Journal of Economic Cooperation and Development, **43**, 3 (2022), 21-48

Efficiency of Bangladeshi Private Commercial Banks with Stochastic Frontier Models: The Role of ICT Determinants

Shakera Begum[1] Md. Azizul Baten[2] Rahmat Ali [3] and Mohammad Nayeem Hasan[4]

ABSTRACT

In global terms, ICT has been emerged as one of the biggest catalysts in banking sectors that is a casual for both Bangladesh banking industry too. This study evaluated the cost and profit efficiency of Private Commercial Banks (PCBs) by Stochastic Cobb-Douglas and Trans-log frontier models during the time period 2008-2017. Then the role of ICT determinants of both cost and profit efficiency of PCBs were investigated by Tobit regression model. Translog model were observed to be more suitable than Cobb-Douglas model in case of both cost and profit. The average cost and profit efficiency scores were found at 65.8% and 50.5% respectively based on Cobb-Douglas cost and profit models while in Translog cost and profit models, these were noticed at 66.3% and 53.9%. The cost efficiency of PCBs estimated from Stochastic Cobb-Douglas cost model were influenced positively and significantly by the IT personnel expanses (0.00087), ATM card expenses (0.00306) and Credit card transaction (0.00005) while the IT personnel expenses (0.0006) and Credit card transaction (0.000006) were found positive and significant for Translog cost model. Again, the IT personnel expenses (0.0018) and Credit card transaction (0.0013) were noticed to be positive and significant effect on profit efficiency obtained from Stochastic Cobb-Douglas profit model while IT income (0.00003), IT personnel (0.0006), IT personnel expenses (0.0009), ATM transaction (0.00005), and ATM expenses (0.00002) played a positive role to enhance the profit efficiency of PCBs in case of Translog profit frontier model. The ICT determinants have positive impact on PCBs so it can be concluded that the PCBs system are technologically more sophisticated.

[1] Masters Student, Department of Statistics, The University of Akron, USA.
E-mail: shakerabgm@gmail.com
[2] Deartment of Statistics, School of Physical Sciences, Shahjajal University of Science and Technology, Sylhet-3114, Bangladesh.
E-mail: baten-sta@sust.edu
[3,4] Deartment of Statistics, School of Physical Sciences, Shahjajal University of Science and Technology, Sylhet-3114, Bangladesh.
E-mail: ralistat@sust.edu; nayeem5847@gmail.com

ملخص

برزت تكنولوجيا المعلومات والاتصالات، على الصعيد العالمي، كأحد أكبر المحفزات في القطاعات المصرفية التي تعتبر أمرا عرضيا للصناعة المصرفية في بنغلاديش أيضا.وقد قيمت هذه الدراسة كفاءة التكلفة والأرباح للبنوك التجارية الخاصة (PCBs) باستخدام نموذجي Stochastic Cobb-Douglas وTrans-log frontier خلال الفترة الزمنية 2008-2017. ثم تم استكشاف دور محددات تكنولوجيا المعلومات والاتصالات لكل من كفاءة التكلفة والربح للبنوك التجارية الخاصة من خلال نموذج الانحدار توبيت.لوحظ أن نموذج Translog أكثر ملاءمة من نموذج Cobb-Douglas في حالة التكلفة والربح. وسجل متوسط درجات الكفاءة في التكلفة والأرباح نسبتي 65.8% و 50.5% على التوالي بناء على نموذجي Cobb-Douglas للتكلفة والأرباح بينما في Translog، سجلت نسبتي 66.3% و 53.9%. وتأثرت كفاءة تكلفة البنوك التجارية الخاصة المقدرة من نموذج تكلفة Stochastic Cobb-Douglas بشكل إيجابي وكبير بنفقات موظفي تكنولوجيا المعلومات (0,00087) ونفقات بطاقات الصراف الآلي (0,00306) ومعاملات بطاقات الائتمان (0,00005) في حين كشف عن أن نفقات موظفي تكنولوجيا المعلومات (0,0006) ومعاملات بطاقة الائتمان (0,000006) كانت إيجابية وذات أهمية كبيرة بالنسبة لنموذج تكلفة Translog. ومجددا، لوحظ أن نفقات موظفي تكنولوجيا المعلومات (0.0018) ومعاملات بطاقات الائتمان (0.0013) كان لها تأثير إيجابي وكبير على كفاءة الأرباح التي تم الحصول عليها من نموذج أرباح Stochastic Cobb-Douglas بينما لعب كل من دخل تكنولوجيا المعلومات (0.00003)، وموظفو تكنولوجيا المعلومات (0.0006)، ونفقات موظفي تكنولوجيا المعلومات (0.0009)، ومعاملات أجهزة الصراف الآلي (0.00005) ، ونفقات أجهزة الصراف الآلي (0.00002) دورا إيجابيا في تعزيز كفاءة الربح للبنوك التجارية الخاصة في حالة نموذج الربح Translog. وعليه، لمحددات تكنولوجيا المعلومات والاتصالات تأثير إيجابي على البنوك التجارية الخاصة بحيث يمكن استنتاج أن نظام هذه الأخيرة أكثر تطورا من الناحية التكنولوجية.

ABSTRAITE

Au niveau mondial, les TIC sont apparues comme l'un des plus grands catalyseurs du secteur bancaire, ce qui est une chance pour le secteur bancaire du Bangladesh également. Cette étude a évalué l'efficacité des coûts et des bénéfices des banques commerciales privées (PCB) par les modèles stochastiques Cobb-Douglas et Trans-log Frontier pendant la période 2008-2017. Ensuite, le rôle des déterminants TIC de l'efficacité des coûts et des bénéfices des PCB a été étudié par un modèle de régression Tobit. Le modèle Translog s'est avéré plus approprié que le modèle Cobb-Douglas dans le cas des coûts et des bénéfices. Les scores moyens d'efficacité des coûts et des bénéfices ont été de 65,8% et 50,5% respectivement sur la base des modèles de coûts et de bénéfices Cobb-Douglas, tandis que dans les modèles de coûts et de bénéfices Translog, ils ont été remarqués a 66,3% et 59,9%. Le rapport coût-efficacité des PCB estimé à partir du modèle de coût Cobb-Douglas stochastique a été influencé de manière positive et significative par les dépenses en personnel informatique (0,00087), les dépenses liées aux cartes de retrait (0,00306) et les transactions par carte de crédit (0,00005), tandis que les dépenses en personnel informatique (0,0006) et les transactions par carte de crédit (0,000006) se sont avérées positives et significatives pour le modèle de coût Translog. Une fois de plus, les dépenses en personnel informatique (0,0018) et les transactions par carte de crédit (0,0013) ont eu un effet positif et significatif sur l'efficacité du profit obtenu à partir du modèle de profit stochastique Cobb-Douglas, tandis que les revenus informatiques (0,00003), le personnel informatique (0,0006), les dépenses en personnel informatique (0,0009), les transactions des guichets automatiques (ATM) (0,00005) et les dépenses ATM (0,00002) ont joué un rôle positif pour améliorer l'efficacité du profit des PCB dans le cas du modèle Translog profit frontier. Les déterminants TIC ont un impact positif sur les PCB, on peut donc conclure que le système des PCB est technologiquement plus sophistiqué.

Keywords: Efficiency, Stochastic cost and profit frontier models, Tobit model, Private Commercial Banks, ICT, Bangladesh.

