(X_t, Y_t)}{D_{v,t}^k(X_t, Y_t)} \frac{D_{v,t}^k(X_{t+1}, Y_{t+1})}{D_{c,t}^k(X_{t+1}, Y_{t+1})}\right]^{1/2}$$

$$= EC^k * TC^k * SC^k \tag{2}$$

From (2) we can see that the Malmquist index is calculated as the ratio of distance functions and it is given by the product of three components: the change in efficiency (EC), technological change (TC), and scale change (SC).[10] For each of these components, a score larger/smaller than unity indicates an improvement/worsening of the corresponding measure and a score equal to 1 indicates no change. The same is true for the overall TFP measure resulting from the multiplication of the three scores.

Equation (1) is usually estimated separately for each time period, and the resulting Malmquist index therefore compares year pairs every time independently; this often translates into wide oscillations, as shifts of the frontier induced by random shocks are confused with changes in

technology. We avoid this problem by estimating (1) and (2) sequentially (Tulken and Vanden Eeckaut, 1995). This means that the estimation of (1) (and therefore subsequently of (2)) is conducted each time including not only the current year but also all the years preceding it, which is equivalent to assuming that technological knowledge accumulates over time.[11] The sequential estimation has also the additional advantage of reducing the well known dimensionality problem of DEA[12], and it also enhances the comparability with SFA that uses time trends to model technological change (O' Donnell *et al*, 2008).

The stochastic frontier model is an econometric method that consists of a (cost or production or profit) function with a composite error term, made up of two separate, although jointly estimated, components: stochastic noise and inefficiency (Aigner *et al*., 1977; Meeusen and Van den Broek, 1977). In this paper we estimate a stochastic translog cost frontier with non constant inefficiency whose mean depends upon a set of covariates (Battese and Coelli 1995)[13]. We choose a translog functional form so our model is

$$\begin{aligned}
\ln C_{it} &= \beta_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mit} + \sum_{j=1}^{J} \beta_j \ln w_{jit} + \sum_{m=1}^{M}\sum_{q=1}^{M} \alpha_{mq} \ln y_{mit} \ln y_{qit} + \\
&+ \sum_{n=1}^{J}\sum_{j=1}^{J} \beta_{nj} \ln w_{nit} \ln w_{jit} + \sum_{j=1}^{J}\sum_{m=1}^{M} \gamma_{jm} \ln w_{jit} \ln y_{mit} + \\
&+ \lambda_1 T + \lambda_2 T^2 + \sum_{m=1}^{M} \theta_m T \ln y_{mit} + \sum_{j=1}^{J} \zeta_j T \ln w_{jit} + \\
&+ a_r R + a_{rt} RT + \sum_{m=1}^{M} \ell_m R \ln y_{mit} + \sum_{j=1}^{J} \rho_j R \ln w_{jit} + \sum_{p}^{P} \eta_p E_{pit} + v_{it} + u_{it}
\end{aligned} \tag{3}$$

Where $v_{it} \sim N(0, \sigma^2)$ is noise and $u_{it} \sim N^+(\delta' Z_{it}, \sigma_u^2)$ is inefficiency, modelled as

$$u_{it} = \delta_0 + \delta_1 T + \delta_2 TT + \delta_3 R + \varepsilon_{it} \tag{4}$$

With $\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2)$ truncated at the variable point $-\delta' Z_{it}$ to allow for the non-negativity constraint on u_{it}, so that $\varepsilon_{it} \geq -\delta' Z_{it}$.

In (3) C_{it} is the observed total operating cost of bank *i* at time *t*, and it depends on inputs prices *w* and outputs *y*. *R* is a dummy variable set equal to 1 for the period following re-regulation (1998-2009) and *T* is time; together with their interaction with inputs and outputs they model (neutral and non neutral) technical change and changes in technology following re-regulation. The exogenous environmental variables that we described in the data section are in the vector *E*.

Equation (4) models inefficiency as a function of time and re-regulation, as the relevance of the difference between ownerships is already captured by the estimation of separate frontiers[14]. Equations (3) and (4) are estimated simultaneously by Maximum Likelihood.

Following the procedure outlined in Kumbhakar and Lovell (2003) we define and calculate the Divisia index of TFP change for each of the *k* ownerships as

$$\dot{TFP}^k = \left[1-\varepsilon(Y,W,R,T,E;\beta)\right]\dot{Y}^c - \dot{C}(Y,W,R,T,E;\beta) - \frac{\partial \ln C}{\partial E} + \\ + \sum_{j=1}^{J}\left[S_j - S_j(Y,W,R,T,E;\beta)\right]\dot{wj} - \frac{\partial U}{\partial t} + (\dot{Y} - \dot{Y}^c) \qquad (5)$$

The index therefore is computed as the sum of six components, a positive net value in each of which translates into a positive growth in TFP, to be interpreted as follows. The first component measures *the scale effect* (SC^k). The second component represents technological progress, measured as shifts of the frontier due to the passing of time (TC^k). The third component measures the impact on TFP of all the environmental variables in (3) (EX^k). The fourth term is a measure of allocative inefficiency, specified as a deviation of the observed inputs cost shares from their optimal ones ($ALLC^k$). The fifth component measures the change in cost efficiency (EC^k) and finally the last is the so-called *mark-up effect* (MU^k), representing departures from marginal cost pricing and/or from an equi-proportionate mark-up for every output (Denny *et al.*, 1981; Kumbhakar and Lozano-Vivas, 2005).

To compute equation (5) for the ownership specific cases we use the parameters estimates of equations (3) and (4).

