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Technical, allocative and cost efficiency of private commercial banks in Bangladesh

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Abstract

Purpose – Considering the fact that an efficient bank is able to allocate its resources effectively, reduce its operating costs and maximize profitability, this study investigates the technical, allocative, and cost efficiency (TE, AE, CE) of private commercial banks (PCBs) in Bangladesh from 2017 to 2023 to gain insight into the current condition of Bangladesh's private banking industry and provide policy recommendations for managers. The paper also determines a few determinants of banking efficiency. Due to the unavailability of data, 39 banks out of 43 private commercial banks were observed.

Design/methodology/approach – The study used the data envelopment analysis (DEA) and the modern network DEA (NDEA) as the research tools. The input variables include total deposits, fixed assets, and personnel expenses with their prices, while the output variables consist of total loans and off-balance sheet items for DEA. Total deposits were considered as an intermediary product in NDEA. In addition, a Bayesian Tobit Regression Analysis is conducted to define the determinants of banking efficiency in conjunction with Tobit Censored Regression Analysis. The predictors selected for the analysis are bank size, share of loans, profitability, cost management ability, and credit risk.

Findings – The DEA results suggest that Bangladesh's PCBs performed well in terms of TE, AE, and CE during the study period, averaging 91%, 94%, and 86%. The NDEA model, on the other hand, shows the average scores of 54%, 73%, and 38%, respectively. The determinants of TE are the bank size, share of loans, and cost management ability, while only the first two act as determinants of CE. There is no evidence that these variables act as determinants of AE. The findings have some limitations due to issues with the model's goodness of fit.

Originality/value – By comparing the DEA and NDEA scores, this study contributes to the body of research by looking at how efficient Bangladesh's private commercial banking sector is as a whole while also defining the determinants of efficiency. This study differs from other studies as it applies frequentist and non-frequentist statistical methods for identifying banking efficiency determinants.

Keywords Technical efficiency, Allocative efficiency, Cost efficiency, Data envelopment analysis, Tobit regression, Bayesian statistics

Paper type Research paper

JEL Classification — C34, C61, C67, D24, G21, L25

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1. Introduction

Banks are thought to be the most important and oldest type of financial institution for any economy, acting as the principal sources of loanable funds provided to individuals, families, small and large businesses, and many more (Rose, 2002). The modern banking system not only includes the roles of intermediation, guarantor, or risk management but also various activities like granting loans, providing financial advice, cash management, insurance services, etc. (Rose, 2002). This system has been going through radical changes caused by globalization, the development of information technology, evolving legislative rules, shifts in consumer wants and needs, and many more over the last few decades (Vaithilingam *et al.*, 2006). As a result, banks have been experiencing a constant need to adapt to the changing environment to keep up with their competitors.

When considering the banking industry's role, measuring how it contributes to economic productivity while dealing with internal and external forces is crucial. If a bank cannot perform better than its competitors, it can be said that it will be difficult for them to ensure their sustainability. The extent of competition positively correlates with a bank's financial intermediation function and ability to contribute to social well-being (Boamah *et al.*, 2022). As stated by Fagge (2019), to ensure operational sustainability and economic growth, it is a must for the banks to measure their performance efficiency. Alongside the banking authorities and policymakers, the efficiency of the banks is also important from the masses' perspective, as they are more interested in lower service charges, interest rates, and service quality (Elyasiani and Mehdian, 1990). Furthermore, a bank's high efficiency demonstrates its superior ability to manage business risks (Chen, 2024). Therefore, evaluating the efficiency level of banks operating in an economy is critical. In a service industry like banking, efficiency is the ability to generate the maximum output by utilizing minimal resource input. It is often defined as the ratio of outputs to inputs (Sherman and Zhu, 2006). As a bank's key function is financial intermediation, the efficient performance of banks results in the allocation of adequate resources for productive improvements and enhancements in social welfare (Boamah *et al.*, 2022).

This paper focuses on three key forms of bank efficiency—technical efficiency (TE), allocative efficiency (AE), and cost efficiency (CE). The ability of a firm to obtain a maximum output level from a specific input level is called TE (Coelli, 1996). A high score in TE is closely related to the managerial efforts of a firm, where the goal of the management is to use the minimum level of inputs, which can result in the optimal level of outputs (Othman *et al.*, 2016). A firm will be considered technically inefficient if the same or higher outcomes can be obtained from fewer inputs (Palmer and Torgerson, 1999). The concept of allocative efficiency signifies the firm's competence in choosing the optimal set of inputs with their prices in order to achieve the expected outcome (Alber *et al.*, 2019). AE is not innate; rather, it is an acquired skill over time. So, it plays a vital role for firms when it comes to responding to changes in the economic environment of a country. AE is not innate; instead, it is an acquired skill over time. So, it plays a vital role for firms when it comes to responding to changes in the economic environment of a country. CE mainly refers to the extent to which a bank's costs can be used to generate the highest result at a specific input level under certain circumstances in the business (Bradrania *et al.*, 2017). This means a firm can be cost-efficient if the amount of waste is negligible or minimal during its operations. CE is considered one of the most crucial aspects that can influence a firm's decision-making process, especially in cases of financial uncertainty (Narawish *et al.*, 2021). From a broader perspective, CE implies that a bank can provide its services without wasting resources due to its its technical and allocative efficiency measures (Alber *et al.*, 2019). That means the CE score is the product of TE and AE scores.

In Bangladesh, there are mainly four types of banks operating currently: six state-owned commercial banks, three specialized development banks, 43 private commercial banks, and nine foreign commercial banks, all of which are regulated by the Bangladesh Bank (Annual Report of Bangladesh Bank for the financial year 2022–2023, 2024). The people of the country take services like safekeeping of their funds, financial advice and assistance, credit facilities,

savings and investment opportunities, payment services, etc., from those banks. However, we cannot generally say that customers are delighted with the services they receive from the banks. Since competition is high in Bangladesh's banking sector and improvements in the quality of services are needed, analyzing a bank's efficiency level is essential. Moreover, an efficient bank can allocate resources more effectively, reduce operating expenses, and maximize profitability.

This research aims to study the technical, allocative, and cost efficiency of the private commercial banks (PCBs) in Bangladesh from the year 2017 to the year 2023. The popular Data Envelopment Analysis (DEA) approach is used in this research. Alongside that, a comparison with the modern Network Data Envelopment Analysis (NDEA) scores is made to show the variability of the scores. Later, a few determinants are regressed separately with the banks to determine whether these factors impact banking efficiency. The Tobit Regression Analysis method is applied in this process, following the methods applied by Brack and Jimborean (2010), Batir *et al*. (2017), Banna *et al*. (2017), and Milenković *et al*. (2022), as the data are censored. Again, since Tobit Regression Analysis is a frequentist technique, and many scholars criticize it, a non-frequentist technique (e.g. Bayesian Tobit Regression Analysis) is also conducted to show the differences for a more comprehensive outcome.

In the past, few studies took place regarding the analysis of banking efficiency in Bangladesh, including those by Hoque and Rayhan (2013), where the researchers ranked the selected banks in terms of their technical efficiency scores; Qamruzzaman and Jianguo (2016), where the researchers analyzed the data of 30 PCBs in Bangladesh to compare the TE scores under Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) in both input and output orientation; Hassan and Hassan (2018), where the researchers employed a single stage stochastic frontier analysis approach to measure the CE of the banking sector in Bangladesh; Solaiman *et al*. (2021), where the researchers described the efficiency of both local and foreign banks in terms of TE, AE and scale efficiency (SE); Nabi (2022), where the researcher provided insights on the TE, AE and CE of five out of ten Islamic banks, four out of six state-owned banks, and only ten out of forty three private commercial banks; and Yesmine *et al*. (2023), where the researchers employed DEA to contrast the efficiency of all four types of banks in terms of TE and SE to determine the best performer, none have offered a thorough analysis covering all the private commercial banks in Bangladesh. Moreover, only one previous research study was found during this study, i.e. Azad *et al*. (2020), which applied a network DEA model to compare with traditional DEA scores, taking PCBs and specialized banks of Bangladesh together to benchmark the best performers. However, none of these studies provided a detailed analysis of all the PCBs in Bangladesh, where a significant gap exists.