JEL Classification: H21, C23, C13, C21, C87

1. Introduction

In modern times, Information Communication and Technology (ICT) is a crucial resource to have, just like land, labor, or capital, for banking facilities to remain up and running. Technology has opened up new views for the banking services; for instance, ATM has become a very popular delivery mechanism which makes it immensely easier to get the money at any time. A changing world which is highly dependent on technology, the bank has to change its transaction system and modernize its branch network strategies, and widen the delivery options. Nowadays, most of the transactions are conducted via online internet bank, e-banking channels and m-banking services. People are going to be benefited from the internet bank facilities. The financial institutions in Bangladesh are increasingly adopting ICT banking and improving the banking capabilities. ICT enhances efficiency of banking industry value chain by facilitating services and minimizing the risk by producing quality advantages. ICT investments can boost the work performance of enterprises by the reduction of the costs, profit border, growing production, augmentative the services, and ensuring customer satisfactions. In this context, some studies were conducted about the impact of ICT on banking in Bangladesh (Haque & Reza, 2009; Sadekin & Shaikh, 2015, 2016; Ashraf et al., 2017) who asserted that ICT investments is an important cause for the forthcoming improvement of banking commercial enterprise.

The researchers showed that ICT components (i.e. Software Investment, Hardware Investment, IT services) had a great impact on the bank efficiency estimated by Stochastic Frontier Analysis (SFA) (for instance, Beccalli, 2007; Lee & Menon, 2000; Romdhane, 2013; Safari & Yu, 2014; Surulivel et al., 2013). Some of the researchers used both SFA and Data Envelopment Analysis (DEA) (for instance, Ariff & Can, 2008; Romdhane, 2013; Lee & Menon, 2000) or only DEA method (Girardone et al., 2004) or only SFA method (Abdul-Majid, Saal & Battisti, 2011; Altunbas et al., 2000; Carvallo & Kasman, 2005; Casu & Molyneux, 2003; Christopoulos, Lolos & Tsionas, 2002; Christopoulos & Tsionas, 2001; Duygun et al. 2015; Fries & Taci, 2005; Košak, Zajc & Zorić, 2009; Shen, Liao & Weyman-Jones, 2009; Thi & Ngan, 2014) to evaluate the efficiency of Private Commercial Banks (PCBs) in the context of cost and profit excluding the ICT variables. On the other hand, Chu-Fen (2007) used both DEA and SFA to evaluate the technical efficiency of banks and measured the correlation and regression analysis among the ICT variables in terms of pre-tax profit and total IT expenses but he did not focus the PCBs efficiency in terms of cost and profit. Again, a few studies have been conducted by SFA (Rai & Patnayakuri, 1997; Safari & Yu, 2014b; Surulivel et al., 2013) to estimate the bank efficiency considering only one or two ICT variables.

A couple of bank's efficiency studies related to both cost and profit are accessible in Bangladesh using both SFA and DEA method (Hasan and Hasan, 2018; Hasan & Hasan, 2018; Ara, 2016; Baten et al., 2015a) but none of them focused to examine the effect of ICT on PCBs cost and profit efficiency. At present, several PCBs offer limited services of telebanking, internet banking and e-banking artifact within the branches of single bank. So, one of the challenges faced in Bangladesh is to find out the role of ICT determinants of PCBs efficiency.

This study was dealt into two stages. In the first stage, both cost and profit efficiency of PCBs were analyzed from 2008 to 2017 in order to determine in which PCBs are most efficient. For the purpose of this analysis, both Cobb-Douglas and Trans-log models have been used. In the second stage, the role of ICT determinants of PCBs' cost and profit efficiencies was investigated by using Tobit regression model.

This study is comprised as follows. In Section 1, a brief overview of the research background, problem statement and work objectives is provided. The Section 2 includes the literature review that provides an overview of the previously published research on which the research gap was shown. The Section 3 is divided into four parts. The first part shows the data description and the variables, the second part shows two empirical methodology stages, and the third part represents the likelihood-ratio tests. The Section 4 part is separated into two parts. One shows the results of the SFA models and the second demonstrates the findings of the Tobit model. This part also includes the discussion, which determines and validates the compatibility of this study findings with previously conducted research. The Section 5 part provides the conclusion, implications for PCBs efficiency improvements based on existing results and recommendations for future study.

2. Literature Review

A number of bank efficiency studies on SFA were conducted over the last decade supported by the researchers. Casu et al. (2002) showed that bigger banks are less efficient than smaller banks. According to Fries and Taci (2005), private banks are more efficient than state-owned banks (SOCBs), but there have divergent. Carvallo and Kasman (2005) evaluated that the efficiency of banks and found that it varied from country to country. Kasman and Yildirim (2006) observed that foreign banks execute better than domestic banks. Girardone et al. (2004) observed that the efficiency gap decreased while conducting an alternative profit model. Thi and Ngan (2014) noticed that the profit efficiency of SOCBs was comparatively better than commercial banks and foreign banks. Shen et al. (2009) compared the cost efficiency in ten Asian banking commercial enterprise and found that china had the fourth position after India, Singapore and Malaysia. Kosak et al. (2009) showed that the banks played an crucial role for cost efficiency change than the possession artifact. Abdul Majid et al. (2011) estimated the cost performance of Malaysian banks through SFA. Hasan and Hasan (2018) showed that the cost efficiency among the SOCBs was get down than PCBs and Islamic banks.

Both cost and profit efficiency studies together were dealt a little in Bangladesh and abroad. Mertens and Urga (2001) estimated that small banks are more cost efficient and little profit efficient. Casu and Girardone (2004) observed that profit efficiency was higher than cost for large banks. Tahir and Haron (2010) examined that Islamic banks in Europe were comparatively more cost and profit efficient than the other banks. Middle East banks were significantly less efficient than Islamic banks in Africa but they were more efficient than Far East and Central Asian banks. Aiello and Bonanno (2013) evaluated that both cost and profit efficiency were around 90% and steady. Rahman and Islam (2011) investigated that in terms of cost, IBBL were less efficient than than profit. Baten et al. (2015b) examined the cost and profit efficiency by both SFA and DEA models and found that private banks were slenderly higher than PCBs. Baten, Kasim and Rahman (2015) observed that the mean inefficiency of cost and the efficiency of profit were discovered 16.3% and 91% respectively. The profit efficiency for commercial bank and cost efficiency for Islamic banks provided the momentous visual image to policy makers and governance considering the best usage of capability and origin in Bangladesh (Ara, 2016).

A number of studies on bank efficiency based on SFA with ICT variables are available in the literature. Beccalli (2007) investigated that IT investment impacted positively to profit efficiency. Chu-Fen (2007) explored that banks are able to decrease the operational costs by issuance of the financial cards and ameliorate the functional efficiency by the instalment of ATM machines and rendering IT services to the customers. Surulivel et al. (2013) found that the old private bank's cost inefficiency decreased 28% and new private bank's cost inefficiency weakened 11.3% by IT. Romdhane (2013) investigated the ICT determinants of banks' cost efficiency and showed that bank size and it's managerial capacity have significant effect to Tunisian banks. Safari and Liu (2014a) showed that ICT components and possession, bank size had a significant causation towards efficiency of PCBs, compared to SOCBs. Baten (2021) measured the ICT components of PCBs' cost and profit efficiency in Bangladesh using DEA and Ordinary Least Square (OLS) method. Shakera, Baten and Ali (2022) assessed the role of ICT of SOCBs' efficiency related to cost and profit in Bangladesh using DEA.

From the above literature it was found that the studies on PCBs' efficiency with SFA in the literature are a very little. Therefore, both SFA and Tobit regression analysis have been the methods to evaluate the effect of ICT on PCBs efficiency used in this study as this type of research along with the ICT determinants are not very communal.

3. Data and Methodology

3.1 Data Description and the Variables

This study included 17 Private Commercial Banks (PCBs) of Bangladesh. The data were accumulated from the yearly report of individual bank over the time period 2008 to 2017.

3.1.1 Dependent Variable for SFA

Total Profit (π): It is defined as the deviation of the total income and total cost. It occurs after the tax.

Total Cost (Y): It admits the income paid to depositor, staff and operational expenses.

3.1.2 Output Quantities of PCBs for SFA

Loan (LOA): The sum of loan, trade financial statement and discounted bills and some other loans.

Off-balance Sheet Items (OBS): It is measured as the sum of assurance, seriousness and financial derivative device.

3.1.3 Input Prices of PCBs for SFA

Price of Fund (POF): It is formed as the ratio of total interest disbursement to all deposits.