C. The estimation of metafrontiers

When firms in different groups (countries, industry, ownership types etc.) face different technologies their (production or cost functions and) frontiers have to be estimated separately, precluding the possibility of comparisons among them. More formally, if there are *k* different technology sets in an input perspective at every time *t* there will be *k* different input sets each defined as

$$L_t^k = \left\{ X_t^k : (Y_t^k, X_t^k) \ is\ feasible \right\}$$

The idea behind the metafrontier is that all L^k_t sets belong to a common unrestricted technology set L^*_t:

$$L_t^* = \{ L_t^1 \cup L_t^2 \cup L_t^3 \cup ..... \cup L_t^k \}$$

to which each of the *k* groups has potential access.

The metafrontier is defined as the boundary of this unrestricted technology set and it is derived as the envelope of the group frontiers, identifying a metatechnology that is assumed to be available to all the firms in the sample.

In SFA the metafrontier is estimated by linear or quadratic programming (Battese 2004) as an overarching function that envelops the single group frontiers. Define

$$C_{it}^k = f(X_{it}\beta^k)\exp(v_{it}^k + u_{it}^k) = \exp(X_{it}\beta^k)\exp(v_{it}^k + u_{it}^k) \qquad (6)$$

as the *k*-th group cost frontier, depending on the matrix of independent variables *X* and a vector of group specific parameters β^k. The metafrontier can be defined as the envelope of the *k* estimations of (6) as

$$C_{it}^* = f(X_{it}\beta^*) = \exp(X_{it}\beta^*) \qquad (7)$$

So it has the same functional form of (6) with a vector of parameters β^* that has to be estimated subject to the constraint that

$$X_{it}\beta^* \leq X_{it}\beta^k \qquad (8)$$

That is the meta cost technology gives the minimum possible cost available among all the groups.

Equation (7) can be estimated by linear programming, hence solving

$$\text{Min L}=\sum_{i=1}^{N}\sum_{t=1}^{T}(X_{it}\hat{\beta}^k - X_{it}\beta^*) \qquad (9)$$

subject to (8).[15] The radial distance of each unit from the metafrontier is called *metaefficiency* and it is defined as

$$EFF_{it}^* = \frac{\exp(X_{it}\beta^*)\exp(v_{it}^k)}{C_{it}^k} \qquad (10)$$

which given (6) is equivalent to

$$EFF_{it}^* = \exp(-u_{it}^k)\frac{\exp(X_{it}\beta^*)}{\exp(X_{it}\beta^k)} \qquad (11)$$

Equation (11) means that the metaefficiency of firm *i* of group *k* at time *t* is made of two parts: the first is its group specific cost efficiency $EFF_{it}^k = \exp(-u_{it}^k)$, with $0 \leq EFF_{it}^k \leq 1$. The second is known as *technological gap ratio* (TGR), and it measures the distance between the metafrontier and the group specific frontier; TGR ≤ 1 with higher values indicating a closer proximity to the metafrontier and lower values indicating a larger gap between the two. Empirically one would first estimate EFF^k and TGR and compute EFF* subsequently as their product.

In DEA, which is already a linear programming technique, the estimation of a metafrontier is the estimation of a general unrestricted frontier using all the group data together. Similarly to SFA also in DEA we will have $TGR_{it} = \frac{EFF_{it}^{*}}{EFF_{it}^{k}}$.

Coming finally to the calculation of TFP change, this has to be based upon the metafrontier results. For the Divisia index we perform the calculations in (5) using the estimated coefficients from the metafrontier obtained from (9) and (8). Given the specification of (10) and to avoid double counting of technological progress the cost efficiency measure used in the Divisia has to remain the group-specific cost efficiency.

The metafrontier Malmquist index is computed as in (2) but using the metatechnology as a reference point so that

$$M*(X_{t+1},Y_{t+1},X_t,Y_t) = \left[\frac{D_{v,t}^{*}(X_t,Y_t)}{D_{v,t+1}^{*}(X_{t+1},Y_{t+1})}\right] * \left[\frac{D_{v,t+1}^{*}(X_t,Y_t)}{D_{v,t}^{*}(X_t,Y_t)}\frac{D_{v,t+1}^{*}(X_{t+1},Y_{t+1})}{D_{v,t}^{*}(X_{t+1},Y_{t+1})}\right]^{1/2} *$$

$$* \left[\frac{D_{c,t+1}^{*}(X_t,Y_t)}{D_{v,t+1}^{*}(X_t,Y_t)}\frac{D_{v,t+1}^{*}(X_{t+1},Y_{t+1})}{D_{c,t+1}^{*}(X_{t+1},Y_{t+1})}\frac{D_{c,t}^{*}(X_t,Y_t)}{D_{v,t}^{*}(X_t,Y_t)}\frac{D_{v,t}^{*}(X_{t+1},Y_{t+1})}{D_{c,t}^{*}(X_{t+1},Y_{t+1})}\right]^{1/2} \qquad (12)$$

$$= EC^{*} * TC^{*} * SC^{*}$$

V. Empirical results

To test whether the various ownership types are operating under the same technology and therefore the data can be pooled under a single frontier, we used both parametric and non-parametric techniques: t-test, Mann-Whitney, Kruskall-Wallis (KW) test and Kolmogorov-Smirnov (KS) test for DEA, as well as an LR test in SFA (Aly *et al*., 1990; Elyasiani and Mehdian, 1990; Isik and Hassan, 2002). The results are reported in Table A1 in the appendix and show that the null hypothesis of a common technology is generally rejected, leading us to

conclude that it is appropriate to construct cost efficiency frontiers separately for each ownership group.