By conducting DEA and NDEA, taking all the PCBs into account, this research caters to a clearer insight into the overall state of PCBs in Bangladesh. The reason behind choosing only Bangladeshi banks, in this case, lies in the fact that there are cultural differences in the banking behavior of Bangladeshi people from that of other countries, and selecting only Bangladeshi banks can help avoid such exogenous effects. Moreover, private commercial banks are less prone to corruption than state-owned banks, as suggested by Yesmine *et al*. (2023), and the specialized and foreign banks have different banking standards; it would be ideal to select all the private commercial banks to get a comprehensive insight on their overall performance instead of taking other types of banks into consideration.

Private commercial banks serve as crucial sources of investable capital for both public and private sectors, significantly contributing to the economic development of Bangladesh. Their service models have transformed the trajectory of agriculture and the country's small and medium-sized enterprise sector. Nonetheless, this industry's obstacles include ineffective leadership and management, inadequate governance, and non-adherence to legal and ethical standards (Khuda, 2019). From customers' perspectives, only efficient banks can provide better services as their operational expenses are reasonable. If a bank can operate efficiently, it can grow its business effectively by utilizing its deposits and credits, reaching customers, and guiding policymakers to make data-driven decisions (Maity and Sahu, 2022).

The results of this study will help devise better strategic plans for increasing the operational efficacy of the private commercial banking sector in Bangladesh, as policymakers will be able to make informed decisions on specific efficiency categories. The determinants of efficiency will indicate the factors banks need to emphasize to maintain stable growth. On top of that, this study will contribute to the body of literature on efficiency studies by comparing the results of traditional DEA and NDEA tests, as well as conventional Tobit Regression and Bayesian Tobit Regression tests. These results can be a starting block for even more groundbreaking research in this area.

In the subsequent parts of this paper, Section 2 provides an overview of relevant literature, Section 3 presents the methods and variables used to conduct the research, and Section 4 shows the results of the data analysis with their corresponding discussion. Finally, a conclusion is drawn from the research in Section 5, showing the future implications and areas for further research in this field.

2. Literature review

2.1 Overview of the private commercial banks in Bangladesh (PCBs)

PCBs typically make commercial loans and issue transaction deposits to their customers (Berger and Bouwman, 2017). Currently, the total number of PCBs in Bangladesh is 43 out of 61 scheduled banks (Annual Report of Bangladesh Bank for the financial year 2022–2023, 2024). Since the liberation war of 1971, banks have grown exponentially in Bangladesh and contributed to economic growth (Uddin and Bristy, 2014). The modern banking industry is also crucial to society's development. In Bangladesh, various studies have shown that the growth prospect is significant. Banks play crucial roles in the economy of Bangladesh by promoting savings for all sorts of people, investing in agriculture, trade, and others, and acting as intermediaries in foreign trade during exports and imports (Chowdhury and Ahmed, 2009). Islam *et al*. (2013) demonstrate a significant rise in bank branches, employees, loans, deposits, advances, and earnings per share, pointing to a considerable reliance on private commercial banks.

Be it an entrepreneurial small business or an established medium- or large-scale business, the loans provided by the banks act as the key to its growth and contribute to accelerating the national economy (Zohra, 2020). Uddin and Bristy (2014) found that the increased activities and services of the banks cause an increasing number of employees and branches every year. This conclusion shows the significance of studying commercial banks, especially private ones. Another study by Roy and Khan (2013) found that increasing the reputation of a bank is dependent on improving the service quality and corporate social performance of the bank, which are linked to their efficiency levels. In recent years, the private commercial banking industry has become more competitive due to the growth of international banks, and their advanced technology frameworks and efficient credit management systems (Islam *et al*., 2015). As a result, there is a need to ensure higher performance and customer satisfaction for PCBs. The customers of the PCBs in Bangladesh are perceived to be satisfied when they are served with tangibility, reliability, responsiveness, and empathy in the service (Al Karim and Chowdhury, 2014). However, as studied by Faruque and Rahman (2018), the private commercial banks in Bangladesh are not performing rhythmically, where they should emphasize both their development and the development of the overall economy.

2.2 Approaches to determining input and Output components to measure efficiency of banks

Researchers have faced challenges in choosing input and output variables for their studies on banking efficiency over the years. Two core approaches exist for determining input and output variables: (1) the production approach and (2) the intermediation approach, as proposed by Berger and Humphrey (1997). The banks are considered the firsthand account of financial

services for the account owners under the first approach, where the loan applications, insurance policies, other credit reports, or payment instruments are the output components processed over a specific period (Berger and Humphrey, 1997). On the other hand, under the intermediation approach, banks are referred to as the intermediary entity to exchange funds between savers and investors, where funds are considered raw material that transforms in the intermediation process (Berger and Humphrey, 1997).

Neither of those approaches fit perfectly in measuring banking efficiency, as they do not fully play the roles of financial institutions in providing transaction services or being financial intermediaries; therefore, it would be best to implement both methods in a research design. However, if the researcher wants to use only one method, Berger and Humphrey (1997) recommend using the production method to determine the efficiencies of branch activities of banks, while the intermediation approach calculates the efficiencies of the entire organization. It is because:

(1) Banking branches work with customer documents, and branch managers do not directly influence how the bank's funds and investment-related decisions are made, making the production approach more effective.

(2) In a banking institution, the interest expenses and total costs, including the production costs, are considered, where the intermediation approach becomes more effective.

Following the fact that the intermediation approach will be more effective in measuring the efficiency of an entire bank, many authors such as Al-Jarrah (2007), Brack and Jimborean (2010), Yannick *et al*. (2016), Batir *et al*. (2017), Fagge (2019), Nguyen *et al*. (2019), Yagli (2022), and many others have used an intermediation approach to determine the efficiency scores of the banks they aimed to analyze over the last few years.

2.3 Data envelopment analysis (DEA) vs Network Data Envelopment Analysis (NDEA)

DEA is a linear programming method to assess efficiency levels across various public, private, and non-profit organizations. Its popularity is growing, particularly in the context of non-parametric approaches (Zhu, 2014). The DEA score is measured by productivity indices based on the inputs and outputs of the organization (Jayamaha and Mula, 2011). Generally, the efficiency scores range from 0 to 1, indicating either inefficient or efficient firms. As the upper limit is 1, if there is any firm for which the reflected score is higher than the upper threshold, it will be considered a super-efficient firm (Fagge, 2019). In DEA, the firms or entities are called Decision Making Units (DMUs), which utilize the given inputs to produce the outputs (Malik *et al.*, 2018).

Figure 1 demonstrates a basic DEA technology model adapted from Farè and Grosskopf (2000).

The traditional DEA model is based on a single-stage black box model that only converts inputs into outputs. However, in modern days, the inter-relationships between the factors that structure an industry or a situation are considered important, for which the traditional DEA model is customized to suit its application better (Farè and Grosskopf, 2000). That is how the network DEA (NDEA) model is developed; it can address the refinements of the conventional DEA models. The NDEA model is a cluster of models with the same characteristics of

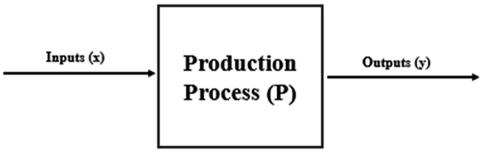

Figure 1. The DEA technology. Source(s): Farè and Grosskopf (2000)

containing linear constraints (Farè and Grosskopf, 2000). The plus point of employing the NDEA model is that it yields more informative and acceptable results, enabling management to formulate improved strategies in response to key factors (Ratner *et al.*, 2023).