Price of Fixed Assets (POFA): It is measured as the non-interest disbursal divided by fixed assets.

Price of Labor (POL): It is measured as the ratio of individual expenses to the number of staff.

3.1.4 Explanatory Variables for Inefficiency Effects Model for SFA

Non-Interest Income (NII): It is a income generated initially from deposit and transaction, insufficient fund, annual fees, monthly account service charges, in-activeness fees, check and deposit slip fees and so on.

Non-Performing Loan (NPL): It is a sum of lend money that has not paid by the debtor within the specified time period.

Return on Assets (ROA): It is the ratio of yearly gross income to total assets during a fiscal year.

Return on Equity (ROE): It is characterized as the gross profit divided by the average equity of the shareholder.

Capital Adequacy Ratio (CAR): It is a sum of the bank's capital of both tier one and tier two divided by the risk-weighted assets.

3.1.5 ICT Variables for Tobit Regression Model

IT Expenses (ITE): The total IT expanses refers to incurred expanses for care and fix, annuity in advance, reduction of IT instrumentation and message sourcing services.

IT Income (ITI): It is a entire income from bank's IT.

IT Investment (ITIN): IT investment is total IT monetary fund that admit hardware, software, network, safety training and other IT intention.

IT Personnel (ITP): It is the total number of IT staff member.

IT Personnel Expenses (ITPE): It is calculated as the total wage of IT staff over the number of full time staff.

ATM Card Transaction (ATMT) : The total amount of deposit is withdrawn by ATM Card.

ATM Card Expenses (ATME): Banking service charge used by ATM Card is defined as ATME.

Credit Card Transaction (CCT): It is the total deposit which is withdrawn by Credit Card.

Credit Card Expenses (CCE): Credit card is used for repayment of the value of products and services. This service charge is calculated in the context of the price of credit card.

3.2 Empirical First Stage Methodology

The specification of Cobb-Douglas stochastic frontier cost model originated from Battese & Coelli (1995) for PCBs is formulated as:

$$\ln Y_{it} = \beta_0 + \beta_1 LOA_{it} + \beta_2 OBS_{it} + \beta_3 POF_{it} + \beta_4 POFA_{it} + \beta_5 POL_{it} + v_{it} + u_{it} \quad (1)$$

where, i and t represent the number of banks and time respectively. Y_{it} represent the total cost of bank i in time period t; LOA_{it} and OBS_{it} stand for the output quantities (loan and off-balance sheet items) of bank i in period t; POF_{it}, $POFA_{it}$ and POL_{it} are the price of input variables (price of fund, price of fixed assets and the price of labour) of bank i in period t; v is a error term, u is a non-negative technical inefficiency term and β_0 is the intercept, β_1, β_2, β_3, β_4, and β_5 are unknown parameters. The parameters for each variable is obtained by PCBs from (1), the technical efficiency level for PCBs is estimated by (2).

$$TE_{it} = \frac{Y_i}{e^{\beta_0 + \beta_1 LOA_{it} + \beta_2 OBS_{it} + \beta_3 POF_{it} + \beta_4 POFA_{it} + \beta_5 POL_{it} + v_{it} + u_{it}}} = e^{-uit} \quad (2)$$

The empirical cost inefficiency effects model can be written as:

$$u_{it} = \delta_1 NII_{it} + \delta_2 NPL_{it} + \delta_3 ROA_{it} + \delta_4 ROE_{it} + \delta_5 CAR_{it} + \omega_{it} \quad (3)$$

where u_{it} is the inefficiency components of bank i in period t; NII_{it} is the non-interest income, NPL_{it} is the non-performing loan, ROA_{it} is the return on assets, ROE_{it} is the return on equity, CAR_{it} is the capital adequacy ratio; ω_{it} is the error term.

The specification of Cobb-Douglas stochastic frontier profit model originated from Battese & Coelli, (1995) is formulated as:

$$ln(\pi_{it} + \theta) = \beta_0 + \beta_1 LOA_{it} + \beta_2 OBS_{it} + \beta_3 POF_{it} + \beta_4 POFA_{it} + \beta_5 POL_{it} + \mathrm{v}_{it} + u_{it} \quad (4)$$

where π_{it} is the profit after tax of bank i in time period t; θ is a constant. All the independent variables are the same line as the described in the equation (1). The technical efficiency is estimated as like as the equation (2) and the profit inefficiency effects model can be estimated as the same line as the equation (3).

The empirical Stochastic Translog Cost frontier model is formulated by

$$\begin{aligned} ln(C_{it}) = {} & \beta_0 + \beta_1\, ln(LOA_{it}) + \beta_2\, ln(OBS_{it}) + \beta_3\, ln(POF_{it}) + \beta_4\, ln(PFA_{it}) + \\ & \beta_5\, ln(POL_{it}) + \frac{1}{2}[\beta_{11}\, ln(LOA^2{}_{it}) + \beta_{22}\, ln(OBS^2{}_{it}) + \beta_{33}\, ln(POF^2{}_{it}) + \beta_{44}\, ln(PFA^2{}_{it}) \\ & + \beta_{55}\, ln(POL^2{}_{it})] + \beta_{12}\, ln(LOA_{it}) * ln(OBS_{it}) + \beta_{13}\, ln(LOA_{it}) * ln(POF_{it}) \\ & + \beta_{23}\, ln(OBS_{it}) * ln(POF_{it}) + \beta_{45}\, ln(PFA_{it}) * ln(POL_{it}) + \beta_{14}\, ln(LOA_{it}) * ln(PFA_{it}) \\ & + \beta_{15}\, ln(LOA_{it}) * ln(POL_{it}) + +\beta_{24}\, ln(OBS_{it}) * ln(PFA_{it}) + \beta_{25}\, ln(OBS_{it}) * ln(POL_{it}) \\ & + \beta_{34}\, ln(POF_{it}) * ln(PFA_{it}) + \beta_{35}\, ln(POF_{it}) * ln(POL_{it}) + V_{it} + U_{it} \qquad (5) \end{aligned}$$

where, C_{it} is the total cost of bank i in time period t. All the independent variables are the same line as the described in the equation (1). The empirical cost inefficiency effects model can be estimated as the same line as the equation (3) with the exception of the output variable total cost in this Translog case.

The specification of stochastic Translog profit frontier model is formulated as:

$$
\begin{aligned}
ln(\pi_{it} + \theta) = {} & \beta_0 + \beta_1\, ln(LOA_{it}) + \beta_2\, ln(OBS_{it}) + \beta_3\, ln(POF_{it}) \\
& + \beta_4\, ln(PFA_{it}) + \\
\beta_5\, ln(POL_{it}) + \frac{1}{2}[\beta_{11}\, ln(LOA^2{}_{it}) + \beta_{22}\, ln(OBS^2{}_{it}) \\
& + \beta_{33}\, ln(POF^2{}_{it}) + \beta_{44}\, ln(PFA^2{}_{it}) \\
+\beta_{55}\, ln(POL^2{}_{it})] + \beta_{12}\, ln(LOA_{it}) * ln(OBS_{it}) + \beta_{13}\, ln(LOA_{it}) \\
& * ln(POF_{it}) \\
+\beta_{14}\, ln(LOA_{it}) * ln(PFA_{it}) + \beta_{15}\, ln(LOA_{it}) \\
& * ln(POL_{it})\beta_{23}\, ln(OBS_{it}) * ln(POF_{it}) + \\
\beta_{24}\, ln(OBS_{it}) * ln(PFA_{it}) + \beta_{25}\, ln(OBS_{it}) * ln(POL_{it}) \\
& + \beta_{34}\, ln(POF_{it}) * ln(PFA_{it}) \\
+\beta_{35}\, ln(POF_{it}) * ln(POL_{it}) + \beta_{45}\, ln(PFA_{it}) * ln(POL_{it}) + V_{it} \\
& - U_{it} \qquad (6)
\end{aligned}
$$

where π_{it} is the profit after tax of bank i in time period t; θ is a constant. All the independent variables are the same line as the described in the equation (1). The empirical profit inefficiency effects model can be estimated as the same line as the equation (3) with the exception of the output variable profit after tax in this Translog case.