A. Ownership specific analysis of Total Factor Productivity

The first part of the analysis therefore consists of estimating ownership-specific frontiers and their TFP changes and components. For the parametric analysis, we follow Battese and Coelli (1995) and estimate equations (3) and (4) simultaneously with a Maximum Likelihood one-step procedure. Linear homogeneity of degree one in input prices and Young's symmetry are imposed prior to estimation. In the non-parametric analysis, we follow a sequential Data Envelopment Analysis approach (Tulken and Vanden Eeckaut, 1995). This particular approach assumes that technical knowledge accumulates over time hence implying dependence in the production process; this reduces the wide oscillations typical of DEA as the frontier will be moving forward in the presence of technical progress and remain static otherwise. The use of sequential DEA should improve the comparability of the two methodologies. Nonetheless, due to the fundamental characteristics of the two approaches, we would expect the DEA results to be more extreme and, in the presence of technological progress, to show larger technology changes than efficiency changes.

The most important things to notice about this initial part of the analysis are that the SFA coefficients and elasticities have the expected signs, inefficiency is significant for all ownerships, whilst the passing of time and the introduction of re-regulation have mixed effects on the technological choices of the three ownerships.[16] Furthermore, foreign banks show an increase in the optimal scale of production of performing loans and a decrease in that of other earning assets, contrary to both private and state banks. This is consistent with the removal of restrictions on their operations, which progressively allowed foreign banks to increasingly familiarise themselves with the local loans market. As illustrated in Table 3,

both SFA and DEA show high average levels of efficiency (about 90%) that slightly worsen after re-regulation; these results are not significantly different between the two methodologies, with the exception of private banks which DEA ranks as remarkably less efficient than SFA.[17]

<Insert Table 3>

Moving on to the measurement of productivity, as we can see in Table 4 TFP overall is increasing over time, and the difference between the DEA Malmquist and the SFA Divisia is not statistically significant; the only difference between the two methodologies is in the estimates of technology change, but the general trends and the actual change rates of TFP are not statistically different.[18] This improvement is mainly due to improvements in technology, with DEA recording as expected higher values than SFA.

<Insert Table 4>

These ownership-specific results do now allow us to draw any inference at the industry level. Therefore, to compare results across ownership groups we move on to compute estimates relative to a metafrontier.

B. Metafrontier analysis of Total Factor Productivity

We estimate metafrontiers using both DEA and SFA techniques, followed by a generalised sequential metafrontier Malmquist index and a metafrontier Divisia index. To allow a more flexible modelling of the passing of time on technology in SFA we estimate two separate metafrontiers, one for 1992-1997 and one for the 1998-2009.[19]

The coefficients of the two SFA-based metafrontiers are reported in Table A3 in the appendix. Tables 5 and 6 report the metafrontier Divisia index results and the metafrontier Malmquist index results derived from SFA and DEA respectively.

<Insert Table 5 and 6>

The results are very consistent across methodologies, all the comparable series are not significantly different at a 5% level (except from scale changes) and find an increase in overall TFP especially after 1998. If we do not take into account the environmental factors in the Divisia index the figures are even closer (refer to column TFP2 in Table 5), with an overall average yearly improvement between 0.4% and 1.4% before 1998 and increasing to about 3% per year afterwards. The main contributor to these TFP changes is always technological progress. As expected, in DEA this is more marked and translates into a worsening of efficiency, whereas SFA gives lower technical improvements and marginally positive efficiency changes. Finally, the scale component worsens in all cases, going from mildly increasing returns to scale pre-1997 to mildly decreasing returns to scale post 1998.

C. Metaefficiency and Technology Gap Ratios

The metafrontier framework allows us to decompose differences in overall performance (metaefficiency) into cost efficiency and technology gap ratio (TGR), where the TGR measures the distance between the group frontiers and the metafrontier.[20] While cost efficiency relates mainly to the performance of a firm's management, the TGR represents the nature of the production environment (O'Donnell *et al.*, 2008). In this context, regulatory changes influence the environmental characteristics of the market; therefore an analysis of technology gaps can provide important information on the outcomes of the deregulation process.

Table 7 reports the average technology gap ratios (TGR), cost efficiency and metaefficiency scores for the whole industry and the different ownerships, for DEA and SFA. Table 7 shows that industry technology improves over time, as indicated by the widening gap between the metafrontier and the single ownership frontiers (the decreasing TGR values). [21] In particular, while before 1998 state banks are the sector leaders in terms of technology and

metaefficiency, after 1998 they lose technological leadership in favour of foreign banks. This is true for both DEA and SFA.

<Insert Table 7>

This improvement in the position of foreign banks is confirmed when we look at individual data points and calculate the number and sample proportion of technology leaders for each ownership. In this context, we define *technology leaders* or *innovators* those banks with a TGR =1, i.e. those which are using the best available technology. This is shown in Table 8 where again we can see the increasingly dominant position of foreign banks after 1998.[22]

<Insert Table 8>

To corroborate these results, in Figures 1 and 2 we present the histograms and kernel density estimations of technology gap ratios for the three ownership types, separately for the periods 1992-1997 and 1998-2009.

<Insert Figures 1 and 2>

The figures quite clearly show how the TGR distribution changes after 1998, with state banks in particular losing their lead position whilst the concentration of leaders for foreign banks becomes higher than for the rest of the sample.

