Financial deregulation and productivity growth in banking sector: empirical evidence from Bangladesh

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Abstract

This article examines the effects of regulatory reform on productivity growth in the Bangladesh banking industry. We use a unique balanced panel dataset comprising bank-level annual data from the early deregulation year (1984) to the most recent available period (2012) from major commercial banks in Bangladesh. Applying the Färe-Primont index, the paper provides estimates of productivity growth and identifies sources of total factor productivity (TFP) change. Empirical results show the sample banks have experienced positive TFP change after the financial deregulation. On average, TFP growth is higher in private banks than their public sector counterparts in the post-reform period. In addition, the decomposition analysis shows technological progress is the main driver of productivity change. Similar results are obtained by using the stochastic frontier analysis (SFA). Thus, empirical results remain robust irrespective of the methodology used. The regression analysis finds a positive technical change in the first stage of the reform program, i.e., during the transition period, as leading banks employ advanced technology to compete with potential new entrants. The result also shows that the banking industry still remains concentrated within the state-owned banks.

Keywords: productivity, banks, Färe-Primont TFP index, financial deregulation

JEL: E23, D24, G21, G28

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1. Introduction

Banking efficiency and productivity continue to be important issues in the economics and finance literature, especially with financial deregulation and globalization of financial markets. Efficiency measures how close a system gets to the maximum output from a given set of inputs, while productivity growth is measured as the difference between the growth of output and the growth of inputs, i.e. the growth of output not attributable to the growth of inputs. The measurement of productivity growth goes back to the pioneering works of Abramovitz (1956) and Solow (1957), where productivity change, either across producers or through time, is a residual.

Effects of deregulation on productivity and efficiency in the banking sector have been widely studied across the world, especially in developed economies. However, the empirical evidence on the relationship between financial deregulation and banking performance is inconclusive. For example, Wheelock and Wilson (1999) find U.S. commercial banks became more technically inefficient between 1984 and 1993 with small banks declining in productivity compared to large ones. In contrast, Isik and Hassan (2003) find substantial improvement in productivity in Turkish commercial banking after deregulation. Similarly, Kumbhakar and Loazano-Vivas (2005) find deregulation contributed positively to TFP growth for Spanish savings and commercial banks. In fact, the consequences of deregulation may depend on industry conditions prior to the deregulation process as well as on the deregulation measures implemented (Robin, et al. 2018).

The banking sector in Bangladesh has undergone a series of legal, policy and institutional reforms over the past three decades. Bangladesh implemented a banking sector reform program largely during 1990-1995 although some reform initiatives took place since 1983 on ad hoc basis. While it has been more than two decades since reform measures were implemented, no research has been done so far to examine whether banking sector has become more productive due to financial reforms. Therefore, it is timely to evaluate the productivity of the banking sector in Bangladesh in the context of financial deregulation. Such evaluation should also help policy makers to understand the limitations of the reform policies taken and formulate accommodative policies in light of the contemporary challenges, especially due to recent global financial crisis.

This article explores the productivity dynamics and the sources of productivity growth for the 12 major commercial banks (which have both pre- and post-reform operation history) in Bangladesh in the context of financial liberalization. The question addressed here is whether financial deregulation has enhanced the productivity of the sample banks. We contribute to the literature by applying the Färe-Primont TFP index, suggested by O'Donnell (2008a), to compute and decompose the TFP change of the sample banks. TFP change can be decomposed into two main components, technical change and efficiency change. Efficiency change is then further decomposed into technical efficiency change, residual scale efficiency change and mix efficiency change. Alternatively, efficiency change is decomposed into technical efficiency change and scale-mix efficiency change. Once TFP change and its components are measured, a panel data regression framework is employed to examine the link between the estimated TFP change including its components and explanatory variables including reform period dummy variables and other key determinants of TFP growth.

The remainder of the paper is organized as follows: Section 2 presents an overview of the banking policy reforms undertaken in Bangladesh, followed by a discussion on the empirical design, data sources and variable construction in Section 3. Section 4 discusses the analytical framework of the Färe-Primont TFP index to be estimated. Section 5 presents the empirical results. Section 6 provides robustness check of the results and Section 7 concludes.

2. Banking policy reforms in Bangladesh: an overview

Since independence in 1971 Bangladesh experienced a variety of development approaches in different economic and political regimes. A command economy structure prevailed in the 1970s, which was characterized by administrative price-setting practices that lacked flexibility and responsiveness to relative scarcities, with attendant inefficiency in resource allocation (Salim, 2003). Low administered interest rates on savings in the inflationary environment discouraged financial savings and retarded financial intermediation. By the later 1970s, the negative effect of the command economy regime on the financial sector was recognized, which led to rationalization of interest rates in1980 with general upward revision, licensing of new private banks and privatization of two state-owned commercial banks in the early 1980s. Although significant, these reforms were seen as piecemeal and ad hoc steps.

After several reviews, the ‘Financial Sector Reform Program (FSRP)’ was implemented during 1990-1995. The main objective of the reform was to ensure an efficient and productive banking sector. The program addressed various policy reforms including introduction of market based interest rate policy, privatization of state-owned commercial banks and greater freedom for the operation of private sector banks and financial institutions, abolition of directed sectoral credit, revision of loan classification and provisioning criteria, revision of legal provisions and procedures for enforcing loan recovery, availability of credit information for loan risk assessment, application of advanced technology (e.g., ICT) in banking services and enhanced compliance with prudential regulations. A snapshot of the different banking policy reforms is presented in Appendix I.

Financial reform is a continuous process and it takes considerable time to get the benefit out of the deregulation initiatives. The policy measures of FSRP basically aimed at increased efficiency and productivity of the financial sector in Bangladesh. Although the management of both public and private sector banks has not been completely freed from undue influences, banking infrastructure and payment systems have been modernized to reduce systemic risks and increase efficiency of the banking sector. Both public and private sector banks have increasingly been using advanced technology in providing competitive banking services in the post-reform era.

3. Empirical design, data sources and variables

Estimates are provided of the TFP growth for 12 major commercial banks in Bangladesh, of which four banks are public or state-owned commercial banks (SCBs) and the rest are private sector commercial banks (PCBs). Since the focus of this research is to examine the effects of financial deregulation, the sample consists of all commercial banks that have operational history from 1984 through 2012, covering both pre- and post-reform periods. TFP change is compared over the three different periods, 1984-1990 as the pre-reform period, 1991-1995 as the transition period, and 1996-2012 as the post-reform period, in order to investigate whether banking reform policies have had any impact on bank productivity.

We calculate the Färe-Primont TFP index and apply the decomposition method suggested by O’Donnell (2008a, 2011a), which has several advantages. First, no strong assumption concerning the functional specification of the production technology is required. Second, no assumption is required concerning either the degree of competition in product markets or the optimization behaviour of the firms. Third, within the class of productivity indices, the Färe-Primont TFP index satisfies all the required properties (axioms and tests) of index number theory, including multiplicative completeness, additive completeness and transitivity. Finally, the Färe-Primont TFP index can be exhaustively decomposed in an economically meaningful way into three different components; a technical change component that measures movements in the production frontier, a technical efficiency change component that measures movements towards or away from the frontier, and a scale-mix efficiency change component that measures movements around the frontier surface. The computer program DPIN3.0 developed by O'Donnell (2011b) is used for computing and decomposing the Färe-Primont TFP index.

3.1 Data

We use a unique balanced panel dataset constructed from the balance sheets, income statements and other financial statements of the sample banks. The sample contains bank-level annual data for 12 major commercial banks in Bangladesh for the period 1984-2012. We construct the sample with the banks having both pre- and post-reform operation history. The sample banks contain 70 percent of the total assets and 56 percent of the total deposits of the banking industry in Bangladesh in 2012 (Bangladesh Bank, 2015).

The aggregate level banking data have been collected from the Central Bank of Bangladesh (Bangladesh Bank). The macro-financial data have been collected from the national statistical department, Bangladesh Bureau of Statistics (BBS), Ministry of Finance, the Government of Bangladesh, Bangladesh Security and Exchange Commission (BSEC), International Financial Statistics (IFS) of the IMF and World Development Indicator (WDI) of the World Bank.

3.2 Construction of the variables

Banks are modelled as multi-product firms producing two outputs and employing three inputs. Inputs are (1) labour (x_1), measured by the number of employees, (2) capital expenses (x_2), which equals total expenditure on premises and fixed assets and is measured by total operating expenses except salary and allowances and charges on loan/investment losses, and (3) loanable funds (x_3), which equals deposit and non-deposit funds. The output vectors are (1) total loans and advances (y_1), which include loans, cash credits and overdrafts and bills discounted and purchased, and (2) other earning assets (y_2), which comprises government securities, treasury bills, shares (fully paid), debentures, bonds and other investments (gross total assets less loans and physical capital/fixed assets).

