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DEA Approaches: Variable and Model Selection for Bank's Efficiency Measurement

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ABSTRACT

Data Envelopment Analysis (DEA) is one of the most widely used tools for measuring efficiency, especially in the banking sector. However, one of the major issues that arise in front of the researchers or practitioners is the selection of input or output variables. Different DEA approaches are available based on literature review, which views banks from different perspectives; some view banking as an intermediate while others view it as a producer. The main motive of this paper is to provide insight into different approaches of DEA

and the specification of variables as input or output variables based on it. The present study discussed five approaches: intermediate, production, asset, value-added, and user cost. Moreover, the study discusses different software for measuring DEA efficiency to provide information to novice researchers or practitioners.

Keywords: Data envelopment analysis, approaches, software, efficiency.

INTRODUCTION

Data Envelopment Analysis is a linear programming-based approach first initiated by Charnes et al. (1978), based on Farrell's 1957 research work used for measuring the relative efficiency of decision-making units (DMU'S) using multiple inputs and multiple outputs as a variable. Decision-making units in the DEA model are the set of peer units that measure efficiency. It is a non-parametric approach capable of handling multiple inputs and outputs (Asmild *et al.* (2004). The efficiencies of all the decision-making units are measured by comparing with other decision-making units by allocating weights to the corresponding input and output variable and putting simple restrictions that all DMU lays on or below the efficiency frontier. If a DMU lies on the frontier, it is referred to as an efficient unit; otherwise, it is considered inefficient (Sufian, 2011).

A DEA model developed is either input-oriented or output-oriented. An input-oriented DEA model reduces the input amount as much as possible while keeping the output at present levels. In contrast, an output-oriented DEA model focused on maximizing the output level without changing the input amount (Cooper *et al.*, 2004) (Mukherjee *et al.*, 2002). The basic DEA model that CCR presents (Charnes et al., 1978) is based on the assumption that scales of operations and efficiency have no significant relationship by assuming constant returns to scale (CRS). It applies only where the DMUs operate at their optimal level and provide only overall technical efficiency. The CCR model was then modified (Banker et al., 1986), which adjusted the model to variable return to scale and provided overall technical efficiency, pure technical efficiency, and scale efficiencies.

The basic idea behind the present study is to answer questions that arose to every researcher, reviewer, or stakeholder before initiating banks' efficiency measurement study. These are the appropriate approach for inputs and outputs specification as performance indicators for bank efficiency studies using DEA, the appropriate model (input or output-oriented), and the appropriate assumption (constant return to scale or variable return to scale). As discussed in this study, researchers face these problems repeatedly. The present paper is different from the previous studies that generally focused on bank efficiency measurement (Barr et al., 2002; Gupta et al., 2008; Bhatia & Mahendru, 2016; Chaluvadi et al., 2018; andSufian, 2011) and determinants of bank's efficiency measurement (Delis & Papanikolaou, 2009; Sufian et al., 2016a; Řepková, 2015; and Gardener et al., 2011).

The rest of the paper is structured as preceding the introduction; the second is about the relevant literature review; the third is about the input and output variable approaches for the efficiency measurement of banks; the fourth is about the study's conclusion.

LITERATURE REVIEW

Several studies examined the banks' efficiency in many contexts; the present study has referred to some. In one of the areas of DEA-based efficiency measurement method of banks, Barr *et al.* (2002) applied a constrained-multiplier input-oriented data envelopment analysis (DEA) model to measure the productive efficiency of U.S commercial bank performance using an intermediation approach for input and output selection. Bhatia and Mahendru(2016) applied DEA on an assumption of a variable return to scale(VRS)

for measuring the technical efficiency(overall technical efficiency, pure technical efficiency, and scale efficiency (SE) scores) of Indian public sector banks (PSBs) by employing an intermediation approach for input and output selection and results demonstrated that out of 26 banks, 7 banks operate at total efficiency. Chaluvadi (2018) evaluated a comparative performance efficiency of Indian public sector and private sector banks using a two-stage network DEA approach (variable return to scale and constant return to scale) and studied the soundness of the study using sensitivity analysis at the end of the study. Kaur and Gupta (2015) investigated the productive efficiency of Indian banks using the DEA intermediation approach of 57 banks from 2009 to 2013. The results show that SBI and its associates' banks are most efficient, followed by private and public sector banks. Hanif Akhtar (2010) applied the DEA intermediation approach to examine Saudi banks' efficiency and Malmquist productivity indices to measure the changes in productivity. It concluded that there is a productivity improvement due to technology change, not efficiency change.

