MODELING BANK EFFICIENCY IN MALAYSIA: AN ADAPTIVE NETWORK DATA ENVELOPMENT ANALYSIS APPROACH

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THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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ABSTRACT

This study proposes an adaptive Network Data Envelopment Analysis (NDEA) technique, which examines efficiency of all 43 commercial banks operating in Malaysia by utilizing the three traditional bank efficiency measurement approaches (intermediation, production and profitability). From past studies, separate bank efficiency measurement approaches have proven to produce biased results. For instance, when bank efficiency is measured solely based on its profitability, banks' long-term sustainability (capital ratio) could be ignored and affect the bank's profitable status. This study also proposes CAMELS (Capital adequacy, Assets, Management-capability, Earnings, Liquidity, Sensitivity) rating in selecting the variables to measure bank efficiency by explaining how the variables are linked to each other. This has not been done in any previous studies. The contributions of this study are three-fold. This study explains how the traditional 'black-box' of input-output has failed to probe into the bank's true efficiency. Secondly, by using the proposed model, the study empirically contributes in providing a better comparative efficiency measurement platform in Malaysian context. Thirdly, this study addresses the existence of undesirable bank output (i.e., bad debts) in determining bank efficiency. Findings of this study suggest that efficiency scores vary with respect to variable and approach selection. When considering the effect of business cycles, profitability approach is recommended. Whereas, intermediation approach should be more suitable in examining the bank performance with large time series data because it lies on the "going concern" accounting concept. This measure of bank performance refers to the ability of a bank to convert deposits into loans. Lastly, the production approach would give a holistic idea on the banks' ability to serve the economy. In order to measure bank efficiency more accurately, it is also important to consider the undesirable outputs generated from banking operations. Past research stated that benchmarking of banks based only on net income could lead to bankruptcy even if that bank had high efficiency score. Lastly, the empirical findings of this study reveal that foreign Islamic banks are pioneer in all three nodes in the proposed NDEA model. These results signify an advanced capacity of foreign banks in risk mitigation, investment portfolio and liquidity management. In the context of Malaysian's current bank regulations, with existing discriminations and government restrictions on foreign bank ownership, these results reveal that even in a favorable business condition, the Malaysian local conventional banks have not been performing well.

Keywords: Network Data Envelopment Analysis, Adaptive Efficiency Network, Decision-Making Unit, Sub-Processes for Malaysian Banks.

ABSTRAK

Kajian ini mencadangkan teknik analisis rangkaian Data Envelopment (NDEA) mudah suai yang meneliti kecekapan kesemua 43 bank perdagangan yang beroperasi di Malaysia dengan menggunakan tiga pendekatan pengukuran kecekapan tradisional (pengantaraan, pengeluaran dan keuntungan). Telah terbukti daripada kajian lepas bahawa pendekatan pengukuran kecekapan bank tradisional yang dibuat secara berasingan telah menghasilkan keputusan yang berat sebelah. Sebagai contoh, apabila kecekapan bank diukur semata-mata berdasarkan keuntungan, kemampanan jangka panjang bank (nisbah modal) mungkin telah terabai dan menjejaskan status sebenar keuntungan bank. Kajian ini juga mencadangkan untuk mengambilkira CAMELS (Capital adequacy, Assets, Management capability, Earnings, Liquidity, Sensitivity) sesebuah bank dalam memilih pembolehubah bagi mengukur kecekapan bank. Penggunaan CAMELS sebagai asas pemilihan pembolehubah seperti dicadangkan kajian ini tidak pernah digunakan dalam kajian terdahulu. Terdapat tiga sumbangan kajian ini. Pertama, kajian ini menerangkan bagaimana konsep 'kotak hitam' tradisional berkaitan input-output telah gagal untuk menyiasat kecekapan bank yang sebenar. Kedua, dengan menggunakan model yang dicadangkan, kajian memberikan sumbangan empirikal dengan menyediakan platform perbandingan pengukuran kecekapan yang lebih baik untuk membuat perbandingan di antara Bank Islam dan Bank konvensional dalam konteks Malaysia. Sumbangan penting yang ketiga ialah kajian ini mengenengahkan kepentingan keluaran bank yang tidak diingini (contohnya, hutang lapuk) dalam mengukur kecekapan bank yang sebenar. Hasil dapatan daripada menggunakan model penyesuaian NDEA kajian ini mencadangkan bahawa skor kecekapan adalah berbeza-beza mengikut pemilihan pembolehubah dan pendekatan pengukuran kecekapan yang diambil. Apabila mempertimbangkan kesan kitaran perniagaan, pendekatan keuntungan adalah disyorkan. Manakala, pendekatan pengantaraan adalah lebih sesuai dalam mengukur prestasi bank dengan data siri masa yang besar kerana ia berdasarkan kepada konsep "usaha berterusan" dalam perakaunan. Pengukuran prestasi bank ini merujuk kepada keupayaan bank menukar simpanan kepada pinjaman. Terakhir, pendekatan pengeluaran akan memberikan satu idea menyeluruh mengenai keupayaan bank-bank menyumbang kepada ekonomi. Untuk mengukur kecekapan bank dengan lebih tepat, adalah juga penting untuk mempertimbangkan output tidak diingini yang terhasil daripada operasi perbankan. Kajian-kajian lepas telah menunjukkan bahawa tanda aras bank yang hanya berdasarkan pendapatan bersih boleh membawa kebankrapan bank walaupun bank itu telah mempunyai skor kecekapan tinggi. Akhir sekali, penemuan empirikal kajian ini mendedahkan bahawa bank Islam asing adalah peneraju di dalam ketiga-tiga pendekatan dalam model NDEA yang dicadangkan. Keputusan ini menunjukkan bank-bank asing berkeupayaan untuk berdayamaju dalam pengurangan risiko, pengurusan portfolio dan kecairan pelaburan. Dalam konteks peraturan-peraturan semasa bank-bank Malaysia, ketidak-samarataan sedia ada dan sekatan kerajaan ke atas pemilikan bank asing, penemuan kajian ini menunjukkan bahawa walaupun di dalam keadaan perniagaan yang menguntungkan, bank konvensional tempatan di Malaysia belum menunjukkan prestasi yang baik berbanding bank Islam asing.

Katakunci: Rangkaian Data Envelopment Analysis, Kecekapan Rangkaian Adaptif, Unit Pembuat Keputusan, Sub-proses Bank Malaysia.

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AHP	:	Analytical hierarchy process
ASSQ	:	Loan-loss provision to total assets
BCC	:	Banker, Charnese and Cooper model
BNM	:	Bank Negara Malaysia
BSC	:	Balanced scorecard
BPG	:	Best practice gap
CE	:	Cost efficiency
CAR	:	Capital adequacy ratio
CAPADQ	:	Book value of shareholders equity to total assets
CAMELS	:	capital adequacy (C), asset quality (A), management quality (M), earnings (E), liquidity (L), and sensitivity to interest rate risk (S)
CB	:	Conventional banks
CRS	:	Constant returns-to-scale
DEA	:	Data envelopment analysis
DFA	:	The distribution free approach
DDF	:	Directional distance function
DRS	:	Decreasing returns-to-scale
DIVERSI	:	Non-interest income to total assets
DMU	:	Decision making unit
EC	:	Efficiency change ratio
FDI	:	Foreign direct investment
FDH	:	Free disposal hull
FSMP	:	Financial Sector Master Plan
FB	:	Foreign banks

FCR	:	Technological change ratio
GAAP	:	Generally accepted accounting principles
GDP	:	Gross domestic product
GDPGTH	:	GDP growth
IRS	:	Increasing returns-to-scale
IB	:	Islamic banks
INF	:	Inflation
IFRS	:	International financial reporting standards
LB	:	Local banks
LIQ	:	Total loans to total assets
MFA	:	Meta frontier
MSHAR	:	Total deposits
MI	:	Malmquist index
MLI	:	Malmquist Luenberger index
MCDM	:	Multiple criteria decision making
M&A	:	Merger and acquisition
MGTQ	:	Non-interest expenses to total assets
NDEA	:	Network data envelopment analysis
NN	:	Neural network
OLS	:	Ordinary least square
PCA	:	Principal component analysis
PMM	:	Performance measurement matrix
ROA	:	Return on assets
ROE	:	Return on equity
SFA	:	Stochastic frontier approach
SBM	:	Slack-based measure

SIZE	:	Total assets
TE	:	Technical efficiency
TGR	:	Technological gap ratio
TGC	:	Technical gap change
TGR	:	Technical gap ratio
TOPSIS	:	Technique for order preference by similarity to ideal solution
TFA	:	Thick frontier approach
N	:	Number of DMUs
β	:	Rate of change for good outputs
x	:	Inputs
y	:	Outputs
z	:	Bad outputs
g	:	Direction vector
w	:	Vector of weights
U	:	Outputs vector of weights
P(x)	:	Production possibility set
D(x, y)	:	Distance function
V	:	Inputs vector of weights
u	:	Weights corresponding to each output

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Efficiency measurement is a regular activity for many organizations. While efficiency is the measure of relative performance of a decision-making unit (DMU) i.e., bank, analyzed in the frontier of the best practices, productivity measures the change of efficiency between two consecutive times. The major motivations for these practices are; i) to define and narrate the actual performance not only in quantity but also in qualitative form for example profitability (Chenhall & Langfield-Smith, 2007), ii) to examine the process of a business, for example to identify the sources of inefficiency (Evans, 2004; Hwang, Chen, Chen, Lee, & Shen, 2013), and iii) to examine the extent of decision making power which is either the improvement is planned or just happened (Ketokivi & Schroeder, 2004; Melnyk, Bititci, Platts, Tobias, & Andersen, 2014). Studying efficiency or productivity by adopting data envelopment analysis (DEA) has become common practices for bank operations (Liu, Lu, Lu, & Lin, 2013a, 2013b; Paradi, Yang, & Zhu, 2011; Paradi & Zhu, 2013; Sufian & Chong, 2008).

Date envelopment analysis (DEA) is a non-parametric approach. Among the Malaysian bank efficiency studies, majority have used DEA as the measurement technique (Ng, Wong, Yap, & Khezrimotlagh, 2014; Sufian, 2009a; Sufian, Kamarudin, & Noor, 2014). In the traditional DEA, performance is calculated using the ex-post information (Berger & Humphrey, 1997; Charnes, Cooper, & Rhodes, 1978). However, later studies like Battese & Rao (2002) revealed that examining efficiency using DEA can produce better discrimination if ex-ante information can be considered through meta-frontier DEA analysis. Meta-frontier applications in bank efficiency measurements are scarce in practice (Bos & Schmiedel, 2003). In particular, in depth analysis of Malaysian bank efficiency and productivity using meta-frontier DEA has been neglected.

In the year 2000, Bank Negara Malaysia (BNM) introduced the Financial Sector Master Plan (FSMP), which outlined a three-phase plan to restructure the Malaysian financial sector in ten-year period (from 2001 to 2010). The restructuring process involved major mergers and acquisitions among the existing banks to ensure strong liberalization of the banking sector. The financial sector also experiences successful introduction of dual-full financial systems i.e. Conventional and Islamic banks, during the timeframe. According to Huang (2014), Malaysian banks have been growing rapidly for the past decade due to strong regulatory actions and government initiatives in restructuring the banking sector which took place just after the Asian financial crisis in 1997-1998. The existence of foreign banks in Malaysia has been continuing for quite a long time. Now, Malaysian banking sector consists of 27 conventional banks and 16 Islamic banks (BNM, 2016). In the form of ownership structure, it can also be said that Malaysia has 18 local owned and 25 foreign owned commercial banks operating in the country.

This chapter identifies research problems based on the background of this study. Research questions and research objectives are developed based on the statement of research problems. Both methodological and empirical contribution of this research are explained in this chapter. The final section presents the outline of the thesis.

1.2 Bank efficiency measurement

Banks play a key role in economic development through its financial operations- mainly collecting funds from the surplus group of the society and supplying it among the deficit groups. Thus, the economic activity is often highly associated to banks' efficiency within an economy. As a result, examining bank efficiency has received greater attention by both the academics and researchers over the past decades. According to monetary theory, banks facilitate to monetize private fund in exchange of deposit obligations, which are exchangeable. In light of this definition, banks' output can be grouped into three major classes: (a) state payment intermediary, (b) intermediary of debit and credit of funds, and (c) other financial services. State payment intermediary includes services for demand deposits.

The reason for banks' existence has been evolving over the time. A bank's specialty has conventionally been traced to its monetary nature. Among the earlier studies on banks, Tobin (1964) established the monetary circuit theory where banks beget money from money; Fama (1980) examined banks from the financial view as supplier of transactions and asset management; Corrigan (1982) underlined banks as the source of backup liquidity for all organizations including the government, and Kareken (1985) emphasized banks as the national payment systems. Hence, proper examination of banks requires identification of the core activities of a bank.

Over the last 30 years of time or more, banks are equipped with a long list services. The bank services parameter has been spread from a niche market to a global market. In connection to global market, globalization, bilateral economic relations and technological developments are vigorously changing the nature bank business and putting banks in competition. On top of that, bank ownership (i.e., private, public, foreign) has mixed types of effects on bank performance. In an extensive study of 7900 banks from 80 countries, Claessens, Demirgüç-Kunt, & Huizinga (2001) revealed that among the developing economies, local banks are to sacrifice their performance in the presence of foreign banks. In contrast, within the developed economies, an opposite performance indicator is observed. So, not only competition but also bank ownership structure and macroeconomic condition may effect on bank performance.

From the very beginning of banking revolution, countless investigation on bank performance connote its importance to the interest groups/ stakeholders (i.e. researchers, customers, investors, economists, government regulators, managers and many others). But the most cited problem lies in selecting appropriate variables that fit with the true definition of banking- inputs and outputs (Colwell & Davis, 1992; Kinsella, 1980, 1981). Some authors used pure commercial items from balance sheets and income statements for the measurement purpose (Liu et al., 2013b). While, researchers like Colwell & Davis (1992), Soteriou & Stavrinides (1997), Soteriou & Zenios (1999), Athanassopoulos (2000), Sherman & Zhu (2006) Secme, Bayrakdaroglu, & Kahraman (2009), & Paradi & Zhu (2013) reasoned for incorporating other indicators in banks' performance measurement. Thus, a diverse research has created a paradox in selecting the right variables for an identical measurement. As in the word of Gorman (1969, p. 155);

> *"Despite the strategic role of that commercial banks play in monetary policy and in the real world, there is little agreement on what it is that banks produce."*

Kinsella (1980) identified few explanations behind such inconsistency. These are banks' product and service mix, hidden charges, service charge policies, etc. In addition to that Colwell & Davis (1992) included some environmental factors such as government regulation, market concentration, interest rate, customers power and global financial condition. Kinsella (1980), however, suggested three approaches to measure banks' variables namely- research interest, ability to define banks' services or "packages" of services, and data availability. In a recent study, Paradi & Zhu (2013) suggested to adopt bank managers' view from the very beginning of performance measurement. They also stressed on the appropriate understanding of a model to be used and to define how the result may help managers to implement based on the research findings. A long listed research has identified the issue of highlighting the need for continuous research by updating existing models (Avkiran & Morita, 2010; Aysan & Ceyhan, 2008; Beck, Demirgüç-Kunt, & Merrouche, 2013; Colwell & Davis, 1992; Corrigan, 1982; Dima, Dincă, & Spulbăr, 2014; Fama, 1980; Fernández, González, & Suárez, 2013; Grigoroudis, Tsitsiridi, & Zopounidis, 2013; Malyarchuk, 2010; Paradi et al., 2011; Pastor, Perez, & Quesada, 1997; Ray, 2004, p. 328; Resti, 1999; Simpson, 2009; Sufian, 2009b; Thanassoulis, 1999; Wanke, Barros, & Faria, 2015). These contradictory results reveal that bank performances can present biased results based on variable (inputs and outputs) and measurement approach selection.