Apart from input and output variables, bank-specific characteristics and environmental variables may influence the TFP change and its components. However, this is still a judgmental issue what variables should be taken into account (Kumbhakar and Lovell, 2003). We include several explanatory variables in the panel data regression model that may drive TFP change. These are equity capital (EQ), financial intermediation ratio (FI), bank ownership dummy variable (OWN), bank size (SIZE), market concentration (3-bank concentration) ratio (CR3), dummy variables for independent director (ID) and political director (PD) in the bank board, and deregulation period dummies for transition (DTr) and post-reform period (DPs). The pre-reform period is considered as the base period and therefore, a dummy variable for this period is not included in the model. The definition of each variable is reported in Appendix II along with the source for the data.

4. Analytical framework: measurement of the Färe-Primont Productivity Index

Total factor productivity change (TFP) and its components can be measured estimating both parametric (e.g., SFA) and nonparametric (e.g., DEA) efficiency frontiers. However, employing the SFA or the DEA approach, productivity scores of firms operating under a given production technology are not comparable with those operating under a different production environment and/or technologies (Battese et al., 2004). Hayami (1969) and Hayami and Ruttan (1970, 1971) propose the concept of metaproduction function to solve the incomparability of productivity measurement of different groups of farms with heterogeneity. In the SFA, the metafrontier function is as an overarching function of a given mathematical form that encompasses the deterministic components of the stochastic frontier productions for the firms operating under the different technologies involved (Battese et al., 2004). Amsler, O'Donnell and Schmidt (2017) include the random or stochastic portion of the frontier in addition to the deterministic part of the frontier while evaluating the metafrontier distance function. O'Donnell, Rao and Battese (2008b) also develop the DEA-based metafrontier framework.

Casu, Ferrari and Zhao (2013) examine the productivity change of different groups of Indian banks with technological heterogeneity within a metafrontier framework in both parametric and nonparametric settings. The DEA-based metafrontier CM (cost Malmquist) productivity index analysis of Taiwanese and Chinese commercial banks reveals that DEA is attractive over parametric techniques for its advantages on requiring little knowledge on functional specification of the production technology and handling the modelling of multiple inputs and multiple outputs (Huang et al., 2015). Zhu et al. (2018) utilize a DEA-based non-radial and non-oriental biennial-Luenberger productivity indicator within the metafrontier framework to investigate TFP growth of the Chinese banking sector and three banking groups for the period 2004-2012. Oh and Lee (2010) compare productivity changes and the decomposed components of economic agents under different production technologies across 58 countries employing the nonparametric Malmquist productivity index based on a metaproduction frontier.

There exists one technological frontier for all sample firms (or banks) operating under homogeneous production environment and/or technology. Nguyen and Simioni (2015) employ DEA-based Färe-Primont productivity index to measure the TFP growth and its components for a sample of Vietnamese banks operating under homogeneous production technology. Similarly, we assume each of our sample bank experiences the same production technology considering the sample size of 12 banks (four public and eight private). We employ the non-parametric DEA technique to compute the Färe-Primont productivity index as suggested by O'Donnell (2011a) to estimate the TFP growth of our sample banks.

TFP measurement using input and output distance functions calculated from data envelopment analysis (DEA) is considered superior to the traditional econometric TFP measures, as in Solow (1957), which are residuals from ordinary least squares (OLS) estimates of average production functions that cannot separate technical efficiency from technological change or progress (Colwell and Davis, 1992). Further, the econometric estimation of distance functions is not straight forward because there is a possibility that some of the explanatory variables may be correlated with the composite error term (Coelli et al., 2005, Färe and Primont, 1995). O'Donnell (2013) makes a similar observation that more than one variable in the econometric estimation of distance functions may be endogenous and, in such cases, maximum likelihood estimation can lead to biased and inconsistent parameter estimates.

Change in the Färe-Primont TFP index can be decomposed into a measure of technical change and several measures of efficiency change. The efficiency measures include a measure of overall productive efficiency and component measures of technical, scale and mix (or scope) efficiency. Technical change reflects movements in the production frontier and technical efficiency change measures the movements towards or away from the frontier. Scale efficiency change measures the movements around the frontier surface to capture economies of scale and mix efficiency change measures the movements around the frontier surface to capture economies of scope.

The total factor productivity of a firm is the ratio of an aggregate output index to an aggregate input index (Jorgenson and Griliches, 1967). Let $y_{it} = (y_{1it},......y_{jit})'$ and $x_{it} = (x_{1it},......x_{kit})'$ denote the output and input vectors respectively for firm i in period t. The multi-factor productivity (MFP) or total factor productivity (TFP) of a firm is then:[1]

$$TFP_{it} = Y_{it} / X_{it} \qquad (1)$$

where $Y_{it} = Y(y_{it})$ is an aggregate output index, $X_{it} = X(x_{it})$ is an aggregate input index. Both Y(.) and X(.) are non-negative, non-decreasing and linearly homogeneous aggregator functions. The associated index number that measures the relative TFP of firm i in period t and firm m in period s is:

$$TFP_{ms,it} = \frac{TFP_{it}}{TFP_{ms}} = \frac{Y_{it} / X_{it}}{Y_{ms} / X_{ms}} = \frac{Y_{ms,it}}{X_{ms,it}} \qquad (2)$$

where $Y_{ms,it} = Y_{it}/Y_{ms}$ and $X_{ms,it} = X_{it}/X_{ms}$ are output and input quantity indices, respectively. Equation (2) expresses TFP growth as a measure of output growth divided by a measure of input growth, which is defined as productivity change (Jorgenson and Griliches, 1967).

Following Shephard (1953), output and input distance functions, which are non-negative, non-decreasing and linearly homogeneous, are expressed as:

$$Y(y) = D_O(x_o, y, t_o)$$
$$X(x) = D_I(x, y_o, t_o)$$

where y and x are vectors of output and input quantities respectively and $D_O(.)$ and $D_I(.)$are output and input distance functions. The Färe-Primont index can then be expressed as:

$$TFP_{ms,it} = \frac{D_O(x_o, y_{it}, t_o)}{D_o(x_o, y_{ms}, t_o)} \frac{D_I(x_{ms}, y_o, t_o)}{D_I(x_{it}, y_o, t_o)} \qquad (3)$$

4.1 Technical change (TC) and TFP efficiency (TFPE)

The Färe-Primont TFP index can be exhaustively decomposed into measures of technical change (TC) and efficiency change (TFPE). Technical change is the change in the maximum

[1] The terminology ‘multi-factor productivity (MFP)’ is used in the literature considering the fact that multiple but not all factors of production are accounted for production process. However, O’Donnell (2008a, 2011a) uses the term total factor productivity (TFP) instead of MFP in productivity analysis.

productivity possible using the production technology.TFP efficiency is an overall measure of productive efficiency defined as the difference between observed TFP and the maximum TFP possible using the available production technology.

Therefore, TFP efficiency of a firm in period t is given by:

$$TFPE_t = \frac{TFP_t}{TFP_t^*} = \frac{Y_t / X_t}{Y_t^* / X_t^*} \tag{4}$$

where TFP_t^* denotes the maximum TFP possible using the period-t technology and Y_t^* and X_t^* denote the aggregate output index and aggregate input index at the TFP-maximizing point.

Technical change (TC) between the two periods (period t and period s) technology is a measure of the shift in the production frontier (Figure 1) and is given by:

$$TC_{t.s} = \frac{TFP_t^*}{TFP_s^*} \tag{5}$$

where the industry experiences technological progress or regress if TFP_t^* / TFP_s^* is greater than one or less than one, respectively.