Sufian et al. (2016b) developed a two-stage framework for investigating the effect of the origin of a bank on the efficiency of Malaysian banks and also analyzed the determinants of bank efficiency. In the first stage, efficiency was measured using Data envelopment analysis. The bootstrap regression is employed in the second stage to measure the effect of banks' origin on their efficiency from 1999 to 2008. The intermediation approach was used for input and output selection. The study results show an increase in the Malaysian banking sector efficiency, and Asian countries' banks are relatively more efficient than foreign countries' banks. The size, non-interest, and capitalization positively affect productive efficiency, while stock market capitalization adversely affects Malaysian banks' technical efficiency. The comparative study of Eyceyurt Batir et al. (2017) examined Turkey's conventional and participation banks' technical, allocative, and cost-efficiency using the DEA intermediation approach and identified the factors that affect efficiency using Tobit regression analysis. It was found that conventional bank is comparatively less efficient than participation bank. In the case of conventional bank expenses, loan quality has a negative relation with efficiency, while these have a positive relation with efficiency in the case of participation banks. Total loans have a positive relationship, while external factors negatively affect the efficiency of both types of banks. Kumar (2008) analyzed the relationship between efficiency and profitability of Indian public sector banks using the DEA intermediation approach. Zhu et al.(2020) measured the operational efficiency and productivity growth change using the DEA intermediation approach and Malmquist productivity index (MPI) of Pakistan's private, public, and foreign banks from 2006 to 2017. The study's findings show that foreign banks performed better than the domestic banks (public and private sector banks), while in comparison to private sector banks, public sector banks performed better.

Sufian(2011) critically examined the inefficiencies in the Korean banking sector using three different approaches of DEA-intermediation approach, value-added approach, and functional approach for showing efficiency score change with change in input and output, and the result shows that technical efficiency is higher under operating approach than the intermediation approach and value-added approach. Bhattacharyya et al. (1997) measured the productive efficiency and the impact of liberalization on commercial banks' productive efficiency in India using the DEA intermediation approach. Public sector banks were most efficient, followed by the foreign-owned and private sectors. Liberalization has a positive effect on foreign banks, not the private sector, and an adverse effect on public sector banks. Gupta et al. (2008) examined the productive efficiency Indian banking sector using the DEA intermediation approach and determinants of productive efficiency using Tobit regression analysis from 1999 to 2003, and the findings of the study show that there is an increase in the efficiency of the Indian banking sector; out of all

the banks, SBI and its group is most efficient, followed by private sector banks and other nationalized banks; the capital adequacy ratio (CAR) positively affects efficiency.

Ataullah and Le (2006) studied the relationship between three elements of economic reforms (fiscal reforms, financial reforms, and private investment liberalization) and the efficiency of the Indian banking industry. The empirical findings derived from the DEA intermediation approach, OLS, and the GMM estimations show improvement in efficiency during the post-economic reforms era. At the same time, there is a negative relationship between the fiscal deficit and the efficiency of Indian banks. Davidovic et al.(2019) studied the efficiency changes of the Croatian banking industry and the effect of the EU on efficiency from 2006 to 2017 using the DEA intermediation approach on variable return to scale assumption, and the finding shows that the crisis has a baneful effect on Croatian banking industry but benefited from EU membership. Novickytė and Drozdz (2018) evaluated the efficiency and performance of Lithuania banks by employing the input-oriented DEA intermediation method with the constant return to scale (CRS) and variable return to scale (VRS) assumption. The local banks show better results, while based on the CRS assumption; Nordic parent group-owned banks show better efficiency than the local banks. Hon et al. (2011) summed that there was an improvement in the efficiency of Malaysian banks during the post-liberalization and post-deregulation period from 2001 to 2005 by employing the input-oriented DEA intermediation method.