1.3 Variable selection in measuring bank efficiency

Even in recent times, similar conclusions are given by many researchers (Claessens et al., 2001; Malina & Selto, 2004). In earlier days, bank performance was examined based on liquidity and transactions. For instance, Gorman (1969) examined US bank performance using two types of outputs- liquidity (ability for smooth bank operation) and transactions approaches (managerial performance). Within his study period (1948-1965), a contradictory result was found. Productivity indexes from "liquidity" showed a declining result whereas productivity results from "transactions" scored an increasing trend. In the discussion of Gorman (1969, p. 189), such findings was referred to as **"difference in choices"**.

Among these studies, the two main efficiency measurement techniques are non-parametric and parametric (Berger & Humphrey, 1997; Lampe & Hilgers, 2015). DEA is a non-parametric efficiency measurement technique developed by Charnes et al. (1978), and has been widely used as performance measurement tool. DEA generalizes the single input and single output measure of Farrell (1957) into multiple inputs-outputs measures to evaluate relative efficiency among DMUs (Charnes, Cooper, Lewin, & Seiford, 1997). A DMU is considered as efficient if no other DMU can produce such outputs without increasing the required inputs. An example of popular parametric efficiency techniques is stochastic frontier approach (SFA). One of the major benefits of using DEA rather than parametric efficiency techniques is that it does not require detailed theoretical process knowledge (Cooper, Seiford, & Tone, 2006). On top of that, the more advanced approach of meta-frontier DEA allows separating DMUs based on their specific operating characteristics. With DEA meta-frontier approach, the heterogeneity issue of Malaysian banks could be resolved as revealed by a previous study (Battese, Rao, & O'Donnell, 2004).

In addition, the traditional DEA applications in measuring bank performance utilize the "black box" concept. In "black box" concept, input(s) received by the "black-box" produces the output(s). The traditional "black box" analogy, however, did not explicate all "processes" within the "black box". As a solution for modifying this DEA problems when applied to specific applications, Färe & Grosskopf (2000) proved that a network DEA could be applied to explain what actually is happening within the "black-box". In doing so, a network DEA can partition its "black box" into different sub-processes (or also termed as node in network analogy) which link the variables comprising a process or a node to another. The intermediate variable is first treated as the output of a node and later become the input to the following node. Finally, a network is created while explaining all processes involved in the actual operations within a DMU. A network DEA calculates not only the overall efficiency but also divisional efficiency for each sub-process or node. Thus, exploring bank's total efficiency in a stationary mode (as a total) can be further scrutinized by measuring divisional efficiency of each sub-process. This dynamic approach of efficiency measurement has been given higher priority in many recent studies. The increasing trend in using network DEA is evidently discussed in a recent study by (Kaffash & Marra, 2016).

Fairly recently, the pioneer of DEA, himself, i.e. William W. Cooper has examined the opportunities and challenges of DEA as the operations management tool in his recent paper (Cooper, 2014). This paper was published after his death but has been carrying the significance of his insight. He strongly recommended for continuing the development by upgrading DEA models with an insight to address new problems in social sciences. The developments in DEA model without any theoretical or practical problem solving attributes is said to be the research in wrong direction (Cooper, 2014, p. 8). He suggested dealing with the trend within DEA research, an **"application driven theory"** is the sound approach. Application driven theory is linked with the actual social science problem where the solution extends with proper explanation and supported with theoretical advances.

The earlier studies on bank efficiency have clearly indicated that DEA, stochastic frontier approach (SFA) and Malmquist DEA are pioneer ones. For the past decade, moreover, DEA related studies have demonstrate significant amount of application driven theory that rigorously combine the applied and basic research. Such studies adapted network analogy and meta-frontier approach. Whereas, the more recent studies adapted various and more diverse techniques and approaches to examine bank efficiency. Such examples are dynamic slacks based model to assess the evolution of Malaysian banks' potential input–saving/ output–increase from 2009 to 2013[1]; Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) & Neural Network (NN)[2] to produce a model for banking performance with effective predictive

[1] Published in SCI (web of science ™) indexed journal: Wanke, P., Azad, M. A. K., & Barros, C. P. (2016). Financial distress and the Malaysian dual baking system: A dynamic slacks approach. Journal of Banking & Finance, 66, 1-18.

[2] Published in SCI (web of science ™) indexed journal: Wanke, P., Azad, M. A. K., & Barros, C. P. (2016). Predicting efficiency in Malaysian Islamic banks: A two-stage TOPSIS and neural networks approach. *Research in International Business and Finance, 36*, 485-498.

ability; Pooled Ordinary Least Squares (Muhmad & Hashim, 2015), Generalized Least Square (Muda, Shaharuddin, & Embaya, 2013), Output distance function (Abdul-Majid, Saal, & Battisti, 2010, 2011b), Generalized Method of Moment (Sufian, 2010) and Translog stochastic cost frontier (Karim, 2001).

To a certain extent, the application of DEA are associated to the actual social science problems where the prevailing banking conditions and situations have confronts the selection of selection of variables for the DEA adaptive models and are supported with theoretical advances, for instance, the one proposed by Cooper in his last article.

1.4 Research problem

From the background of this research, it could be said that the existing research in DEA and bank efficiency have not completely explained bank efficiency (Cooper, 2014). The core objective of a bank lies under all activities involved within a bank: production, intermediation, and profitability (Corrigan, 1982; DCIBF Annual Report, 2014; Zeff, 1978). These activities should be considered in the overall bank performance. However, till date, the major bank efficiency models were only limited to measuring only one of the three banking approaches: profitability, intermediation and production. Here, the problem is to define a bank's core activities in examining the bank efficiency and thus, the corresponding selection of input and output variables. . Some literature defined bank as the producers of transactions (hence, production approach), while some other studies examined bank as a profit seeking organization (i.e. profitability approach). Thus, examining banks' efficiency based on one approach may lead to biased results. The existing DEA models, thus far, have failed to examine efficiency that could explain the core of bank operations. These lead to the first research problem, which is related to variable selection for a DEA model. Largely, this give emphasis to the right selection of inputs and outputs of the DEA bank efficiency model. In addition, more importantly, the overall bank performance need to be addressed. Therefore, measuring the three aspects of bank productivity, profitability and intermediation are also important for the adaptive model design.

In order to examine efficiency, proper identification of variables to be selected must be made. However, this could not be achieved as the DMU operates under variable returns to scale. On the other hand, examining bank efficiency using DEA under constant returns to scale, hold the assumption that the inputs and outputs do not change proportionality. In DEA, fine-tuning between efficiency scores and decision-making is often accomplished not only by choosing the proper input and output variables set, but also by looking at their slack values. A slack-based DEA model also assumes that inputs and outputs do not change proportionately (Pastor, Ruiz, & Sirvent, 1999; Tone, 2001). Under the slacks-based approach, inefficiencies are defined as non-radial excesses in inputs and non-radial shortfalls in outputs that is different from the traditional CCR and BCC. More specifically, the slacks-based approach presents some interesting properties for decision-making (Tone, 2001): (i) the optimal solution is not affected by variables measured in different units; (ii) negative values can be handled; (iii) non-proportional input-reducing/output-increasing potentials are handled by non-radial functions; and (iv) inputs and outputs are simultaneously, and respectively, minimized and maximized.

Inappropriate selection of variables for the efficiency measurement model, as in the earlier studies could lead to inaccurate concluding remarks when examining the impact of external variables on bank efficiency. Only a few research have suggested the idea of using variables related to CAMELS while examining bank efficiency. CAMELS stands for capital adequacy (C), asset quality (A), management quality (M), earnings (E), liquidity (L), and sensitivity to interest rate risk (S); in short CAMELS. CAMELS rating ranges in whole numbers from 1 (strong performance and practices, posing the least supervisory concern) to 5 (critically deficient performance, posing the most supervisory concern). For more details, see OCC Bulletin 97-1, "Uniform Financial Institutions Rating System and Disclosure of Component Ratings," January 3, 1997.

The issue of bank heterogeneity (e.g., Islamic banks, conventional banks, public banks, private banks) has been examined over the years. Although there are a good number of research papers in bank efficiency measurement, many suggested the banks to be in a common group (Kamarudin, Sufian, & Nassir, 2016; Sufian & Habibullah, 2015; Sufian & Kamarudin, 2015; Sufian, Kamarudin, & Nassir, 2016). Even several studies have evaluated the banks as in group performance by assigning them into two-stage DEA model (Sufian & Habibullah, 2015; Sufian & Kamarudin, 2015). As a result, these studies examine banks heterogeneity by applying regression or other methods could have led to biased results. The last aspect of banking operation that could have been completely ignored is undesirable output (i.e., loan loss provision) together with the desirable outputs (i.e., net income).

Thus far, efficiency studies on Malaysian banks have examined efficiency by considering heterogeneity: bank origin (foreign vs. local banks) and bank nature (conventional vs. Islamic banks) in the second stage of DEA. But, in considering bank heterogeneity, meta-frontier technology should be proposed (Battese & Rao, 2002; Hayami, 1969; Oh & Lee, 2010). Thus far, as my knowledge goes, only one research has accounted for examining bank heterogeneity using meta-frontier[3]. Thus, there is a clear literature gap in Malaysian bank efficiency literature where meta-frontier DEA

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[3] Published in ESCI (web of science ™) and Scopus indexed journal: Azad, M. A. K., Munisamy, S., Masum, A. K. M., Saona, P., & Wanke, P. (2016). Bank efficiency in Malaysia: a use of malmquist meta-frontier analysis. Eurasian Business Review, 03 September 2016, 1-25.

application is concerned. Apparently, the application of network DEA is completely missing in the Malaysian bank efficiency studies.

1.5 Research questions

Based on the background of study and research problems above, the research questions are given below.

i. Given the nature of Malaysian banks, what are the variables to be selected in proposing an adaptive network DEA model in examining bank efficiency?

ii. Based on the proposed adaptive model, what is the current state of bank efficiency in Malaysia?

iii. Based on the proposed adaptive model, what are the sources of bank inefficiency in Malaysia?

1.6 Research objectives

The core research objectives of this study are outlined below.

i. To propose an adaptive network DEA model by taking into account of banking operations.

ii. To measure the efficiency of banks in Malaysia by applying the proposed adaptive network DEA model.

iii. To identify the sources of bank inefficiency in Malaysia based on the outcome of the proposed model.

1.7 The conceptual framework

From past studies, several internal and external factors have been identified to have significant impact on bank efficiency measurement. Figure 1.1 presents the conceptual framework of this study.

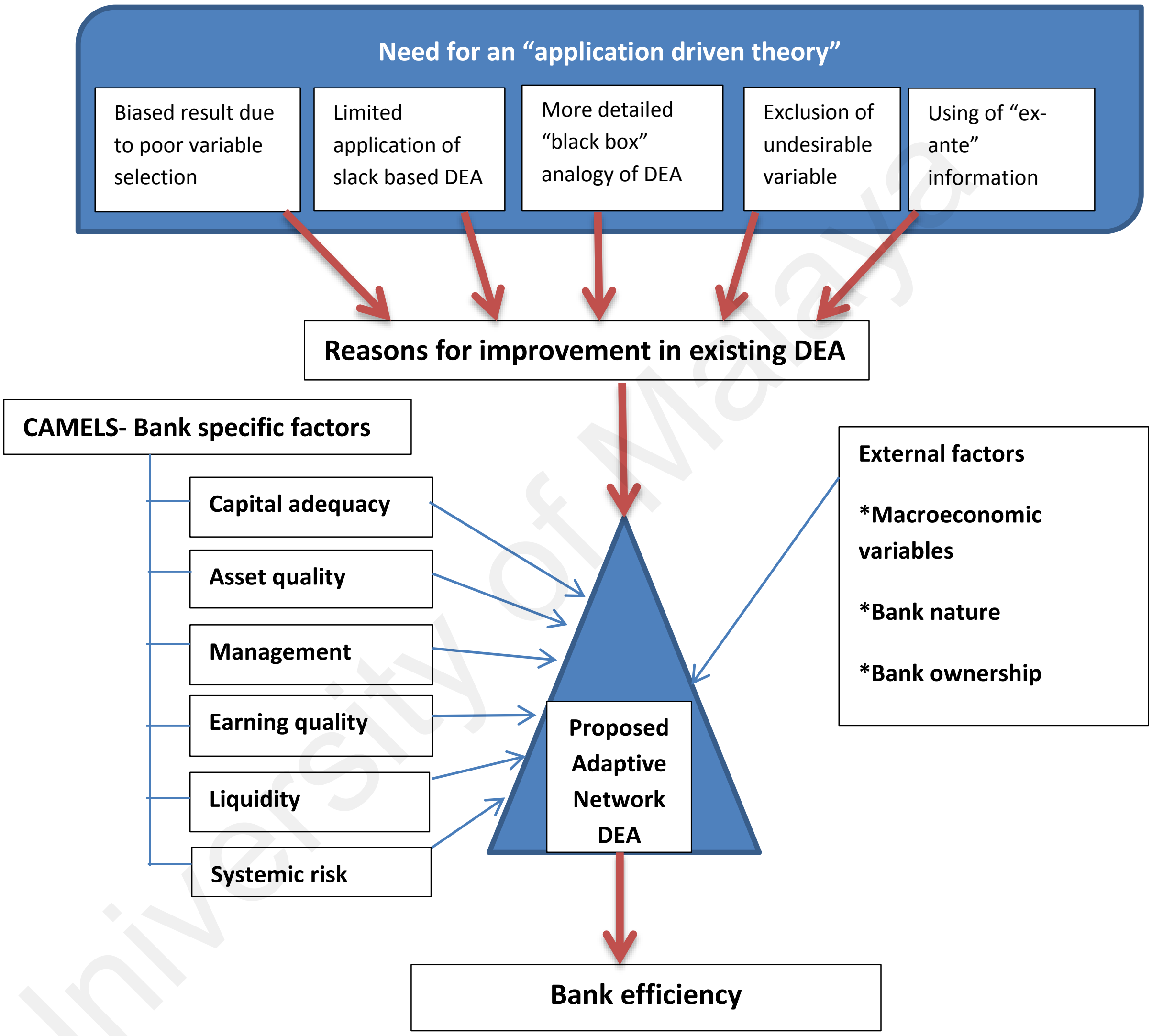
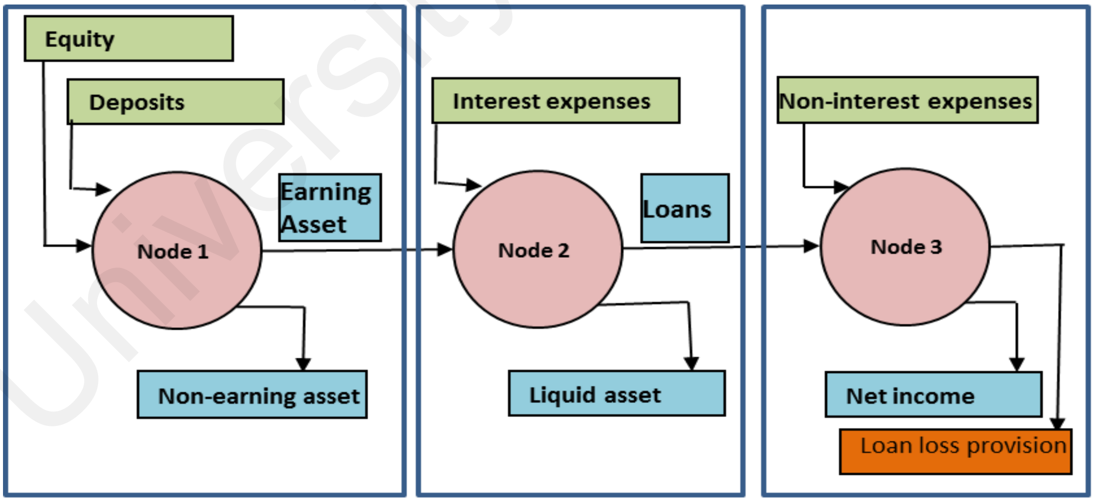