In a network model, several nodes exist, each indicating sources, subprocesses, and outputs. The difference with the traditional DEA model is that the network model provides the opportunity to explicitly model intermediate inputs (Farè and Grosskopf, 2000). For example, in the banking intermediation process, an intermediary product is an item that is produced and consumed fully or partially, i.e. customer deposits. Therefore, the sources or inputs that produce customer deposits would create node 1; then, deposits will act as inputs to produce the ultimate outputs in node 2.

Figure 2 illustrates a full network technology used for DEA, with one source, three subprocesses, and one outlet.

2.4 Applications of NDEA in banking efficiency studies

Several authors have applied the network DEA model in their studies to unravel the black box of the traditional DEA model and consider the internal processes. The NDEA model is generally a two-stage model, following either a series network structure, a parallel network structure, or a combination of both, e.g. Kao (2014), Fukuyama and Matousek (2017), etc. However, some researchers have also applied multi-stage models in their research, e.g. Zhou *et al*. (2018).

While applying a two-stage NDEA model, researchers utilized different variables that supported them in giving those stages names for more precise indications. The research by Fukuyama and Matousek (2017) was based on a two-stage NDEA model where the first stage was considered a fundraising process, while the second stage was considered a loan/investment process to conduct the efficiency test. Using Simar and Wilson's single bootstrap and double bootstrap procedures, they provided conclusions on the efficiency factors in the Japanese banks studied.

An interesting investigation was carried out by Wanke *et al*. (2019), where the researchers analyzed data from the banking industry of the Middle East and North Africa (MENA) countries to determine their efficiency scores in a relational model of two-stage NDEA and then applied bootstrapped Simplex, Simar and Wilson truncated regression, Beta, and Tobit censored regression analysis to assess effects of several factors, namely, bank type, ownership impact, origin, etc.

In their research, Phung *et al*. (2020) compared the technical efficiency scores under CRS with the scores that arrive under the network DEA model. They also proposed two new network DEA models, such as Relational Decomposition NDEA and Additive Aggregation NDEA for comparison purposes. The findings from their research indicated how significantly the scores vary from the traditional DEA model.

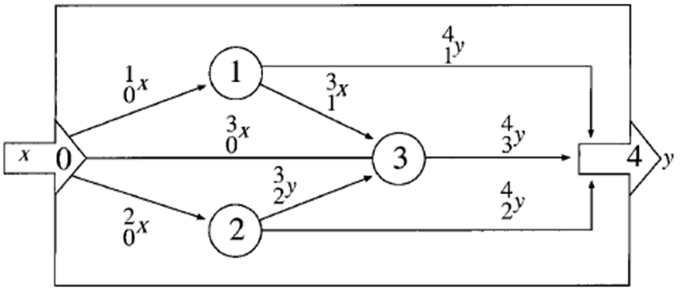

Figure 2. The network DEA model. Source(s): Farè and Grosskopf (2000)

Azad *et al*. (2020) divided the two stages based on the bank's core and additional operations. It was the only paper on Bangladeshi banks found while this research was conducted. However, the goal of this paper was to benchmark the banks that performed efficiently in single-stage DEA models and two-stage DEA models, considering a selected number of local banks. Later, a truncated bootstrap regression was conducted using bank- and country-level variables to determine the disparity between public and private banks.

The study by Li *et al*. (2022) was also based on a two-stage model, where the primary stage was named the value operation stage, and the latter was named the value creation stage. The authors conducted the Kruskal-Wallis Test to explore the probability of difference between the distribution of the samples from multiple populations after conducting the efficiency test.

Tong *et al*. (2023) categorized the two stages of the NDEA model into management efficiency and profitability efficiency. Then, they compared the results derived from the CCR-based model of DEA and the NDEA model, which provided them with the insight that NDEA has more excellent explanatory capability when considering the banking industry's internal structure in Taiwan.

Chen (2024) employed a two-stage network DEA model, with the initial stage assessing the operational efficiency of banking branches and the subsequent stage evaluating their investment efficiency in China. The author applied the Kruskal-Wallis test to assess the statistical significance of the efficiency scores.

The findings of those papers mostly recommended that policymakers and regulatory bodies focus on improving bank-specific variables while considering the overall structure of the banking infrastructure.

2.5 Empirical studies on banking efficiency: global and Bangladeshi perspective

There has been extensive research on banking efficiency across various countries and periods, providing important insights into how efficiently banks use their physical, financial, and human resources to generate outputs in various desired forms. The studies were not limited to determining the technical efficiency of specific banks in certain regions; rather, several investigations have been done to explore the banks' allocative, cost, and scale efficiency measurements. Some studies compared the efficiency differences among Islamic Shariah-based, public-owned, and foreign commercial banks. A few were also extended to find the determinants directly or indirectly influencing banking efficiency.

In a study by Brack and Jimborean (2010), it was found that among the ten major banks from Germany, France, the United States, Spain, and the United Kingdom, the French and Spanish banks could enhance their cost efficiency, while there were deteriorations in the cases of other banks. Using a second-step Tobit censored regression analysis, the study found that foreign ownership banks, fewer years of operations, GDP per capita, etc., affect the bank's efficiency performance.

During the study period of 2008–2010, the Ivorian banks struggled to allocate loans for their customers, while the foreign-owned private banks in that country performed more efficiently (Yannick *et al*., 2016). Among the 17-euro area countries, the cost efficiency was approximately 84% on average from 2006 to 2017 (Huljak *et al*., 2019). The study period of 2010–2017 found a moderate consistency between cost and technical efficiency for the deposit banks in Nigeria, an African country, while the allocative efficiency scores were higher (Fagge, 2019). An analysis of 409 banks across 17 Latin American countries during the period from 2014 to 2016 identified that bank size, the ratio of loans to total assets, and the percentage of non-performing loans act as direct determinants of bank efficiency (Jiménez-Hernandez *et al*., 2019). Nguyen and Pham (2020) compared the CE of Vietnamese banks by employing DEA and Stochastic Frontier Analysis (SFA). Their investigation revealed that the determinants of efficiency, identified by second-stage regression analysis, were liquidity, loan-to-deposit ratio, non-performing loans, type of bank ownership, and crisis time, all of which positively or negatively influence efficiency. However, bank size and management's cost-handling capacity have no direct impact on a bank's efficiency, as found by this study.

The Macedonian commercial banking system exhibited higher efficiency than that of Croatia and Serbia from 2015 to 2019, indicating that the resource allocation strategy and fact-based decision-making should be improved in the commercial banks of the latter two countries (Cvetkoska *et al.*, 2021). In their 2021 study, Gardijan Kedžo and Tuškan Sjauš (2021) had taken an approach to DEA differently. They looked at the DEA results of Croatia's biggest private banks and then compared them to several financial indicators and accounting ratios.

In another African country, Ethiopia, a study between 1990–2022 revealed that the publicly owned banks were technically more efficient than the privately owned ones, while every bank experienced allocative inefficiency because of poor utilization of physical assets and loanable funds (Getinet Chane *et al.*, 2024). A recent study of eight member states from the SADC region from 2010 to 2021 reported that the relatively technical inefficiency accounted for 40%, suggesting they should increase their asset base and invest in research and automation (Abel *et al.*, 2024).