DATA ENVELOPMENT ANALYSIS

Farrell (1957) was the pioneer of the efficient frontier for defining technical and allocative efficiency. Its work was further extended by Charnes, Cooper, and Rhodes-CCR (1978) by introducing the term Data Envelopment Analysis. DEA is a non-parametric approach that assesses a firm's performance on the set of other decision-making units (DMUs) using different inputs to produce different outputs. All firms with certain homogeneity and inclusion in the study for efficiency measurement are known as decision-making units (DMU). The firm with a score of 1 on the production frontier is the most efficient, while the others scoring between 0 and 1 are less efficient.

Overall Technical efficiency that assumes a constant return to scale (CRS) is broken down into two parts; pure technical efficiency assumes a variable return to scale (VRS) and scale efficiency (SE). The constant return to scale (CRS) means that output will be changed with the same amount as the input amount change. While the variable return to scale (VRS) is the opposite of it and includes both the increasing return to scale (IRS) and decreasing return to scale (DRS), where the former means that the propionate increase in input amount results in more than propionate increase in the amount of output, while the latter means that propionate increase in input results in lower propionate increase in the output amount.

The basic model for DEA is the CCR model introduced by Charnes et al. (1978) based on the assumption of constant return to scale (CRS) and assumes no significant relationship exists between efficiency and scale of operations. It delivers overall technical efficiency. However, the assumption of CRS is justifiable only where all the firms in the set (DMUs) operate optimally. Then the CCR model was modified by Banker et al. (1984) BCC model, which is based on a variable return to scale (VRS) assumption is used to measure the efficiency of DMUs. The assumption of VRS allows measuring pure technical efficiency (PTE), which measures technical efficiency except for scale efficiency (Sufian, 2007).

A DEA model is either input minimization or output maximization orientation. The input-oriented model focuses on reducing the input at a minimum level by maintaining the output at present levels. In contrast, the output maximization model maximizes the output level by maintaining the input at the present level.

For DMU, the basic CRS input-oriented model is calculated as follows: x_1, x_2… are inputs, and y_1, y_2…. are outputs, and s is the slack variable.

$$\text{Min } \theta\text{-}\varepsilon\left(\sum_{i=1}^{m} s_{\bar{i}} + \sum_{r=1}^{s} s_r^+\right)$$

Subject to

$$\sum_{j=1}^{n} x_{ij\lambda_j} + s_r^+ = \theta x_{io}\ i = 1,2,3 \ldots., m;$$

$$\sum_{j=1}^{n} y_{rj}\,\lambda_{\text{j}}\,\_s_r^+ \;=\; y_{ro}\ r = 1,2,3 \ldots., s;$$

$$\lambda_{j\geq 0} \qquad\qquad\qquad\qquad\qquad\qquad j=1,2,3 \ldots.,n;$$

The CRS output-oriented model is calculated as following:

$$max\varphi - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{m} s_r^+\right)$$

Subject to

$$\sum_{j=1}^{n} x_{ij\,\lambda_j} + s_i^+ = x_{io} \quad i = 1,2,3 \ldots., m;$$

$$\sum_{j=1}^{n} y_{rj}\ \lambda_j\ - s_r^+ = \phi y_{ro} \quad r = 1,2,3 \ldots., s;$$

$$\lambda_j \geq 0 \qquad\qquad\qquad\qquad j = 1,2,3 \ldots., n;$$

The BCC model, which considers variable returns to scale, can be formulated as below:

$$\text{Min}(\vartheta) = \theta$$

Subject to

$$\Theta x_o - X\lambda = s^-$$
$$Y\lambda = y_o + s^+$$
$$e_\lambda = 1$$
$$\lambda \geq 0,\quad s^+ \geq 0,\quad s^- \geq 0$$

DEA APPROACHES

A widespread problem encountered during the banks' efficiency studies is the selection of variables (Input or output). The main reasons for the problem generally occurred due to the scarcity of sufficient data on relevant variables, difficulty in measuring banks' cost and output because many services are jointly produced, and prices are typically assigned to a bundle of financial services (Sufian, 2011). Further, DEA does not describe selecting a variable as an input or output; the model assumes that input and output variables are pre-identified for the study (Subramanyam, 2016). Moreover, some studies treat deposits as input, while some other studies treat them as output (Ahn & Le, 2014)

It is empirically approved that the choice of variables significantly affects the efficiency score of decision-making units (DMUs) (Favero & Papi, 1995) (Sufian, 2011). The leading DEA approaches that dominate the literature are intermediation, production, operating, asset, and value-added for variable specification banks efficiency studies.