D. Catch up Index

Whilst very informative, the TGR is a static measure of leadership. To look further into the issue of technological leadership we follow Chen and Yang (2011) and construct a catch-up index, given by the ratio of the technical change of the *i-th* bank against the metafrontier (TC_{it}^{*}) to its technical change against the *k-th* ownership frontier (TC_{it}^{k}), that is:

$$CU_{it} = \frac{TC_{it}^{*}}{TC_{it}^{k}} \qquad (13)$$

CU therefore measures the dynamics of the changes in technological leadership among different ownership types, with lower values indicating a speeding of the catch up process and viceversa. The results are reported in Table 9; they are not significantly different between DEA and SFA and indicate that the best practices among foreign banks are narrowing their technical gap at a faster speed than state or private banks. The speed of the catch up process decreases over time for all ownership types. State banks appear to be the slowest in the sample in terms of catching up with the best available technology.

The overall picture therefore seems to indicate that the change in regulatory regime generated a very favourable environment for the best practices of foreign banks to use the best available technology and engage in cost technology innovation.

<Insert Table 9>

D. Further robustness and convergence test

Finally, to check on the robustness of the above conclusion we test for the convergence of the ownership specific frontiers towards the metafrontier, based on a reduced form of their respective dynamic processes (see for example Thirtle *et al.*, 2003). Define TC_t^k the change of technology of the *k-th* ownership frontier at time *t*, TC_t^* the change of technology of the metafrontier at time *t*, and assume that the growth processes are given by:

$$\ln TC_t^k = \gamma_k + \lambda \ln\left(\frac{TC^*_{t-1}}{TC_{t-1}^k}\right) + \ln TC_{t-1}^k + \varepsilon_t \qquad (14)$$

and

$$\ln TC^*_t = \gamma^* + \ln TC^*_{t-1} + \eta_t \qquad (15)$$

where γ_k and γ^* are the asymptotic growth rates of TC^k and TC^* respectively and λ measures the speed of catch up between them. Combining (14) and (15) we get:

$$\ln\left(\frac{TC_t^k}{TC^*_t}\right) = (\gamma_k - \gamma^*) + (1-\lambda)\ln\left(\frac{TC_{t-1}^k}{TC^*_{t-1}}\right) + \phi_t \qquad (16)$$

We estimate (16) for each of the ownership types, using both DEA and SFA results, and conduct an ADF test to check for the presence of a unit root; namely the presence of a unit root ($\lambda = 0$) implies that there is no technological spill-over between the metafrontier and the ownership specific frontiers. Conversely the difference between them will be stationary if the null hypothesis of a unit root is rejected and $\lambda > 0$, with full convergence found if also the intercept (γ_k-γ^*) is not significantly different from 0.

The results of the tests are reported in Table 10 and indicate that only the frontier of foreign banks converges consistently across methodologies towards the metafrontier in the long run. This confirms our conclusion that the metafrontier is led by foreign banks and suggests a lack of significant technological spillovers between ownerships.

<Insert Table 10>

VI. Conclusion

The main aim of this study is to assess the impact of regulatory reform on TFP growth and its sources and on the ownership-performance relationship for the case of Indian banks. We do so by implementing a novel methodological framework which leads to the estimation of TFP by means of a non-parametric sequential metafrontier Malmquist index and a parametric metafrontier Divisia index.

Guided by two Narasimham Committee reports (in 1991 and 1998 respectively), the Indian Government introduced a series of financial sector reforms which fostered a uniform regulatory framework, theoretically creating a market with a level playing field. Despite the

fact that nearly two decades have passed since the first Narasimham Committee report, we find evidence of continued heterogeneity across the industry. Departing from the existing literature on efficiency and productivity measurement, we explicitly tested and rejected the assumption of the existence of a common production technology, leading us to construct cost efficiency frontiers separately for each ownership type. Both DEA and SFA results indicate relatively high levels of efficiency, which worsen after 1998. Results are consistent across methodologies for state-owned and foreign banks. Private banks are however a very heterogeneous group; they experience the largest number of entries (particularly post 1996) as well as exits or M&As. Research shows that the performance of firms entering the market is normally below that of the average incumbent. When new small firms enter and exit the market, the variance of the distribution is likely to increase and this can explain the lower efficiency of private banks measured by DEA compared to SFA. Overall productivity, measured both by the DEA Malmquist and the SFA Divisia, is increasing over time. Consistently with previous literature, we find that this improvement is mainly due to improvements in technology.

To be able to compare the results across ownership types, we estimate a generalised sequential metafrontier Malmquist index and a metafrontier Divisia index. Again, the overall TFP is positive and mainly driven by technological progress. Results also indicate that different ownership types reacted differently to changes in policy and to the operating environment. In particular, changes in regulatory regime generated a very favourable environment for foreign banks, which enabled them to use the best available technology in the industry and engage in cost technology innovation. The position of foreign banks becomes increasingly dominant over time and their production technology is becoming the best available technology in the industry. This is consistent with the removal of restrictions on their operations, which progressively allowed foreign banks to increasingly familiarise

themselves with the local loans market. Foreign banks seem to have capitalised on the relative advantages of their asset portfolio. On the other hand, the increasing technological gap between the best practice and the private and state banks frontier indicates a lack of significant technological spillovers. To conclude, financial reforms have benefited the Indian banking sector and resulted in sustained productivity growth. However, the benefits of reforms have not being uniformly distributed across ownership types, with state-owned banks losing the ability to act as undisputed industry leaders as well as losing customers and market share. An interesting extension to the current study would be a micro level analysis of the characteristics and determinants of ownership differences, with particular focus on bank risk.

APPENDIX

Table A1: Summary of parametric and nonparametric tests for the null hypothesis of a common technology among different ownership groups.