Many studies have been conducted on banking efficiency in the Asian region. The cost efficiency scores for Middle Eastern countries like Saudi Arabia, Jordan, Bahrain, and Egypt were between 0.50 and 0.70 in the study period between 1992 and 2000. Thus, from 1992 to 2000, the banks examined could have produced the same output using 50%–70% of their inputs (Al-Jarrah, 2007). In a sample of 21 banks, comprising eight local and 13 foreign banks in Malaysia, it was noticed that domestic banks exhibited somewhat superior performance compared to foreign banks from 2005 to 2014 (Hamid *et al.*, 2017). In determining the efficiency of 30 joint-stock commercial banks in Vietnam, Nguyen *et al.* (2019) mentioned that the country's banking efficiency was improving steadily, where the bank size, years of operations, and ownership by the state had positive relationships with the increased efficiency scores. A recent study employing the DEA approach in India from 2014 to 2020 indicated that private-sector banks outperformed public-sector banks, which faced continuous declines in efficiency from 2014 to 2017 (Dar *et al.*, 2021). In the same study, the non-performing assets were declared the most detrimental factor, hindering banking efficiency. In determining the TE, AE, and CE of Turkey's conventional and participation banks from 2005 to 2013, Batir *et al.* (2017) found that the average efficiency scores of the participation banks were higher than those of the conventional banks each year during the period studied. Their research findings also suggested that expenses and loan quality exhibit a positive correlation with the participation bank's efficiency while a negative correlation with the conventional bank's efficiency, following the results of Tobit regression analysis. Total loans and external factors, like GDP growth and inflation, influence banking efficiency.

A later study found that the TE of the Turkish banking industry was around 85% from 2019 through 2021, which was because of the poor management tactics of the authority (Yagli, 2022). This study also aimed to inquire about the influence of the COVID-19 pandemic on the bank's operational efficiency; however, due to the relatively stable scores, no particular regression analysis was run to ascertain the causal relationship of the pandemic. The study by Milenković *et al.* (2022) applied the DEA model to determine the efficiency of banks in West Balkan countries. In the second stage, Tobit censored regression analysis results suggested mergers and acquisitions, bank type, bank size, etc., to drive banking efficiency.

A study conducted in Pakistan from 2011 to 2020 involving seventeen commercial banks found that corporate governance, return on equity, and ownership structure positively influence the efficiency of the banking sector. This efficiency measurement allows bank managers to establish standards for their overall performance (Ullah *et al.*, 2023). The study employed logit and probit regression models to determine the association between independent and dependent variables.

Focusing on Bangladesh, the efficiency dynamics of the country's banking sector have been an integral part of its economic development. Hoque and Rayhan (2013) conducted a study of 21 selected banks to analyze their annual report for 2009 and rank them according to

their technical efficiency. The research found that City Bank PLC, Prime Bank PLC, One Bank PLC, Islami Bank PLC, Social Islami Bank PLC, and Janata Bank PLC were technically 100% efficient, where all of them except for Janata Bank PLC were private commercial banks. In another study of 24 private commercial banks between 2011 and 2015, it was observed that none of the sample banks performed efficiently during that period and required the management to adopt necessary measures to overcome their weaknesses (Qamruzzaman and Jianguo, 2016). Banna *et al*. (2017) implemented DEA in their studies to determine the TE of the Bangladeshi banking sector, followed by a Tobit regression analysis to determine several independent factors, such as inflation, real interest rate, global financial crisis, GDP growth, etc., that could affect a bank's profitability.

Using the stochastic frontier approach, Hassan and Hassan (2018) determined that the average cost efficiency in 6 state-owned, 22 conventional commercial, and 7 Islamic Shariah-based banks was 88.50% from 2011 to 2015. According to the research of Solaiman *et al*. (2021), only six banks out of 36 commercial banks in Bangladesh performed efficiently between 2011 and 2016 in terms of TE, AE, and SE. Chaity and Islam (2022) studied the efficiency of DSE-listed PCBs from 2007 to 2016 with a sample of 22 commercial banks that do not follow the Islamic banking system. The investigation explored how corporate governance mandates and earnings management practices correlate to a bank's efficiency. Through panel regression analysis, the findings indicate that banks demonstrating high efficiency and adherence to corporate governance guidelines exhibit a reduced likelihood of engaging in earnings management. Another study aimed at comparing the TE, AE, and CE of conventional commercial banks, state-owned banks, and Islamic banks revealed that Islamic banks in Bangladesh attained higher scores in all these aspects, even though there was room for adopting measures to enhance managerial efficiency and reduce wastage of inputs (Nabi, 2022). A new study by Yesmine *et al*. (2023) examined 20 banks, including all types of banks, from 2011 to 2018. The findings indicated that both private commercial banks and state-owned banks experienced significant inefficiency between 2013 and 2018, potentially attributable to the former government's reforms of the money market structure and enhancements to the regulatory framework.

The literature above reveals that a considerable number of studies have been conducted aimed at studying the efficiency levels of banks, making efficiency comparisons between various bank types, or identifying the factors influencing their efficiency. Some studies have concentrated on private commercial banks, but the number of sample banks may not accurately represent all PCBs, even if the sample size is sufficient for conducting comparisons. Again, the applications of NDEA have been minimal, even though the concept was established long ago. This paper fills these gaps by comparing the scores obtained from the traditional DEA model and the network DEA within the context of Bangladeshi PCBs. Moreover, the conventional Tobit Regression and Bayesian Tobit Regression Analysis results will comprehensively showcase the banking efficiency indicators with their corresponding model fit.

3. Research methodology

3.1 Collection of data

The data for the PCBs is collected from the respective banks' annual reports published on their websites. The population for the research was supposed to be 43 private commercial banks in Bangladesh, which are listed on the Bangladesh Bank's website. However, as the required data of four banks (i.e. Bengal Commercial Bank PLC, Citizens Bank PLC, Community Bank Bangladesh PLC, and Padma Bank PLC) is not available on their websites for the study period of 2017–2023, they are eliminated. Under this circumstance, the population for this study comprises 39 private commercial banks in Bangladesh (see Appendix). Under these 39 PCBs are 29 conventional banks and 10 Islamic Shariah-based banks.

3.2 Selection of variables

This paper employs an intermediation approach to assess the efficiency of the banks being observed. Under this approach, banks play the primary role of financial intermediaries, obtaining funds from the savers to provide debtor loans and generating profit (interest) for the savers and the banks (Alber *et al.*, 2019).

After studying the previous literature, some input and output variables were selected. The output variables for this study are total loans and total off-balance sheet items. On the other hand, the input variables selected for this study are total deposits, total fixed assets, and total personnel expenses. The prices of total deposits, total fixed assets, and total personnel expenses are determined using specific formulas to assess cost efficiency. Deposits act as the intermediary product while determining the two-stage network DEA scores.

Table 1 provides information regarding the input variables, input price variables, and output variables used under the intermediation approach for this study.