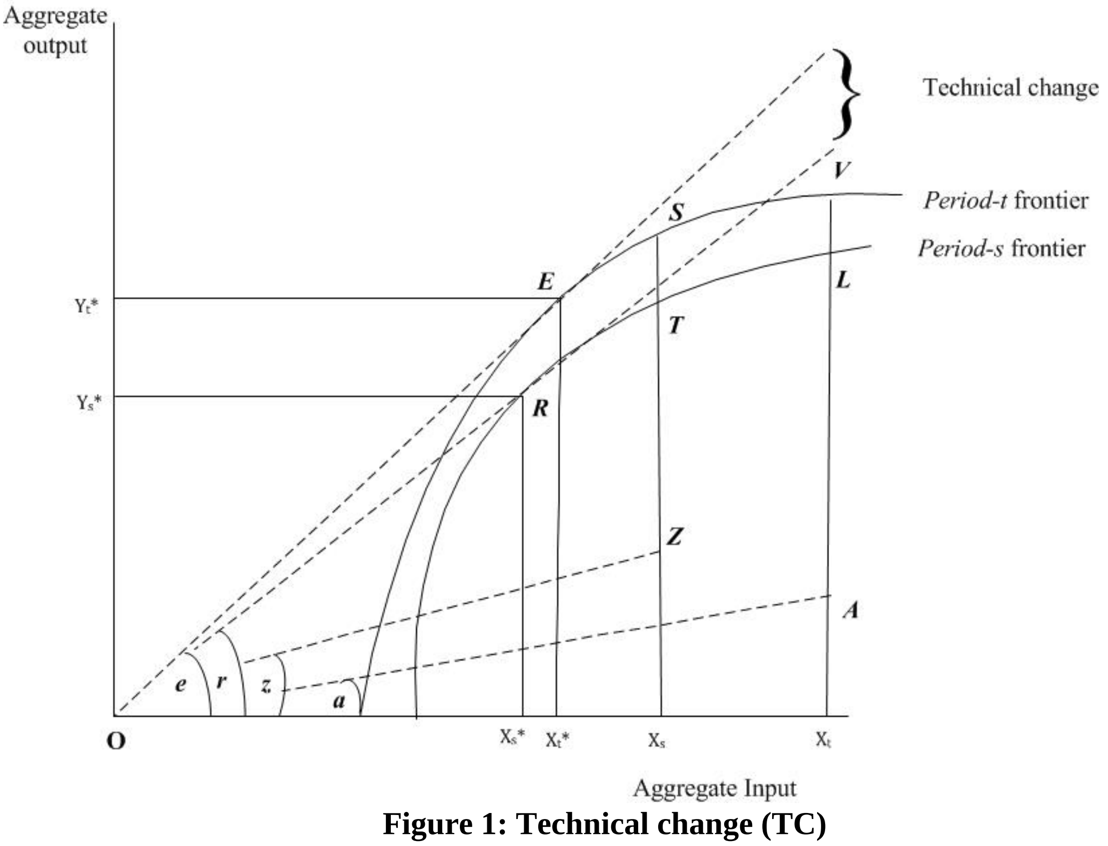

Figure 1: Technical change (TC)
Source: O'Donnell(2008a)

4.2 TFP change and its components

Following Equations (2), (4) and (5), the multiplicatively-complete TFP index in period *t* relative to period *s* is defined as:

$$TFP_{s,t} = \frac{TFP_t}{TFP_s} = \left(\frac{TFP_t^*}{TFP_s^*}\right) \times \left(\frac{TFPE_t}{TFPE_s}\right) \tag{6}$$

The first term in parentheses measures the change in the maximum TFP over time and, thus, is a natural measure of technical change. The second term in parentheses is a measure of overall efficiency change.

The TFP index comparing productivity (output-oriented) in periods, *s* and *t* can be decomposed further as is shown in O'Donnell (2012):

$$TFP_{s,t} = \frac{TFP_t}{TFP_s} = \left(\frac{TFP_t^*}{TFP_s^*}\right) \times \left(\frac{OTE_t}{OTE_s}\right) \times \left(\frac{OME_t}{OME_s}\right) \times \left(\frac{ROSE_t}{ROSE_s}\right) \tag{7}$$

$$= \left(\frac{TFP_t^*}{TFP_s^*}\right) \times \left(\frac{OTE_t}{OTE_s}\right) \times \left(\frac{OSE_t}{OSE_s}\right) \times \left(\frac{RME_t}{RME_s}\right) \tag{8}$$

$$= \left(\frac{TFP_t^*}{TFP_s^*}\right) \times \left(\frac{OTE_t}{OTE_s}\right) \times \left(\frac{OSME_t}{OSME_s}\right) \tag{9}$$

O'Donnell (2008a) defines the terms, OTE, OME, ROSE, OSE, RME and OSME in terms of TFP measures. OTE is output-oriented technical efficiency given by the ratio of observed TFP to the maximum TFP possible holding the input vector and the output mix fixed. OSE is output-oriented scale efficiency, which measures the difference in TFP at a technically-efficient point and the point of MIOS (mix-invariant optimal scale, the TFP-maximizing point where input and output mixes are both held fixed). OME is output-oriented mix efficiency defined as the difference between TFP at a technically-efficient point on a (mix-) restricted frontier and TFP at a point on an unrestricted frontier holding the input vector fixed. ROSE is residual scale efficiency defined as the ratio of TFP at a technically- and mix- efficient point to the maximum TFP when input and output mixes are varied, which is residual in terms of arising from different input and output mixes even though all the points on the unrestricted frontier are mix-efficient. RME is residual mix efficiency, which is defined as the difference between TFP at the point of mix-invariant optimal scale (MIOS) and the maximum TFP possible when input and output mixes are varied as in the measurement of ROSE. OSME, output-oriented scale-mix efficiency, can be obtained: $OSME_t = OME_t \times ROSE_t = OSE_t \times RME_t$

Similar TFP decompositions can be obtained for input-oriented production technology as follows:

$$TFP_{s,t} = \frac{TFP_t}{TFP_s} = \left(\frac{TFP_t^*}{TFP_s^*}\right) \times \left(\frac{ITE_t}{ITE_s}\right) \times \left(\frac{IME_t}{IME_s}\right) \times \left(\frac{RISE_t}{RISE_s}\right) \qquad (10)$$

$$= \left(\frac{TFP_t^*}{TFP_s^*}\right) \times \left(\frac{ITE_t}{ITE_s}\right) \times \left(\frac{ISE_t}{ISE_s}\right) \times \left(\frac{RME_t}{RME_s}\right) \qquad (11)$$

$$= \left(\frac{TFP_t^*}{TFP_s^*}\right) \times \left(\frac{ITE_t}{ITE_s}\right) \times \left(\frac{ISME_t}{ISME_s}\right) \qquad (12)$$

O'Donnell (2008a) defines the terms, ITE, IME, RISE, ISE, RME and ISME in parallel to the corresponding output-oriented measures. For example, ITE is input-oriented technical efficiency given by the ratio of observed TFP to the maximum TFP possible holding the output vector and the input mix fixed. Other input-oriented variables are defined in a similar in relation to the corresponding output-oriented variable aside from RME, which is defined identically for both output-oriented and input-oriented measures.

We use both input-oriented and output-oriented distance functions to compute the Färe-Primont TFP index and its decomposition. Equations (9) and (12) reveal productivity change can be broken into three intrinsically different components: a technical change component that measures movements (or shifts) in the production frontier, a technical efficiency change component which measures movements towards the frontier and a scale-mix efficiency change component that measures movements around the frontier surface. The detail theoretical explanation for computing output- and input-oriented Färe-Primont TFP index using the DEA technique is described in Appendix III.

4.3 Determinants of productivity change

A panel data regression model is constructed following Suyanto, Bloch and Salim (2012) to estimate the influence of various bank-specific and environmental variables on the estimated Färe-Primont TFP index and its components separately. The proposed empirical model is as follows:

$$FPI_i^{s,t} = \alpha_i + \beta X_{it} + \varepsilon_{it} \qquad (13)$$

where, $FPI_i^{s,t}$ is the relative measure of productivity for bank i between two time periods *s* (the base period) and *t* (the reference technology period). The Färe-Primont productivity index ($FPI_i^{s,t}$) gives the value of each productivity measure in period t divided by the value of same measure in period s, so it indicates the change in TFP (ΔTFP), technology (ΔTC) and the efficiency components, such as ΔOTE and ΔOSME. The independent variable X_{it} represents bank-specific and environmental variables discussed in sub-section 5.3, α is the constant term, β is a vector of parameters to be estimated and ε denotes the error term. The Hausman (1978) test is undertaken to choose the model that best represents the sample data.

5. Empirical results and discussion

This section reports the estimates of Färe-Primont TFP change and its components, technical change and efficiency change, obtained under the assumption the production technology exhibits variable returns to scale (VRS). Since the production possibilities set may expand or contract, the index of technical change (ΔTC) may be greater than one (i.e., technical progress) in some periods and less than one in other periods (i.e., technical regress). Technical change is interpreted as the shift in the production frontier. In terms of efficiency change estimates, a technical efficiency index (ΔOTE) estimate greater than one indicates that the corresponding bank is closer to the frontier, while an index below the unity means that the corresponding bank is moving further from the frontier. Similar interpretations apply to the efficiency change components. Both input- and output-oriented productivity changes are estimated. The estimated results for both orientations are very similar and only output-oriented estimates are reported in the next sub-section, while input-oriented estimates are reported in Appendices IV(a) and IV(b).

5.1 TFP change: technical change and efficiency change

The estimated average Färe-Primont TFP change and its principal components, technical and efficiency change are reported in Table 1 and 2, respectively, for public banks and private banks. The individual bank estimates are not presented here due to space limitation. However, they can be provided upon request. Since the Färe-Primont TFP index satisfies the index number axiom of transitivity, the reported estimates can be used to make meaningful comparisons of performance across banks (inter-spatial) and time periods (inter-temporal).

The calculated DEA based Färe-Primont TFP index scores range between zero (0) to one (1), where one being the maximum efficient and the scores less than one indicates different levels of inefficiency. Since productivity changes are measured as the ratio of the value of the productivity index in two adjacent years, the value can be greater or less than one even though each index is less than or equal to one. The estimated values greater than unity indicate an improvement in performance. Conversely, estimated values less than unity indicate deterioration.