Intermediate Approach: As per the intermediation approach, the banks are considered intermediated institutes that convert savings into credits. It is based on the primary role of banks as intermediate between the lenders and borrowers. The founder of this approach is Sealey & Lindley (1977), and in the study, his main focus is on constructing the banking behavior in the context of a profit maximization firm. The production role in financial intermediaries (Sealey & Lindley, 1977) seeks to capture both the technical and financial sides. The transformation process from input to output collecting funds from the surplus side and providing these to the deficit side is the focal point on the technical side. On the financial side, creating a higher value than the original value is the purpose of the process. As per this approach, we can conclude that inputs and outputs are specified based on the transformation process and preference regarding the market value of intermediary services.

In terms of input and output variables, the intermediation approach utilizes the monetary value of deposits and loans instead of the number of deposits and loan accounts (Ahn & Le, 2014). Inputs variables taken generally are: deposits, fixed assets, personnel expenses, borrowings, and physical capital, while output variables taken are: loans/ advances, investments, and income (Sufian, 2011),(Ahn & Le, 2014),(Sufian et al., 2016a)(Eyceyurt Batir et al., 2017) (Das et al., 2005),(Karimzadeh, 2012)(Phung et al., 2020)

Most studies have employed the intermediation approach, as proved by a comprehensive survey (Berger & Humphrey, 1997) and (Fethi & Pasiouras, 2010). The main reason behind using the approach is better reflects the bank's primary function: to work as an intermediate between the depositors and borrowers (Abdul-Wahab & Haron, 2017). Therefore (Favero & Papi, 1995) and (Berger & Humphrey, 1997) suggest that this approach is superior to other approaches and is appropriate for those banks whose principal activities include converting the deposits and significant funds purchase from other institutions into loans and financial investment. Another reason for the widespread use of this approach is that data (bank liabilities and assets) in monetary terms required for efficiency measurement is readily available in published sources.

This approach has certain limitations despite its comprehensive utilization for the efficiency measurement of banks. First, its use of deposits as an input does not justify the importance of deposits service that banks provide to customers and the operating cost incurred for this, generally in the case of Rural banks where their main motive is to provide deposits service to the vast spread population in rural and remote areas(Reddy, 2011). Second, it has considered banks a typical financial intermediate institution between depositors and borrowers, ignores the role of banks in the national payment system, and last, this approach ignores the risk factor and other non-interest services provided by the banks (Ahn & Le, 2014).

Production Approach: As per the production approach, bank institutions are treated as service producers to the clients by focusing on operating cost minimization (Ahn & Le, 2014). The developer of this approach is Beston (1965) and based on a cost analysis study done by First Federal Reserve District Bank employees of the US in 1957.

Under this approach, banks are considered producers of deposits and services provided, so the output is measured in terms of no. of accounts, and the number of transaction related to it means it includes all types of deposits, loans, income, and transactions to these. Inputs include only the physical variable required to produce items, like the number of employees/ labor, physical capital, and other related costs, excluding interest expenses.

The production approach is different from the intermediate approach in terms of deposit treatment: in the latter, deposits are treated as inputs while the latter are treated as output. Also, these two approaches are different in terms of the monetary value of the variables in the intermediate approach; all the variables are taken only in monetary value, while in the production approach, certain input variables are taken like no.

of employees, no. of accounts in non-monetary terms (Ahn & Le, 2014). Per (Berger & Humphrey, 1997), none of these two approaches is ideal because both the models do not fulfill the dual role of banks as service producers and as an intermediate between the borrower and lenders. They suggest that the approach is slightly appropriate for measuring branch efficiencies, and an intermediate approach is suitable for measuring banks' efficiency.

The main limitations of this approach are that it ignores the intermediate function of the bank; secondly, it does not consider the interest expense as an input variable; and last, the data available on the variables is also a prominent issue because the no. of employees, no. of transaction data are not published generally.