3.3 Specification of DEA model

The technical efficiency of the banks is assessed by addressing the following linear programming problem, where θ represents the technical efficiency score of banks (B) within the output-oriented DEA model (Banker *et al.*, 1984):

Table 1. Variables for conducting data envelopment analysis (DEA)

Input variables	Description	References
Deposits	Sum of current accounts and other accounts, bills payable, savings bank deposits, fixed deposits, other deposits	Al-Jarrah (2007), Brack and Jimborean (2010), Yannick *et al.* (2016), Batir *et al.* (2017), Fagge (2019), Nguyen *et al.* (2019)
Fixed assets	Sum of the book value of fixed assets including premises, furniture, and fixtures	Al-Jarrah (2007), Brack and Jimborean (2010), Batir *et al.* (2017), Fagge (2019), Nguyen *et al.* (2019)
Personnel expenses	Salaries and allowances paid to the employees excluding directors' and auditors' fees	Al-Jarrah (2007), Batir *et al.* (2017), Nguyen *et al.* (2019)
Price of deposits	The ratio of total interest expense to total deposits (Interest Expense ÷ Total Deposits)	Brack and Jimborean (2010), Batir *et al.* (2017), Fagge (2019)
Price of fixed assets	The ratio of the book value of total fixed assets to that of total assets (Fixed Assets ÷ Total Assets)	Al-Jarrah (2007), Fagge (2019)
Price of personnel expense	The ratio of personnel expense to total assets (Personnel Expense ÷ Total Assets)	Al-Jarrah (2007), Batir *et al.* (2017)

Output variables	Definition	References
Loans	Sum of loans, cash credits, overdrafts, bills purchased and discounted	Al-Jarrah (2007), Brack and Jimborean (2010), Yannick *et al.* (2016), Batir *et al.* (2017), Fagge (2019), Nguyen *et al.* (2019)
Off-balance sheet items	Sum of contingent liabilities and other commitments	Al-Jarrah (2007), Batir *et al.* (2017)

Source(s): Authors' work

$$\text{Minimize } \theta$$
$$\text{Subject to : } \sum_{B=1}^{n} \lambda_{\mathrm{B}}\, O_{\mathrm{rB}} \geq O_{\mathrm{rBo}}$$
$$\sum_{B=1}^{n} \lambda_B I_{iB} \leq \theta \cdot I_{iBo}$$
$$\lambda_B \geq O$$

Addressing the following linear programming problem will illuminate the cost efficiency and its corresponding technical and allocative efficiency. The price data serve as prerequisites for evaluating the cost efficiency of a decision-making unit, or DMU. The method is known as the cost minimization DEA model, as Coelli (1996) stated. If "n" banks employ "m" distinct inputs to generate "y" outputs, the formulation of the linear programming problem will be structured as follows:

$$\text{Minimize } \sum_{i=1}^{m} W_{iB} I_{iB}^{*}$$
$$\text{Subject to, } \sum_{B=1}^{n} \lambda_j O_{rB} \geq O_{rBo},$$
$$\sum \lambda_j I_{iB} \leq I_{iBo},$$
$$\sum_{B=1}^{n} \lambda_B = 1,$$
$$\lambda_B \geq 0$$

According to the linear programming problem,

w_{iB} = Vector input prices of Banks (B)

I_{iB}^{*} = Cost minimizing vector of input quantities for Banks (B)

λ_{B} = Intensity variable

w_{B} = Input prices

O_{rB} = r-th output variable of the Bank

I_{iB} = i-th input variable of the Bank

O_{rBo} = Observed output vector

I_{iBo} = Observed input vector

The following formula is used to determine the overall cost efficiency of their observed banks:

$$\textit{Cost Efficiency}, CE = \frac{\textit{Minimum Cost of Producing Outputs}}{\textit{Actual Cost of Producing Outputs}}$$

As cost efficiency is the product of the overall TE and AE of an observed DMU, the allocative efficiency of the DMU can be derived by using the following formula (Coelli, 1996):

$$\textit{Allocative Efficiency}, AE = \frac{\textit{Cost Efficiency}, CE}{\textit{Technical Efficiency}, TE}$$

3.4 Specification of NDEA model

Most previous studies on the general two-stage NDEA models used the CCR or BCC models to determine the efficiency scores of the DMUs. This study will apply the most commonly used CCR model, following Phung *et al*. (2020) and Tong *et al*. (2023). This is because, along with determining technical efficiency scores, we are also determining cost efficiency scores, which can only be obtained from the CRS-based CCR model of data envelopment analysis.

Figure 3 indicates the Network DEA model used for this particular study. The input variables are the fixed assets and personnel expenses; the intermediary variable is the deposits; and the output variables are the loans and off-balance sheet items, as is used in the traditional DEA model. With its dual role as an input and output variable, the deposit is the intermediate product used by many researchers (Ratner *et al*., 2023). For explanation purposes, we have named stage 1 as the Accumulation stage, where the deposits are gathered by utilizing fixed assets and personnel expenses, and stage 2 as the Deployment stage, where the deposits are deployed to generate loans and off-balance sheet items.

3.5 Data analysis techniques and procedures

DEAP Version 2.1 is employed to perform the data envelopment analysis. This computer program has been designed specifically to conduct data envelopment analysis to determine the indices of total factor productivity change, technological change, technical efficiency, scale efficiency, and cost efficiency (Coelli, 1996). A score of 1 indicates the bank's efficiency, while a score less than 1 indicates the extent to which the bank is inefficient.

Table 2 shows the descriptive statistics of the variables from 2017 to 2023. The test of normality is not conducted here. Because DEA makes no distributional assumptions about the data, testing normality is irrelevant. In fact, Chen (2024) stated that the sample variables would be non-normal in conducting network DEA, which validates the approach.

In the further stage of this study, the efficiency scores obtained are treated as dependent variables, while the five bottom-line variables are chosen as independent factors to assess their

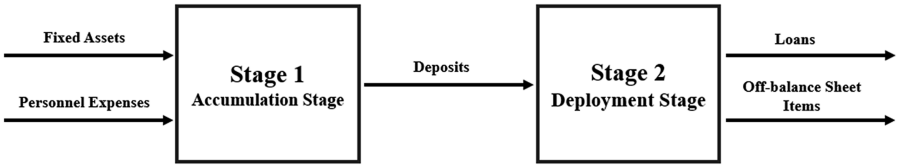

Figure 3. Network diagram for banking Industry's intermediation process. Source(s): Authors

Table 2. Descriptive statistical summary of variables

Variable	Obs	Mean	Std. dev	Min	Max
Loans	273	22835089869.60	194983021421.432	2744822928	1600265662100
Off-balance sheet items	273	84786038710.82	67133911185.535	70889297	291676237243
Total deposits	273	241783742120.62	199285912041.733	3793917768	1534566006233
Fixed assets	273	4376386756.06	3691761314.045	24948999	18,437,320,088
Personnel expenses	273	3391802969.88	2948474343.129	105521924	22023407478
Price of deposits	273	0.05359637562	0.013500283004	0.016421513	0.087099749
Price of fixed assets	273	0.01342145461	0.007044794239	0.002215715	0.081441811
Price of personnel expenses	273	0.01180054611	0.008335222060	0.004383344	0.134345112

Source(s): Authors' calculation based on Stata 17

impact on the banks' efficiency levels. The Tobit Censored Regression Analysis is conducted using Stata 17, the most widely utilized software for analyzing ranged data, such as efficiency. Additionally, we conducted Bayesian Tobit Regression Analysis in our study. Such an application will help us make decisions on model goodness and ensure the robustness of the findings (Briggs, 2023).

As the banking efficiency scores range from 0 to 1 (censored data), Tobit regression analysis perfectly fulfills the need of this study because it handles data censoring effectively. The equation for the bank's Tobit regression would be:

$$\theta_{it} = \beta_0 Bankize + \beta_1 ShareofLoans + \beta_2 Profitability + \beta_3 Cost\ Management\ Abillity + \beta_4 CreditRisk + \epsilon_{it}$$

In the equation, θ_{it} represents the calculated average efficiency scores, β symbolizes the independent variable coefficients, and ϵ_{it} portrays the disturbance term. Table 3 illustrates a list of independent variables considered for this study, which may or may not impact the efficiency scores of private commercial banks in Bangladesh. It is to be noted that only the efficiency scores of 39 banks in the year 2023 were considered as dependent variables, and only data from the same year is used for independent variables since they represent the most likely condition of the banks in the current timeline.