	State vs. Private	*Foreign vs. Private*	*Foreign vs. State*
T-test (equality of means)			
1992-1997	0.0000	0.0000	0.8217
1998-2009	0.0000	0.0000	0.0561
1992-2009	0.0000	0.0000	0.0769
Mann-Whitney test (equality of medians)			
1992-1997	0.0000	0.0000	0.2145
1998-2009	0.0000	0.0000	0.1321
1992-2009	0.0000	0.0000	0.0476
Kolmogorov-Smirnov test (equality of distributions)			
1992-1997	0.000	0.000	0.018
1998-2009	0.000	0.000	0.000
1992-2009	0.000	0.000	0.000
Kruskall-Wallis test (equality of distributions)			
1992-1997	0.0000	0.0000	0.2145
1998-2009	0.0000	0.0000	0.1321
1992-2009	0.0000	0.0000	0.0476
Likelihood Ratio test (of parameter stability across ownerships)			
1992-2009		0.0000	
		(LR statistic = 386.8164)	

Note: the figures are the p-values associated with each test.

Table A2: Key results from the estimation of the group specific SFA frontiers

	STATE	FOREIGN	PRIVATE
Elasticities			
92-97			
Y1	0.466	0.533	0.509
Y2	0.500	0.446	0.439
Y3	0.028	0.015	0.028
W1	0.686	0.751	0.690
W2	0.314	0.249	0.310
Elasticities			
98-09			
Y1	0.587	0.491	0.531
Y2	0.423	0.474	0.429
Y3	0.053	0.043	0.002
W1	0.662	0.668	0.721
W2	0.338	0.332	0.279
T	-0.003	0.100**	0.026**
TT	-0.001	-0.0002	0.0002
Br	0.000**	0.002***	0.000
R	-0.839***	0.046	0.069**
CRR	0.003**	-0.004	-0.0004
SLR	0.004**	0.0013	0.0012
Mac	0.093	0.413**	0.112*

Inefficiency			
Const	0.057**	-	0.00
R	0.167*	-	0.066
T	0.016	-	-0.005
TT	-0.002***	-	-0.001
O/n	-	-	-0.183
O/nR	-	-	0.100
Loglk	***895.217***	***198.139***	***680.998***
Sigmasq	***0.003***	***0.029***	***0.018***
Gamma	***0.828****	***0.8733****	***0.926****

O/n is a dummy taking value 1 for "old" private banks who were in business prior to 1995, and 0 otherwise.

Table A3: Results from the estimation of the SFA Metafrontier

	1992-1997	*1998-2009*
Const	4.373	9.448
lnY1	-0.142	-0.779
lnY2	0.848	1.099
lnY3	-0.009	-0.078
lnP*	0.312	0.023
lnY1lnY1	0.049	0.021
lnY2lnY2	0.014	-0.046
lnY3lnY3	-0.004	-0.005
lnP*lnP*	0.123	0.202
lnY1lnY2	-0.057	0.040
lnY1lnY3	0.005	0.000
lnY2lnY3	0.002	0.013
lnY1lnP*	0.016	0.104
lnY2lnP*	-0.031	-0.079
lnY3lnP*	0.027	-0.008
T	-0.108	-0.076
TT	-0.002	0.003
lnY1T	-0.024	-0.008
lnY2T	0.039	0.014
lnY3T	-0.011	-0.007
lnP*T	0.003	-0.014
Br	0.00001	0.00001
CRR	0.003	-0.014

SLR	0.003	-0.049
Mac	0.256	0.28

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Table 1: Number of banks relative weight of different ownerships

	Number of banks			**Proportion of total assets**			
	State	***Foreign***	***Private***	***Industry***	***State***	***Foreign***	***Private***
1992	27	13	23	0.986	0.89	0.07	0.04
1998	27	15	32	0.988	0.82	0.08	0.10
2009	27	13	22	0.994	0.72	0.08	0.20

Note: The column industry reports the proportion of total assets of our sample over the whole industry.

Table 2: Inputs and outputs summary statistics (1992-2009)

Variable	***Mean***	***Median***	***Min***	***Max***	***Stdev***
TC	10261	4182	12.67	250381	21005
y_1	66129	20522	48.48	2277632	151871
y_2	45929	16333	31.98	1179795	98846
y_3	2000	775	0.621	54257	4402
w_1	0.073	0.068	0.004	0.812	0.069
w_2	0.027	0.025	0.002	0.281	0.023

Note: TC= total operating cost; y_1: performing loans; y_2: other earning assets; y_3: fee-based income; w_1: loanable funds price; w_2 = non-operating cost price. Cost and outputs are in Rs mil and deflated using 1994 as the base year.

Table 3: Yearly average efficiency scores

	STATE		***FOREIGN***		***PRIVATE***	
	SFA	***DEA***	***SFA***	***DEA***	***SFA***	***DEA***
1992-1997	0.923	0.910	0.888	0.906	0.945	0.692
1998-2009	0.922	0.891	0.884	0.866	0.945	0.628
1992-2009	0.922	0.897	0.885	0.880	0.945	0.649

Table 4: Total Factor Productivity Change

	TFP^k		**TC^k**		**EC^k**		**SC^k**	
	Divisia	***Malmq***	***Divisia***	***Malmq***	***Divisia***	***Malmq***	***Divisia***	***Malmq***
STATE								
92-09	0.999	1.021	1.003	1.051	1.001	0.985	0.995	0.993
92-97	0.998	1.012	1.01	1.041	1.000	0.980	1.00	0.985
98-09	0.999	1.025	1.001	1.055	1.002	0.987	0.993	0.988
FOREIGN								
92-09	1.071	1.048	1.051	1.116	1.002	0.985	0.999	0.956
92-97	1.070	1.045	1.049	1.132	1.003	0.973	1.002	0.958
98-09	1.071	1.049	1.052	1.110	1.001	0.989	0.997	0.955
PRIVATE								
92-09	1.024	1.029	1.015	1.095	1.001	0.972	1.005	0.965
92-97	1.029	1.074	1.013	1.165	0.998	0.968	1.005	0.957
98-09	1.022	1.011	1.016	1.067	1.002	0.974	1.005	0.969

Note: The superscript k indicates results obtained with reference to group specific frontiers. TFP = total factor productivity; TC = technical change; EC = efficiency change; SC= scale change. Along with TFP the table reports only the 3 components of the Divisia index directly comparable with the Malmquist index: technical change, efficiency change and scale change. The Divisia values have been transformed from change rates into changes to make the comparison with the Malmquist possible.