Assets Approach: Under the asset approach, the banking activities primarily focus on required asset quality maintenance for increasing the bank's performance. The role of banks as loan creators is recognized under this approach. The asset approach of Sealey and Lindley (1977) is a modified form of intermediation approach in which *output* is defined as assets in the form of loans in which banks have an advantage over the other financial institutions (Favero & Papi, 1995).

The input variables under this study are time and saving deposits, demand deposits, capital (fixed assets and premises), Labour (employees), and the output variables: loans and investments (English et al., 1993) (Elyasiani & Mehdian, 1990). The approach has certain limitations; it does not consider most of the services provided by the banks. It ignores the interest and non-interest expenses and income, which are a significant part of the bank's income and expenses. Like, the intermediation approach does not consider the risk factors in the study.

Value-Added Approach: The value-added approach is when output is considered value addition made by judicious use of operating cost as an input (Berger et al., 1987). Berger and Humphrey (1992) is the pioneer of the approach. The value-added approach is different from all the other approaches in considering all the liabilities and assets as an output variable rather than input or output.

In this approach to gaining a competitive advantage, banks focus on maximizing the economic value added to every banking activity (Ahn & Le, 2014). value addition of each banking activity is the basis of output specification. Significant types of deposits(time, saving, and demand) and loans (real estate, commercial, and installments) are recognized as output by focusing on the cost-profit relationship (Berger et al., 1987) because all these are mainly responsible for value addition, while like non-loan investments and govt. Securities are ignored as an output specification due to low value-added contribution.

The output is specified in monetary terms, and only these activities that create high value like deposits, loans, and income are specified as output. The input includes purchased funds, labor, and physical capital.

The main advantage of this approach is that it focuses on the economic side of banking activities. Secondly, accounting data is used for value addition calculation, which is readily available, which is also a plus point of this approach. Nevertheless, it also has certain limitations; it has not specified the input and output.

User Cost Approach: The user cost approach usually credited goes to the work of (Hancock, 1986). As per this approach, banks are expressed as producers of financial services to minimize liabilities & assets, maximizing the economic return. The user cost approach is based on the opportunity cost of holding financial assets and liabilities over time.

From financial liabilities, the financial services user cost produced can be calculated as financial cost minus the opportunity cost of using the funds; opportunity cost minus financial return from the assets is the user cost produced from financial services. The bank's assets and liabilities can be classified as input or output variables based on user cost. The favorable user cost is the input variable; the negative is the output variable.

According to Hancock (1985), if the financial returns are more than the opportunity cost of funds or if the financial cost of liability is less than the opportunity cost, that can be described as output; otherwise, its described as input (Reddy, 2011). The main advantage of this approach is its focus on the economic aspect of the production process. However, it also has certain limitations. There is no clear-cut definition of input and output, so calculating user cost is not easy. The availability of required data like expected gain and loss is also challenging.

Table 1 depicts the information related to the DEA models, DEA approaches, and input and output selection based on the DEA approach. The review of the literature shows that the intermediation approach is the most widely used in the studies for variable selection for efficiency measurement studies of banks(Rangan et al., (1988), Charnes et al., (1990), Elyasiani & Mehdian,(1990), Berger & Humphrey, (1991), Bhattacharyya et al., (1997), Barr et al., (2002), Ataullah & Le, (2006), Kumar & Gulati, (2008), Kumar,(2008), Hanif Akhtar, (2010), Hon et al., (2011), Karimzadeh, (2012), Titko et al., (2014), Kaur & Gupta, (2015), Sufian et al., (2016b), Mahendru & Bhatia, (2017), Eyceyurt Batir et al., (2017), Chaluvadi et al., (2018), Goyal et al., (2019), Davidovic et al., (2019), Phung et al.,(2020)). In most of the studies, labor and capital are selected as input variables and loans as an output variable, whereas the variable deposits are taken as input (Elyasiani & Mehdian, (1990), Barr et al., (2002), Kumar & Gulati, (2008), Sufian & Habibullah,(2009), Karimzadeh,(2012), Titko et al., (2014), Sufian et al., (2016b), Mahendru & Bhatia, (2017), Chaluvadi et al., (2018),) in some studies while taken as output (Berger & Humphrey, (1991), Bhattacharyya et al., (1997) in others. The reason behind this contradictory view about the deposits is because some researchers consider the deposit as a variable that is used for generating revenue for banks, and that is why it is used as an input variable; however, others consider it as a by-product of the inputs that banks employed for creating deposits. The table also shows that the CCR model, both input-oriented and output-oriented, is used in most of the studies as the place of the BCC model of DEA.