3.3 Empirical Second Stage Methodology

The specification of the Tobit regression model can be formulated as:

$$
E_{it} = \varphi_0 + \varphi_1 ITE_{it} + \varphi_2 ITI_{it} + \varphi_3 ITIN_{it} + \varphi_4 ITP_{it} + \varphi_5 ITPE_{it} + \varphi_6 ATMT_{it} + \varphi_7 ATME_{it} + \varphi_8 CCT_{it} + \varphi_9 CCE_{it} + \xi_{it} \qquad (7)
$$

where E_{it} represent both cost and profit efficiency scores of bank i in time period t estimated from both Stochastic Cobb-Douglas and Translog frontier models respectively; ICT determinants are represented by ITE_{it} which is the IT expenses, ITI_{it} is the IT income, $ITIN_{it}$ is the IT investment, ITPit is the IT personnel, $ITPE_{it}$ is the IT personnel expenses, $ATMT_{it}$ is the ATM transaction, ATMEit is the ATM expenses, CCT is the Credit Card Transaction, and CCE_{it} is the Credit Card Expenses of bank i in time period t. ξit is the error term.

3.4 Likelihood-Ratio Tests for both Stochastic Frontier Cost and Profit Models

The Likelihood Ratio test determines whether Cobb-Douglas or Translog frontier model is an appropriate or not. It also renders other likelihood ratio tests where the null hypotheses are tested that there exists no technical inefficiency effect in stochastic frontier cost and profit models and there exists no interaction effect effect on Translog Stochastic frontier cost and profit models.

The Likelihood-Ratio test statistic can be calculated by:

$$\lambda_{LR} = -2\{\ln[L(H_0)/L(H_1)]\} = -2\{\ln[L(H_0)] - \ln[L(H_1)]\} \qquad (8)$$

where $L(H_0)$ and $L(H_1)$ are the likelihood function of the null and alternative hypothesis respectively and the test statistic (8) follows a mixed Chi-square distribution. The null hypothesis is rejected if $\lambda_{LR} > \chi_c^2$.

4. Results and Discussion

4.1 Estimation of both Cobb-Douglas and Translog Stochastic Frontier Models

The results of stochastic Cobb-Douglas and Translog cost and profit frontier models for PCBs are presented in Table 1. In case of Cobb-Douglas cost frontier model, the loan with (β_1 =0.554) was found positively significant effect on cost, implies that PCBs' reduce their cost from loan given to the customer by making proper collection efforts. The input price of fixed assets (β_4 = 0.09) was found to be positively significant implying that they had caused a positive effect on the PCBs' cost. The input price of fund was found negatively significant with the coefficient of (β_3 = -0.149) that seems to suggest that the price of fund impacted negatively to total operating cost. In case of Translog cost frontier model, the coefficient of off-balance sheet items was noticed significant with negative value (β_2 = -2.767) implied that off-balance sheet items had not a great influence on the bank's cost. The square of inputs such as price of fund (β_{33} = -0.106) and price of fixed assets (β_{44} = 0.623) were negatively and positively significant respectively. The interaction terms such as loan & off-balance sheet items (β_{12} = 0.284), loan & price of fixed assets (β_{14} = 0.244), loan & price of labor (β_{15} = 0.619) were found positively significant where off-balance sheet items & price of labor (β_{25} = -0.753), price of fund & price of labor (β_{35} = -0.152) and price of fixed assets & price of labor (β_{45} = -0.442) were recorded significant and negative effects on bank's cost.

Table 1: Maximum Likelihood Estimates of both Cost and Profit for Private Commercial Banks with Cobb-Douglas and Translog Models

		Coefficient of Cost		Coefficient of Profit	
Variable	Parameter	Cobb-Douglas	Translog	Cobb-Douglas	Translog
Constant	β_0	2.66***	15.18*	5.21***	18.42***
LOA	β_1	0.554***	0.666	-0.008	-1.03
OBS	β_2	-0.042	-2.767**	-0.004	-1.156**
POF	β_3	-0.149***	0.299	-0.021	2.295*
POFA	β_4	0.09*	-1.368	0.043	1.301
POL	β_5	-0.063	-0.489	-0.153*	-0.908
(LOA)2	β_{11}		-0.230		-0.152
LOA * OBS	β_{12}		0.284*		0.148*
LOA * POF	β_{13}		-0.092		0.019
LOA * POFA	β_{14}		0.244*		-0.006
Loan *POL	β_{15}		0.619***		0.057
(OBS)2	β_{22}		-0.060		-0.050
OBS * POF	β_{23}		0.037		-0.212*
OBS *POFA	β_{24}		-0.021		-0.237*
OBS*POL	β_{25}		-0.753***		0.177
(POF)2	β_{33}		-0.106*		0.124
POF * POFA	β_{34}		-0.049		-0.115
POF *POL	β_{35}		-0.152*		0.183
(POFA)2	β_{44}		0.623***		-0.503
POFA *POL	β_{45}		-0.442***		0.449**
(POL)2	β_{55}		-0.076		-0.325***

*, ** . *** means significant at 1%, 5% and 10% level respectively

In case of Cobb-Douglas profit frontier model, only the price of labor was noticed negatively significant with (β_5 = -0.153), suggested that banks may be overstaffed. Based on Translog Stochastic profit frontier model, the off-balance sheet items (β_2 = -1.156) was negatively significant and the price of fund (β_3 = 2.295) was recorded positively significant. These mean that off-balance sheets and price of fund contributed to reduce bank's profit and increase bank's cost respectively. The square input price of labour (β_{55} = -0.325) was noticed negatively significant and the mixed products such as off-balance sheet items & price of fund (β_{23} = -0.212), off-balance sheet items & price of fixed assets (β_{24} = -0.237) were recorded negatively significant, and loan & off-balance sheet items (β_{12} = 0.148) and price of fixed assets & price of labor (β_{45} = 0.449) were noticed positive and significant effects on PCBs' profit. These results were supported by (Abdul-Majid, Saal & Battisti, 2011; Ara, 2016; Christopoulos, Lolos & Tsionas, 2002; Duygun et al., 2015; Hassan & Hassan, 2018; Košak, Zajc & Zorić, 2009).

4.2 Cost and Profit Inefficiency Effects Estimates for Private Commercial Banks with Cobb-Douglas and Translog Models

The cost and profit inefficiency effects estimates of PCBs for both stochastic Cobb-Douglas and Translog models are shown in Table 2.

Table 2: Cost and Profit Inefficiency Effects Estimates for Private Commercial Banks with Cobb-Douglas and Translog Models

Variable	Parameter	Coefficient of cost		Coefficient of Profit	
		Cobb-Douglas	Translog	Cobb-Douglas	Translog
NII	δ_1	-0.32***	-0.305***	-0.244	0.058
NPL	δ_2	-0.039	-0.045	-0.572*	-0.467
ROA	δ_3	-0.344	-0.229	-1.704*	-2.513**
ROE	δ_4	0.871**	0.341*	2.38***	2.868***
CAR	δ_5	0.356	0.961***	-1.75*	-2.806**
Sigma Sq	σ^2	0.26***	0.121***	3.41***	2.704***
Gamma	γ	0.862***	0.669***	1.00*	0.999***