Figure 1.1: Conceptual framework of the adaptive NDEA model

Both internal and external variables of bank efficiency are considered in the developing the conceptual framework model. Internal variables are selected from the variables employed by CAMELS. It is, however, not anticipated that CAMELS would detect the scope of profitability or reduce risk through its findings. The most achievable outcome through CAMELS is to detect banks failure in advance. Supervisory authority provides ratings between scale 1 and scale 5. A high score represents higher regulatory concern for future problems. Predicting banks failure using CAMEL became a common practice over the last three decades because of its ability to consider banks total functionality (Betz, Oprică, Peltonen, & Sarlin, 2014; Doumpos & Zopounidis, 2010; Secme et al., 2009; Thomson, 1991; Wang, Lu, & Wang, 2013). Other than internal variables, the external variables like macroeconomic variables (Gross domestic product-GDP, GDP growth and inflation), bank ownership (Foreign vs. local banks) and bank nature (conventional vs. Islamic banks) were also of worthy to be considered to propose the adaptive model of bank efficiency measurement (Sufian & Habibullah, 2010a).

Figure 1.2 reveals that banks' core operation can be designed in a network by adapting the three most common approaches to bank efficiency measurement model within banking operation: : production, Intermediation and profitability.



Production Intermediation Profitability

Figure 1.2: Proposed adaptive network DEA model

Therefore, to meet the underlined research objectives, a unique adaptive network DEA model is proposed to help in explaining the three core bank operations (production, intermediation and profitability) as illustrated in Figure 1.2.

This model unveils the connection among the common three approaches of bank performance and connect them in a network. Variables (inputs, outputs and intermediations) are selected using the CAMELS ratings. On top of that, during variables selection, undesirable output (i.e., loan loss provision) is also considered and included. The application of meta-frontier technology helps to benchmark banks' performance taking different groups (bank origin and bank nature) in consideration. Thus, the conceptual framework in Figure 1.1 illustrates all the significant aspects of bank operations to adequately measure banks performance in the context of Malaysian banking sector by proposing an adaptive network model. While Figure 1.2 further explicate the performance measurement of the network model by unveiling the measurement of the production, productivity and intermediation aspect of bank operation.

1.8 Brief methodology and research design

This study proposes a novel model for examining bank performance. The proposed model comprises meta-frontier technique with network DEA. This is a slack-based approach. For unveiling bank operation, a unique network DEA was proposed.

This proposed adaptive model is used to empirically examine efficiency of Malaysian banking sector. All 43 commercial banks in the Malaysian banking sector was considered in this study. The data was collected from BankScope database, bank annual reports and official website of Bank Negara Malaysia (central bank of Malaysia). This study covers data from 2009 to 2015. To run the proposed model, variables (inputs and outputs) have selected based on core bank performance indicator- CAMELS. Please mention here the name of software used to run the NDEA analysis on 43 banks input and output data.

1.9 Methodological significance

The methodological significance of this study is threefold. First, unlike any production or manufacturing business, banking business is far complex in nature. Here, the nature refers to what banks are actually doing. Whether creating transactions by receiving deposits and creating loans or making profit out of banks' operation. Thus, this study answers the core functionality of a bank by proposing a network which unveils banking as a combination of both transactions and profitability. The focus of this model would incorporate all possible aspects of a bank through its variable selection, so that a holistic performance result is achieved. In doing so, undesirable output of a bank (non-performing loans) is also considered. Second, a major literature, thus far, presents an anomaly in benchmarking efficiency when any individual approach (production, intermediation or profitability) of banking has taken in consideration. This study has provided substantial evidence that these individual banking approaches give biased result. Thus, in this model, input and output variables have selected with relation to CAMELS. Last but not least, this study employs meta-frontier Malmquist index for the first time in the context of Malaysian banking sector to evaluate yearly changes of banks' productivity (frontier change or technological change) while considering bank origin (local bank or foreign bank) and bank nature (conventional or Islamic). These breakdowns help managers as well as regulatory agencies to evaluate any individual bank in a holistic manner.

1.10 Research contribution

Therefore, this study contributes in threefold by filling the efficiency literature gap in the context of Malaysian banks. First, this study proposed a model for selecting the variables (i.e., inputs, desirable outputs, undesirable outputs and intermediation) in association with the core bank assessment indicators- CAMELS. The selection based on CAMELS variables for examining bank efficiency is utilized for the first time in the context of Malaysian banks. The application of CAMELS based variables in efficiency study provides unbiased results and helps to benchmark competing banks accordingly. Secondly, meta-frontier DEA model is also applied for the first time in the context of examining efficiency of banks in Malaysian. And thirdly, better approach to measure Malaysian bank efficiency is unveiled with the help of adaptive network DEA. The comprehensive network model is proposed for revealing bank performance in terms of deposit creation and bank profitability while excluding the influence of undesirable outputs (non-performing loans). Thus, applying this proposed model, not only it measures bank efficiency but also it incorporate managers' insight on banks specific conditions by particularly highlighting what bank considers as its performance. Eventually, a complete picture of total banks' performance is revealed to evaluate the individual bank's performances by comparing it to the other banks.

Malaysian banking sector has gone through a tough time during the previous financial crises. Over the last two decades, a number of banks operating in Malaysia have gone under forcefully equity concentration to adequately fortify the banking sector to absorb external financial shocks. Thus, a comprehensive analysis of bank performance would give further enlightenment on the important areas to improve within the economic sector which is in the interest of nation. Last but not least, the decomposition of bank efficiency scores by applying this proposed model allows examining the sources of inefficiency within the Malaysian bank performances and, more importantly, it would help to detect financial distress in advance.

1.11 Outline of the thesis

This thesis is presented in six additional chapters. The following chapter presents a critical literature review of relevant research findings in bank efficiency. Chapter two includes a number of tables to demonstrate the literature gap in earlier works which works as the theoretical foundation of bank efficiency and the appropriateness of the proposed model. This chapter presents a brief development on the various performance measurement techniques in past years. The literature here is focused on identifying the best practiced method. Literature review also includes the comparative demonstration of different available models and approaches of bank efficiency measurement to highlight the rationale of using DEA technique. This chapter also includes the literature on bank efficiency in Malaysian context. Different aspects of existing literature and the extent of literature gaps are also presented. The literature here is focused on identifying the best practiced method.

Next, chapter three demonstrates the theoretical review of data envelopment analysis along with the constructions and presentation of relevant models. Methodological description of different existing models and their appropriateness in explaining the requisite research question have been examined and presented. The conceptual development of the proposed adaptive network DEA model is shown in the following chapter. Chapter 4 describes the proposed adaptive model which evaluates the rationale of using the proposed adaptive network model in order to fill the methodological gap in examining bank efficiency.

Chapter 5 presents the analysis of results generated by applying the proposed adaptive model. Firstly, this chapter presents the measurement of bank efficiency based on the proposed model. The descriptions are mainly bank nature and the related bank origin. Only descriptive discussions on acquired results are shown in this chapter. Next, empirical results and their analyses are presented. Thirdly, the robustness check of the results. Finally, a summary of these results is drawn at the end of this chapter.

Chapter 6 follows next with more discussions on the findings based on the results in chapter four. Discussions on the analysis of results presented in earlier chapter are summarized into findings. This chapter further examines the results to provide a comparative analysis. Robustness tests of this study are also presented. Finally, the concluding chapter presents research contributions and future research opportunities in Chapter 7. This chapter summarizes the key points of this study by including the empirical contribution, theoretical contribution and managerial implications. In addition, possible future studies based on this study are also discussed. Limitations of this thesis is also included d at the end of the last chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter summarizes the most relevant and most cited findings that contribute to the understanding of proposed adaptive three-stage network DEA model for evaluating efficiency of Malaysian banking sector. The first section explains how different performance management techniques have evolved with the changes of business environment. The changes of performance management techniques have confined within ratio analysis, regression analysis and frontier analysis. Among the frontier analysis, large number of bank efficiency studies apply data envelopment analysis (DEA) which are examined in the following sections. The following section describes data and variables of the earlier studies that include variable selection based on CAMELS rating and different approaches to bank efficiency studies. Finally, contextual variables are evaluated for examining sources of inefficiency.

2.2 Business evaluation of performance management

The evaluation of bank performance aids managers to see its status and to compare with the desired level. Through performance measurement, managers can keep update on what aspect of firms' performance is measured and what is not Melnyk et al. (2014). The topic area of performance measurement is so diverse that researchers unable to run review on total academic works.

Moreover, it is reported that research on performance has come in the radar screen to test with any specific area and its multidisciplinary nature which has made it even more complex (Kennerley & Neely, 2002; Neely, 2002). The main challenges in business performance measurement are instantaneous diverse nature and the ever-changing business trend. The issue of **"fit"** in applying efficiency measures within the firms also has been stressed (Melnyk et al. (2014). It was argued that even if the uses of performance index help managers to focus on future strategy building, erroneous approach in developing the index might be misleading in its interpretation or, even worse, absolute shock. Such condition is termed it as "paradox" and to solve such situation, managers must focus on the trend of business environment and revisit the measurement approach to be fitted. Therefore, both issues of multidisciplinary nature and best-fit assessment of bank performance measurement techniques should be deliberated and aligned before expecting for meaningful results from the bank efficiency measurements. Table 2.1 presents the key factors of business environment.

Table 2.1: Key factors of business environment

Business Trends	References
Deregulation: Merger and acquisition, globalization, government intervention	Sufian & Habibullah (2012b), Cook (2009), Claessens et al. (2001)
Business accuracy: transparency and accountability in business	Brewer, Choi, & Walker (2007); Rayner (2003)
Sustainable business: Corporate social responsibility and social perspective with long term view	BinMahfouz & Hassan (2013); Chang, Kuo, & Chen (2013); Lo (2010); Piot-Lepetit & Nzongang (2014); Wu (2000)
Empowerment: decision making in a way either centralization of decentralization	Demirbag, Tatoglu, Glaister, & Zaim (2010); Du, Duan, & Han (2012); Fernandez-Montes, Velasco, & Ortega (2012); Rydval (2012); Seydel (2006); Yousefi & Hadi-Vencheh (2010)
Flexibility: Management to cope environmental changes and response with sensible manner	Narasimhan, Talluri, & Das (2004); Petroni & Bevilacqua (2002); Phillips & Tuladhar (2000)
Customer satisfaction: customer retention and loyalty	Chen, Lu, Lee, & Lee (2009); Grigoroudis et al. (2013); Secme et al. (2009); Soteriou & Stavrinides (1997)
Risk management: Dealing the banking risk factors in an optimal way	Chen, Chiu, Huang, & Tu (2013); Chiu & Chen (2009); Gunay (2012); Ozdincer & Ozyildirim (2008)

With reference to Table 2.1, among the major changes in banks in developing a strategy based on an ever-changing business environment are deregulation (Sufian &

Habibullah, 2012); business accuracy (Brewer, Choi, & Walker, 2007); sustainable business (BinMahfouz & Hassan, 2013); empowerment (Demirbag, Tatoglu, Glaister, & Zaim, 2010); flexibility (Narasimhan, Talluri, & Das, 2004); Customer satisfaction (Soteriou & Stavrinides, 1997) and risk management (Chiu & Chen, 2009). The issues of 'multidisciplinary' nature and 'best-fit' of bank efficiency techniques have indirectly limits the selection of techniques for bank efficiency measurement.

More often than not, the techniques tend to vary from one study to another. This is because of the nature of business itself and different needs from various interest groups. Consistent major changes in business environment and its structure require the managers to change their business strategy timely and if possible particulate the change in advance to receive possible rewards (Melnyk et al., 2014). In their extensive literature review, Bititci, Garengo, Dörfler, & Nudurupati (2012) concluded that it is imperative to analyze the future trend of business in advance. Efforts to identify the business trends in developing the 'best fit' management strategy are imperious demand of today's business world.

On different needs from various interest groups, Lauras, Marques, & Gourc (2010) criticized the trend of using single report produced and distributed to all stakeholders in explicating performances. They argue that managers describe firms' performances in different units and in different formats that a single report cannot meet the accurate manifestation to all of its readers. For example, decision makers are more likely to see aggregate results for forecasting purposes. The mid-level managers may require more specific and detailed information, while government and regulators may appeal for sustainable issues. Whereas shareholders may only query on firms' profitability. To handle such situation Nudurupati, Bititci, Kumar, & Chan (2011) and Lauras et al. (2010) affirmed a combined model for analyzing bank performance that could represent a readymade global value for all and, at the same time, enlighten on the firms' performances.

The review of the literature hints the truth that it is not the technique that examines changes in the environment and the changes in banks' performances. Instead, it is the need for changes in the measurement techniques following any significant changes in business environment. This would assist in determining the best fit of model to explain a business event and understands the creed of future success.

2.2.1 Ratio analysis- the accounting perspective

Before 1980s, ratio analysis was the traditional mainstream instrument (i.e. financial) for analyzing bank performance (Otley, 2002; Paradi & Zhu, 2013). Otley (2002) outlined three faces of ratio analysis technique in practice. Firstly, the financial aspect; used by the finance managers which contains mostly internal users of a firm. Examining the ratios and the capacity of their explanative ability, generally top and mid-level managers understand their capacity and compare with the benchmark (Lev, 1989).

According to Lev (1989) and Otley (2002), all the ratios that used in performance analysis are focused either of the three key issues; cash flow, profitability and balance sheet, described in different styles using the same accounting figures. Benchmarking of these ratios are also complex since the discussion on the results are mostly subjective and the overall business aspect deals with both internal and external stakeholders. Following industrialization and few financial crises, several literature have uncovered that the traditional accounting of measuring firms' performance is not adequate. Accounting approach of measurement ignores firms' competitiveness (Hayes & Abernathy, 1980) and most likely stressing on the importance of short term analysis only (Banks & Wheelwright, 1979).