5.1.1 TFP change and public banks

Table 1 presents the average TFP change (ΔTFP) and its components, technical change (ΔTC) and efficiency change for public banks. The components of the output-oriented efficiency change are output-oriented technical efficiency change (ΔOTE) and scale-mix efficiency change (ΔOSME), where ΔOSME=ΔOME×ΔROSE. ΔOME is mix efficiency change and ΔROSE is residual scale efficiency change.

Table 1: TFP change for public banks

Period	ΔTFP	ΔTC	ΔOTE	ΔOSME
Pre-reform Period, 1984-1990				
1985/ 84	1.235	1.127	1.001	1.090
1986/85	0.993	0.917	1.008	1.074
1987/86	0.879	0.702	1.000	1.253
1988/87	1.012	1.079	1.000	0.937
1989/88	1.048	0.939	0.984	1.135
1990/89	0.947	1.021	0.983	0.943
Transition Period, 1991-1995				
1991/90	1.012	1.082	1.008	0.928
1992/91	1.025	0.997	0.986	1.042
1993/92	1.107	1.077	1.044	0.987
1994/93	1.082	1.117	0.958	1.019
1995/94	1.066	0.988	1.006	1.074
Post-reform Period, 1996-2012				
1996/95	1.078	2.721	0.981	0.404
1997/96	1.083	0.369	1.045	2.821
1998/97	1.004	1.085	0.993	0.933
1999/98	1.200	0.982	0.979	1.249
2000/99	1.072	0.977	1.010	1.086
2001/00	1.245	1.007	1.029	1.201
2002/01	1.076	1.059	0.991	1.026
2003/02	0.913	0.978	1.009	0.925
2004/03	1.049	1.064	0.999	0.987
2005/04	1.079	0.997	0.999	1.089
2006/05	1.035	1.203	1.017	0.846
2007/06	1.019	1.099	1.000	0.927
2008/07	1.010	1.156	0.969	0.904

2009/08	1.028	0.798	1.022	1.263
2010/09	1.183	1.213	0.982	0.994
2011/10	1.001	1.054	1.025	0.927
2012/11	1.021	0.974	1.002	1.046

Source: Authors' calculation

As shown in Table 1, the public banks have been experiencing positive TFP change during the transition and the post-reform period except in 2002-2003. The change in TFP components during these two periods shows that no single component either ∆TC or ∆OTE or ∆OSME dominates in TFP change. Both technical change and efficiency change contribute to TFP change. Their contribution occurs together in the same year or separately in different years.

Positive technical change during the transition and post-reform periods in Table 1 suggests that the implementation of the reform policies creates an environment where public banks attain technological progress, perhaps due to the adoption of advanced information and communication technology (ICT). This is consistent with the findings obtained from a study of Greek banking (Rezitis, 2006).

5.1.2 TFP change and private banks

The private banks have been experiencing positive TFP change since 1987/86. However, negative change was observed during 1985/1984 and 1986/1985 (as shown in Table 2), perhaps due to higher cost of funds during the initial years of their establishment. There are also several years in the post-reform period when TFP for private banks deteriorates, which is different from the experience of the public banks.

Table 2 shows technical change (∆TC) along with the efficiency change components. Scale-mix efficiency change (∆OSME) and technical efficiency change ∆OTE deteriorate in several years during the sample period. The estimated scores (less than one) for efficiency changes indicate loss of efficiency relative to the best-performing bank in that year. Annual variations in the measures may be due to reporting errors or temporary shocks to operations and suggest the need for caution in interpreting annual data.

A general comparison of the different indices in Table 1 and Table 2 reveals technical change (∆TC) contributes most to TFP change over the years for both public and private sector banks. This is consistent with the findings of Maredza and Ikhide (2013). One possible reason for such technical progress is the adoption of advanced technology in developing banking products and services. Technology based banking services include online banking, mobile phone banking, credit card, debit card and ATM services.

Table 2: TFP change for private banks

Period	∆TFP	∆TC	∆OTE	∆OSME
Pre-reform Period, 1984-1990				
1985/84	0.990	1.127	0.972	0.924
1986/85	0.996	0.917	0.983	1.113
1987/86	1.049	0.702	1.095	1.364
1988/87	1.025	1.079	1.017	0.934
1989/88	1.008	0.939	0.996	1.079
1990/89	1.008	1.021	0.985	1.001
Transition Period, 1991-1995				
1991/90	1.036	1.082	1.005	0.953
1992/91	1.029	0.997	0.941	1.136
1993/92	1.069	1.077	1.111	0.928
1994/93	1.045	1.117	0.941	0.996
1995/94	0.987	0.988	1.050	0.956
Post-reform Period, 1996-2012				
1996/95	1.794	2.721	0.921	0.706
1997/96	0.993	0.369	1.104	2.551
1998/97	1.032	1.085	0.999	0.952
1999/98	1.197	0.982	1.051	1.167
2000/99	1.124	0.977	1.021	1.126
2001/00	1.075	1.007	0.984	1.084
2002/01	1.052	1.059	0.983	1.011
2003/02	0.982	0.978	1.047	0.965
2004/03	0.988	1.064	0.991	0.937
2005/04	1.091	0.997	0.997	1.100
2006/05	1.087	1.203	1.000	0.903
2007/06	1.072	1.099	1.007	0.969
2008/07	1.071	1.156	0.992	0.936
2009/08	1.036	0.798	1.019	1.274
2010/09	1.131	1.213	0.979	0.955
2011/10	1.051	1.054	1.020	0.982
2012/11	1.017	0.974	1.003	1.041

Source: Authors'calculation

5.2 Periodic average of TFP change and its components

Table 3 reports the estimated period averages of TFP change and its components for the three sample periods, the pre-reform period 1984-1990, the transition period 1991-1995 and the post-reform period 1996-2012. The estimated period averages in Table 3 show a positive average TFP change is observed in both the transition and the post-reform period compared to the pre-reform period. The increase in average positive TFP change for the sample banks is three percent in the transition period and seven percent in the post-reform period compared to the pre-reform period. Mainly technological progress (ΔTC) contributes in gaining positive TFP change in both the periods.

Table 3: Periodic average of TFP change and its components

Banks	ΔTFP	ΔTC	ΔOTE	ΔOSME
Pre-reform Period, 1984-1990				
Public Banks	1.019	0.964	0.996	1.072
Private Banks	1.013	0.964	1.008	1.069
Transition Period, 1991-1995				
Public Banks	1.058	1.052	1.000	1.009
Private Banks	1.033	1.052	1.009	0.994
Post-reform Period, 1996-2012				
Public Banks	1.064	1.102	1.003	1.095
Private Banks	1.105	1.102	1.007	1.098

Source: Authors' calculation

The growth in average TFP is higher in public banks in the transition period compared to their private sector counterpart. On the other hand, the growth in average TFP is observed higher in private banks compared to public banks during the post-reform period. Casu et al. (2004) find a positive change in TFP, ascribing it to technical progress in the European banking in the post-deregulation period. The improvement in technical change is attributed to the application of advanced technology, especially ICT in producing cost-effective banking products and services after the implementation of financial reform program.

In terms of efficiency gain, Table 3 shows that the public and private banks gain positive change in average technical efficiency (ΔOTE) during the transition and the post-reform period. Both public and private banks attain higher levels of average scale-mix efficiency change (ΔOSME) in the post-reform period compared to both the transition and pre-reform period. One possible reason is the banks increase the scale of production expanding their branch network and also use input mix more cost effectively. Empirical studies by Isik and Hassan (2003) and Rezitis (2006) find similar results for Turkish and Greek banking, respectively.

5.3 Determinants of productivity change and its components

With the calculated values of the Färe-Primont TFP index, we can empirically model the panel data regression framework following the section 4.3 to investigate the drivers and determinants of TFP change and its components. Equation (13) can be modelled as follows:

$$FPI_i^{s,t} = \alpha_i + \beta_1 EQ + \beta_2 FI + \beta_3 OWN + \beta_4 ID + \beta_5 PD + \beta_6 SIZE +$$
$$\beta_7 DTr + \beta_8 DPs + \beta_9 CR3 + e_i \qquad (14)$$

where, FPI_i is the measured Färe-Primont TFP index for i banks. As outlined in Section 3.2, the explanatory variables are equity capital (EQ), financial intermediation ratio (FI), ownership (OWN), dummy variable for independent director in the bank board (ID), dummy variable for political director in the bank board (PD), bank size (SIZE), 3-bank concentration ratio (CR3), dummy variable for transition period (DTr), dummy variable for post-reform period (DPs). The pre-reform period dummy is treated as the base, so the coefficient of (DTr) and (DPs) can be interpreted as the change in productivity from the pre-reform period to the transition and the post-reform period respectively. α is the constant term, β is the vector of parameters to be estimated and ε denotes the error term.

Both random effect (RE) and fixed effect (FE) models are estimated for Equation (14). The Hausman specification test is performed to choose which of the models is appropriate for representing the sample data. Based on the results shown for the probability for λ^2-statistic in Appendix V, the RE model is chosen. The estimated parameters for the RE model are reported in Table 4, while the estimated parameters for FE model are presented in Appendix V.