Table 1: Bank Efficiency Studies Using Different DEA Approaches for Input-Output Specification

Author/Year	Country	Sample and Time Period	Model	Approach	Input	Output
Sherman & Gold, (1985)	USA	14 Branch Offices	CCR model	Account approach	Labor Rent of office paid	No. of transaction
Rangan et al., (1988)	USA	215 Independent Banks 1986	Input-oriented CCR DEA model	Intermediation	Labor Capital Purchased funds	Real estate loans Commercial and industrial loans Consumer loans Demand deposits Time and saving deposits
Charnes et al., (1990)	USA	48 Commercial Banks 1980-1985	CCR DEA model	Intermediation	Total operating expense Total noninterest expense Provision for loan losses Actual loan losses	Total operating income Total interest income Total noninterest income Total net loans
Elyasiani & Mehdian, (1990)	USA	U.S Commercial Banks 1980-1985	CCR DEA model	Intermediation	Deposits Labor, Capital	Loans Investments
Berger & Humphrey,(1991)	USA	U.S. banks 1984	CCR DEA model	Intermediation	Labour Purchased funds Capital	Deposits Loans
Favero & Papi, (1995)	Italy	174 Italian Banks 1991	Input-oriented CCR DEA model	Intermediation and Asset	Labour number of full-time employee Capital- Book value of fixed assets and premises, Loan able funds, including current accounts and saving deposits, CDs Net funds borrowed by other banks.	Loans to other banks and non-financial institutions Investment in securities and bonds, and non-interest income.

Bhattacharyya et al., (1997)	India	Commercial Banks 1986-1991	Output-oriented Charnes-Cooper-Rhodes (CCR) model	Intermediation	Capital Labor Other non-financial	Advances Investments Deposits
Barr et al., (2002)	USA	Commercial Banks 1984-1998	Input-oriented CCR DEA model	Intermediation	Salary expense, Premises Fixed assets, other noninterest expense, interest expense Purchased funds (which are large dollar deposits	Earning assets, Interest income, noninterest income
Das et al., (2005)	India	71 banks in the year 1996-97 and 68 banks in the terminal year of India 1997-2003	Input-oriented CCR DEA model	Intermediation	Borrowed funds (deposits and other borrowing) Number of employees Fixed assets and equity	Investments Performing loan assets Other non-interest fee based incomes
Ataullah & Le, (2006)	India	Commercial Banks 1992-1998	Output-oriented Charnes-Cooper-Rhodes (CCR) model	Intermediation	Interest expenses operating expenses are the inputs for both the models	Model A loans and advances, Investments. Output Model B Interest income Operating income.
Kumar & Gulati, (2008)	India	27 Public Sector Banks 2004-2005	CCR DEA model	Intermediation	Physical capital- Value of fixed assets Labour – Number of employees Loanable funds – The sum of deposits and borrowings	Net interest income (measured as the difference between interest earned and interest expanded), Non-interest income (proxied by 'other income').
Ketkar, (2008)	India	62 banks – 8 state owned, 19 nationalized, 20 old	CCR DEA model	Intermediation and Production	Branches Equity Total operating expenses	Loans Non-interest Income Deposits ,