*, ** . *** means significant at 1%, 5% and 10% level respectively

The non-interest income was found negatively significant for both Cobb-Douglas and Translog cost inefficiency effects models, which pointed out a negative and significant effect on PCBs cost inefficiency. This means that the PCBs were able to reduce the cost by non-interest income and saving their revenue. A negative coefficients of non-performing loan estimated from Cobb-Douglas frontier model (δ_2 = -0.572) was found significant but negative causation on the bank's profit inefficiency, implying that non-performing loan contributed to reduce bank profit inefficiency. This implied that non-performing loan had negative effect on cost inefficiency and it played a role to reduce the cost efficiency of PCBs. This result also supported by the works of (for example, Altunbas et al., 2000; Carvallo & Kasman, 2005; Girardone, Molyneux & Gardener, 2004; Košak, Zajc & Zorić, 2009; Mertens & Urga, 2001) and showed that non-performing loan had positive effect on cost inefficiency. Return on assets had negatively significant ($\delta_3 = -1.704$) and ($\delta_3 = -2.513$) for Cobb-Douglas and Translog profit models respectively implied that PCBs gained profit but could not reduce cost using their total assets. The relation between return on assets and efficiency scores of PCBs is conclusive. That is, Řepková (2015) confirmed that return on assets is significantly connected to efficiency evaluation of PCBs but negative which is supported by the works of this study. These findings were contradicted to the works of (for instance, Andries, 2011; Thangavelu & Findlay, 2010; Yildirim & Philippatos, 2007). The positive coefficients of return on equity (ROE) ($\delta_4 = 0.871$), ($\delta_4 = 0.341$), ($\delta_4 = 2.38$) and ($\delta_4 = 2.868$) estimated from Cobb-Douglas cost, Translog cost, Cobb-Douglas profit, and Translog profit models, indicated that PCBs could reduce cost efficiency and increase profit inefficiency significantly by implementing the investments properly. Capital adequacy ratio of PCBs represented by the CAR was recorded a positive ($\delta_5 = 0.961$) and significant influence on the bank cost efficiency in case of Translog cost frontier model. This result implies that the CAR has a positive effect on PCBs in Bangladesh and it is in line with other works (Carbo et al., 2003; LozanoVivas et al., 2002; Mester, 1996). This result states that big banks can deal their origin efficiently and can hold positive CAR. It is negatively significant in case of Cobb-Douglas profit and Translog profit frontier models with the coefficients of ($\delta_5 = -1.75$) and ($\delta_5 = -2.806$) respectively. These mean that bank CAR played a role to increase the profit efficiency of PCBs. These findings indicated that CAR is crucial for banks and it has adversely affected their cost efficiency too. These results were matched with the works of (Andries, 2011; Thangavelu & Findlay, 2010; Yildirim & Philippatos, 2007). Former studies (Carbo, Gardener & Williams, 2003; Casu & Molyneux, 2003; Lozano-Vivas, Pastor & Pastor, 2002) recovered affirmative relation between PCBs efficiency and ROE implying that highly efficient banks increase much profit and higher ROE guides to higher efficiency flat. The Sigma squared was obtained positively significant. The estimated gamma was found close to unity that showed strong impact of PCBs' cost inefficiency and the results were supported by (Thi & Ngan, 2014).

4.3 Likelihood-Ratio Tests Results for Stochastic Cost and Profit Frontier Models

The results of the generalized likelihood-ratio test statistic for both cost and profit models was shown in Table 3. The 1st null hypothesis is H_0: $\rho = 0$ indicates that whether Cobb-Douglas or Translog model is an appropriate or not for both cost and profit models of PCBs. As this null hypothesis was found rejected for both models, so, the Translog model was observed to be more suitable than the Cobb-Douglas model. The 2nd null hypothesis is $H_0 : \gamma=0$, specifies that there exists no technical inefficiency effect either in cost model or in profit model. This hypothesis was accepted for the cost model of PCBs, which showed that there exists no technical cost inefficiency effect in PCBs. The hypothesis was rejected for profit model of PCBs, which asserted that there is a technical profit inefficiency effect in PCBs. The 3rd null hypothesis is $H_0 : \beta_{ij} = 0$, shows that there exists no interaction effect on either Translog cost or profit model. As this null hypothesis was rejected for both cost and profit models, so there exists an interaction effect for both Translog cost and profit efficiency models of PCBs. This result was supported by (Thi & Ngan, 2014).

Table 3: Results of Likelihood-Ratio Tests of Stochastic Cost and Profit Frontier Models for Private Commercial Banks

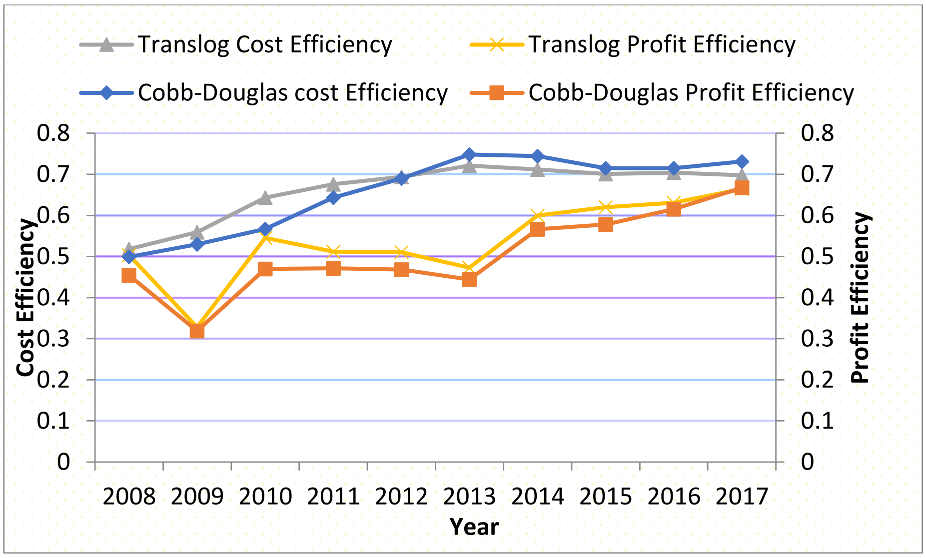
Models	Null Hypothesis	Log-Likelihood Function	Test Statistics λ	Critical Value	Decision
Cost	$H_0 : \rho_i = 0$		-54.96	38.301	Reject H_0
	Cobb-Douglas	-65.61			
	Translog	-38.13			
	$H_0 : \gamma = 0$	-33.64	1.3172	35.827	Accept H_0
	$H_0 : \beta_{ij} = 0$	-64.82	48.9	5.138	Reject H_0
Profit	$H_0 : \rho_i = 0$		16.31	35.83	Reject H_0
	Cobb-Douglas	-165.32			
	Translog	-157.17			
	$H_0 : \gamma = 0$	-165.93	88.654	35.827	Reject H_0
	$H_0 : \beta_{ij} = 0$	-165.32	112.54	5.138	Reject H_0

Note: all critical values are at a 5% level of significance and the critical values are obtained from a table of (Kodde et al. 1986)

4.4 Yearly Average Cost and Profit Efficiency Scores

Year-wise average both cost and profit efficiency scores for PCBs are demonstrated in both Figure 1 and Appendix 1.