More shortcomings of accounting approach for performance measurement are highlighted on absence of strategic vision for decision making (Kaplan, 1986; Turney & Anderson, 1989). Miller & Vollmann (1985) quoted similar pitfalls of accounting approach of performance measurement in management literature. Since then, a number of new approaches (i.e. multi-dimensional, two stage, fuzzy data etc.) have been serving the field of performance measurement and all of them have their own limitations and strengths (Franco-Santos et al., 2007; Melnyk et al., 2014; Neely, 2002). In turn, development of performance measurement techniques has rip-off well thought out both financial and non-financial aspects. Financial ratios are to be pondered in methodical manner rather formulaic ones (Otley, 2002). Selection, calculation and interpretation of financial ratios, as performance measurements, therefore, require special attention and approach that is more systematic.

2.2.2 Regression analysis

Regression analysis is the other commonly applied technique in analyzing banks' input and output (Hensel (2003), Avkiran (1997) , Berger, Hancock, & Humphrey (1993),Olsen & Lord (1979)). The main advantages of regression methods are the ability of using statistical interface and measurement of errors; and that the regression technique enable more than one independent variables to be analyzed to provide an average performance and mean values are one of them. While effective in the aforementioned aspects, regression analysis has inherited few limitations too.

The most important limitation is the requirement of a defined model since regression is a parametric test. Since bank business is complex in nature and attributes of banks often come in bundle, accurate model of banks' production technology in not possible. Secondly, regression analysis provides the average (expected) value using central tendency method whereas, in efficiency analysis, relative value of any DMU is examined comparing the distance from the benchmarked (either maximum or minimum) value (Paradi & Zhu, 2013, p. 63) Moreover, using regression can only test one input with multiple outputs or one output with multiple inputs as variables.

2.2.3 Frontier analysis

The limitations of ratio analysis and regression analysis have led to the development of more advanced and sophisticated tools for efficiency measurement. One of these efforts is the frontier method that evaluates the efficiency of a decision-making unit (DMU) (i.e. the unit targeted for performance measurement, e.g. bank, for this study) relative to the best-practiced peers.

The most attractive feature of frontier analysis is its ability to examine complex method of economic optimization (multiple inputs and multiple outputs) and it can provide single quantitative results as efficiency scores (Berger & Humphrey, 1997). Paradi & Zhu (2013, p. 63) strongly highlighted the contribution of frontier methods in management decision-making capacity. They argued that, managers can, not only, highlight the efficiency of a DMU with comparison to it peer groups but also include environmental factors as a signaling concept for the overall production systems. The popular dominating frontier techniques in the performance measurement literature include both parametric and non-parametric. Berger & Humphrey (1997) and Thanassoulis, Boussofiane, & Dyson (1996) suggested that the choice for parametric frontier techniques is mostly depends on priori assumptions and specification of production technologies, random error for inefficiency scores and a random error. The nonparametric frontier techniques, nevertheless, do not require any priori assumption and random errors.

2.3 Data envelopment analysis

Data envelopment analysis (DEA) fits for performance measurement in single index value taking multiple inputs and multiple outputs. This method was pioneered by Charnes et al. (1978). DEA provides a frontier with efficient unit(s) of observation termed as decision-making unit(s) (DMUs). DEA simply allows calculating distance of other participated DMUs from the attained frontier. According to Charnes et al. (1978, p. 443), the DEA "gurus":

"In golfing terminology it is, so to speak, a measure of distance rather direction with respect to what has been (or might be) accomplished."

This non-parametric linear model gets attention to practitioners and researchers of all areas in short period of time (Charnes, Cooper, Lewin, & Seiford, 1994; Liu et al., 2013a, p. 3). DEA has quite a number of good features that turn it as a popular model in performance measurement. Golany & Storbeck (1999) listed that DEA has been becoming favorite statistical tool for the following reasons:

- Capacity of identifying inefficiency among the examined DMUs
- Ability to ranks DMUs according to the performance
- Evaluate management capacity among the DMUs
- Resource allocation using quantitative results

A few of softness in DEA application have also been reported by Dyson et al. (2001). Along with the pitfalls, Dyson et al. (2001) also guided possible solution to handle these conditions named as "protocol". These "pitfalls" make the exercise of DEA as puny to unwary operators. Till date, these plugs remain hazard points for the DEA users. The major pitfalls listed by them are listed below:

- Homogeneity assumptions. (i.e. non-homogeneous units, non-homogeneous environment and economics of scale due to inhomogeneity)
- Input/output sets. (more specifically- total number numbers, correlated factor, mixing indices and volume measures)
- Measurement issue. (specially- percentage value, normalized data, qualitative data, undesirable data, exogenous and constrained issues)
- Weights. (mainly- linearity assumption, zero value, relative values and interlinked data)
- Weight restrictions. (explicitly- justification of weight restriction and non-transferability of weight restriction, interpretation of results and efficiency nature, i.e. absolute vs. relative)

In addition to that, Angulo-Meza & Lins (2002) and (Adler & Yazhemsky, 2010) examined few latest technical conditions of DEA. These include poor discrimination of efficient units; giving variable weight is subjective that may lead to impractical results and extreme efficient units.

However, the growth of studying DEA in last thirty and some years is attention-grabbing (Liu et al., 2013a, 2013b). Literature review of these papers insinuate that among research in this area, the application of DEA is double than the model development itself. But, before 2000, research on methodological development of DEA was higher than its application (Liu et al., 2013b, p. 896). Moreover, they identified DEA application in 24 areas with minimum of 20 published articles in ISI web of science database. Starting from the first ever paper on DEA in 1978 (Charnes et al., 1978), research has been continuing without any sign of weakness (Liu et al., 2013a). A total number of over 4500 papers are found in ISI web of science data base until 2009

(Liu et al., 2013b). Liu et al. (2013a) expected that the number of total papers would be 12000 by the end of 2015. In such a prodigious possibility and speed of development, it assumes to be stiff for any person to track on the true advances in DEA literature. Till now, a number of review papers have been assured that even the review papers have not been able to cover all the aspects of DEA publications and research trends. In Table 2.2, a list of review papers are presented. This table articulates a major scope of more DEA research in almost every aspect of society and economy as a whole.

Table 2.2: Survey and bibliography studies on DEA literature

Reference	Duration	Papers
Liu et al. (2013a)	2009-2013	Over 4500
Liu et al. (2013b)	1978-2010	3136
Cooper, Seiford, Tone, & Zhu (2007)	1978-2003	3200
Gattoufi, Oral, Kumar, & Reisman (2004)	1978-2001	1797
Gattoufi, Oral, & Reisman (2004)	1978-1995	Over 800
Seiford (1997)	1978-1996	800
Seiford (1996)	1978-1995	Around 800
Seiford (1990)	1987-1990	51

2.3.1 Data envelopment analysis in banking

After seven years of DEA invention, the first research work in banking applying DEA was transcribed by Sherman & Gold (1985). From then on, bank efficiency study has turned out to be the most vast and interesting research areas within DEA application in last three decades and has rated as the top priority in DEA studies (Liu et al. (2013b)). Within the 2005-2009 period itself, banking studies using DEA remained top with 45.5% of total DEA publications. Paradi & Zhu (2013) reviewed 225 DEA papers from 1997 to 2010 and identified that both institutional and branch level study are dominating the research works covering 43 countries/regions of study interest. The trend of studying DEA in banking is expected to be in boost aftermath 2008-2009 world financial crunches (Paradi & Zhu, 2013). In the banking sector, theoretically the inputs and outputs of a bank do not have proportionate relationship. Hence, a slack-based DEA model assumes that inputs and outputs do not change proportionately. Moreover, Paradi & Zhu (2013) stated eight international journals have published special issues on DEA in banking from 1993 to 2009. They also strongly suggested that the trend of studying DEA in banking would be in boost aftermath of 2008-2009 world financial crunches. Table 2.3 spotlights the major survey studies in banking using DEA.

Table 2.3: Survey studies on DEA

Reference	Papers	Notes
Kaffash & Marra (2016)	620	Examined 620 DEA papers on financial institutions (banking, money market fund and insurance) from 1985 to 2016. They used citation network analysis. According to them, network model and slack-based model are the dominant methods of today's bank efficiency studies.
Paradi & Zhu (2013)	275	Analyzing 80 published papers on banking have examined which have focuses only on bank branch efficiency. Research duration was 1985-2011. Major categories of these studies based on productivity, deregulation, ownership, market structure, economic factors and international comparison.
Fethi & Pasiouras (2010)	196	Banks and bank branches were examined based on their method application: DEA and artificial intelligence.
Berger (2007)	100	Bank performance among major banking sectors worldwide was examined using frontier technology.
Berger & Humphrey (1997)	130	Studying performances of 130 financial institutions from 21 countries, Berger & Humphrey (1997) concluded that use of frontier techniques can create different results and hence careful consideration of model application and explanation of the obtained results from management perspective are required.

Sherman & Gold (1985) started DEA application in banking and claimed that the method explains more managerial aspects in financial performance than other models. Parkan (1987), then, examined efficiency on Canadian banks. The first two stage of contextual paper was written by Rangan, Grabowski, Aly, & Pasurka (1988). Later, three seminal papers examined the efficiency of banks over a period of time (Berg, Forsund, Hjalmarsson, & Suominen, 1993; Berg, Forsund, & Jansen, 1992; Elyasiani & Mehdian, 1990). Meanwhile, Thompson, Dharmapala, Humphrey, Taylor,

& Thrall (1996) introduced some assurance region (AR) in banking efficiency concept. Both, Berger & Humphrey (1997) and Thanassoulis (1999) geared up the progress of DEA-banking studies with their survey work and guidance for future research issues. The following Table 2.4 presents survey of bank efficiency literature worldwide.

Table 2.4: Literature on bank efficiency (worldwide survey)

Reference	Data year	Comparison study	Method	Sample banks	Major findings
Triki, Kouki, Dhaou, & Calice (2017)	2005-2010	Regulation, bank size and banks' risk levels.	DEA	Total 42 African countries, 269 commercial banks and 1306 observations.	Generally, entry restrictions help in progress in efficiency among the major African banks. However, the restrictions have most positive influence for high-risk banks and negatively influence low-risk banks. Small banks' efficiency decreases when transparency increases in a country.
Apergis & Polemis (2016)	1997-2011	Bank competition	DEA and bootstrap approach	Total 217 commercial banks from MENA with 3255 bank observation	Results reveal that increase in bank competition do not influence in cost efficiency increase.
Du & Sim (2016)	2002-2009	Pre M&A vs. post M&A	DEA	Total 96 bank observations from 120 banks of six emerging countries.	Among the emerging countries, M&A improves banks' efficiency only for the target banks.
Kamarudin et al. (2016)	2004-2011	Pre and post financial crisis, bank ownership	SBM-DEA, OLS, GLS	31 commercial banks	Economic growth and market concentration negatively affect bank efficiency. Ownership has limited influence on bank efficiency in Bangladesh.
Rouse & Tripe (2016)	2010-2014	Bank size	DEA	Balanced panel data of 120 bank observations from 6 banks from New Zealand	Authors strongly recommend for not examining technical efficiency alone. This could provide misleading information.

Table 2.4: Continued

Reference	Data year	Comparison study	Method	Sample banks	Major findings
Stewart, Matousek, & Nguyen (2016)	1999-2009	Bank size, bank ownership, bank branches and networks	DEA and Double bootstrap approach	Un paneled bank data of 48 Vietnamese banks	Bank size affects banks' efficiency. Large banks are found to be more efficient than small and medium sized banks. Considering ownership of banks, foreign banks are found more efficient than the state owned banks.
Shi & Zou (2016)	2011	Joint stock commercial banks vs. state owned banks.	Fuzzy SBM DEA and Super SBM DEA	Total 13 bank from China	Risk factors have varying degree of influence on bank efficiency. Risk factors have more influence on joint stock banks rather than state-owned Chinese banks.
Thi, Daly, & Akhter (2016)	2005-2012	Bank competition and market concentration among the 6 emerging countries	SFA	Total 212 commercial banks with 1685 observations	Bank efficiency receives positive influence from market concentration but negative influence from bank competition. Moreover, GDP and bank size has positive impact on increasing bank X-efficiency.
Wanke, Barros, & Emrouznejad (2015)	2003-2011	Fuzziness vs. randomness	Fuzzy DEA and Bootstrap truncated regression	Total 117 bank observations from 9 Mozambican banks.	During interpretation of results, fuzziness is more dominant than randomness. Missing value can also be effectively examined using fuzziness. Labor, capital and market share remain the most significant external variables for bank efficiency.

Table 2.4: Continued

Reference	Data year	Comparison study	Method	Sample banks	Major findings
Islam & Kassim (2015)	2009-2013	Islamic vs. conventional	DEA	25 commercial banks from Bangladesh	Islamic banks are lagging behind due to poor scale efficiency. For conventional banks, pure efficiency.
Wang, Huang, Wu, & Liu (2014)	2003-2011	Joint stock ve. State-owned commercial banks	Two stage network DEA	16 major Chinese commercial banks	Chinese banks' efficiency is up-warding. State owned banks' efficiency is much higher than joint stock banks.
Titko, Stankevičienė, & Lāce (2014)	2012	Variable selection model	DEA	15 commercial banks from Latvia	DEA results vary with choice of variables.
Matthews (2013)		risk management practice and risk management organizational metrics	Network DEA with 27 semi structured questionnaires	19 banks with 20 interviews	There is con constructive relationship between risk management practice and risk management organizational metrics.
Shyu & Chiang (2012)	2007-2008		Three stage DEA	123 branches from Taiwan	Branches that operate loan and have wealth management services have higher efficiency. Additionally, branches with higher deposits have also scored as most efficient branches.
Luo, Bi, & Liang (2012)		DEA, CVA, PLZ, PCA	DEA	14 Chinese commercial banks	DEA results have predominant influence from cash value addition and variable selection.
Avkiran (2011)	2007-2008	Bank ownership	Super efficiency with DEA	21 Chinese banks	Two financial ratios: profit after tax/total assets and return on average equity are found to be the most significant financial ratios.

Table 2.4: Continued

Reference	Data year	Comparison study	Method	Sample banks	Major findings
Chiu, Chen, & Bai (2011)	1998-2002		SBM DEA model with Malmquist index	43 Taiwanese banks	Loan quality is the most influential factors for bank efficiency
Staub, Souza, & Tabak (2010)	2000-2007	Bank size and bank nature	DEA	An unbalanced panel data of 127 bank year.	Most of the Brazilian banks are technical efficient rather allocative efficient. Bank activity and bank size are found to be the most efficient external factor on bank efficiency.
Thoraneenitiyan & Avkiran (2009)	1997-2001	bank restructuring and post-crisis	DEA, SFA	Bank numbers varied from 89 in 1998 to 66 in the year 2007 from six Asian countries	Though merger in local banks improve efficiency, overall market restructuring has no significant relationship with bank efficiency improvement.
Chiu, Jan, Shen, & Wang (2008)	2000-2008		Super efficiency model and Malmquist DEA	46 Taiwanese banks	Capital adequacy model influences bank efficiency scores more than others.
Cook, Hababou, & Liang (2005)	1992-1997	Bank ownership	DEA	10 Tunisian banks	Private banks are found to be more efficient than the state-owned banks.
Taylor, Thompson, Thrall, & Dharmapala (1997)	1981-1991		DEA	13 Mexican banks	Bank size and bank ownership have significant effect on bank efficiency.