4. Results and discussion

4.1 Technical, allocative and cost efficiency

Table 4 exhibits the TE, AE, and CE scores of the 39 private commercial banks in Bangladesh for the reference timeline between 2017 and 2023. For illustration purposes, the average scores are considered here. The results are derived directly from the output of DEAP 2.1. The multiplicative decomposition model is applied in this context for NDEA-based efficiency scores, with the overall efficiency scores represented by the product of first-and second-stage efficiency scores. Kao and Hwang (2008) also used such an approach in their research.

The results suggest noteworthy differences in efficiency using two different models of DEA. The efficiency scores derived from the CCR model are generally high, showing around 91% for TE, 94% for AE, and 86% for CE during the seven years studied, indicating that the PCBs in Bangladesh are performing well enough, although not to their full potential. Conversely, the NDEA model shows a significant deviation, approximately 53% for TE, 73% for AE, and only 38% for CE. This model breaks the bank's activities into two stages: Accumulation Stage and Deployment Stage. In the accumulation stage, the efficiency scores are lower, especially for CE. However, in the deployment stage, the efficiency scores are higher, reaching 100% AE every year studied. The scores of TE and CE also increased by a

Table 3. Specification of independent variables

Variable	Description	References
Bank size	Log of total assets of the bank	Batir *et al*. (2017), Nguyen and Pham (2020) Chaity and Islam (2022), Milenković *et al*. (2022)
Share of loans	The ratio of total loans to total assets	Batir *et al*. (2017)
Profitability	The ratio of net income to total assets	Raina and Kumar Sharma (2013), Batir *et al*. (2017), Narawish *et al*. (2021)
Cost management ability	The ratio of operating costs to net income	Nguyen and Pham (2020)
Credit risk	The ratio of Non-performing Loans to Total Loans	Batir *et al*. (2017), Nguyen and Pham (2020), Dar *et al*. (2021)

Source(s): Authors' work

Table 4. Efficiency scores of PCBs in Bangladesh

Year	Efficiency	CCR-model	NDEA model		Overall efficiency score
			Accumulation stage	Deployment stage	
2017	Average TE	0.908	0.575	0.833	0.479
	Average AE	0.951	0.757	1.000	0.757
	Average CE	0.863	0.430	0.833	0.358
2018	Average TE	0.916	0.620	0.835	0.518
	Average AE	0.913	0.659	1.000	0.659
	Average CE	0.836	0.403	0.835	0.337
2019	Average TE	0.936	0.672	0.897	0.603
	Average AE	0.960	0.523	1.000	0.523
	Average CE	0.898	0.343	0.897	0.308
2020	Average TE	0.902	0.615	0.846	0.520
	Average AE	0.941	0.742	1.000	0.742
	Average CE	0.847	0.448	0.846	0.379
2021	Average TE	0.909	0.632	0.851	0.538
	Average AE	0.939	0.807	1.000	0.807
	Average CE	0.855	0.502	0.851	0.427
2022	Average TE	0.908	0.643	0.860	0.553
	Average AE	0.951	0.787	1.000	0.787
	Average CE	0.863	0.500	0.860	0.430
2023	Average TE	0.892	0.638	0.846	0.540
	Average AE	0.952	0.817	1.000	0.817
	Average CE	0.846	0.511	0.846	0.432

Source(s): Authors' calculation based on DEAP 2.1

substantial proportion in this stage. As the overall efficiency scores are the product of the two stages, they are lower than both for all three efficiency measures. However, the calculation is based on the mean efficiency scores for which a very minimal and negligible deviation may occur if we consider the efficiency scores for each bank and each year.

The probable reason for low CE during the accumulation stage may be higher costs or inefficient resource allocation. This means that the outcome from the first stage—deposits—would have been higher if the fixed assets and personnel expenses had been appropriately utilized. The scenario changed in the deployment stage, where there were improvements in all three efficiency measures, probably because of the greater efficiency in managing deposits. In other words, resources are deployed efficiently in the deployment stage, but the weakness in optimally using them and aligning them with cost-minimizing proportions during the accumulation stage limits the overall performance. Over time, there were fluctuations in the accumulation stage's efficiency and deployment stage's efficiency scores, but never enough to elevate the overall efficiency scores to reach a high-efficiency level. The mentionable fact is that the average TE and CE scores found from the network DEA model were nearly half of the scores from applying the traditional CCR-based DEA model. On the other hand, the average AE scores were somewhat close in both applications, although there were at least 10% deviations.

The overall efficiency scores were lower in all cases during those seven years, meaning that internal processes can provide better insights regarding the efficiency scores of DMUs, which the traditional DEA method cannot provide. Such results align with the findings of Tong *et al.* (2023). A difference is found in the results of Azad *et al.* (2020), where the researchers applied a slack-based DEA model, which is different from the radial model we used without considering input excesses (slacks). In their study, Azad *et al.* (2020) found that the overall technical efficiency scores were higher when the network DEA model was applied. That being

said, our study is different because, while other researchers looked at how the efficiency scores for each DMU varied, we looked at the average efficiency scores for each year during the study period to get a bigger picture of Bangladesh's private commercial banking sector.

The study of efficiency scores provides crucial insight for policymakers in banking organizations, highlighting that their primary bottleneck is the accumulation stage, an area they must address. If they can take appropriate actions to address inefficiencies in resource allocation and cost control during this stage, they can yield substantial improvements in the overall performance of the private commercial banking industry in Bangladesh.

4.2 Goodness of fit test

To make decisions of the banking efficiency determinants, we performed both conventional Tobit Censored Regression Analysis and Bayesian Tobit Regression Analysis. Table 5 and Table 6 indicate how the decisions were made for further interpretation of the outcomes from conducting the analysis in Stata 17.

In the conventional Tobit Regression Analysis, it is found that only the technical efficiency scores derived from conducting the CCR-based DEA method provide some explanatory power to identify the determinants of efficiency. The pseudo R^2 is negative in all cases except for the model "TE under traditional DEA." Therefore, they are discarded for being poor model fits, and the only model retained is the one mentioned. The positive log-likelihood is also a reason for discarding those models, which were supposed to be negative. The reason for retaining TE under DEA is that the *p*-value is significant due to being less than 0.05 and the Likelihood Ratio (LR) Chi Square is high. In the case of Pseudo R^2, the value should be between 0 and 1 (Veall and Zimmermann, 1994), but there is no evidence that it perfectly defines the goodness of fit. As Pseudo R^2 exceeds 1 here, we determined the Akaike information criterion (AIC) and Schwarz' Bayesian information criterion (BIC), where the negative AIC value and low but positive BIC value indicate a relatively better fit in this

Table 5. Model fit summary of Tobit regression analysis

Model	LR chi square	*p*-value	Pseudo R^2	Log likelihood	Decision	Reasoning
TE under DEA	27.86	0.000	7.903	12.168	Retain	Moderate Explanatory Power
AE under DEA	3.79	0.579	−0.042	47.015	Discard	Poor Model Fit
CE under DEA	37.50	0.000	−1.043	36.726	Discard	Poor Model Fit
TE under NDEA	14.73	0.012	−0.574	20.197	Discard	Poor Model Fit
AE under NDEA	2.86	0.721	−0.248	7.217	Discard	Poor Model Fit
CE under NDEA	6.68	0.245	−0.215	18.895	Discard	Poor Model Fit

Source(s): Authors' calculation based on Stata 17

Table 6. Model fit summary of Bayesian Tobit regression analysis

Model	Log marginal likelihood	Decision	Reasoning
TE under DEA	−32.6114	Discard	Poor Log Marginal Likelihood
AE under DEA	−4.1981	Retain	Best Log Marginal Likelihood
CE under DEA	−11.9342	Retain	Second Best Log Marginal Likelihood
TE under NDEA	−26.6155	Discard	Low Log Marginal Likelihood
AE under NDEA	−35.2462	Discard	Worst Log Marginal Likelihood
CE under NDEA	−25.3592	Discard	Poor Log Marginal Likelihood

Source(s): Authors' calculation based on Stata 17

context, suggested by Chakrabarti and Ghosh (2011). Table 7 shows the outcome of the AIC and BIC tests. Moreover, the log-likelihood of 12.168 is higher than that of the null model, which is −1.763, indicating the model is a better fit than a model that has no predictor.