		private, 8 new private, and 7 foreign banks 1996-2003				
Kumar,(2008)	India	27 Public Sector Banks 2005	Input-oriented CCR DEA model	Intermediation	Physical capital Labour loanable funds	Spread Non-interest income
Sufian & Habibullah,(2009)	Korea	Commercial Banks 1992-2003	BCC model	Intermediation, Value-added and Operating	Deposits, Value added Labor Capital Interest expense Operating Interest expenses Labor	loans , Investments Value added ,Deposits Loans Investments, Operating, Interest income Non-interest income emanating mostly from commission, exchange, brokerage, etc.
Hanif Akhtar, (2010)	Saudi Arabia	9 Commercial Banks 2000-2006	Output- oriented CCR DEA model	Intermediation	Interest expenses Non-interest expenses (which are, in fact, operating expenses)	Net interest income Non-interest income
Hon et al., (2011)	Malaysia	10 Banks 2001-2005	CCR DEA model	Intermediation	Deposits from customers personnel costs total assets	Loans, Advances
Sufian, (2011)	Malaysia	31 Commercial Banks 1992-2003	CCR DEA model	Intermediation approach, Value-added approach, and Operating approach,	Deposits, Labour capital, Operating interest expenses labor, value-added labour, capital interest expenses	Interest income Non-interest income emanating mostly from commission, Exchange, brokerage, etc. deposits, loans investments
Reddy, (2011)	India	192 RRB'S & 27 PSB's 1996-2002	CCR DEA model	Production	Interest expenses , Operational expenses excluding pro-visions.	liquid assets, Total advances Total income (interest income plus non-interest income). Total deposits.
Karimzadeh, (2012)	India	8 major commercial banks - 5 public sector	CCR and BCC model under both the constant	Intermediation	Fixed assets, Deposits	Loans Financial investments

		and 3 private sector banks 2000-2010	return to scale and variable return to scale assumption		Number of employees.	
Karray & Chichti, (2013)	Tunisia	402 commercial banks from 15 developing countries 2000-2003	Input oriented CCR model	Intermediation and Value Added	Physical capital Borrowed funds Work Physical capital Borrowed funds	Loans Other paying assets Deposits Loans Other paying assets.
Titko et al., (2014)	Lativa	15 Latvian banks 2012	Input oriented BCC model	Intermediation	Deposits Labour Capital	Loans Securities
Kaur & Gupta, (2015)	India	57 banks state banks and its subsidiaries(7), other public sector banks(19) and old and new private sectors banks(30) 2009-2013	CCR and BCC model under constant return to scale	Intermediation	Interest expenses Operating expenses	Interest incomes Fee based income (Commission, Brokerage etc.) Investment income
Sufian et al., (2016b)	Malaysia	commercial bank operating in Malaysia during 1999 – 2008	Input oriented BCC model	Intermediation	Total Deposits Capital Labour	Total Loans Investments Non-Interest Income
Mahendru & Bhatia, (2017)	India	26 public sector banks of India 2007-2012		Intermediation	Deposits Borrowing Interest expenses Operating expenses	Investments Advances Interest income Non-interest income
Eyceyurt Batir et al., (2017)	Turkey	49 Turkish banks-4 Participation banks, 32-commercial banks and 13- investment and development banks. 2005-2013	Input-oriented CCR DEA model	Intermediation	Labor Capital Funds	Total loans (Sum of long term and short term loans) and Off-balance sheet items (Sum of guarantees, commitments and financial derivative instruments)
Chaluvadi et al., (2018)	India	26 public sector banks	Network data envelopment analysis (DEA) approach (i.e. variable return to scale	Intermediation	Branches Number of employee Deposits,	ROA ROE Investments

		, and 18 private sector banks 2008-2013	and constant return to scale)		Operating expenses Interest expenses Wages as per cent of total costs	
(Novickytė & Droždz, 2018)	Lithuania	6 commercial banks operating in Lithuania	Input oriented DEA approach under variable return to scale and	Production, Profitability and	Deposits Labor expenses Debts to banks and	Operating profits Loans Profit before tax
Goyal et al., (2019)	India	66 banks that include Public Banks, Private Banks and Foreign Banks 2015-2016	Both the input oriented (minimization)and output oriented (maximization) CCR approach	Intermediation	Total loanable funds (sum of all deposits and borrowings) Personnel and operating charges Physical capital.	Net interest income Non-interest income
Davidovic et al., (2019)	Croatia	Croatian banks 2006-2015	Input oriented BCC model	Intermediation	Interest and Non-interest expenses	Interest and Non-interest revenues
Ning Zhu et al., (2020)	China	16 Chinese's commercial banks operating during 2005-2015	Multi-Directional Meta-Frontier DEA Model	Profit oriented	Interest expenses Non-interest expenses	Interest income Non-interest income (NII). Undesirable output: Non-performing loans (NPLs).
Phung et al.,(2020)	Beijing	26 banks of Taiwan 2013-2015	Mixed Network DEA approach	Intermediation	Labor Capital Funds	Loans Investments Non-interest income
Sakouvogui et al.,(2020)	USA	122 U.S agricultural banks 2000-2017	Cluster adjusted DEA model		Total interest expenses Total non-interest expenses	Total interest income Total non-interest income
Nan Zhu et al., (2020)	Pakistan	29 commercial banks - 24 private, 5 public, and 4 foreign banks 2006-2017	Output oriented CCR and BCC model		Interest expense Non-interest expense	Interest income Non-interest income