Table 2.4 presents literature summary of DEA studies worldwide. Literally, the recent trends of two-stage DEA have been observed in key studies of Lo & Lu (2006), Luo (2003) and Giuffrida & Gravelle (2001). They separated bank operation into two sub segments namely profitability and marketability, which is known as the basic form of, network DEA model for bank efficiency. These developments in DEA-banking studies are mainly methodological and all related articles just varied in terms of industry specification, environment, or contextual settings.

2.3.2 Advanced DEA application in banking

2.3.2.1 Malmquist DEA

Among other techniques of productivity e.g. ratio (Farrington, 2000); Fisher index (Kuosmanen & Sipilainen, 2009); Tornqvist index (Diewert & Fox, 2010), Malmquist DEA index (MI) is the most often used method (Bassem, 2014; Liu et al., 2013a, 2013b). The three major benefits of using MI compared to Fisher and Tornqvist index are: i) MI does not require presumption of profit minimization or cost minimization, ii) no need for input/output prices, and iii) MI decomposes the results into efficiency changes (catching up) and technical changes (changes in the best practice). The imperative feature of MI is examining efficiency of a DMU using multiple inputs and outputs. Moreover, the capacity of comparing a DMU's efficiency between two consecutive periods makes MI as the most useful tool in efficiency measurement (Bassem, 2014; Coelli & Rao, 2005; Zofio, 2007).

2.3.2.2 Meta frontier DEA

The concept of meta-frontier was originated by Hayami (1969). He conceptualized that studying efficiency in comparison basis would become difficult since because different technological groups (i.e., local ownership vs. foreign ownership) have been enjoying different set of production factors. For instance, the local banks in Malaysia enjoy greater flexibility and government support to capture the market in lending public sector credit (Cook, 2009). However, a large section of bank efficiency literature uncovered higher level of efficiency among foreign banks is because of their expertise in risk adjustment and capitalization (Gardener, Molyneux, & Hoai, 2011; Jeon & Miller, 2005). Oh & Lee (2010) introduced three technological advancement in meta-frontier- i) contemporaneous distance function, ii) intertemporal distance function and iii) global distance function.

The applications of meta-frontier on bank efficiency was found to be scarce (Bos & Schmiedel, 2003), although efficiency has been the focus of much recent studies (Lin, Lee, & Chiu, 2009; Paradi & Zhu, 2013; Piot-Lepetit & Nzongang, 2014; Titko & Jureviciene, 2014; Wang, Lu, & Liu, 2014; Wanke & Barros, 2014). Since the inception of DEA in banking, most of the studies have only considered developed economies as the focus group. Paradi et al. (2011) specified top ten countries focused by the researchers worldwide and all of these countries are developed economies except India. Sufian et al. (2014) reported that only limited researches focused on banks of developing economy like Malaysia.

2.3.2.3 Network DEA (NDEA)

One of the most cited criticisms of traditional DEA is that DEA technique does not explore the internal structure of a DMU while calculating its efficiency (Avkiran, 2009; Kao, 2014; Wu, Yang, & Liang, 2006). Researchers refer the internal structure as "black-box". In DEA technique, only inputs and outputs are considered. But, what happens within the box was unknown until network DEA (NDEA) came into existence (Kao, 2014). NDEA explicates DEA technique to measure relative efficiency of a DMU by considering how inputs and outputs of that DMU are processed within the black box. The interdependence of inputs and outputs of a system is what been explored by NDEA which is unattainable with the traditional DEA. As the results of this, NDEA are found to be more meaningful and informative (Kao, 2014).

Application of NDEA for efficiency measurement has been applied in a wide range of research since Charnes et al. (1986). Kao (2014) published a comprehensive review article stating the growth, development and diversity of NDEA application over these years. According to him, the literature on NDEA has grown mostly on model development and real world problem solving.

Till today, NDEA models for efficiency measurement can be categorized into nine major groups based on distance measure and input-output nature of DEA. These are independent, system distance measure, process distance measure, factor distance measure, slacks-based measure, ratio-form system efficiency, ratio-form process efficiency, game theoretic, and value-based model (c.f. Kao (2014); Lozano (2016)). Based on DMUs' internal structure, NDEA models are classified in six major groups: basic two-stage (Ma, Liu, Zhou, Zhao, & Liu, 2014; Wang, Huang, et al., 2014), general two-stage (Akther, Fukuyama, & Weber, 2013; Wanke & Barros, 2014), series (Lozano, 2016; Matthews, 2013), parallel (Ebrahimnejad, Tavana, Lotfi, Shahverdi, & Yousefpour, 2014; Kwon & Lee, 2015), mixed (Lin & Chiu, 2013), hierarchical (Avkiran, 2015), and dynamic (Fukuyama & Weber, 2015). Literature survey on NDEA (**Error! Reference source not found.**) reveals that independent NDEA model is found o be the basic of most studies (Kao, 2014).

Table 2.5: Literature survey on application of Network DEA for bank efficiency

Reference	Inputs	Intermediate products	Desired outputs	Undesired outputs
Lozano (2016)	Operational costs, fixed assets, deposits	Personnel costs, other assets, interest expenses, number of branches	Non-interest income, interest earning	Non-performing loans
Avkiran (2015)	Personnel expenses, interest expenses, classified loans (t-1), proportion of non-performed referrals (t-1)	Referrals	Interest income, other income, commissions, operating income	classified loans, proportion of non-performed referrals
Kwon & Lee (2015)	Employee, equity, expenses	Loans, deposits, investment	profit	
Fukuyama & Weber (2015)	Non-performing loans (t-1), labor, capital, equity, carryover loans and securities	Deposits, raised fund	Loans, securities	non-performing loans (t)
Ebrahimnejad et al. (2014)	Capital, operational costs	Deposits	ROA, Fees income, interest income	Loan delinquencies
Huang, Chen, & Yin (2014)	Equity, personnel expenses, fixed assets	Deposits, short term funding	Other earning assets, gross loans	Classified loans
Ma et al. (2014)	Employees, assets, equity	revenues	Market value, EPS, ROE	
Wanke & Barros (2014)	Branches, employees	Admin expenses, personnel expenses	Assets, equity	
Fukuyama & Weber (2013)	Capital, labor	Liabilities	Loans, securities	Bad loans

Table 2.5: Continued

Reference	Inputs	Intermediate products	Desired outputs	Undesired outputs
Matthews (2013)	Fixed assets, operational costs	Personnel costs	Interest income	
Jalali Naini, Moini, & Jahangoshai Rezaee (2013)	Assets, employees	Operating income, deposits	Loans, returns	
Lin & Chiu (2013)	Equity, fixed assets, operating expenses, bad loans	Loan recovery, branches, deposits	Revenues, commission	
Akther et al. (2013)	Equity, physical capital, non-performing loans (t-1)	Deposits	Loans	Non-performing loans
Avkiran & McCrystal (2012)	Customer service, personnel costs, capital, training	No. of referrals	Transactions, referrals, sales	
Yang & Liu (2012)	Personnel costs, interest costs, operational costs	Deposits	Interest income, commissions	
Ashrafi & Jaafar (2011)	Labor costs, depreciation, personnel expenses	Total resources	Income, transactions	Receivables
Fukuyama & Matousek (2011)	Physical labor, equity, labor	Deposits	Loans, securities	
Fukuyama & Weber (2010)	Capital, labor, equity	Raised funds	Loans, investment, business activities	Non-performing loans
Zha & Liang (2010)	Number of employees, assets, equity	Revenue	Market value, ROE, EPS	

One criticism against independent NDEA model is its over simplicity (Kao, 2014) which allows other models to come into potential alternatives. According to Kao (2014), system distance measure, process distance measure, factor distance measure, ratio-form system efficiency and ratio-form process efficiency are the main stream NDEA models. However, the latest research interest are slacks-based measure, game theoretic, and value-based (Kao, 2014). Finally, the application of dynamic NDEA in bank efficiency is found to be limited (Avkiran, 2015; Kao, 2014). Kao (2014) critically evaluated literature on NDEA application and found that dynamic NDEA is rare in practice. He also suggests that while application of dynamic NDEA is available in efficiency literature, application of Malmquist index NDEA is not found.

2.4 Data and variables

In DEA calculation, the selection and measurement of input-output variables are crucially important. There are few preconditions regarding choice of variables in DEA. These are:

2.4.1 CAMEL for selecting variables

CAMEL is frequently used as on-site bank monitoring tool. CAMEL proposes on examining the overall condition of a bank, the core functional areas of bank operation are classified in five groups; capital adequacy (C), asset quality (A), management expertise (M), earnings strength (E) and liquidity (L). A new addition is sensitivity to market risk (S)-CAMELS. Sensitivity to market risk, in particular-interest rate risk, was not put into practice until 1997. Table 2.6 presents a summary of literature on CAMELS literature for selecting the widely used variables in CAMELS rating by the academics. In almost all instances, the variables that are used as proxy to CAMELS are expressed as a ratio.

Table 2.6: Literature summary of variable selection for CAMELS ratings

Group		Betz et al. (2014)	Maghyereh & Awartani (2014)	Wang et al. (2013)	Wang, Lu, & Lin (2012)	Poghosyan & Čihak (2011)	Doumpos & Zopounidis (2010)	Secme et al. (2009)	Zhao, Sinha, & Ge (2009)	Hays, De Lurgio, & Gilbert (2009)	Arena (2008)	Hirtle & Lopez (1999)	DeYoung, Flannery, Lang, & Sorescu (1998)	Cole & Gunther (1998)	Cole & Gunther (1995)
Capital adequacy	Total Regulatory Capital Ratio%	√	√	√	√		√	√			√	√	√		√
	Equity/total assets	√	√	√	√	√	√	√	√	√	√		√	√	√
Assets Quality	Loan Loss Res / Gross Loans					√	√	√	√		√	√		√	√
	Loan Loss Provision / Net Interest Rev	√	√	√				√	√						√
Management	Net Interest Margin	√	√	√	√	√	√	√	√					√	√
	Net Interest Revenue / Average Assets	√		√	√		√	√	√	√		√	√		√
Earning quality	Return On Assets (ROA)	√	√	√	√		√	√	√	√	√	√	√	√	√
	Return On Equity (ROE)	√	√		√	√	√		√						√
Liquidity	Net Loans / Tot Deposits & Borrowings				√		√	√		√					√
	Liquid Assets / Tot. Dep. & Borrowings	√	√			√	√	√	√	√	√		√		
Sensitivity	Rate Sensitive Assets/Rate Sensitive Liabilities	√													
	Growth Rate of Deposits										√				

These six broad categories of a bank's function are directed to depict the overall condition. It is not expected that CAMELS will detect the scope of profitability or reduce risk through its findings. The true achievement through CAMELS is to detect banks failure in advance. Supervisory authority provides ratings between scale 1 and scale 5. A high score represents higher regulatory concern for future problems[4]. Predicting banks failure using CAMEL became a common practice over the last three decades because of its ability to consider banks total functionality (Betz et al., 2014; Doumpos & Zopounidis, 2010; Erol, Hasan, Berna, & Gökçe, 2014; Secme et al., 2009; Thomson, 1991; Wang et al., 2013).

Regulators and supervisory body necessitate more specific information in the course of examining CAMELS. So, CAMELS information remains very confidential to both the management and state supervisory committee (Jin, Kanagaretnam, & Lobo, 2011). But, academics have been using few repetitive variables to present the stated areas of banks' total operation. However, there is hardly a big difference between the data that are publicly available and the data for on-site examination. Hence, the results from both the on-site and off-site examinations can predict the risk of banks' failure (Cole & Gunther, 1998; DeYoung et al., 1998).

In some cases, authors (e.g., Cole & Gunther (1998), Hirtle & Lopez (1999) and Barker & Holdsworth (1993)) argued that economic variables and the use of publicly available information to predict banks failure is more useful rather than relying on solely CAMELS. All of them specified the reason as "The CAMEL rating decays". This

[4] CAMEL rating ranges in whole numbers from 1 (strong performance and practices, posing the least supervisory concern) to 5 (critically deficient performance, posing the most supervisory concern). For more details, see OCC Bulletin 97-1, "Uniform Financial Institutions Rating System and Disclosure of Component Ratings," January 3, 1997.

is the most cited problems of CAMELS as the quality of CAMELS results in predicting banks failure decays very quickly.

The literature summary of the variable selection is shown in Table 2.7. Exploratory variables, mainly from the banks' balance sheets and income statements are selected to depict the financial characteristics of the banks. Cole & White (2012) found that CAMELS is capable to postulate banks' operation better and predict banks' failure in advance compared to the other sets of financial ratios.

Table 2.7: Definition of used variables

Approach	Inputs/Outputs	Definition
Production approach	Inputs	
	Interest expenses	Interest expenses to customer's deposits + other interest expenses
	Salary expenses	Personnel expenses
	Operating expenses	Personnel expenses + other operating expenses
	Output	
	Net income	((Operating profit + non-recurring income – non-recurring expenses + other non-operating incomes and expenses + equity-accounted profit/loss – changes in fair value of own debt) – tax expenses + profit/loss from discontinued operations)) – profit transfers to parent companies
Profitability approach	Inputs	
	Salary expenses	"Do"
	Interest expenses	"Do"
	outputs	
	Total deposits	(customer deposits-current + customer deposits-savings + customer deposits-term + deposits from banks + repos and cash collateral + other deposits and short-term borrowings)
	Total loans	(Residential mortgage loans + other mortgage loans + other customer and retail loans + corporate and consumer loans + other loans – reserve for impaired loans/ NPLs)
Intermediation approach	Inputs	
	Total capital	Total capital
	Total deposits	"Do"
	Salary expenses	"Do"
	Output	
	Total loans	"Do"
CAMEL approach	Inputs	
	Total Regulatory Capital Ratio	Tier 1 ratio
	Loan Loss Reserve to Gross Loans	(Loan Loss reserve/ (Loan Loss reserve + loan))*100
	Net Loans to Deposits & Short term Fund	(Net loans / deposits & short term fund)*100
	Outputs	
	Net Interest Margin	(Net interest revenue/ total earning assets)*100
	Return on Assets	(Net income/total asset) *100
	Return on Equity	(Net income/total equity) *100

The commonly used proxy variables for capital adequacy (C) are total regulatory capital ratio (%), Equity to total assets ratio, (Equity – Fixed assets) to total assets ratio and capital adequacy ratio (CAR). These ratios have separate meanings but equal understandings with the subject to the term "capital adequacy". Capital adequacy is an inverse to the concept of leverage. All of these ratios measure banks' capacity of meeting liabilities with comparison to total asset.

The oldest and widely used ratio of capital adequacy is "equity to total assets ratio". The concept underlying the ratio is, the higher the ratio, the less resilience the banks is to shocks from financial distress of the bank (e.g., an unexpected decline in the banks' asset value due to economic crisis, huge credit default in a particular year, etc). Unlike the un-weighted measures, some authors have used capital adequacy ratio with risk weighted asset as the measure of banks' capital adequacy (Cole & Gunther, 1998; Doumpos & Zopounidis, 2010; Maghyereh & Awartani, 2014) despite, some critics of using risk weighted ratios which indicate the attachment of dishonesty among the bankers (Blum, 2008).