The estimated constant term (Table 4) captures any trend movement in change in the dependent variable. A value greater than one indicates trend improvement and, a value less than one indicates trend deterioration. None of the constant terms differ from the value of one (the estimated coefficient minus one divided by the standard error is less than 1.0 in each regression), so there is no evidence of a statistically significant time trend.

Table 4: Determinants of TFP change and its components

	ΔTFP	**ΔTC**	**ΔOTE**	**ΔOSME**
Constant	2.449	1.104	1.009***	1.537
	(2.553)	(0.718)	(0.210)	(1.995)
Equity (EQ)	0.021	-0.007	0.000	0.031
	(0.038)	(0.009)	(0.003)	(0.030)
FI	-0.687***	-0.109*	-0.006	-0.592***
(financial intermediation)	(0.204)	(0.062)	(0.018)	(0.161)
OWN	-0.034	-0.031	-0.002	-0.008
(ownership)	(0.251)	(0.068)	(0.019)	(0.195)
Independent Director (ID)	0.169	-0.044	0.008	0.200

	(0.281)	(0.085)	(0.025)	(0.221)
Political Director (PD)	0.029	0.007	0.005	0.015
	(0.191)	(0.052)	(0.015)	(0.149)
Size (SIZE)	-0.173	0.039	-0.006	-0.149
	(0.296)	(0.083)	(0.024)	(0.231)
Transition (DTr)	-0.015	0.303***	-0.003	-0.103
	(0.189)	(0.058)	(0.017)	(0.149)
Post-reform (DPs)	0.194	-0.144**	0.025	0.505***
	(0.217)	(0.066)	(0.019)	(0.171)
Concentration (CR3)	0.992	-0.428**	0.062	1.819***
	(0.710)	(0.212)	(0.062)	(0.559)
R-squared	0.056	0.182	0.010	0.101
Wald Chi-square	20.62	75.27	3.57	38.56
Total observations	348	348	348	348

Source: Authors' estimation using STATA14. The pre-reform period is treated as the base period. Standard errors are in parentheses;*** denotes statistical significance level at 1%; ** denotes the level of statistical significance at 5%; * denotes statistical significance level at 10%.

The negative and statistically significant coefficients for financial intermediation ratio (FI) for technical change (ΔTC) and efficiency change component ΔOSME, suggest banks are setting their FI too high to achieve scale efficiency, as reflected in the estimated highly significant negative coefficient in the TFP regression. One possible reason for such a decline in productivity is competition among the banks to invest their deposits to risky businesses expecting higher returns without doing proper feasibility studies, resulting increase in non-performing assets of the banks.

The positive and statistically significant coefficient for deregulation dummy variable DTr (transition period) is consistent with the liberalization process, with positive technical change (ΔTC) in the first stage of the reform program, i.e., during the transition period as leading banks employ modern technology to compete with potential new entrants. The negative and significant coefficient for DPs (post-reform period) for technical change is offset by more efficient use of inputs (higher OSME) as all banks move towards the best-practice input mix and scale. This pattern fits with the positive technical change and little efficiency change in the transition period in the average results in Table 3. There is also substantial OSME gain in the post-reform period in the results in Table 3, although the high TC gain in the post-reform period is not reflected in the Table 4 results.

The significant results for the CR3 variable suggest higher concentration reduces technical progress, but increases efficiency. Delis (2012) argues that financial liberalization policies may not increase competition in relatively underdeveloped countries. Similarly, the banking industry in Bangladesh still remains concentrated within the state-owned banks. However, using more efficient input mixes helps the banking sector gaining scale mix efficiency (OSME).

6. Robustness check

To check the robustness of the empirical results presented in Section 5, we employ the alternative stochastic frontier analysis (SFA) to re-estimate the Färe-Primont TFP index of the sample banks. Following O'Donnell (2016), TFP index can be decomposed into several components using the SFA method, i.e., TFPI= OTCI×OTEI×OSMEI×SNI, where, OTCI is the output-oriented technology index, OTEI is the output-oriented technical efficiency index, OSMEI is the output-oriented scale mix efficiency index and SNI is the statistical noise index. Here, SNI= exp (ν - υ), where ν ~iid $N(0,\sigma_{\nu}^{2})$ is an independently distributed normal random variable with a mean of zero and a variance of $\sigma_{\nu}^{2};\upsilon$ is an independently distributed half-normal random variable obtained by lower-truncating the $N(0,\sigma_{\upsilon}^{2})$ distribution at zero. The computer program DPIN3.0 in the 'R' environment is used for the SFA estimation.

Table 5: TFP change for public banks

Period	ΔTFPI	ΔOTCI	ΔOTEI	ΔOSMEI
Pre-reform Period, 1984-1990				
1985/84	1.185	1.024	1.013	1.082
1986/85	0.991	1.024	1.001	0.97
1987/86	0.855	1.024	0.985	0.898
1988/87	1.011	1.024	0.986	1.031
1989/88	1.048	1.024	0.985	1.066
1990/89	0.945	1.024	0.994	0.927
Transition period, 1991-1995				
1991/90	1.012	1.024	1.015	0.954
1992/91	1.024	1.024	0.987	1.028
1993/92	1.106	1.024	1.016	1.045
1994/93	1.081	1.024	1.007	1.034
1995/94	1.065	1.024	0.994	1.059
Post-reform Period, 1996-2012				
1996/95	1.076	1.024	0.999	1.058
1997/96	1.083	1.024	1.003	1.047
1998/97	1.004	1.024	0.992	1.004
1999/98	1.198	1.024	1.025	1.072

2000/99	1.071	1.024	1.003	1.042
2001/00	1.228	1.024	1.033	0.995
2002/01	1.076	1.024	1.003	1.039
2003/02	0.905	1.024	0.960	1.111
2004/03	1.049	1.024	1.000	1.025
2005/04	1.076	1.024	0.996	1.067
2006/05	1.035	1.024	0.993	1.033
2007/06	1.017	1.024	1.029	0.890
2008/07	1.008	1.024	0.991	1.017
2009/08	1.027	1.024	0.999	1.005
2010/09	1.180	1.024	1.026	1.017
2011/10	0.998	1.024	0.987	1.069
2012/11	1.020	1.024	0.994	1.023

Source: Authors' calculation

Comparisons between the SFA estimates and the DEA estimates involve comparing an index change shown in each column in Tables 1 and 2 to the corresponding column in Tables 5 and 6 with I added to the index label. Thus, values in the column ΔTFPI in Table 5(or 6) are compared to those in the column ΔTFP in Table 1(or 2). The SFA estimates show positive TFP growth for both public and private banks in all years in the transition and almost all years in the post-reform periods similar to the corresponding results employing the DEA approach. In the pre-reform period (1987/86-1990/89), both private and public banks experience a mix of years with falling and rising TFP under both estimation methods.

Table 6: TFP change for private banks

Period	ΔTFPI	ΔOTCI	ΔOTEI	ΔOSMEI
Pre-reform Period, 1984-1990				
1985/1984	0.956	1.024	0.989	0.981
1986/1985	0.993	1.024	0.997	1.001
1987/1986	1.028	1.024	1.001	1.025
1988/1987	1.020	1.024	1.001	0.995
1989/1988	1.004	1.024	0.985	1.025
1990/1989	1.002	1.024	0.988	1.010
Transition Period, 1991-1995				
1991/1990	1.035	1.024	0.990	1.033
1992/1991	1.028	1.024	0.970	1.064
1993/1992	1.068	1.024	1.032	0.983
1994/1993	1.034	1.024	1.015	0.949
1995/1994	0.985	1.024	0.99	1.010
Post-reform Period, 1996-2012				
1996/1995	1.259	1.024	1.016	1.084
1997/1996	0.835	1.024	0.971	0.942
1998/1997	1.030	1.024	1.005	0.997
1999/1998	1.178	1.024	1.027	1.083
2000/1999	1.112	1.024	1.019	1.030

2001/2000	1.073	1.024	1.000	1.057
2002/2001	1.050	1.024	1.001	1.026
2003/2002	0.978	1.024	0.981	1.013
2004/2003	0.985	1.024	0.989	0.995
2005/2004	1.087	1.024	0.986	1.100
2006/2005	1.083	1.024	1.002	1.048
2007/2006	1.068	1.024	1.011	1.014
2008/2007	1.069	1.024	0.997	1.050
2009/2008	1.028	1.024	1.006	0.992
2010/2009	1.130	1.024	1.007	1.082
2011/2010	1.049	1.024	1.010	0.992
2012/2011	1.016	1.024	1.007	0.970

Source: Authors' calculation

As with the DEA estimates, the estimated impact of technical progress is constrained to be identical for each of the public and private banks. Both DEA and SFA estimates show that technological progress (ΔTC and ΔTCI) is generally positive, but under SFA estimation technical progress is constrained to be constant over the sample period. In contrast, estimates of technical change can and do vary substantially from year to year under DEA estimation, with some years showing extreme values of both technical progress and technical regress.