In order to accept a model in Bayesian Tobit Regression, a log marginal likelihood close to zero indicates strong evidence. Our findings show that the log marginal likelihoods are negative in all cases, where AE under DEA and CE under DEA are close to zero. Therefore, we retained these two models and discarded the rest. This shows that, according to our findings, TE, AE, and CE under CCR-based DEA provide better insights regarding their corresponding determinants, while Bayesian Tobit Regression is more suitable for AE and CE under DEA only. Owing to this, although our initial plan was to find the determinants with Tobit Regression and corroborate them with Bayesian Statistics, we ended up making decisions on the determinants for TE by performing Tobit Regression and Bayesian Tobit Regression for the rest of the two (AE and CE). Such an issue may have arisen due to the limited number of observations (39) with only a one-year timeline. If the number of observations was high, there would be a possibility that we would be able to use both analyses to serve our purpose, as like Kalia (2024), who used 136 observations over the 10 years period.

4.3 Determinants of technical, allocative and cost efficiency

The results from Tobit Regression and Bayesian Tobit Regression Analysis are shown in Tables 8–10 for both the CCR-based DEA and network DEA models. As per the decision on the goodness of fit of the models, we will only discuss the determinants of TE under DEA from Tobit Regression and the determinants of AE and CE under DEA from Bayesian Tobit Regression. The calculations are done under a 5% level of significance. Therefore, if the *p*-value is less than 0.05, the general null hypothesis would be rejected, connoting a positive or negative effect on banking efficiency.

From the CCR-based DEA model, it is observed from conducting Tobit Regression Analysis that larger bank size and higher share of loans positively affect the banking industry's technical efficiency. Therefore, a one-unit increase in bank size would increase TE by 13.3%. Such a positive causal correlation was also found in the studies of Banna *et al*. (2017), Nguyen *et al*. (2019), and Milenković *et al*. (2022). Besides, a one-unit increase in the share of loans can boost TE by 94.3%. This result aligns with the findings of Batir *et al*. (2017).

The cost management ability of a bank may have a considerable negative impact at the 10% level of significance, which means higher costs can reduce TE, but there was no such evidence in the study by Nguyen and Pham (2020). The *p*-values of profitability and credit risks are way higher than 0.05, so they do not have any impact on the technical efficiency of PCBs in Bangladesh. Batir *et al*. (2017), Nguyen and Pham (2020), and Dar *et al*. (2021), on the contrary, mentioned the negative impact of credit risk caused by non-performing loans on the bank's TE. In the case of Bayesian Tobit Regression, the results corroborate the previous findings, although the model is not fit for Bayesian Statistics.

As our model goodness of fit test suggests, Tobit Regression Analysis for traditional CCR-based DEA and network DEA results is not fit for determining the predictors of AE. Besides, due to a poor model fit, the efficiency scores derived from NDEA are also not the best for determining the predictors. So, the only thing that could be done was to choose the CCR-based

Table 7. AIC and BIC values for model TE under DEA

Model	*N*	ll(null)	ll(model)	df	AIC	BIC
.	39	−1.76286	12.16834	7	−10.3367	1.308246

Note(s): ll = Log Likelihood
Source(s): Authors' calculation based on Stata 17

Table 8. Regression results for TE under CCR-Based DEA and NDEA approach

	CCR-based DEA Tobit regression		Bayesian Tobit regression		Network DEA Tobit regression		Bayesian Tobit regression	
Variable	Coefficient	$p > \|t\|$	Posterior mean	CI	Coefficient	$p > \|t\|$	Posterior mean	CI
Bank size	0.133	0.023	0.135	[−0.007, 0.276]	0.068	0.338	0.086	[−0.058, 0.234]
Share of loans	0.943	0.003	1.077	[0.306, 1.887]	0.967	0.008	1.044	[0.268, 1.717]
Profitability	3.405	0.414	3.153	[−7.358, 13.870]	3.697	0.480	4.967	[2.958, 7.671]
Cost management ability	−0.021*	0.086	−0.025	[−0.059, 0.004]	−0.016	0.261	−0.018	[−0.048, 0.012]
Credit risks	−0.027	0.943	−0.058	[−0.982, 0.956]	0.075	0.873	0.185	[−0.220, 0.620]

Note(s): Tobit Regression is conducted under 95% Confidence Interval
* Means 10% level of significance
CI = Credential Interval
Source(s): Authors' calculation based on Stata 17

Table 9. Regression results for AE under CCR-Based DEA and NDEA approach

	CCR-based DEA Tobit regression		Bayesian Tobit regression		Network DEA Tobit regression		Bayesian Tobit regression	
Variable	Coefficient	$p > \|t\|$	Posterior mean	Cred. Interval	Coefficient	$p > \|t\|$	Posterior mean	Cred. Interval
Bank size	−0.005	0.858	−0.006	[−0.076, 0.062]	0.009	0.926	0.003	[−0.205, 0.221]
Share of loans	−0.122	0.410	−0.117	[−0.467, 0.248]	−0.330	0.481	−0.271	[−1.378, 0.845]
Profitability	−0.830	0.706	−0.862	[−6.188, 4.650]	3.985	0.573	3.708	[−10.658, 19.117]
Cost management ability	−0.004	0.553	−0.004	[−0.018, 0.104]	−0.007	0.728	−0.008	[−0.050, 0.036]
Credit risk	−0.186	0.349	−0.194	[−0.685, 0.298]	0.576	0.368	0.548	[−0.766, 1.903]

Note(s): Tobit Regression is conducted under 95% Confidence Interval
CI = Credential Interval
Source(s): Authors' calculation based on Stata 17

Table 10. Regression results for CE under CCR-Based DEA and NDEA approach

	CCR-based DEA Tobit regression		Bayesian Tobit regression		Network DEA Tobit regression		Bayesian Tobit regression	
Variable	Coefficient	$p > \|t\|$	Posterior mean	Cred. Interval	Coefficient	$p > \|t\|$	Posterior mean	Cred. Interval
Bank size	0.113*	0.006	0.110	[0.018, 0.208]	0.064	0.384	0.067	[−0.098, 0.226]
Share of loans	0.541*	0.009	0.568	[0.094, 1.022]	0.544	0.134	0.549	[−0.231, 1.380]
Profitability	2.827	0.334	3.273	[−3.211, 10.522]	6.752	0.216	6.729	[−4.446, 18.356]
Cost management ability	−0.013	0.128	−0.012	[−0.030, 0.007]	−0.017	0.257	−0.016	[−0.048, 0.016]
Credit risk	−0.135	0.606	−0.107	[−0.699, 0.531]	0.467	0.340	0.473	[−0.580, 1.556]

Note(s): Tobit Regression is conducted under 95% Confidence Interval
* Means 10% level of significance
CI = Credential Interval
Source(s): Authors' calculation based on Stata 17

DEA-generated AE scores and do a Bayesian Tobit Regression Analysis. This method was chosen because, according to our calculations, it had a slightly higher log marginal likelihood. The regression analysis suggests that the credible intervals include a zero (0) in the cases of all independent variables, indicating the effect as statistically insignificant. Therefore, we cannot confidently say that bank size, share of loans, profitability, cost management ability, or credit risk—any of these—impact the allocative efficiency of PCBs in Bangladesh.