About the second CAMEL covariate, asset quality (A) stands for additional clarification of the banks' asset. The definition of asset quality is complex and contain element from both quantitative and qualitative aspects- frequently reported by loan loss reserve, loan loss provisions and net charge off (NCO) of the banks' operation. Poghosyan & Čihak (2011) reported that 75% of his total sample was out of this information representing management intention of not letting the customers to know about their subjective estimations. While higher loan loss provision of NCO signals for a future distress in the bank's asset. In some other cases, managers purge bad debt through NCO and found that they were wrong and the client repaid the loans. In that case, the paid amount requires adjustment and in some other cases, it become negative. Both the regulators and stakeholders would expect a minimum level of these ratios.

The quality of management in operating banks' performance is denoted by the third covariate of CAMEL- management quality (M). In the earlier studies of banks performance evaluation, interest income and net interest margin ware the most frequently used indicator of management quality. As time goes, revenue diversification becomes banks' strongest capacity to divert interest rate risk. Nowadays, both interest income and non-interest income are used separately to determine managers' capacity in creating bank profit.

Next, the fourth covariate of CAMEL is the earning capacity of the banks. This character is by nature very sensitive to the stakeholders. Income compared to the equity (ROE) is the other frequently used tool. However, robustness improves if return to asset (ROA) is used instead of ROE. Some authors (e.g., Cole & Gunther (1995); Secme et al. (2009); Wang et al. (2013)) argued for using cost to income ratio as the measure of banks' earning quality. However, few authors proved this ratio indicates the managers' capacity within banks performance calculation (Arena, 2008; Maghyereh & Awartani, 2014). Between the two attributes, higher ratio would predict bank performance better during the study period.

Liquidity, the fifth covariate of CAMEL, is presented by the ratios concerning banks capacity to make the banks' immediate and short-term payments. The ratios would give negative impact on banks' profitability if the ratios are found to be very high which signifies that banks failed to properly operate their business. In counter effect, very low ratio indicates banks' disability in making its nearest payments. The sixth covariate of CAMEL is the sensitivity of market risk especially risks associated with interest rate. In the past literature, a number of methods have been used by the researchers, e.g. rate sensitive assets to rate sensitive liabilities, share of trading income (Betz et al., 2014), and growth rate of deposits (Arena, 2008).

2.4.2 Variables- inputs/outputs and approach selection

From the global perspective, Asian economy has been gaining significant attention over the last decades (Peng, Bhagat, & Chang, 2010). The Asian financial crisis in 1997 has hit the financial stability in this region. On the other hand, the financial crisis of 2008 has no significant effect on Asian economy (Soedarmono, Machrouh, & Tarazi, 2013). Sachs & Woo (2000) reasoned unfettered bank competition as the main cause for the 1997 crisis and the aftermath of 1997 crisis is an overall banking restructure and reform of corporate governance within these countries (Soedarmono, Machrouh, & Tarazi, 2011). Bank consolidation (e.g., merger and acquisition- M&A) and foreign direct investment (FDI) in Asian countries have scored significant upward conversions after the 1997 crises (Moshirian, 2008). Moreover, the status of corporate governance reforms has overcome the imprudent strategies (Soedarmono et al., 2011).

In the wave of financial crises, corporate governance in the banks has received steadfast attention due to associated corporate scandals (Erkens, Hung, & Matos, 2012). To be precise, the scandals are only one of the underlying structural reasons for which corporate governance has become a critical success factor: the government regulations and interventions, worldwide trend of privatization of the banking industry, the increased market competition, and the integration of capital market (Becht, Bolton, & Röell, 2003). Good corporate governance is assumed to mitigate the adverse possible effects of agency risk (Min & Smyth, 2014).

Prior literature has underlined a positive association of corporate governance with economic development. Claessens (2006) summarized the channels as a better option for external financing, lower cost of capital, higher firm value, optimal allocation of resources and stakeholders' acceptability. Since banks are the most influential partner of countries' economic growth and development (Levine, 1997), a higher level of corporate governance practices is expected in the banking sector. Polo (2007) revealed that the corporate governance of a bank is significantly different from the other nonfinancial firms because of their opaqueness and government regulation. Similarly, a recent study by Tan (2014) also found that corporate governance at banks are mostly for governance structure, government safety-nets, and opaqueness. Till date, three available bank approaches are found in literature (c.f. Table 2.8).

Table 2.8: Literature survey on variable and approach selection

Reference	Inputs/ Independent variables/ negative impact	Outputs/ Dependent variables/ positive impact	Method/ approach
Triki et al. (2017)	Deposits and short-term funding, fixed assets, total assets, interest expenses, non-interest expenses	Loans, net fees and commissions income, other earning assets	Intermediation
Apergis & Polemis (2016)	Fixed assets, personal expenses, deposits	Net loans	Production
Du & Sim (2016)	Fixed assets, operating expenses, interest expenses	Net interest income, operating income	Profitability
Kamarudin et al. (2016)	Deposits, labor, capital	Loans, investment	Intermediation
Rouse & Tripe (2016)	Branch number, equity	Interest earnings, non-lending assets	Production
Stewart et al. (2016)	Staff, purchase funds, deposits	Customer loans, other loans, securities	Intermediation
Shi & Zou (2016)	Deposit, fixed assets, operating expenses	Net credit, pretax profit	intermediation
Thi et al. (2016)	Deposits, labor, physical capital	Total assets	Intermediation
Wanke, Barros, & Emrouznejad (2015)	Total costs	Total deposits, income before tax, total credit	Production
Islam & Kassim (2015)	Total deposits, fixed asset, personnel expenses	Total loans, other earning assets, off-balance sheet items	Intermediation
Wang, Huang, et al. (2014)	Fixed assets, labor	Non-interest income, interest income, non-performing loans	Intermediation
Titko et al. (2014)	Deposits, balance due to credit institutions, equity, interest expenses, commission, staff expenses, admin expenses	Loans, securities, interest income, commission, operating profit, net interest margin	Intermediation and profitability
Shyu & Chiang (2012)	Operating staff, number of business personnel, branch office rent, operating expenses	Net fees income, interest income	Profitability
Chiu et al. (2011)	Total deposits, number of banks	Loans, investment	Intermediation

Table 2.8: Continued

Reference	Inputs/ Independent variables/ negative impact	Outputs/ Dependent variables/ positive impact	Method/ approach
Staub et al. (2010)	Fund, capital, labor	Investment Loans Deposits	Intermediation
Du & Sim (2016)	Fixed assets, total non-interest operating expense, and interest expense	Net interest income and other operating income	Production
Ghroubi & Abaoub (2016)	Physical capital, financial capital and labor	Total loans and total securities portfolio	Intermediation
Lin, Doan, & Doong (2016)	Interest expenses, non-interest expenses, personal expenses, total costs	Total loans, other earning assets, total deposits, liquid assets	Production
Thi et al. (2016)	Total asset	Fixed assets, total equity	Intermediation
Hasan & Kamil (2015)	Total deposits, total overhead expenses	Total earning assets	
Khan (2015)	Interest income, non-interest income	Interest expense, non-interest expense	Production
Salami & Adeyemi (2015)	Total deposits, capital	Total loans, income, total investments	Production
Sufian (2015)	Total deposits, capital, personnel expenses	Loans, investments, non-interest income,	Intermediation
Sufian & Habibullah (2015)	Total deposits, Labor	Total loans, investment	Intermediation
Lai, Ling, Eng, Cheng, & Ting (2015)	Cost saving ratio, liquidity ratio and leverage ration	Profitability ratio, market-based performance ratio	CAMEL
Muhmad & Hashim (2015)	All CAMEL ratios	ROA, Return on equity (ROE)	CAMEL
Sufian et al. (2014)	Deposits, labor	Loans, income	Intermediation
Ismail & Ab Rahim (2013)	Labor, capital, total deposits and short-term fundings.	Total loans, other earning assets and off-balance sheet items.	Production
Sufian & Habibullah (2013)	Total deposits, physical capital, personal expenses	Loans, investment, non-interest income	Intermediation
Ahmad & Rahman (2012)	Labor, capital, total deposits	Loans and advances, total income	Intermediation
Sufian & Habibullah (2012a)	Total deposits, capital, labor	Total loans, investment	Intermediation

Table 2.8: Continued

Reference	Inputs/ Independent variables/ negative impact	Outputs/ Dependent variables/ positive impact	Method/ approach
Abdul-Majid et al. (2011b)	Labor, deposits, and capital	Loans and total other earning assets	Intermediation
Abdul-Majid, Saal, & Battisti (2011a)	Labor, financial capital and physical capital	Loans and other earning assets	Intermediation
Fadzlan Sufian (2011c)	Labor, cost of capital, cost of funds	Total assets	Intermediation
Marimuthu & Arokiasamy (2011)	Fixed assets, deposits	Earning assets and loans	Intermediation
Abdul-Majid et al. (2010)	Total operating expenses, deposits and equity	Loans and other earning assets	Intermediation
Sufian (2010)	Deposits, labor, capital, internet expenses	Loans, investments, interest income and noninterest income	Intermediation
Sufian & Habibullah (2009)	Total deposits, capital and labor	Total loans, investments and non-interest income	Intermediation
Sufian (2009a)	Deposits, labor and capital	Loans and investments	Intermediation
Mokhtar, Abdullah, & Alhabshi (2008)	Total deposits, total overhead expenses	Total earning assets	Intermediation
Sufian (2007a)	Total deposits, capital, labor	Total loans, investment	Intermediation
Sufian (2007b)	Total deposits, labor and fixed assets	Total loans and income	Intermediation

Three bank efficiency measurement approaches have been identified based on three types of bank operations. First, the production approach pioneered by Benston (1965) commonly views a bank as a producer of bank services. This approach explicates both financial and non-financial activities of a bank. Secondly, Sealey & Lindley (1977) proposed intermediation approach that examines bank's capacity in transforming deposits into loans and advances. Intermediation approach examines how much progress or regress a bank has achieved in the ever-challenging environment by producing profit out of its inputs? Paradi & Zhu (2013) revealed that this approach examines bank's ability of "going concern"- a bank will function without the threat of liquidation for the likely future. Again, Fethi & Pasiouras (2010) found that major studies in bank DEA have used profitability model. The aptness of each approach is largely depend on a number of environmental issues and circumstances (Wagner & Shimshak, 2007). The selection of each of the variables has literature significance and has been used in previous studies (Paradi & Zhu, 2013). The mostly used input and output variables are listed in Table 2.9.

The current period of time, it is has been highlighted that a bank actually perform all tasks in stages that by applying only one efficiency measurement approach could give biased result depending on which approach is selected[5]. This might suggest that Malaysian banks scored differently for different approach to be undertaken i.e., either production, intermediation, or profitability. Earlier studies have also advocated the use of CAMELS in selecting input and output variables as suggested by contemporary findings. Having considered all the above literature, this research finds a literature gap in examining bank efficiency by using CAMEL along with above mentioned methodology.

Table 2.9: Selection of inputs and outputs for DEA

Production approach		Profitability approach		Intermediation approach	
Inputs	Outputs	Inputs	outputs	Inputs	Outputs
Interest expenses Salary expenses Operating expenses	Interest income Net income	Total Capital Salary expenses Interest expenses	Total deposits Total loans	Total capital Total deposits Salary expenses	Total loans

[5] Published in ESCI (web of science ™) and Scopus indexed journal: Azad, M. A. K., Munisamy, S., Masum, A. K. M., Saona, P., & Wanke, P. (2016). Bank efficiency in Malaysia: a use of Malmquist meta-frontier analysis. Eurasian Business Review, 03 September 2016, 1-25.

2.5 Sources of bank inefficiency and contextual variables

With prior knowledge, DEA can only examine efficiency with *ex post* information (Berger & Humphrey, 1997; Bhatia, Basu, Mitra, & Dash, 2018; Charnes et al., 1978; Z. Chen, Matousek, & Wanke, 2018; Diallo, 2018; Doan, Lin, & Doong, 2018; Haque & Brown, 2017; Triki et al., 2017). Until the current period of time, Battese & Rao (2002) revealed that examining efficiency with DEA can produce better efficiency discrimination if *ex ante* information are considered by incorporating meta-frontier technology. Technically, in the present business environment, organizations continues to put more efforts to be unique in producing and delivering product or services to their target customers. While, product differentiation is getting popular, finding unique cultural environment among the organizations became unusual. The management and regulatory issues are not the same for all banks in Malaysia. There are several types of bank (i.e., local banks, foreign banks, conventional interest based banks, Islamic Shariah based banks etc.). Thus, examining Malaysian bank efficiency by considering their *ex ante* is more appropriate. In recent years, the research on what contributes to bank efficiency (or inefficiency) by taking into account the effect of other contextual variables have received considerable interest too. For instance studies on bank ownership (foreign versus local) and efficiency which has expanded. The existing theory implies that different efficiency rate between local and foreign banks owes to their own inherent characteristics. Berger, DeYoung, Genay, & Udell (2000) described the theory from the perspective of 'global advantage' and 'home field advantage'.

According to global advantage hypothesis, foreign banks could benefit from competitive advantage, use of advanced technology and available workforce in a host country. In contrast, home field advantage hypothesis describes that foreign banks would encounter control in their operation and production cost or only secure lower revenue for the same financial services compared to their local peers. With regards to “institutional framework” (where there is gap between home and host countries’ legal and regulatory frameworks), foreign banks would suffer if the host country’s institutional framework is poor than the home country (Lensink, Meesters, & Naaborg, 2008). As such, these earlier research identified mixed relationship between bank efficiency and bank ownership. In a survey of 130 articles on bank efficiency, Berger & Humphrey (1997) found that the foreign banks are less efficient in the developed economies. As argued, it is the market share of an economy and not the economic status that is served by the foreign banks. However, Jeon & Miller (2005), Fadzlan Sufian (2011a) and some recent studies revealed that foreign banks are found to be more efficient in the developing economies. This further support the anticipation of either positive or negative relationship exist between bank efficiency and ownership.

Apart from bank ownership, the association between macroeconomic variables and bank efficiency also found to be pertinent. Gross domestic product (GDP) and inflation are such examples of macroeconomic variables. An extensive literature have proven GDP to be the most influential one. Apparently, positive association between GDP and bank efficiency is also expected since better GDP is likely to results in more deposits and higher growth in loans (Dietrich & Wanzenried, 2014). Considering GDP as the measure of profit opportunity, Williams (2003), in his study, compared the influence of GDP on foreign and local banks. His findings revealed that banks tends to invest in countries with higher profit opportunities. His findings also tend to confirm foreign banks are reluctant to invest if their home country GDP is higher than the host country and that local banks are found to increase their investment in the host country. Their research supplemented the existing literature on GDP and bank efficiency. Table 2.10 presents the contextual variables.