Both estimation methods have annual variation in estimates of both efficiency change (ΔOTE and ΔOTEI) and scale-mix efficiency change (ΔOSME and ΔOSMEI), but there is substantially less variation in the annual values in the SFA estimates than in the DEA estimates. In both sets of estimates, scale-mix efficiency generally contributes to positive TFP change in both public and private sector banks, although some annual values do contribute negatively. Pure technical efficiency fluctuates between positive and negative contributions to TFP change in both estimation methods and generally does not make a large net contribution for either public or private banks over any of the periods.

Table 7: Periodic average of TFP change and its components

Banks	**ΔTFPI**	**ΔTCI**	**ΔOTEI**	**ΔOSMEI**
Pre-reform Period, 1984-1990				
Public Banks	1.001	1.024	0.994	0.993
Private Banks	1.000	1.024	0.993	1.006
Transition Period, 1991-1995				
Public Banks	1.057	1.024	1.004	1.023
Private Banks	1.030	1.024	0.999	1.007
Post-reform Period, 1996-2012				

Public Banks	1.059	1.024	1.002	1.029
Private Banks	1.057	1.024	1.002	1.027

Source: Authors' calculation

The SFA estimates of periodic averages of TFP change (Table 7) provide similar results as obtained from DEA estimates (Table 3). TFP change for both public and private banks is positive in all the three sample periods and there is higher TFP growth in the transition and post-reform periods than in the pre-reform period under both methods. As noted above, the estimated rate of technical progress is constrained to be constant over time with SFA estimation and is found to be about 2.5% per annum, while with DEA estimation there is a clear upward trend in technical progress rising from technical regress of about 3.5% per annum in the pre-reform period to technical progress of about 5% per annum in the transition period and 10% per annum in the post-reform period. Technical efficiency makes little contribution to TFP change in any period under either estimation method. Scale-mix efficiency shows a rising trend across periods in the SFA estimates for both public and private banks, but has an erratic contribution in the DEA estimates with the contribution for both public and private banks mostly positive in pre-reform and post-reform periods.

7. Conclusion

This article measures the productive performances of 12 major commercial banks in Bangladesh. Employing an aggregate quantity framework, the Färe-Primont TFP index, productivity change is computed and decomposed into components of technical change, technical efficiency change and scale-mix efficiency change. The estimates of productivity change for different bank groups, public and private, reveal that mainly technical change (due to technological progress) contributes in attaining positive and increasing TFP growth over the years. One plausible reason for positive technical change is the adoption of advanced technology in developing competitive banking products and services, for example, online banking, mobile phone banking and ATM services. The growth in average TFP is higher in private banks than their public sector counterparts in the post-reform period (Table 3), but the reverse in earlier periods. Both public and private sector banks attain their highest levels of technical change and scale-mix efficiency change during the post-reform period.

The panel regression analysis finds a positive technical change (ΔTC) in the first stage of the reform program, i.e., during the transition period, as leading banks employ modern technology to compete with potential new entrants. The negative and significant coefficient for

DPs (post-reform period) for technical change is offset by more efficient use of inputs (higher OSME) as all banks move towards the best-practice input mix and scale. The result also shows that the banking industry still remains concentrated within the state-owned banks. The higher concentration reduces technical progress but increases efficiency. Moreover, use of more efficient input mixes helps the banking sector gaining scale mix efficiency (OSME).

We carry out a robustness check of the empirical results using the alternative technique of stochastic frontier analysis (SFA). Our SFA results do not vary much from those we obtain from the DEA estimation. In both sets of estimates substantial improvement in TFP growth occurs between the pre-reform and the post-reform period. The substantially improved TFP performance of public banks in particular suggests the importance of reforms in lessening political interference in the management of public banks. Further, the finding of the importance of technical change to TFP growth suggests it is important for banks, especially state-owned banks having extensive branch networks, to develop adequate capacity to apply advanced technology. Banks may be advised to establish research and development wings for continuous development and innovation of technology driven products and services to face the growing competition among financial institutions.

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References

ABRAMOVITZ, M. 1956. Resource and output trends in the United States since 1870. *American Economic Review,* 46**,** 5-23.

AMSLER, C., O'DONNELL, C. J. & SCHMIDT, P. 2017. Stochastic metafrontiers. *Econometric Reviews,*36**,** 1007-1020.

BANGLADESH BANK 2015. *Monthly Economic Trends*. Dhaka: Bangladesh Bank.

BATTESE, G.E., RAO, D.S.P. & O'DONNELL, C. J. 2004. A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. *Journal of Productivity Analysis,* 21**,** 91-103.

CASU, B., GIRARDONE, C. & MOLYNEUX, P. 2004. Productivity change in European banking: a comparison of parametric and non-parametric approaches. *Journal of Banking & Finance,* 28**,** 2521-2540.

CASU, B., FERRARI, A. & ZHAO, P. 2013. Regulatory reform and productivity change in Indian banking. *The Review of Economics and Statistics,* 95**,** 1066-1077.

COELLI, T. J., RAO, D. S. P., O' DONNELL, C. J. & BATTESE, G. E. 2005. *An Introduction to Efficiency and Productivity Analysis,* New York, Springer.

COLWELL, R. J. & DAVIS, E. P. 1992. Output and Productivity in Banking. *Scandinavian Journal of Economics,* 94**,** 111-129.

DELIS, M. D.2012. Bank competition, financial reform and institutions: the importance of being developed. *Journal of Development Economics, 97, 450-465*.

FÄRE, R. & PRIMONT, D. 1995. *Multi-output Production and Duality: Theory and Applications,* Boston, Kluwer Academic Publishers.

HAUSMAN, J.A. 1978. Specification tests in Econometrics. *Econometrica,* 46**,** 1251-1271.

HAYAMI, Y. 1969. Sources of agricultural productivity gap among selected countries. *American Journal of Agricultural Economics,* 51**,** 564-575.

HAYAMI, Y. & RUTTAN, V. W. 1970. Agricultural productivity differences among countries. *American Economic Review,* 40**,** 895-911.

HAYAMI, Y. & RUTTAN, V. W. 1971. *Agricultural development: an international perspective,* Baltimore, Johns Hopkins University Press.

HUANG, M. Y., JUO, J.C.& FU, T. 2015. Metafrontier cost Malmquist productivity index: an application to Taiwanese and Chinese commercial banks. *Journal of Productivity Analysis*, 44, 321-335

ISIK, I. & HASSAN, M. K. 2003. Financial deregulation and total factor productivity change: an empirical study of Turkish commercial banks. *Journal of Banking & Finance,* 27**,** 1455-1485.

JORGENSON, D. W. & GRILICHES, Z. 1967. The explanation of productivity change. *Review of Economic Studies,* 34**,** 249-283.

KUMBHAKAR, S. C. & LOVELL, C. A. K. 2003. *Stochastic Frontier Analysis,* Cambridge, Cambridge University Press.

KUMBHAKAR, S. C. & LOZANO-VIVAS, A. 2005. Deregulation and productivity: the case of Spanish banks. *Journal of Regulatory Economics,* 27**,** 331-351.

MAREDZA, A. & IKHIDE, S. 2013. Measuring the impact of the global financial crisis on efficiency and productivity of the banking system in South Africa. *Mediterranean Journal of Social Sciences,* 4**,** 553-568.

NGUYEN, P.A. & SIMIONI, M. 2015. Productivity and efficiency of Vietnamese banking system: new evidence using Färe-Primont index analysis. *Applied Economics,* 47**,** 4395-4407.

O'DONNELL, C. J. 2008a. An aggregate quantitiy-price framework for measuring and Decomposing productiivty and profitability change. *Working Paper.* Brisbane: University of Queensland.
O'DONNELL, C. J., RAO, D.S.P.& BATTESE, G.E. 2008b. Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Empirical Economics,*34, 231-255.
O'DONNELL, C. J. 2010. Measuring and decomposing agricultural productivity and profitability change. *Australian Journal of Agricultural and Resource Economics,* 54**,** 527-560.
O'DONNELL, C. J. 2011a. The sources of productivity change in the manufacturing sectors of the U.S. economy. *Working Paper.* Brisbane: University of Queensland.
O'DONNELL, C. J. 2011b. DPIN 3.0 a program for decomposing productivity index numbers. *Working Paper.* Brisbane: The University of Queensland.
O'DONNELL, C. J. 2012. An aggregate quantity framework for measuring and decomposing productivity change. *Journal of Productivity Analysis,* 38**,** 255-272.
O'DONNELL, C. J. 2013. An econometric approach to estimating support prices and measures of productivity change in public hospitals. *Journal of Productivity Analysis,* 40**,** 323-335.
O'DONNELL, C. J. 2016. Using information about technologies, markets and firm behaviour to decompose a proper productivity index. *Journal of Econometrics,*190**,** 328-340.
OH, D. & LEE, J. 2010. A metafrontier approach for measuring Malmquist productivity index. *Empirical Economics,*38**,** 47-64.
REZITIS 2006. Productivity growth in the Greek banking industry : a non-parametric approach. *Journal of Applied Economics,* 9**,** 119-138.
ROBIN, I. SALIM, R. AND BLOCH, H. 2018. Cost efficiency in Bangladesh banking: Does financial reform matter?, *Applied Economics,* 50(8): 891-904
ROBIN, I., SALIM, R. & BLOCH, H. 2018. Financial performance of commercial banks in the post-reform era: Further evidence from Bangladesh.*Economic Analysis and Policy,*58**,**43-54.
SALIM, R. 2003. Economic liberalization and productivity growth: further evidence from Bangladesh, *Oxford Development Studies*, 31, 85-98.
SHEPHARD, R. W. 1953. *Cost and Production Functions,* Princeton, Princeton University Press.
SOLOW, R. M. 1957. Technical change and the aggregate production function. *Review of Economics and Statistics,* 39**,** 312-320.
SUYANTO, BLOCH, H. & SALIM, R. A. 2012. Foreign direct investment spillovers and productivity growth in Indonesian garment and electronic manufacturing. *Journal of Development Studies,* 48**,** 1397-1411.
WHEELOCK, D. C. & WILSON, P. W. 1999. Technical progress, inefficiency, and productivity change in U.S. banking, 1984-1993. *Journal of Money, Credit and Banking,* 31**,** 212-234.
WORLD BANK 2013. *World Development Indicator.* World Bank.
ZHU, N., ZHANG, N., WANG, B. & BALEZENTIS, T. 2018. What contributes to total factor productivity growth in the Chinses banking sector. *Technological and Economic Development of Economy,* 24**,** 792-811.