Table 5: Metafrontier Divisia Index

	*SC**	*TC**	*EX**	*ALLC**	*EC**	*MU**	*TFP**	*TFP2*
92-93	0.998	1.008	0.968	1.007	0.985	1.001	0.967	0.999
93-94	0.995	1.006	1.021	1.000	1.008	0.982	1.012	0.991
94-95	0.994	1.008	0.955	1.001	1.010	1.012	0.980	1.024
95-96	0.992	1.018	0.969	0.993	0.990	1.028	0.990	1.021
96-97	0.984	1.021	1.016	1.001	1.006	0.973	1.000	0.985
98-99	0.992	1.077	0.982	1.002	1.001	0.991	1.044	1.062
99-00	0.987	1.070	0.966	1.000	1.015	1.012	1.049	1.083
00-01	0.992	1.064	0.968	1.003	1.008	0.975	1.009	1.041
01-02	0.992	1.059	0.954	0.998	0.996	1.043	1.042	1.087
02-03	0.994	1.053	0.979	0.986	1.027	1.012	1.050	1.071
03-04	0.990	1.046	0.990	0.976	1.007	1.006	1.015	1.025
04-05	0.988	1.037	0.965	0.986	1.016	0.902	0.894	0.929
05-06	0.984	1.032	0.956	1.001	1.007	0.987	0.966	1.010
06-07	0.991	1.028	0.998	1.021	0.993	0.989	1.020	1.022
07-08	0.965	1.027	0.955	1.024	1.008	1.001	0.979	1.024
08-09	0.985	1.024	0.987	1.001	1.005	1.002	1.004	1.018
92-09	***0.989***	***1.036***	***0.977***	***1.000***	***1.005***	***0.994***	***1.001***	***1.024***
92-97	***0.993***	***1.012***	***0.985***	***1.000***	***1.000***	***0.999***	***0.990***	***1.004***
98-09	***0.987***	***1.047***	***0.973***	***1.000***	***1.007***	***0.992***	***1.006***	***1.033***

Note: The superscript * indicates results obtained with reference to the metafrontier. As in (5) the TFP change rate of the Divisia index is given by the sum of scale effect (SC), technical change (TC), the effects of environmental variables (EX), allocative efficiency (ALLC), cost

efficiency (EC) and the mark-up effect (MU). TFP2 reports overall TFP without taking into account the environmental factors not accounted for in the Malmquist index.

Table 6: Metafrontier Malmquist Index

	SC*	***TC****	***EC****	***TFP****
92-93	0.968	1.028	0.946	0.963
93-94	0.969	1.116	1.041	1.126
94-95	0.958	1.066	0.965	1.018
95-96	1.007	1.029	0.917	0.975
96-97	0.949	1.022	1.012	0.996
97-98	0.983	1.067	1.036	1.109
98-99	0.909	1.064	0.902	0.859
99-00	0.958	1.112	1.109	1.178
00-01	0.929	1.067	0.935	0.914
01-02	1.003	1.401	1.132	1.356
02-03	0.957	1.164	1.008	1.065
03-04	0.924	1.256	0.998	1.132
04-05	0.927	1.030	0.825	0.765
05-06	0.949	1.007	0.973	0.986
06-07	0.998	1.009	0.942	1.054
07-08	1.010	1.050	0.977	1.131
08-09	0.978	1.022	0.977	1.016
92-09	0.963	1.085	0.979	1.030
92-97	0.970	1.052	0.975	1.014
98-09	0.960	1.099	0.981	1.036

Note: The superscript * indicates results obtained with reference to group the metafrontier. TFP = total factor productivity; TC = technical change; EC = efficiency change; SC= scale change.

Table 7: Technological Gap Ratio, Cost Efficiency and Metaefficiency

DEA		**1992-1997**	**1998-2009**	**1992-2009**
TGR	***State***	0.862	0.740	0.781
	Foreign	0.810	0.810	0.810
	Private	0.706	0.764	0.745
	All	0.793	0.771	0.779
EFF^k	***State***	0.910	0.892	0.898
	Foreign	0.908	0.868	0.881
	Private	0.697	0.622	0.647
	All	0.827	0.777	0.794
EFF*	***State***	0.784	0.657	0.699
	Foreign	0.735	0.702	0.713
	Private	0.491	0.475	0.480
	All	0.670	0.611	0.631
SFA				
TGR	***State***	0.949	0.826	0.867
	Foreign	0.935	0.828	0.864
	Private	0.891	0.765	0.806
	All	0.924	0.802	0.842
EFF^k	***State***	0.923	0.922	0.922
	Foreign	0.888	0.884	0.885

	Private	0.945	0.944	0.945
	All	0.924	0.923	0.923
EFF*	***State***	0.876	0.760	0.798
	Foreign	0.830	0.732	0.765
	Private	0.842	0.722	0.761
	All	0.853	0.739	0.777

Note: The superscript k indicates results obtained with reference to group specific frontiers; * indicates results obtained with reference to group specific frontiers. TGR = Technological Gap Ratio; EFF^k= cost efficiency; EFF* = metaefficiency.