***Source**: Author's own compilation*

DEA SOFTWARES

There is a lack of available data on DEA solver software used in bank efficiency measurement studies. However, after extensive literature reviews, some papers with the software used for solving DEA problems are listed in table 2. A wide range of Commercial and non-commercial DEA solver software packages are available for DEA practitioners and researchers. Some of the DEA solvers software is listed below with links and further information.

COMMERCIAL DEA SOFTWARE

1. DEOS (Data Envelopment Analysis Online Software) by DSS Bridge Decision Group Inc. Canada
   https://www.deaos.com/#home
2. DEA-solver-Pro version 15 available by SAITECH, Inc. USA
   http://www.saitech-inc.com/index.asp
3. Frontier Analyst Version 4 available by Banxia Software Ltd. UK
   https://banxia.com/
   Software R packages like- Benchmarking version 0.29, FEAR 1.0, dea R (data envelopment analysis with R software)

NON-COMMERCIAL DEA SOFTWARE

1. DEAP Version 2.1(Data Envelopment Analysis Program version 2.1) written by Tim Coelli, The University of Queensland, Australia
   https://economics.uq.edu.au/cepa/software
2. DEA Frontier TM developed by Professor Joe Zhu
   http://www.deafrontier.net/index.html
   DEA Frontier free version is available for a maximum number of 20 DMUs
3. OSDEA (open source Data Envelopment Analysis) can be downloaded from the link below
   https://opensourcedea.org/

Table 2: Banks Efficiency Papers with DEA Software's Applied

AUTHOR'S/YEAR	COUNTRY	SAMPLE/TIME PERIOD	SOFTWARE
Karray & Chichti (2013)	Tunisia	402 commercial banks from 15developing countries 2000-2003	DEAP software developed
Titko et al. (2014)	Latvia	15 Latvian banks 2012	DEA Frontier software
Kaur & Gupta (2015)	India	57 banks operating India 2009-2013	DEA Frontier software
Bhatia & Mahendru (2015)	India	26 public sector banks operating in India	Data Envelopment Analysis Progra (DEAP 2.1)
Eyceyurt Batir et al. (2017)	Turkey	4 participation banks and 27 conventional banks 2005-2013	Data Envelopment Analysis Program (DEAP 2.1)

Goyal et al. (2019)	India	66 banks that include Public Banks, Private Banks and Foreign Bank 2015-2016	R software
Sakouvogui et al.(2020)	USA	122 U.S agricultural banks 2000-2017	R Software
Nan Zhu et al. (2020)	Pakistan	29 commercial banks operating in Pakistan's- 24 private, 5 public, and 4 foreign banks 2006-2017	MDEAP2 application

CONCLUSION

The motivation of the study came from the continuing disagreement in DEA-based banks studies over the specification of performance indicators as an input-output. The primary five DEA approaches for input-output specification based upon bank behavior models are- the intermediation approach, the production approach, the assets approach, the value-added approach, and the user cost approach. All of the approaches are different in terms of the focus of operations and the objective of banks to create value for the shareholder. Each approach has its pros and cons and is suitable according to the purpose of the study. The main intention behind this study is to guide new researchers or practitioners of DEA in bank efficiency studies on DEA, input-output specifications for bank efficiency studies using DEA, and the selection of DEA software. The author hopes that the article will benefit the researchers and practitioners in selecting variables for the study.

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