Appendices

Appendix I: Reform policies undertaken in the financial sector of Bangladesh during the period, 1983-2015

Period	Policy measures
1983-1988: Reform initiatives undertaken on ad hoc basis;	• Privatization of state owned commercial banks • Allow new private sector banks • Constitute a commission on Money, Banking and Credit to investigate the status of the banking sector in Bangladesh and recommend policy measures to make the sector more efficient and competitive
1989-1995: Implementation of the Financial Sector Reform Program (FSRP);	• Financial sector reform program (FSRP) started in 1989 with the assistance from USAID and IDA • Introduction of market based interest rate policy • Abolition of directed sectoral lending • Revision of legal provisions and procedures enforcing loan recovery • Shift of exchange rate regime: fixed to flexible (pegging) • Bangladesh Bank (Central Bank of Bangladesh) established separate department in order to strengthen its supervision on the banking sector • Enactment of Bank Company Act 1991 in order to empower the Central Bank with more authority to regulate the banking sector • Credit Information Bureau (CIB), another independent department of the Central Bank set up in 1992 to provide credit information of the borrowers to assist banks for loan risk assessment • On-line connectivity of Credit Information Bureau (CIB) with the banks and financial institutions • Automation of the payment systems
1996-2008: Continuation of the reform initiatives;	• Revision of loan classification and provisioning criteria • Introduction of modern monetary policy instruments Repo (Repurchase agreement) and reverse Repo • Amendment of Bank company Act 1991 and Bangladesh Bank Order 1972 • Introduction of free floating exchange rate • Introduction of risk-weighted asset based capital adequacy requirement for banks and financial institutions. • Corporatization of state-owned commercial banks. • Enactment of Money Laundering and Prevention Act 2002 in order to prevent terrorist financing.

2009-2015:Reform measures after the global financial crisis (GFC);	• Implementation of corporate governance regulations • Introduction of risk management system guidelines for banks and financial institutions • Stress testing policies: an independent Risk Management Unit (RMU) is established in each individual bank to conduct stress testing for examining the bank's capacity of handling future shocks. • Enhancement of capital adequacy requirement as per the BASEL III recommendations • Updated the Foreign Exchange Regulations 1947 with inclusion of new provisions

Source: Authors' compilation based on various issues of annual reports of the Central Bank of Bangladesh and, also an updated version of the appendix I [Robin et al. (2018) p.51]

Appendix II: Definition of the variables

Variables	Definition
Outputs	
y_1	Loans and advances: the sum of total loans and bills discounted. The variable is measured in million Taka (Bangladesh currency), deflated using GDP deflator, base: 1996=100 (World Bank, 2013).
y_2	Other earning assets: total assets less total loans and advances and fixed assets. The variable is measured in million Taka (Bangladesh currency), deflated using GDP deflator, base: 1996=100 (World Bank, 2013).
Inputs	
x_1	Labour : number of full-time employees
x_2	Physical capital: the book value of premises and fixed assets. The variable is measured in million Taka (Bangladesh currency), deflated using GDP deflator, base: 1996=100(World Bank, 2013).
x_3	Loanable funds: the sum of deposit (demand and time) and non-deposit funds (borrowed fund). The variable is measured in million Taka (Bangladesh currency), deflated using GDP deflator, base: 1996=100 (World Bank, 2013).

Determinants of TFP change	
EQ	Equity: the sum of core capital and supplementary capital: the sum of paid up capital, statutory reserve, general reserves, other reserves and general provisions. The value of the variable is measured in million Taka (Bangladesh currency), deflated using GDP deflator, base: 1996=100 (World Bank, 2013).
FI	Financial intermediation ratio: the ratio of total loans and advances to total deposits
OWN	Bank ownership dummy variable; OWN=1 if public bank and zero otherwise
DPr	Pre-reform dummy variable for the period, 1984-1990. However, pre-reform period is considered as base period.
DTr	Transition dummy variable for the period, 1991-1995. DTr=1 if transition period and zero otherwise.
DPs	Post-reform dummy variable for the period, 1996-2012. DPs=1 if post-reform period and zero otherwise.
SIZE	Bank size: natural logarithm of the total assets, as deflated using GDP deflator, base: 1996=100 (World Bank, 2013).
CR3	3-bank concentration ratio: an annual index measures the deposit share of three major state-owned banks, Sonali, Janata and Agrani bank limited.
ID	Independent director: dummy variable; ID=1 if independent directors are in the bank board and zero otherwise.
PD	Political director: dummy variable; PD=1 if political directors are in the bank board and zero otherwise.

Appendix III: Estimation of theFäre-Primont TFP index using DEA frontier

The data envelopment analysis (DEA) method is used to compute the frontier and identify the measures of output- and input-oriented efficiency associated with a distance-based Färe-Primont index. The main assumption underpinning the use of DEA is that the frontier is locally linear (O'Donnell, 2010). This means that if firm *i* in period *t* is technically efficient, i.e., on the frontier, then in the neighbourhood of the point $(y_{it}.x_{it})$ the frontier takes the linear form, e.g., $y'_{it}\alpha = \gamma + x'_{it}\beta$. Therefore, the (local) output distance function representing the technology available in period *t* is:

$$D_O(x_{it}, y_{it}, t) = (y'_{it}\alpha)/(\gamma + x'_{it}\beta) \quad (1)$$

where, α and β are non-negative and γ measures returns to scale. If γ =0, the technology exhibits constant returns to scale, while if $\gamma \geq 0$ the technology exhibits local non-increasing returns to scale.

The standard output-oriented DEA problem involves selecting values of the unknown parameters in Equation (1) to minimize the output-oriented technical efficiency function, $OTE_{it}^{-1} = D_O(x_{it}, y_{it}, t)^{-1}$. If the technology is permitted to exhibit variable returns to scale, then the constraints that need to be satisfied are $\alpha \geq 0$, and $\beta \geq 0$ and $D_O(x_{it}, y_{it}, t) \leq 1$ for all observations. However, this constrained optimization problem has an infinite number of solutions, but setting another constraint, $y'_{it}\alpha$ =1, the DEA problem takes the form of a linear program (O'Donnell, 2011a):

$$D_O(x_{it}, y_{it}, t)^{-1} = OTE_{it}^{-1} = \min_{\alpha,\beta,\gamma}(\gamma + x'_{it}\beta : \gamma l + X'\beta \geq Y'\alpha; y'_{it}\alpha = 1; \alpha \geq 0; \beta \geq 0) \quad (2)$$

where, Y is a J×$M_t$matrix of observed outputs, X is a K×M_t matrix of observed inputs, l is an M_t×1 unit vector and M_t is the number of observations used to estimate the frontier in period *t*.