As per our model fit test, the CCR-based DEA score of CE can be used as the best dependent variable in correspondence to the independent variables. The Bayesian Tobit Regression Analysis results suggest that bank size has a positive and credible effect on the banks' cost efficiency. This finding conflicts with the results of Brack and Jimborean (2010), who studied 10 large-sized banks in different countries. The share of loans significantly impacts the cost efficiency of PCBs in Bangladesh. Our results suggest that an increase in one unit of bank size can increase 11.3% of cost efficiency, and an increase in one unit of share of loans can increase 54.1% of cost efficiency. On the other hand, profitability, cost management ability, and credit risks do not have any credible effect on banks' CE as the intervals include zero. The results align with the determinants from conventional Tobit regression analysis at a 10% significance level. A different conclusion was found by Raina and Kumar Sharma (2013) and Narawish *et al*. (2021), who mentioned that profitability affects cost efficiency negatively.

The study identifies that the traditional CCR-based DEA model may not provide a complete picture of the efficiency of private commercial banks in Bangladesh, even though we used the intermediary function approach in our research. When a network DEA model is used, the variation is quite significant, especially in the accumulation stage, compared to the CCR-based DEA model. The most alarming part is the cost efficiency of PCBs, which cannot be considered ideal for any country's banking sector. Therefore, this paper suggests that policymakers put their efforts into a more vigilant cost management practice and optimize their usage of fixed assets and personnel expenses. Since larger bank sizes and higher shares of loans can positively influence TE and CE, small-sized banks can consider mergers to create larger institutions for a more favorable banking policy. However, this suggestion does not align with the results of Milenković *et al*. (2022), who found a negative impact of the merger and acquisition on the bank's technical efficiency. Therefore, the policymakers should conduct an extensive analysis of the context of Bangladesh to see whether this can affect them positively. Taking measures to overcome faulty project appraisals and lack of expertise in loan recovery can improve the ability to improve the share of loans of PCBs (Rahman *et al*., 2023). In addition to those, banks should devise advanced cost management strategies like increased digitalization and automation to mitigate the negative impact of higher operations costs.

5. Conclusion, limitation, future implications

As far as the authors are aware, this is the first study that incorporated the data of all PCBs to provide insight into the industry's condition by comparing traditional and network DEA models. The application of Bayesian Tobit Regression was also not observed in any other study in conjunction with the traditional Tobit Regression in studying banking efficiency. The study reveals the efficiency scores of PCBs in Bangladesh under the CCR-based and Network DEA models. Performance scores from the CCR-based model show a moderately high-efficiency level, with 91% for TE, 94% for AE, and 86% for CE on average. On the other hand, performance scores from the Network DEA model show about half of the results for TE (53%), 38% for CE, and a difference of about 21% for AE (73%). The results make it evident that the application of the Network DEA model reveals the internal structure of the DMU, or banks in our case, more specifically. Thus, the NDEA model's results give us a more profound understanding of how well the private commercial banking industry can turn deposits, fixed assets, and personnel costs into outputs like loans and off-balance sheet items. The ability of the banks to utilize resources is also not up to the mark, and considering the

situation, the banks perform terribly in managing their costs to produce an expected output level. This study also provides information on the determinants of banking efficiency. Larger bank size and a high number of loan shares can increase both TE and CE, as found by performing a Tobit or Bayesian Tobit Regression Analysis, depending on the model fit. On the other hand, no particular determinant can predict the increase or decrease of AE during this study. The key recommendation for the banking industry is to adopt merger strategies cautiously to strengthen banking capacity. Apart from that, improving the loan approval and loan recovery system to enhance the share of loans and the adoption of advanced digitalization and automation to streamline the process should be helpful for PCBs to deal with cost management issues.

The study has a significant limitation due to the limited number of observations and a single-year timeline, which hinders the robustness of the statistical analysis conducted through Bayesian Tobit Regression. The one-year period may be a significant reason for the poor model fit in regression analyses. It could be improved by taking longitudinal data, such as for five years or more, to validate the results. Besides, the geographic and cultural focus on Bangladesh limits the generalizability of the study, especially for the developed countries.

Our study opens up floors for further studies in this field with a cross-country comparison to identify universal trends or contextual disparities. Although we studied for only one year to perform the regression analysis, the analytical findings can be strengthened by extending the study duration to facilitate both conventional and Bayesian Tobit regression models. The analysis would gain more depth if qualitative measurement variables, such as corporate governance practices, technological adaptations, and managerial techniques, could be included as predictors of banking efficiency. Future studies can be conducted to bridge these gaps by using this study as their foundation to provide further recommendations for industry best practices with more specified approaches.

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Appendix

Table A1. List of Banks Selected for Analysis

Bank name	Website
1. AB Bank PLC	https://abbl.com/
2. ICB Islamic Bank Limited	https://icbislamic-bd.com/
3. IFIC Bank PLC	https://www.ificbank.com.bd/
4. Islami Bank Bangladesh PLC	https://www.islamibankbd.com/
5. National Bank Bangladesh Limited	https://www.nblbd.com/
6. National Credit and Commerce Bank PLC	https://www.nccbank.com.bd/
7. Pubali Bank PLC	https://www.pubalibangla.com/
8. City Bank PLC	https://www.citybankplc.com/home
9. Uttara Bank PLC	https://www.uttarabank-bd.com/
10. Al-Arafa Islami Bank PLC	https://www.aibl.com.bd/
11. Bangladesh Commerce Bank Limited	https://bcblbd.com/
12. Bank Asia PLC	https://www.bankasia-bd.com/
13. Dhaka Bank PLC	https://dhakabankltd.com/
14. Dutch-Bangla Bank PLC	https://www.dutchbanglabank.com/
15. Eastern Bank PLC	https://www.ebl.com.bd/
16. Exim Bank Limited	https://www.eximbankbd.com/
17. First Security Islami Bank PLC	https://fsibplc.com/
18. Mercantile Bank PLC	https://www.mblbd.com/
19. Mutual Trust Bank PLC	https://www.mutualtrustbank.com/
20. One Bank PLC	https://www.onebank.com.bd/
21. Premier Bank PLC	https://premierbankltd.com/pbl/
22. Prime Bank PLC	https://www.primebank.com.bd/
23. Social Islami Bank PLC	https://www.siblbd.com/
24. Southeast Bank PLC	https://www.southeastbank.com.bd/
25. Standard Bank PLC	https://www.standardbankbd.com/
26. Trust Bank Limited	https://www.tblbd.com/
27. BRAC Bank PLC.	https://www.bracbank.com/en
28. Jamuna Bank PLC	https://jamunabankbd.com/
29. Shahjalal Islami Bank PLC	https://sjiblbd.com/
30. United Commercial Bank PLC	https://www.ucb.com.bd/
31. Global Islami Bank PLC	https://www.globalislamibankbd.com/
32. Meghna Bank PLC	https://www.meghnabank.com.bd/retail
33. Midland Bank PLC	https://www.midlandbankbd.net/
34. Modhumoti Bank PLC	https://www.modhumotibankplc.com/
35. NRB Bank Limited	https://www.nrbbankbd.com/
36. NRB Commercial Bank PLC	https://www.nrbcommercialbank.com/
37. Shimanto Bank PLC	https://www.shimantobank.com/
38. SBAC Bank PLC	https://www.sbacbank.com/
39. Union Bank PLC	https://www.unionbank.com.bd/

Source(s): Authors' work

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