Figure 1: Year-wise Average Cost and Profit Efficiency Scores of Stochastic Cobb-Douglas and Translog Models

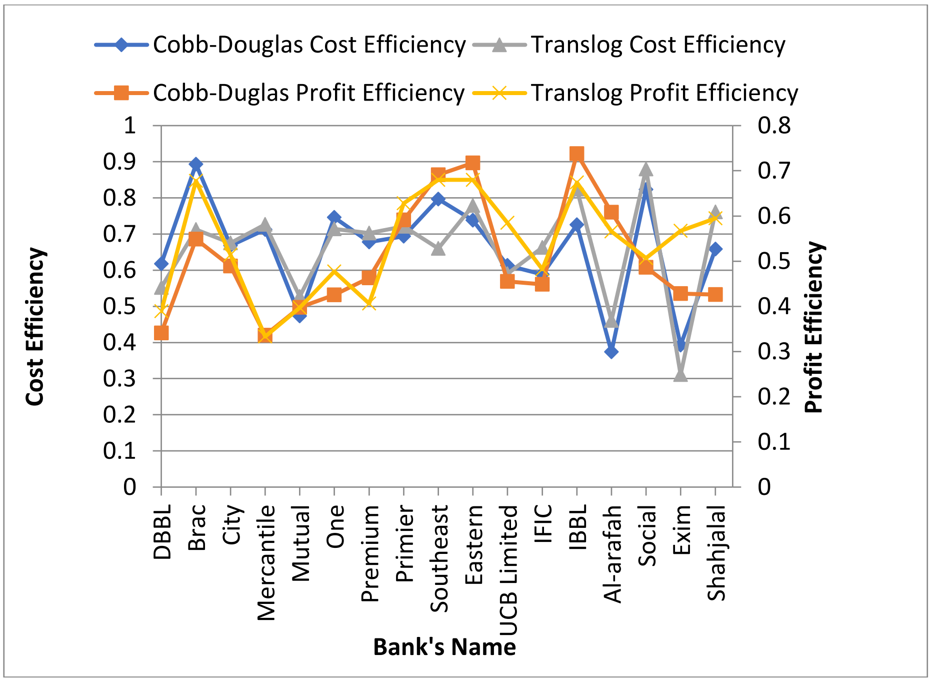


The average efficiencies were varied year by year in both cases of cost and profit. In Stochastic Cobb-Douglas cost model, the average cost efficiency was recorded around from 49.9% to 69.9% during the period of 2008-2012, and it attained the peak percentage amount of 74.8% in 2013. After that, it has been a little drop of 71.5% in 2015 and 2016. In 2017, it has been slightly increased by 73.1%. Conversely, in Stochastic Translog cost model, the cost efficiency was found around 51.1% to 69.9% during 2008-2013, and it obtained the peak amount of 72.1% in 2013. Then it has been slightly decreased by 71.2% in 2014. It remained steady at 70.1% in 2015 and 2016. In the year of 2017, it was a little drop of 69.8%. On the other hand, in Cobb-Douglas profit model, the average profit efficiency of PCBs was observed 45.5% in 2008, and then it has been decreased at 31.7% in the next year. It remained constant at 47% in 2010, 2011 and 2012. Again, it declined slowly in 2013 and thereafter it was gradually increasing and reached the highest value at 66.7% in the year of 2017. Moreover, in Stochastic Translog profit frontier model, the average profit efficiency score of PCBs was noticed 50% in 2008, then it decreased moderately at 32.8% in the following year. It has been obtained 55% in 2010 and remained 51% in 2011 and 2012. Again, it declined slowly 40.7% in 2013 and finally, it was an upward trend and reached the highest value at 66.7% in the last year of 2017. These result were supported by (Ara, 2016; Casu & Molyneux, 2003; Hassan & Hassan, 2018) who measured the PCBs were the most cost efficient rather than profit efficient.

4.5 Average Cost and Profit Efficiency Scores for Individual PCBs

The average cost and profit efficiency scores of individual PCBs during 2008-2017 are presented in both Figure 2 and Appendix 2.

Figure 2: Bank-wise Average Cost and Profit Efficiency of Stochastic Cobb-Douglas and Translog Models



The Brac bank was found the highest cost efficient (89.3%) and Al-Arafah was the lowest cost efficient (37.4%) comparing to other banks in case of Stochastic Cobb-Douglas cost frontier model. Social Islami bank was recorded the highest cost-efficient (88%) and Exim bank was the lowest cost efficient (31.1%) bank related to other banks in Translog cost model. On the other hand, IBBL was the most profit efficient (73.8%) and Mercantile bank was the less profit efficient (33.6%) bank compare to other banks in Stochastic Cobb-Douglas profit frontier model. Both Southeast and Eastern banks were recorded the most profit efficient bank (68%) and Mercantile was found the less profit efficient (33.3%) bank in comparison to other banks in the context of Stochastic Translog profit frontier model. Furthermore, in both Stochastic Cobb-Douglas cost and profit models, Southeast, Al-Arafah, and Prime bank were found 60% above profit efficiency scores and Mercantile, One, Southeast, Eastern, IBBL were recorded cost efficiency scores more than 70%. The most of the PCBs are around 40% to 50% regarding profit efficiency and around 60% to 70% for cost efficiency. Conversely, in Stochastic Translog cost and profit frontier models, IBBL and Prime bank had obtained 60% above profit efficiency scores and Brac, Mercantile, One, Prime, Premium and Shahjalal banks were recorded cost efficiency scores more than 70%. These results were supported to the work of (Ara, 2016)

4.6 Results on ICT Determinants of PCBs' Cost and Profit Efficiency by Tobit Model

The results of ICT determinants of cost and profit efficiency using Tobit regression model for PCBs are shown in Table 4. It can be seen from Cobb-Douglas cost model that the IT income (ϕ_2 = -0.00018) and Credit card expenses (ϕ_9 = -0.00013) were noticed negatively significant, implied that the PCBs costs could not be reduced by increasing the IT income and Credit card expenses of PCBs. Again, the IT personnel expenses (ϕ_5 = 0.00087), ATM Expenses (ϕ_7 = 0.00306) and Credit card transaction (ϕ_8 = 0.00005) had positive impacts on the cost efficiency of Stochastic Cobb-Douglas cost frontier model that means PCBs can reduce their operating costs by installing more automated teller machines, employing credit card transaction and increasing IT person while in Translog cost frontier model, the IT personnel expenses (ϕ_5 = 0.0006) and Credit card transaction (ϕ_8 = 0.000006) were recorded positively significant, these mean that PCBs could be able reduced their costs by increasing the IT personnel expenses, and Credit card transactions but IT income (ϕ_2 = -0.0002), ATM transaction (ϕ_6 = -0.00005), and Credit card expenses (ϕ_9 = -0.0001) were found significant but negative effect on cost efficiency of PCBs. On the contrary, in ICT determinants of profit efficiency of PCBs with Cobb-Douglas profit model, the IT investment (ϕ_3 = -0.0003), IT income (ϕ_2 = -0.0032), IT personnel (ϕ_4 = -0.004), and ATM transaction (ϕ_6 = -0.0008) were found negative and significant effects on profit efficiency but the IT personnel expenses (ϕ_5 = 0.0018) and Credit Card Transaction (ϕ_8 = 0.0013) were recorded positive and significant effects on profit efficiency of PCBs, these mean that by increasing the IT personnel expenses, and Credit card transactions of PCBs can increase their power to pull off its origin and can create outputs with greater economical worth. Besides, in ICT determinants on profit efficiency of PCBs through Stochastic Translog profit model, the IT investment (ϕ_3 = -0.000008), and Credit card expenses (ϕ_9 = -0.0002) were found negative but significant effect on profit efficiency. These implied that the profit of PCBs were affected by increasing IT investment and Credit card expenses. These results were supported by the study of (Safari & Yu, 2014; Surulivel et al., 2013).

Table 4: ICT Determinants of Cost and Profit Efficiency by Tobit Regression Model

Variable	Parameter	Coefficient of Cost		Coefficient of Profit	
		Cobb-Douglas	Translog	Cobb-Douglas	Translog
Intercept	ϕ_0	0.580***	0.619***	0.304***	0.42***
IT Expenses	ϕ_1	0.00002	-0.00003	0.0009	-0.00002
IT Income	ϕ_2	-0.00018*	-0.0002**	-0.0032**	0.00003
IT Investment	ϕ_3	-.0000009	-0.000002	-0.0003*	-.000008*
IT personnel	ϕ_4	0.0002	0.0003	-0.004**	0.0006
IT personnel expenses	ϕ_5	0.00087*	0.0006*	0.0018**	0.0009
ATM Transaction	ϕ_6	-0.00004	-0.00005*	-0.0008*	0.00005
ATM expenses	ϕ_7	0.00306*	0.0002	-0.009	0.00002
Credit Card Transaction	ϕ_8	0.00005*	0.000006**	0.0013***	-.0000007
Credit Card expenses	ϕ_9	-.00013**	-0.0001*	-0.0012	-.0002***

*, ** . *** means significant at 1%, 5% and 10% level respectively

5. Conclusion

This study evaluated both cost and profit efficiency of PCBs in Bangladesh using stochastic Cobb-Douglas and Translog frontier models.