Table 8: Number and proportion of technology leaders per ownership category

	SFA				***DEA***			
	1992-1997		***1998-2009***		***1992-1997***		***1998-2009***	
	No.	***%***	***No.***	***%***	***No.***	***%***	***No.***	***%***
Foreign	11	34	12	48	10	19	40	38
Private	9	28	7	28	9	17	30	29
State	12	38	6	24	34	64	34	33

Table 9: catch-up index pre and post 1998 per ownership group.

	SFA			***DEA***		
	S	***F***	***P***	***S***	***F***	***P***
92-97	0.990	0.976	1.007	1.019	0.928	0.905
98-09	1.047	0.996	1.030	1.082	0.968	1.004

Table 10: ADF test of convergence of (12)

DEA	***Foreign***		***State***		***Private***	
	Estimate	***P-value***	***Estimate***	***P-value***	***Estimate***	***P-value***
(γ_k-γ*)	0.013	0.410	-0.044	0.327	0.000	0.985
λ	0.764	0.021	0.814	0.290	0.461	0.378
SFA						
(γ_k-γ*)	0.003	0.190	-0.001	0.177	-0.001	0.505
λ	0.233	0.06	0.108	0.025	0.106	0.442

Note: This is an ADF test with one lagged difference term. We report directly the value of λ and its p-value is the MacKinnon p-value.

Figure 1: TGR distribution from SFA pre and post 1998 per ownership group

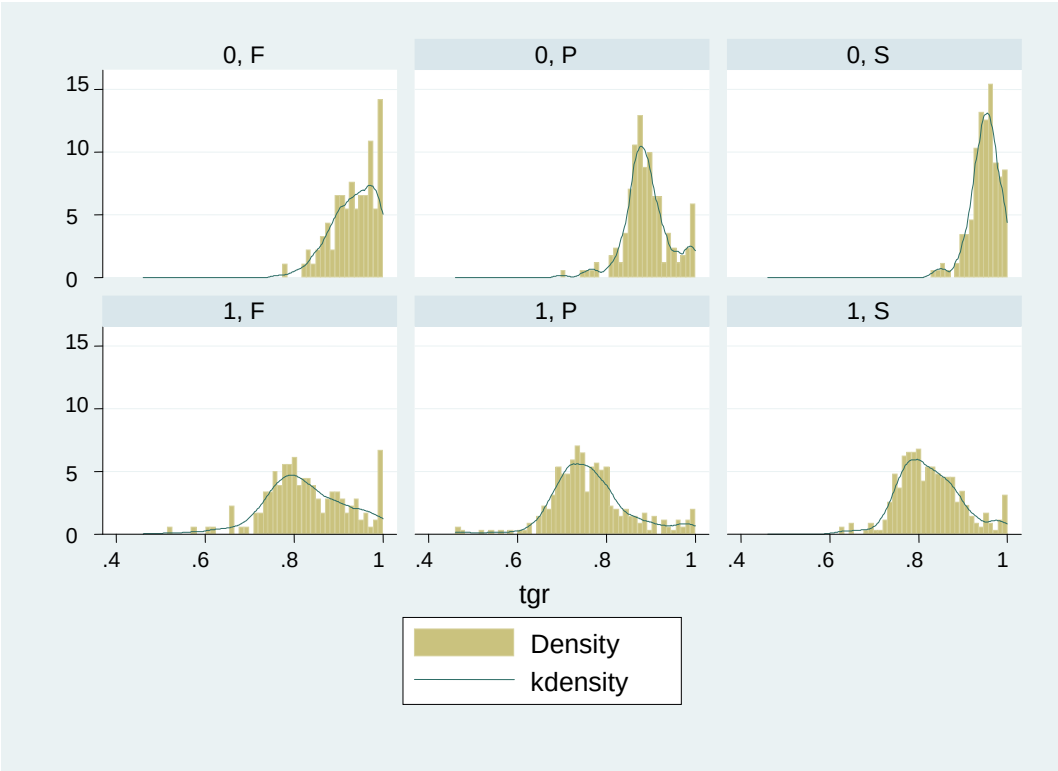
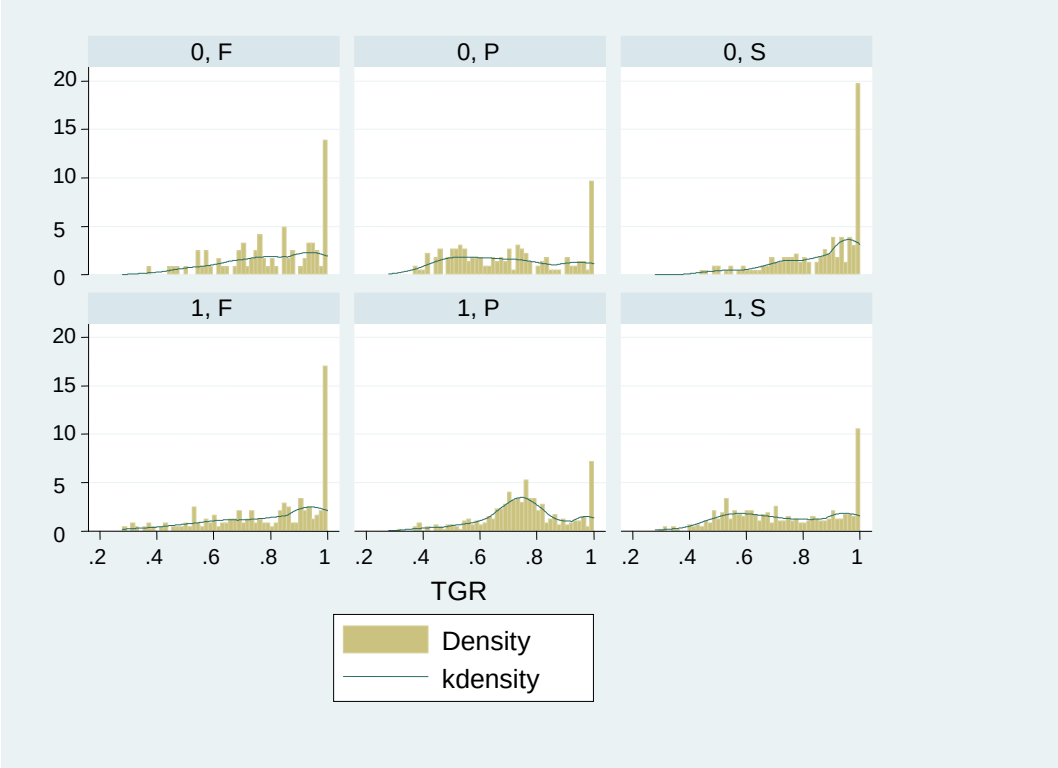