Table 2.10: Contextual variables

Variable	Short name	Description	Expected relationship
Bank Specific variables			
Return on assets	ROA	ROA is used as a proxy for explaining Malaysian bank profitability.	+
Total deposits	MSHAR	Total deposits are considered as a proxy for market share of the banks. Prior literature knowledge has no concrete knowledge on impact of total deposits on bank efficiency.	+/_
Total assets	SIZE	Banks' total assets are considered as the proxy for bank size to capture possible economics of scale- cost advantage for bank size.	+
Total loans to total assets	LIQ	The ratio of total loans to total assets is considered as the proxy of banks liquidity which has proven positive relationship with bank efficiency.	+
Non-interest income to total assets	DIVERSI	Bank's income is a composite of income from different sources. Thus, the more the diversified income the less pressure on banks interest income and hence, the interest sensitivity reduces.	+/_
Book value of shareholders equity to total assets	CAPADQ	Total book value of shareholders equity to total assets is used as the proxy of capital adequacy. This variable is particularly an interest of regulators.	+
Non-interest expenses to total assets	MGTQ	Non-interest expenditure is associated with management quality. Hence the non-interest expenses to total assets are used as a proxy for management quality in this study.	_
Loan-loss provision to total assets	ASSQ	Is used as a proxy for asset quality.	_

Table 2.10: Continued

Variable	Short name	Description	Expected relationship
Macroeconomic variables			
Gross domestic product	GDP	Gross domestic product is used as the proxy for overall economic condition and thus, a positive relationship is expected.	+
GDP growth	GDPGTH	Is used as a proxy for future GDP estimation and opportunity in business expansion.	+
Inflation	INF	Inflation is used as a proxy for economic condition and a negative association with banks' efficiency is expected.	_
Bank Ownership			
Local banks	LB		_
Foreign banks	FB		+
Bank nature			
Islamic banks	IB		+
Conventional banks	CB		_

The other macroeconomic variable found to have impact on bank operation is inflation. With significant impact on the lending behavior of banks, inflation would also associated to total banking efficiency. Boyd, Levine, & Smith (2001) who examined the effect of inflation on bank efficiency, concluded that an increasing inflation rate can negatively influence banks' ability to allocate its resources. In contrast, Athanasoglou, Brissimis, & Delis (2008) have shown positive relationship between inflation rate and banks' profitability. Perry (1992) empirically proved that bank managers can ensure a higher profitability through a planned deposit creation and asset management by an accurate prediction of inflation which points out a critical issue regarding bank efficiency and inflation rate.

As discussed above, the aspects of banking system and operations (Islamic vs. conventional), bank ownership (foreign versus local) and macroeconomics variables have shown to significant impact on bank efficiency. Based on literature too, several other bank specific variables that could have similar effect and worth investigating are return on asset (ROA), total asset, total deposits, banks liquidity, asset quality, management quality, and capital adequacy (Sufian & Habibullah, 2010a).

2.6 Review on DEA-Bank efficiency studies in Malaysia

Studies on bank efficiency in Malaysia can be traced back to early 2000s and, in general, majority of these efficiency studies employed DEA as the measurement technique (Khan, Shamzaeffa, & Rabiul, 2017; Ng et al., 2014; Sufian, 2009a; Sufian et al., 2014). Literature on bank efficiency in Malaysia is not exhaustive, but there are still number of unsolved issues (c.f. Table 2.11). The following paragraphs draw attention to the major literature gaps in the existing literature on Malaysian bank efficiency.

Table 2.11: Efficiency in Malaysian banks- literature survey

Reference	Data year	Comparison study	Method	Sample banks
Du & Sim (2016)	2002-2009	M&A effect on 6 emerging countries	DEA	23
Ghroubi & Abaoub (2016)	2006 - 2012	Conventional vs. Islamic banks	SFA and meta-frontier analysis (MFA)	37
Lin et al. (2016)	2003-2012	Twelve Asian developing countries and foreign vs. local banks	SFA and DEA	Unbalanced panel data from 219 banks
Thi et al. (2016)	2005-2012	Six Asian countries	SFA	32
Sufian et al. (2016)	1999 - 2008	Foreign vs. local banks	Two-stage DEA: DEA and Simar & Wilson's bootstrap regression	Unbalanced panel data ranging from 22 to 33
Chan, Koh, Zainir, & Yong (2015)	1998–2012	ASEAN-5	Two-stage: Slack-Based DEA and the sys-tem Generalized Method of Moments	Unbalanced panel data
Hasan & Kamil (2015)	2005 - 2010		SFA	
Khan (2015)	1999 - 2005		DEA	Unbalanced panel data from 26 to 32
Salami & Adeyemi (2015)	2002 - 2011		Malmquist DEA	5
Sufian (2015)	1999 - 2008	bank size, capitalization, and ownership	Two-stage DEA: DEA and Simar & Wilson's bootstrap regression	22
Sufian & Habibullah (2015)	2000 - 2007	Foreign vs. local banks	DEA	22

Table 2.11: Continued

Reference	Data year	Comparison study	Method	Sample banks
Lai et al. (2015)	1999 - 2010	Pre-merger and post-merger	DEA	9
Muhmad & Hashim (2015)	2008 – 2001	Foreign vs. local banks	Pooled Ordinary Least Squares	Unbalanced panel data from 28 to 35 banks
Sufian et al. (2014)	2006 - 2010	Foreign vs. local banks	DEA	17
Ismail & Ab Rahim (2013)	2006 - 2009	Conventional vs. Islamic	Malmquist DEA	17
Muda et al. (2013)	2007 - 2010	Foreign vs. local banks	Generalized Least Square (GLS)	16
Sufian & Habibullah (2013)	1996 - 2003	Pre-merger and post-merger	Malmquist DEA and OLS	10
Ahmad & Rahman (2012)	2003 - 2007	Conventional vs. Islamic	DEA	10
Sufian, Muhamad, Bany-Ariffin, Yahya, & Kamarudin (2012)	1995-1996 And 2002-2009	Pre-merger and post-merger	DEA	34
Sufian & Habibullah (2012a)	1995 - 2008	Pre-merger and post-merger	DEA and multivariate regression	Unbalanced panel data from 22 to 38 banks
Yahya, Muhammad, & Hadi (2012)	2006 - 2008	Conventional vs. Islamic banks	DEA	29
Abdul-Majid et al. (2011b)	1996 - 2002	Conventional vs. Islamic banks	Output distance function	33
Abdul-Majid et al. (2011a)	1996 - 2002	Full-fledged Islamic Banks vs. Islamic windows	DEA and SFA	33
Fadzlan Sufian (2011c)	1996 - 2008	Pre-merger vs. post-merger	DEA	11
Marimuthu & Arokiasamy (2011)	1998 - 2007		DEA	20
Abdul-Majid et al. (2010)	1996 - 2002	Conventional vs. Islamic banks	Output distance function	36

Table 2.11: Continued

Reference	Data year	Comparison study	Method	Sample banks
Sufian & Habibullah (2010b)	1999 - 2007		Generalized Method of Moment	Unbalanced panel data of 213 bank year
Fadzlan Sufian (2011)	1995 - 1999	Pre- and post-economic crisis	DEA	Unbalanced panel data of 171 bank year
Sufian (2010)	1997 - 2009	Pre- and post-economic crisis	DEA and Tobit regression	36
Sufian & Habibullah (2009)	1997 - 2003	Pre-merger and post-merger	Malmquist DEA	Unbalanced data of 191 bank year
Sufian (2009b)	2000 - 2004	Foreign vs. local banks	Regression	34
Sufian (2009a)	1995 - 1999	Pre- and post-economic crisis	DEA and Tobit regression	Unbalanced data of 171 bank year
Kamarudin, Safab, & Mohd (2008)	1998 - 2004	Foreign vs. local banks (Islamic full vs. Islamic window banks)	DEA	11
Mokhtar et al. (2008)	1997 - 2003	Full-fledged Islamic banks, Islamic windows and conventional banks	DEA	288 panel data (20 Islamic windows, 2 full-fledged and 20 conventional banks)
Sufian (2007a)	1997 - 2003	Pre-merger vs. post-merger	DEA	7 merger cases
Sufian (2007b)	2003 - 2004	Full-fledged Islamic banks, Islamic windows and conventional banks	Malmquist DEA	Domestic Islamic windows 9, full-fledged domestic Islamic banks 2 and 4 foreign banks with Islamic window service

Table 2.11: Continued

Reference	Data year	Comparison study	Method	Sample banks
Sufian & Majid (2007)	2002 - 2003	Pre- and post-economic crisis	DEA	9
Matthews & Ismail (2006)	1994 - 2000	Foreign vs. local banks	Malmquist DEA	32
Mokhtar, Abdullah, & Al-Habshi (2006)	1997 - 2003	Full-fledged Islamic banks, Islamic windows and conventional banks	SFA	42
Omar, Rahman, Yusof, Majid, & Rasid (2006)	2000 - 2004		Malmquist DEA	11
Sufian (2005)	1998 - 2003		Malmquist DEA	10
Krishnasamy, Ridzwa, & Perumal (2004)	2000 - 2001		Malmquist DEA	10
Karim (2001)	1989 - 1996	ASEAN countries	Translog stochastic cost frontier	31

Table 2.11 critically examines and summarizes the literature gap in DEA methodology selection. The discussion on literature gap on methodology selection compares the existing methodologies which have chosen by researchers. As it appears, only the common DEA, SFA and Malmquist DEA methodologies are pioneers among the selected 49 Malaysian bank efficiency literature except Pooled Ordinary Least Squares (Muhmad & Hashim, 2015), Generalized Least Square (Muda et al., 2013), Output distance function (Abdul-Majid et al., 2010, 2011b), Generalized Method of Moment (Sufian, 2010) and Translog stochastic cost frontier (Karim, 2001). However, all of these studies have comparatively studied bank efficiency considering heterogeneity: bank origin (foreign vs. local banks) and bank nature (conventional vs. Islamic banks).

Thus far, as my knowledge goes, only one research has accounted for examining bank heterogeneity using meta-frontier though SFA was used as a benchmarking technology[6]. Though it is established from the Table 2.11 that Malaysian banking sector composites with different categories of banks i.e., Islamic bank, conventional bank, foreign bank, and local banks c.f., Khiyar (2012). Thus, Malaysian bank efficiency literature has a clearly a gap on using meta-frontier DEA for correctly examining bank heterogeneity using both bank nature and bank origin. Moreover, a recent trend for using network DEA (c.f. Table 2.11) is also completely missing among the Malaysian bank efficiency studies.

This literature survey, thus, urges for a comprehensive Malaysian bank efficiency study using all a) slack based measure of benchmarking, b) meta-frontier DEA, and most importantly c) network DEA to reveal the most accurate and robust dispersion in benchmarking scores among bank efficiency in Malaysian context. This research innovates both in terms of data sample and data year. Malaysian banks have not suffered substantially from the effect of global financial crisis in 2008 though have adversely troubled from 1997 financial crisis (Cook, 2008).

This literature survey reveals that a good number of comparison studies have tested effect of 2008 crisis on Malaysian bank efficiency. Note that, most of the recent publications have examined Malaysian bank efficiency using old dataset ranging from (1999-2012) (c.f. Table 2.11). Again, most of these studies have used relatively small sample of banks (5-32) while the total population of bank is now 43. Among the cited

[6] Published in ESCI (web of science ™) and Scopus indexed journal: Azad, M. A. K., Munisamy, S., Masum, A. K. M., Saona, P., & Wanke, P. (2016). Bank efficiency in Malaysia: a use of malmquist meta-frontier analysis. Eurasian Business Review, 03 September 2016, 1-25.

studies, only one article[7] has examined Malaysian bank efficiency using complete population, i.e. 43 banks though their methodology for benchmarking was dynamic slacks approach. Hence, an up to date data year ranging from 2009-2015 has been selected for examining bank efficiency of all 43 commercial banks in Malaysia.

This is obvious when taking into consideration changes in the Malaysian banking systems and operation. Changes in the landscape of Malaysian banking scenery is pertinent following the restructuring process which took place in the Malaysian banking sector. The restructuring process involves major mergers and acquisitions among the existing banks, other regulatory actions following the Asian financial crisis in 1997-1998 (Huang (2014), successful introduction of dual full financial systems-conventional and Islamic banks took place during the financial sector master plan (FSMP) and the existence of foreign-owned banks in Malaysia has been continuing for quite a long time. Currently, Malaysian banking sector consists of 27 conventional banks and 16 Islamic banks (BNM, 2016). In the form of ownership structure, Malaysia has 18 local- and 25 foreign-owned commercial banks operating in the country.

2.7 Summary

This chapter critically reviews the evolution of bank efficiency measurement in the global and Malaysian context. It can be concluded that, the importance of bank efficiency as performance measurement is irrefutable. Past review over last couples of decades in this chapter reveals a gap in existing literature lies on the fact that there is need for continuous understanding of the current nature of bank operational systems.

[7] Published in SCI (web of science TM) indexed journal: indexed journal: Wanke, P., Azad, M. A. K., & Barros, C. P. (2016). Financial distress and the Malaysian dual baking system: A dynamic slacks approach. Journal of Banking & Finance, 66, 1-18.

A number of literature gaps has been explored in the above discussion. Some major highlighting literature gaps are: firstly, to the best of our knowledge, literally no study has combined meta-frontier DEA with double bootstrap regression in second stage to examine bank efficiency in Malaysian settings. Secondly, empirical evidence on conventional bank efficiency among the developed economies are saturated. Therefore, this study will fill the gap by examining comparative performance between 1) Islamic vs. conventional banks and 2) foreign vs. local banks in the context of developing economies like Malaysia.

Narrowing down the literature of NDEA application only on bank efficiency, an updated literature survey as shown in Table 2.5 has revealed that NDEA applications on bank efficiency were limited to a few models and structures only among others, researchers have examined bank efficiency using NDEAā to explore the internal process of banking system. Despite of examining banks' core function, some research explore further on customer service or market performance (Avkiran & McCrystal, 2012). Table 2.9 outlines the variable and approach selection of DEA techniques based on the background of bank under study. However, there is no indication for any pattern in selecting inputs and outputs for describing bank efficiency. Besides, there is not homogeneity of selecting the intermediate variables. By referring to the earlier discussions (sub-section 2.4.2) on bank measurement approaches (i.e., production, profitability and intermediation), a similar approach on identifying inputs and outputs of each node or sub-process is proposed. Thus, error in the identification and selection of input and output variables could lead to, biased approaches hence providing misleading results[8].

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[8] Published in ESCI (web of science TM) and Scopus indexed journal: Azad, M. A. K., Munisamy, S., Masum, A. K. M., Saona, P., & Wanke, P. (2016). Bank efficiency in Malaysia: a use of Malmquist meta-frontier analysis. Eurasian Business Review, 03 September 2016, 1-25.

Table 2.5 also presents a clear literature gap of using undesirable output in NDEA applications. To the best of my knowledge, the first use of bad output in NDEA model was done by Kordrostami & Amirteimoori (2005). In all these days, only a limited number of studies have found compiling NDEA with bad outputs. Among those, Lozano (2016) applied NDEA along with bad outputs for examining bank efficiency using data set provided on Matthews (2013) and Ebrahimnejad et al. (2014). His proposed model of slack-based NDEA with bad outputs produced unbiased and meaningful efficiency results. Relating to this, application of slack based NDEA is also found to be limited in bank NDEA applications (Cook, Hababou, & Tuenter, 2000; Kao, 2014; Lozano, 2016). The uses and benefits of slack based model is has been described in earlier section (best to mention exactly which section) of this chapter.

At this stage, a comprehensive understanding on the background of the bank, in particular, Malaysian banks, for this study is crucial in selecting the input-output variables comprising the "black box" of particular bank, hence, the most appropriate approach in studying the efficiency of these banks. The next chapter explores more on the details of DEA on methodology to reveal the most appropriate and robust approach in examining the level of efficiency among the selected banks in Malaysia.