Then the Tobit model was utilized to examine the role of ICT determinants of both cost and profit efficiency scores of PCBs obtained from both stochastic Cobb-Douglas and Trans-log frontier models. In case of Cobb-Douglas model, the average cost and profit efficiency were found 65.8% and 50.5% respectively. By using Cobb-Douglas stochastic frontier analysis, it was found that IBBL was the most profit efficient and Mercantile was the less profit efficient while Brac was the most cost efficient and Al-Arafah was the less cost efficient bank. Through the Translog model, the average cost and profit efficiency were observed at 66.3% and 53.9% respectively. Again, Social Islami bank was noticed the most cost efficient while both Southeast bank and Eastern bank were found the most profit efficient bank. It was also concluded that Exim bank was the less cost efficient and Mercantile bank was the less profit efficient. The empirical findings indicated that the PCBs showed the highest profit efficiency level in 2017, profit efficiency appears to be lowest in 2009, the highest cost efficiency was shown by PCBs in 2013, while cost efficiency was found the lowest in 2008. The results showed that both return on assets and CAR contributed to gain the profit efficiency of PCBs. Based on likelihood-ratio test result, it is inferred that Translog cost and profit models were found to be more better than Cobb-Douglas model for PCBs in Bangladesh.

The ICT determinants were recorded significant and positive effect on PCBs' efficiency by using Tobit regression model. The IT personnel expenses and Credit card transaction were obtained positive and significant but IT income, ATM transaction and Credit card expenses were negative and significant for PCBs' cost efficiency in Translog cost frontier model. Again, the IT investment, and Credit card expenses were found negative but significant effect on the profit efficiency of PCBs with Stochastic Translog profit model. In ICT determinants of cost efficiency of PCBs with Stochastic Cobb-Douglas frontier cost model, the IT income and Credit card expenses were noticed negatively significant and IT personnel expenses, ATM expenses and Credit card transaction were noticed positive and significant. On the other hand, IT income, IT investment, IT personnel, ATM transaction were recorded negative and significant while IT personnel expenses, and Credit card transaction were observed positive and significant effect on PCBs' profit efficiency with Cobb-Douglas model.

The empirical findings from this study conferred appreciable policy connection. Based on the existing finding, it can be state that PCBs have the ability to gain the remaining 46.1% profit margin by managing their available resources. In particular, both Southeast bank and Eastern bank could have quality to increase the leftover 32% profit by pull off their accessible resources and facilities. Again PCBs have the chances to get save the 33.7% cost by increasing IT personnel expenses and Credit card transactions. In specific, Social Islami bank has the opportunity to salve the rest 12% cost by exploding the existing the ICT variables. In terms of the ICT determinants of PCBs in Bangladesh, PCBs could cut down their operating costs by installation of more Automated teller machines, employing Credit card transactions and increasing IT personnel expenses. On the contrary, by increasing the IT personnel expenses and Credit card transactions, PCBs could increase their profit margin and it would be affected by increasing IT investment and Credit card expenses. There are limited ICT variables used in this study because PCBs were unwilling to disclose data bothering on the issues of competitive reasons, but this study is different from other studies because of measuring the influence of ICT determinants of cost and profit efficiency of PCBs in Bangladesh using Tobit regression model. The PCBs system should be efficient and technologically advanced. Similar types of study can be conducted considering to the other banks such as State Owned Commercial Banks or Foreign banks using both SFA and DEA approaches. The outcome earned from this work can assist government, regulators, and investors to take away the deterrent of advancement in Bangladesh economic system.

References

Abdul-Majid, M. Saal, D. S. & Battisti, G. (2011), "The Impact of Islamic Banking on the Cost Efficiency and Productivity Change of Malaysian Commercial Banks", *Applied Economics*, 43(16), 2033–2054.

Aiello, F., and Bonanno, G., (2013), “Profit and Cost Efficiency in the Italian Banking Industry (2006–2011)”, Project: *Banking Efficiency*, DOI: 10.17811//ebl.2.4.2013.190-205.

Andries, A. M. (2011), "The Determinants of Bank Efficiency and Productivity Growth in the Central and Eastern European Banking Systems", *Eastern European Economics*, 49(6), 38–59.

Ara, S. (2016), "Profit and Cost Efficiencies of Conventional Banking (CB) and Islamic Banking (IB) using Stochastic Frontier Approach: A Comparative Study", *Journal of Islamic Economics Banking and Finance*, 12(1), 63–89.

Ariff, M. & Can, L. (2008), "Cost and Profit Efficiency of Chinese Banks: A Non-Parametric Analysis", *China Economic Review*, 19(2), 260–273.

Ashraf, M., Grunfeld, H., Hoque, M. R., & Alam, K. (2017), "An Extended Conceptual Framework to Understand Information and Communication Technology Enabled Socio-economic Development at Community Level in Bangladesh", *Information Technology & People*, *30*(4), 736–752. doi: 10.1108/ITP-03-2016-0067

Altunbas, Y. Liu, M. H. Molyneux, P. & Seth, R. (2000), "Efficiency and Risk in Japanese Banking", *Journal of Banking and Finance*, 24(10), 1605–1628.

Battese, G. E. & Coelli, T. J. (1995), "A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data", *Empirical Economics*, 20(2), 325–332.

Baten, M. A., Kasim, M. M., & Rahman, M. M. (2015a), "Cost and Profit Efficiency of Banks: Stochastic Frontier Analysis vs Data Envelopment Analysis", *Asia Pacific Journal of Business*, 6(2), 1-17.

Baten, M. A., Kasim, M. M. and Rahman, M. M., (2015b), “Cost and Profit Efficiency of Online Banks: Do National Commercial Banks Perform Better than Private Banks”?, *Journal of Internet Banking and Commerce,* 20(3), 1-6.

Baten, M. M. (2021), "Information Technology Role on Private Commercial Banks’ Efficiency with Cost and Profit DEA Technology", *AFEBI Management and Business Review (AMBR),* 111-122.

Beccalli, E. (2007), "Does IT Investment Improve Bank Performance? Evidence from Europe", *Journal of Banking and Finance*, 31(7), 2205–2230.

Begum, S., Baten, M. M., & Ali, R. (2022), "Evaluation of Information Technology Impact on State-owned Commercial Banks’ Efficiency: The Case of Bangladesh", *Asian Journal of Business Environment*, 12-1, 1-9.

Carvallo, O. & Kasman, A. (2005), "Cost Efficiency in the Latin American and Caribbean Banking Systems", *Journal of International Financial Markets, Institutions and Money*, 15(1), 55–72.

Carbo, S., Gardener, E. P., & Williams, J. (2003), "A Note on Technical Change in Banking: The Case of European Savings Banks", *Applied Economics*, 35(6), 705-719.

Casu, B., & Girerdone, C., (2004), "Efficiency of Large Banks in the Single European Market", *Service Industries Journal*, 24(6), 1-21.

Casu, B. & Molyneux, P. (2003), "A Comparative Study of Efficiency in European Banking", *Applied Economics*, 35(17), 1865–1876.

Chu F. L., (2007), "The Role of Information Technology in Operating Cost and Operational Efficiency of Banks: An Application of Frontier Efficiency Analysis", *Asian Journal of Management and Humanity Sciences*, 2(1-4), 36-56.

Christopoulos, D. K. Lolos, S. E. G. & Tsionas, E. G. (2002), Efficiency of the Greek Banking System in View of the EMU: A Heteroscedastic Stochastic Frontier Approach", *Journal of Policy Modeling*, 24(9), 813–829.

Christopoulos, D. K. & Tsionas, E. G. (2001), "Banking Economic Efficiency in the Deregulation Period: Results from Heteroscedastic Stochastic Frontier Models", *The Manchester School*, 69(6), 656–676.