Figure 2: TGR distribution from DEA pre and post 1998 per ownership group



ENDNOTES

[1] The positive impact of financial reforms on the technology of production is typically based on two arguments. First, the overall cost of producing at a given level of output is reduced by declining compliance costs. Second, regulatory reforms usually reduce restrictions on activities, thereby offering the opportunity for banks to take advantage of economies of scale and scope. Efficiency improvements are expected to arise from the increased competitive pressures that reduce managerial inefficiencies.

[2] For detailed reviews of the impact of financial reforms on the productivity change of banking systems see for example Mukherjee *et al*, (2001), and Kumbhakar and Sarkar (2003).

[3] Deregulation seems to increase efficiency for all banks but does not result in inter-ownership convergence (Bonaccorsi di Patti and Hardy, 2005); different ownerships react with different speeds to the change of regulatory environment (Isik and Hassan, 2003; Leightner and Lovell, 1998); ownership structure becomes neutral in terms of productivity growth and a diverse ownership structure also functions as a stimulus to market competition (Sturm and Williams, 2004). A detailed literature review on this issue can be found in Sturm and Williams (2004).

[4] Structural deregulation was characterised by the removal of entry restrictions to private ownership, liberalization of interest rates on deposits and lending, and an increase in the range of permitted activities. Prudential norms related to assets classification, income recognition, provisioning, risk-based capital adequacy and informational disclosure.

[5] See Cole (2009) for a discussion of the relevance of bank ownership and economic growth.

[6] For a review of early literature see Berger and Humphrey (1997), and Goddard *et al* (2001). Reviews of more recent literature are presented, among others, by Berger (2007); Goddard *et al* (2007), Cook and Seiford (2009); Hughes and Mester (2010).

[7] Performing loans are measured as the difference between total loans and non-performing loans. Other earning assets aggregate government securities, other approved securities, shares, debentures and bonds, subsidiaries and joint ventures and other investment outside India (i.e. total investment).

[8] According to the accounting practice followed by the Indian banking sector post-1992, income accrual would cease once the loan is recognized as non-performing. Therefore, the interest received on loans recorded in the loss and profit account is associated with the performing loans.

[9] For a general review of the methodological approaches to efficiency and productivity measurement see for instance Fried *et al*. (2008).

[10] The subscripts *c* and *v* refer to whether the distance function is with respect to a constant returns to scale frontier or a variable returns to scale frontier.

[11] The estimation of a sequential frontier changes the superscript in Equation (1) from t to all the periods up to time *t*, i.e. 1,2,3,….t. The technical details can be found in Tulken and Vanden Eeckaut (1995) and Thirtle *et al*. (2003).

[12] This is essentially like a problem of degrees of freedom, leading to excessive estimates of efficiency when the number of variables is too high relative to the number of observations.

[13] We did not introduce fixed effects into the model as most of the heterogeneity seemed handled satisfactorily by the chosen variables and the separation of the ownership frontiers, as usefully suggested by an anonymous referee. Indeed as noted by Zhou (2001) a fixed effects estimation uses within-groups variation; since many of the regressors change only gradually over time this can potentially lead to over control and an overshadowing of the cross sectional relationship.

[14] As we will see this choice is based on a test of whether the data can be pooled.

[15] In (9) the hat notation indicates the estimator of the corresponding parameter.

[16] Given the focus of the paper and for reasons of space we do not provide a detailed discussion of the ownership-specific frontiers. The main results of their estimation are reported in Table A2 in the appendix.

[17]Private banks are the most heterogeneous group in the sample, hence the more "noisy" as they experience the largest number of entries and exits, mergers and acquisitions and show significant differences also depending on whether they are "old" or "new", as confirmed by the stochastic cost frontier results. The presence of all this noise cannot be accounted for by DEA which therefore ranks any of the bad performers much worse than SFA does.

[18] To make the comparison possible we transformed the TFP growth rate of the Divisia index into a TFP growth as the Malmquist.

[19] We also estimated a single metafrontier for the whole time period. The results were unsatisfactory and therefore are not reported.

[20] As discussed in the methodology section, TGR is computed as the ratio of metaefficiency to cost efficiency.

[21] Recall that increases in the technological gap ratios imply decreases in the gap between the group frontier and the metafrontier. The higher the ratio, the closer the group frontier is to the metafrontier (i.e. best available technology) and vice versa.

[22] The notable difference in the absolute number of technology leaders between the two methodologies is explained by their deterministic *vs* stochastic nature. Indeed if we were to lower the threshold even just to 99% for SFA the results would be remarkably closer.