Similarly, the distance function representing the technology available in period *t* is:

$$D_I(x_{it}, y_{it}, t) = (x'_{it}\eta)/(y'_{it}\phi - \delta) \quad (3)$$

The input-oriented DEA problem is to maximize $ITE_{it} = D_I(x_{it}, y_{it}, t)^{-1}$subject to the constraints $\phi \geq 0, \eta \geq 0$ and $D_I(x_{it}, y_{it}, t) \geq 1$ for all M_t observations. A unique solution can be obtained by setting $x'_{it}\eta$ =1. Hence, the input-oriented problem takes the form of a linear program is:

$$D_I(x_{it}, y_{it}, t)^{-1} = ITE_{it} = \max_{\phi,\delta,\eta}(y'_{it}\phi - \delta : Y'\phi \le \delta l + X'\beta; x'_{it}\eta = 1; \phi \ge 0; \eta \ge 0) \quad (4)$$

The computer program DPIN3.0 developed by O'Donnell (2011b) uses variants of Equations (2) and (4) to estimate TFP and various components of TFP change. The aggregate outputs are computed using the following aggregator functions:

$$Y(y) = y'p_o^* \quad (5)$$

$$X(x) = x'w_o^* \quad (6)$$

where,

$$p_o^* = \partial D_o(x_o, y_o, t_o)/\partial y_o = \alpha_o/(\gamma_o + x'_o\beta_o) \quad (7)$$

$$w_o^* = \partial D_I(x_o, y_o, t_o)/\partial x_o = \eta_o/(y'_o\phi_o - \delta_o) \quad (8)$$

The Färe-Primont index aggregate output is then computed using Equations (5) and (7):

$$Y_{it} = (y'_{it}\alpha_o)/(\gamma_o + x'_o\beta_o) \quad (9)$$

Finally, the Färe-Primont index aggregate input can be computed using Equations (6) and (8):

$$X_{it} = (x'_{it}\eta_o)/(y'_o\phi_o - \delta_o) \quad (10)$$

where, α_o, $\beta_o, \gamma_o, \eta_o, \phi_o$ and δ_o provide the solutions to Equations (2) and (4). All of these aggregator functions are linear in outputs or inputs.

The maximum TFP in period *t* can be computed as $TFP_t^* = \max_i TFP_{it} = \max_i Y_{it}/X_{it}$. Thus, the measures of efficiency can be computed residually (O'Donnell, 2011a):

$$TFPE_{it} = TFP_{it}/TFP_t^* \quad (11)$$

$$OSME_{it} = TFPE_{it}/OTE_{it} \quad (12)$$

$ISME_{it} = TFPE_{it}/ITE_{it}$ and (13)

$$RME_{it} = OSME_{it}/OSE_{it} = ISME_{it}/ISE_{it} \quad (14)$$

Appendix IV(a): Input-oriented TFP change for public banks

Period	ΔTFP	Δ TC	ΔITE	ΔISME
1985/84	1.2348	1.1267	1.0009	1.08898
1986/85	0.9934	0.9168	1.0098	1.07244
1987/86	0.8792	0.7018	1	1.2525
1988/87	1.0115	1.0797	1	0.93739
1989/88	1.0482	0.9385	0.9825	1.13696
1990/89	0.9474	1.0211	0.9782	0.94841
1991/90	1.0124	1.0824	1.0155	0.92143
1992/91	1.0245	0.9973	0.9867	1.0408
1993/92	1.1068	1.0767	1.0434	0.98742
1994/93	1.0823	1.1165	0.9494	1.03164
1995/94	1.0659	0.9879	1.0039	1.07524
1996/95	1.0781	2.7213	0.9853	0.4031
1997/96	1.0832	0.369	1.0529	2.80013
1998/97	1.0044	1.0852	0.9904	0.93495
1999/98	1.2003	0.9819	0.9804	1.24704
2000/99	1.0716	0.9768	1.0093	1.08663
2001/00	1.2448	1.0071	1.03	1.2003
2002/01	1.0755	1.0589	0.987	1.02967
2003/02	0.9131	0.9783	1.014	0.92018
2004/03	1.0494	1.064	0.998	0.98886
2005/04	1.0795	0.9967	1.0007	1.08339
2006/05	1.0351	1.2025	1.0175	0.8458
2007/06	1.0188	1.0996	1	0.92654
2008/07	1.0101	1.1559	0.9671	0.90628
2009/08	1.028	0.7981	1.0254	1.25894
2010/09	1.1825	1.2125	0.9807	0.99636
2011/10	1.0014	1.054	1.0254	0.92642
2012/11	1.0206	0.9738	1.0027	1.04573

Notes: ΔTFP=ΔTC×ΔTFPE; ΔTFPE=ΔITE×ΔIME×ΔRISE=ΔITE×ΔISME
Source: Authors' estimation

Appendix IV(b): Input-oriented TFP change for private banks

Period	ΔTFP	ΔTC	ΔITE	ΔISME
1985/84	0.9904	1.1267	0.9397	0.96627
1986/85	0.9961	0.9168	1.0403	1.04725
1987/86	1.0487	0.7018	1.0512	1.42353
1988/87	1.0245	1.0797	1.0162	0.93442
1989/88	1.0083	0.9385	0.9961	1.07871
1990/89	1.0079	1.0211	0.9909	0.99554
1991/90	1.0359	1.0824	0.9976	0.95987
1992/91	1.029	0.9973	0.9565	1.09504
1993/92	1.0697	1.0767	1.0717	0.94166
1994/93	1.0451	1.1165	0.9439	0.99535
1995/94	0.9873	0.9879	1.0578	0.94766
1996/95	1.7943	2.7213	0.9854	0.66624
1997/96	0.9932	0.369	0.9681	2.78788
1998/97	1.0317	1.0852	1.0032	0.94848
1999/98	1.1969	0.9819	1.0511	1.16973
2000/99	1.1235	0.9768	1.0297	1.11749
2001/00	1.0747	1.0071	0.9793	1.09036
2002/01	1.0524	1.0589	0.9783	1.01635
2003/02	0.9819	0.9783	1.0609	0.95485
2004/03	0.9877	1.064	0.9899	0.93821
2005/04	1.0913	0.9967	1.0047	1.09087
2006/05	1.0865	1.2025	0.993	0.90968
2007/06	1.0722	1.0996	1.006	0.96954
2008/07	1.0707	1.1559	0.9977	0.92945
2009/08	1.0357	0.7981	1.0129	1.28117
2010/09	1.131	1.2125	0.9839	0.94925
2011/10	1.0507	1.054	1.0139	0.98607
2012/11	1.0165	0.9738	1.0027	1.04098

Notes: ΔTFP=ΔTC×ΔTFPE; ΔTFPE=ΔITE×ΔIME×ΔRISE=ΔITE×ΔISME
Source: Authors’ estimation

Appendix V: Determinants of TFP change and its components

	∆TFP		∆TC		∆OTE		∆OSME	
	FE	RE	FE	RE	FE	RE	FE	RE
Constant	2.389 (3.534)	2.449 (2.553)	0.696 (1.099)	1.104 (0.718)	1.109*** (0.322)	1.009*** (0.210)	1.828 (2.792)	1.537 (1.995)
Equity (EQ)	0.011 (0.041)	0.021 (0.038)	-0.008 (0.013)	-0.007 (0.011)	0.000 (0.004)	0.000 (0.003)	0.026 (0.032)	0.031 (0.029)
FI (financial intermediation ratio)	-0.723*** (0.216)	-0.687*** (0.204)	-0.124* (0.067)	-0.109* (0.062)	-0.003 (0.019)	-0.006 (0.018)	-0.612*** (0.170)	-0.592*** (0.161)
OWN (ownership)	0 (omitted)	-0.034 (0.251)	0 (omitted)	-0.031 (0.068)	0 (omitted)	-0.002 (0.019)	0 (omitted)	-0.008 (0.195)
Independent Director (ID)	0.204 (0.290)	0.169 (0.281)	-0.047 (0.090)	-0.044 (0.085)	0.006 (0.026)	0.008 (0.025)	0.228 (0.229)	0.200 (0.221)
Political Director (PD)	0.211 (0.291)	0.029 (0.191)	0.047 (0.090)	0.007 (0.052)	0.001 (0.026)	0.005 (0.015)	0.116 (0.229)	0.015 (0.149)
Size (SIZE)	-0.175 (0.395)	-0.173 (0.296)	0.082 (0.123)	0.039 (0.083)	-0.017 (0.036)	-0.006 (0.024)	-0.186 (0.312)	-0.149 (0.231)
Transition (DTr)	-0.002 (0.193)	-0.015 (0.189)	0.299*** (0.059)	0.303*** (0.058)	-0.002 (0.018)	-0.003 (0.017)	-0.091 (0.152)	-0.103 (0.149)
Post-reform (DPs)	0.214 (0.225)	0.194 (0.217)	-0.150** (0.069)	-0.144** (0.067)	0.027 (0.020)	0.025 (0.019)	0.526*** (0.178)	0.505*** (0.171)
Concentration (CR3)	1.100 (0.826)	0.992 (0.710)	-0.352 (0.257)	-0.428** (0.212)	0.044 (0.075)	0.062 (0.062)	1.839** (0.653)	1.819*** (0.559)
R-squared	0.052	0.056	0.174	0.182	0.009	0.010	0.099	0.101
Hausman test	Prob χ^2 =0.987:RE		Prob χ^2 =0.999:RE		Prob χ^2 =1.00:RE		Prob χ^2 =0.994:RE	
Total observations	348		348		348		348	

Source: Authors' estimation using STATA14. FE stands for fixed-effect model and RE for random-effect model. Pre-reform period is treated as the base period. Standard errors are in parentheses;*** denotes statistical significance level at 1%; ** denotes the level of statistical significance at 5%; * denotes statistical significance level at 10%.