Duygun, M. Shaban, M. Sickles, R. C. & Weyman-Jones, T. (2015), "How a Regulatory Capital Requirement affects Banks Productivity: An Application to Emerging Economies", *Journal of Productivity Analysis*, 44(3), 237–248.

Fries, S. & Taci, A. (2005), "Cost Efficiency of Banks in Transition: Evidence from 289 Banks in 15 Post-Communist Countries", *Journal of Banking and Finance*, 29(1) 55–81.

Garza-Garcia, J. G., (2012), "Determinants of Bank Efficiency in Mexico: A Two-Stage Analysis", *Applied Economics Letters*, 19(17), 1679-1682.

Girardone, C. Molyneux, P. & Gardener, E. P. M. (2004), "Analysing the Determinants of Bank Efficiency: The Case of Italian Banks", *Applied Economics*, 36(3), 215–227.

Haque, S. M. S. & Reza, M. M. (2009), "Information Technology (IT): The Effects on the Growth of Banking Industry in Bangladesh – A Customer Perception", *Journal of the People's University of Bangladesh*, Dhaka, 1, 72-79.

Hassan, M. H. & Hassan, M. (2018), "Cost Efficiency of Banking Sector of Bangladesh: Evidence using the Stochastic Frontier Analysis", *Asian Journal of Empirical Research*, 8(6), 208–224.

Kasman & Yildrim, (2006), "Cost and Profit Efficiencies in Transition Banking: The Case of New EU Members", *Applied Economics*, 38(9), 1079-1090.

Kodde, D. A. Palm, F. C. Kodde, D. A. & Palm, F. (1986), "Wald Criteria for Jointly Testing Equality and Inequality Restrictions", *Econometrica*, 54(5), 1243–48.

Košak, M. Zajc, P. & Zorić, J. (2009), "Bank Efficiency Differences in the New EU Member States", *Baltic Journal of Economics*, 9(2), 67–

89.

Lee, B. & Menon, N. M. (2000), "Information Technology Value through Different Normative Lenses", *Journal of Management Information Systems*, 16(4), 99–119.

Lozano-Vivas, A., Pastor, J. T., & Pastor, J. M. (2002), "An Efficiency Comparison of European Banking Systems Operating under Different Environmental Conditions", *Journal of Productivity Analysis*, 18(1), 59-77.

Mester, L. J. (1996), "A Study of Bank Efficiency taking into Account Risk-preferences", *Journal of Banking & Finance*, 20(6), 1025-1045.

Mertens, A. & Urga, G. (2001), "Efficiency, Scale and Scope Economies in the Ukrainian Banking Sector in 1998", *Emerging Markets Review*, 2(3), 292–308.

Rai, A., Patnayakuni, R., & Patnayakuni, N. (1997), "Technology Investment and Business Performance", *Communications of the ACM*, 40(7), 89-97.

Rahman, M. M. and Islam, T. A. N. M. (2011), “Stochastic Frontier Approach to Estimate Branch-wise Cost and Profit Efficiency of Islami Bank Bangladesh Limited”, *Journal of Islamic Economics, Banking and Finance*, 7(2), 45-70.

Řepková, I. (2015), "Banking Efficiency Determinants in the Czech Banking Sector", *Procedia Economics and Finance*, 23, 191–196.

Romdhane, S. B. (2013), "Impact of Information Technology on the Performance of Tunisian Banks: A Stochastic Frontier Analysis with Panel Data", *Asian Academy of Management Journal of Accounting and Finance (AAMJAF)*, 9(2), 95–125.

Sadekin, M. & Shaikh, M. (2015), "Current Status of E-Banking Practices in Bangladesh", *Scholar Journal of Business and Social Science*, 1(1), 53-64

Sadekin, M. & Shaikh, M. (2016), "Effect of E-Banking on Banking Sector of Bangladesh", *International Journal of Econom*ics, Finance and Management Sciences, 4(3): 93-97.

Safari, M. R. & Liu, Z. Y., (2014a), "The Effect of Information Technology on Public and Private Sector: Evidence from the Banking Industry", *WHICEB, Proceedings,* 98. http://aisel.aisnet.org/whiceb2014/98.

Safari, M. R. & Yu, L. Z. (2014b), "Impact of Information and Communication Technology (ICT) on Efficiency: Evidence from the Iranian Banking Industry", *World Applied Sciences Journal,* 29 (2), 208-218.

Shen, Z. Liao, H. & Weyman-Jones, T. (2009), "Cost Efficiency Analysis in Banking Industries of Ten Asian Countries and Regions", *Journal of Chinese Economic and Business Studies*, 7(2), 199–218.

Surulivel, S. T. Vijayabanu, C. Amudha, R. & Charumathi, B. (2013), "Impact of Information Technology (IT) Investments on the Cost Efficiency of Indian Private Sector Banks: A Stochastic Frontier Approach (SFA)", *Research Journal of Applied Sciences, Engineering and Technology*, 6(14), 2685–2692.

Tahir, I. M., & Haron, S., (2010), "Cost and Profit Efficiency of Islamic Banks: International Evidence using the Stochastic Frontier Approach", *Banks and Bank Systems*, 5(4),78-83.

Thangavelu, S. M. & Findlay, C., (2010), "Bank Efficiency, Regulation and Response to Crisis of Financial Institutions in Selected Asian Countries", in Findlay, C., F. Parulian and J. Corbett (ed.), Linkages between Real and Financial Aspects of Economic Integration in East Asia. ERIA Research Project Report 2009-1, Jakarta: ERIA. 288-315.

Thi, L. & Ngan, T. (2014), "Profit and Cost Efficiency Analysis in Banking Sector: A Case of Stochastic Frontier Approach for Vietnam", *Journal of Knowledge Management, Economics and Information Technology,* 4(5), 1-17.

Yildirim, H. S. & Philippatos, G. C. (2007), "Efficiency of Banks: Recent Evidence from the Transition Economies of Europe, 1993-2000", *European Journal of Finance*, 13(2), 123–143.

Appendix 1: Year-wise Cost and Profit Efficiency of Cobb-Douglas and Translog Stochastic Frontier Analysis for Private Commercial Banks

Year	Cobb-Douglas		Translog	
	Cost Efficiency	Profit Efficiency	Cost Efficiency	Profit Efficiency
2008	0.499	0.454	0.518	0.503
2009	0.530	0.319	0.559	0.328
2010	0.567	0.470	0.643	0.545
2011	0.643	0.471	0.676	0.512
2012	0.690	0.468	0.694	0.510
2013	0.748	0.444	0.721	0.473
2014	0.744	0.566	0.712	0.600
2015	0.715	0.578	0.701	0.620
2016	0.715	0.615	0.704	0.631
2017	0.731	0.667	0.698	0.664
Mean	0.658	0.505	0.663	0.539

Appendix 2: Bank-wise Cost and Profit Efficiency of Cobb-Douglas and Translog Stochastic Frontier Analysis for Private Commercial Banks

Banks Name	Cobb-Douglas		Translog	
	Cost Efficiency	Profit Efficiency	Cost Efficiency	Profit Efficiency
DBBL	0.618	0.341	0.552	0.389
Brac	0.893	0.549	0.712	0.678
City	0.668	0.489	0.675	0.514
Mercantile	0.712	0.336	0.727	0.333
Mutual	0.473	0.398	0.527	0.397
One	0.746	0.425	0.714	0.477
Premium	0.678	0.463	0.703	0.406
Prime	0.694	0.591	0.721	0.628
Southeast	0.797	0.691	0.660	0.680
Eastern	0.738	0.717	0.779	0.680
UCB Limited	0.613	0.455	0.590	0.585
IFIC	0.588	0.449	0.663	0.482
IBBL	0.726	0.738	0.824	0.674
Al-Arafah	0.374	0.608	0.461	0.566
Social	0.823	0.486	0.88	0.507
Exim	0.393	0.428	0.311	0.567
Shahjalal	0.658	0.426	0.761	0.595
Mean	0.658	0.505	0.662	0.539