CHAPTER 3: THEORETICAL REVIEW ON DEA TECHNIQUE

3.1 Introduction

This chapter critically examines the properties of efficiency measurement techniques with special focus to bank efficiency models. This chapter also compares parametric and non-parametric methods. Among the non-parametric methods of efficiency measurement techniques, data envelopment analysis (DEA) is elaborately discussed. This chapter also explicates the rationale of proposing an adaptive network DEA model in order to fill the methodological gap in examining bank efficiency.

3.2 Overview of production economics

In a general production possibility function[9] N types of different inputs (i.e., deposits, staffs, etc.) are presented as $X=(X_1, X_2, X_3 \ldots, X_N)$ into a N×1 vector. Output is denoted with Y. Now, it is desirable that inputs and outputs are in control and other (i.e., recession, GDP, depositor's interest etc.) uncontrollable inputs/outputs will consider into account in later discussion. The technological production function of this bank can be shown in following equation.

$$\mathrm{P(x)} = f(X) \qquad \textbf{3-1}$$

According to Chambers (1988), some of the inherent properties of equation 3-1 are:

Non-negativity: The value is a real, nonnegative and finite number.

Weak essentiality: At least one input is required to produce positive output.

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[9] Usually textbooks refer input-output relationship and call this as production function. In efficiency measurement literature, this is commonly termed as production possibilities frontier. These two terms can be used interchangeably.

Monotonicity: Also known as non-decreasing in X. This means, an increase of X will never decrease Y.

Concave in X: The vector of X^0 and X^1 equals to linear combination of $f(X^0)$ and $f(X^1)$.

The above properties are not universal or exhaustive in nature. For instance, if all considered inputs become essential for a production function, the weak essentiality assumption may change into stronger assumption. Again, if too many inputs are in the place, the monotonicity assumption may also be relaxed. Figure 3.1 presents a simple production function using single input and single output.

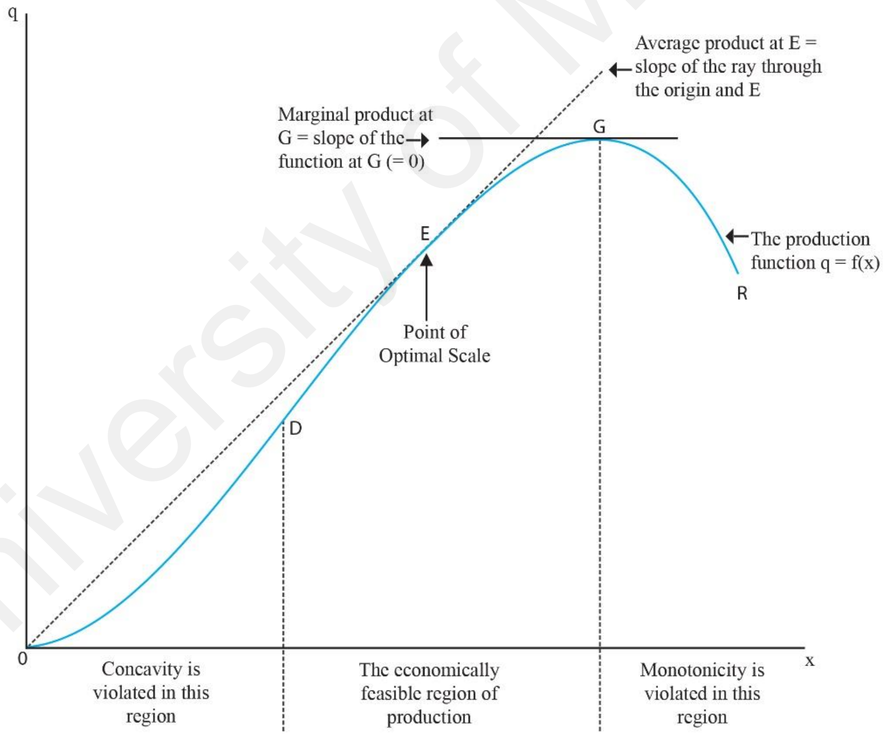

Figure 3.1: Single input-output production function

Region OD violates the concavity property as discussed earlier. It also violates monotonicity property in region GR. The region in DG is consistent with our properties and hence known as economically feasible region. The point E is average production or optimal scale.

3.3 Concept of efficiency

The economic definition of the term “efficiency” refers the capacity of a system (for example a bank) to produce maximum outputs from the given inputs. It is assumed that efficiency of the system will increase if the level of output increases without additional input or the same level of output produces using fewer inputs. The concept of efficiency is important for banking industry. Proper functioning of banking sector ensures long-term sustainability and economic development. Hence, examining bank efficiency allows managers, investors and regulators to take decision in advance. Nevertheless, proper understanding of efficiency terminology is also important. The followings are few common terminologies in efficiency literature.

Technical efficiency (or X-efficiency) deals with physical levels of input and output of a system (Bauer, Berger, Ferrier, & Humphrey, 1998). Thus, technical efficiency does not require any information of price. This approach is only applicable if a manager wishes to know whether the best practiced technology is used within the system. In this thesis, the primary objective would remain with technical efficiency and its implications. If a system became successful in maximizing output or minimizing the use of input, the system seems progressing in the term of efficiency. **Allocative efficiency**, on the other hand requires relative market price to calculate efficiency. Thus, allocative efficiency equals the maximum outputs of a system to the minimum cost for its technical efficient outputs (Thanassoulis, 2001). Next, **economic efficiency** (also known as overall efficiency) is much broader than earlier two concepts. A system is known to be economically efficient if it optimally choice its inputs and outputs to achieve economic goal- profit maximization or cost minimization. Conceptually, economic efficiency is lower than technical efficiency and higher than allocative efficiency scores. Finally, **scale efficiency** compares efficiency of a system with the best possible production scale and gives an idea of how much it can be improved (Kounetas & Tsekouras, 2007). Figure 3.2 graphically depicts the above concepts of technical, allocative and overall efficiency.

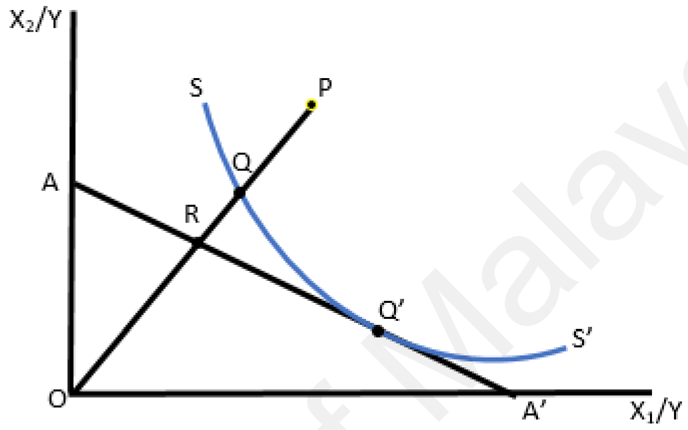

Figure 3.2: Technical efficiency, allocative efficiency and economic efficiency

According to Farrell (1957), if a system produces Y output with X1/Y and X2/Y inputs, the efficient frontier is characterized with SS'. By definition, any efficient point cannot be found under the frontier. If, efficiency point is defined by point P, technical efficiency of P is OQ/OP. That means, the examined system can reduce 1-(OQ/OP) proportion of X1 and X2 inputs without reducing the output.

Now, if it is assumed that AA' is the ratio of input prices, the economic cost minimization point is, therefore, point Q'. Since, the cost at point R is equivalent to point Q', the allocative efficiency may be presented as OR/OQ. Finally, the economic efficiency of the said system may describe as OR/OP which means the maximum cost reduction is possible from moving point P to point Q'.

3.4 Alternative performance measurement techniques

Researchers have classified the performance measurement approaches in a variety based on their research objectives and expected results. For example, Manzoni & Islam (2009) proposed a classification of alternative performance measurement techniques based on certainty (linear programming) and uncertainty (decision theory). They also have discussed the classifications based on ratio analysis, regression analysis, pure programming, deterministic statistical frontier and stochastic frontier approach.

3.4.1 Ratio analysis- the accounting perspective

In present times, both academics and practitioners have been developing non-financial measurement tools highlighting the absence of incomplete information. The motivational aspect which has been outlined as "driver" of the "responsibility center" (Otley, 2002). Since, ratio analysis can take care of any specific aspect of internal activity in many sub-headings; it is possible to guide every department of a firm with specific goal settings. The literature on operations management has identified that the traditional accounting of measuring firm performance is not adequate. Most significantly, accounting approach of measurement ignores firms' competitiveness (Hayes & Abernathy, 1980) and most likely stressing importance on short term analysis (Banks & Wheelwright, 1979). The major differences between ratio analysis and DEA are reviewed by Krivonozhko, Piskunov, & Lychev (2011). They provided both theoretical and empirical evidence that ratio analysis implies a one multidimensional data projection onto others. This particular feature in ratio analysis creates distortion in an assessment. Studying the Russian banks, Krivonozhko et al. (2011) argued that DEA has enabled the efficiency calculation to have an economic interpretation rather a simple numerical result obtained from a ratio analysis. Detailed discussion on ration analysis is presented in subsection 2.2.1 in Chapter 2.

3.4.2 Regression analysis

Another common technology of analyzing banks' input and output is regression analysis. Among the seminal papers on regression and bank performances, the mostly cited ones are Hensel (2003), Avkiran (1997) , Berger et al. (1993),Olsen & Lord (1979) and others. Since bank business is complex in nature and attributes of banks often come in bundle, accurate model of banks' production technology in not possible. Moreover, regression analysis can only test one input with multiple outputs or one output with multiple inputs as variables. Both the importance and limitations of regression analysis are critically examined in subsection 2.2.2 in Chapter 2.

3.4.3 Frontier analysis

The frontier method evaluates efficiency of a decision-making unit (DMU) with relation to the best practiced peers. Paradi & Zhu (2013, p. 63) strongly highlighted the contribution of frontier methods in management decision making capacity. They found that, managers are not only calculating the efficiency of a DMU with comparison to its peer groups but incorporating environmental factors as a signaling concept for the overall production system. A thorough discussion is made in subsection 2.2.3 in Chapter 2.

There are five popular frontier techniques available including both parametric and non-parametric techniques and have been dominating in the performance measurement literature. A brief of the major frontier techniques is described below.

3.5 Parametric vs. non-parametric approach

According to Pastor et al. (1997), the parametric methods of frontier estimation develops as the frontier functions are introduced with some hypotheses and based on properties. Berger & Humphrey (1997) as well as Thanassoulis et al. (1996) found that the choice of method selections among parametric frontier techniques is mostly dependent on three issues; i) priori assumptions and specification of production technologies, ii) random error for inefficiency scores, and iii) a random error term. Moreover, based on the error term, the techniques can be categorized. For a deterministic method, the error term is not used in the model. Alternatively, with the assumption of error term in a model, a stochastic method can be used.

3.5.1 Stochastic frontier approach

Stochastic frontier approach (SFA) was jointly introduced by Meeusen & Van den Broeck (1977) and Aigner, Lovell, & Schmidt (1977) through their projection in stochastic production function. The properties of a SFA are described well by Berger & Humphrey (1997, p. 7). These are;

- SFA posits a composed error model. Unlike the random error model, SFA follows an asymmetric (half normal) distribution. It is also assumed that the inefficiencies must follow a non-negative truncated distribution.
- Both the error term and the inefficiency scores are assumed orthogonal to its variables which are predetermined in the estimated equation.
- The results for inefficiency units are conditional mean or mode value which is subject to the composed error term.

3.5.2 Thick frontier approach

Similar to stochastic frontier approach, the thick frontier approach (TFA) is another parametric approach that requires predetermined functional formation and specification of error. However, unlike the SFA, TFA does not require assumptions on distribution in the efficiency scores. TFA also does not need any specification of random error. Bauer et al. (1998) examined the alternative frontier techniques for measuring performance of financial institutions. Using TFA into banks, they revealed that TFA could only provide efficiency estimation for the industry not for individual company. For instance, among a list of banks, TFA differentiate banks based on their asset size and average cost. Now, for each group, with the best performer bank a thick frontier is created.

Similarly, the lowest average cost for each group is assumed to be in thick frontier. Deviation from the expected performance values, the unit is assumed to have random error and this will vary within the upper and lower boundary of the performance classes. Similarly, the deviation between highest and lowest average cost class is inefficiency. Generally, TFA provides overall efficiency level estimating the highest and lowest classes. Therefore, it finds out the efficiency for industry level and not for all individual banks.

3.5.3 Distribution free approach

The distribution free approach (DFA) is a parametric approach which requires a functional form (Bauer et al., 1998). DFA distinguishes inefficiencies from random error by not assuming any specific shape on the distribution. Unlike TFA, DFA does not deviate the random error within a specified group. DFA also does not assume that deviation between performance groups is inefficiency. DFA imposes that there is constant core efficiency since the random error term tends to be average. A panel data is required in DFA estimation. So, only efficiency estimates over the entire sample period are provided.

3.5.4 Data Envelopment Analysis

In general, the non-parametric frontier technique does not require any priori assumption and random errors. According to Pastor et al. (1997), the observational criteria for non-parametric methods are based on programming techniques used to construct the frontier. Data envelopment analysis (DEA) is a non-parametric approach that fits for performance measurement in single index value taking multiple inputs and multiple outputs. This method was pioneered by Charnes et al. (1978). The growth of studying DEA in last thirty and some years is attention-grabbing (Liu et al., 2013a, 2013b).

Literature review of these papers educated that application of DEA is double than the model development among these research. But, before 2000, research on methodological development of DEA was higher than its application (Liu et al., 2013b, p. 896). Moreover, they identified DEA application in 24 areas with of minimum 20 published articles in ISI web of science database. Starting from the first ever paper on DEA in 1978 (Charnes et al., 1978), research has been continuing without any sign of weakness (Liu et al., 2013a). A total number of over 4500 papers are found in ISI web of science database until 2009 (Liu et al., 2013b). Liu et al. (2013a) expected that the number of total papers would be 12000 by the end of 2015. In such a prodigious possibility and speed of development, it assumes to be stiff for any person to track on the true advances in DEA literature. Till now, a number of review papers have assured that even the review papers have not been able to cover all the aspects of DEA publications and research trends.

A special DEA model that employs a smaller set of units when defining the efficiency frontier is Free Disposal Hull (FDH). In contrast to DEA's linear programming model, FDH is not restricted to convex technologies and assumes that no substitution is possible between observed input combination on a piecewise linear frontier. Unlike DEA that employs piecewise linear frontier, FDH uses a stepwise frontier which is formed by the intersection of lines drawn from the input combinations. Therefore, it ensures that efficiency evaluations are effected by only actually observed performances (Cooper et al., 2006) , Because the FDH frontier is either coincident with or interior to the DEA frontier, it will generate larger estimates of average efficiency than DEA (Tulkens, 1993).

The other non-parametric technique and a popular one is Artificial Neural Networks. Both DEA and NN are non-parametric methods in the sense that no assumptions are made concerning the functional form that links the inputs and outputs used to describe an operating process. In DEA, a set of weights is assessed for the inputs/outputs of each DMU in order to maximize its relative efficiency subject to the efficiency of the other DMUs in the study. Neural networks are also based on the estimation of sets of weights that link inputs with outputs. The ANN efficiency will be determined using the predicted values.

$$E_{rj}^{NNU} = \frac{Y_{rj}}{Y_{rj}^{Pre}}\ \forall r \qquad \textbf{3-2}$$

Here,

Y_{rj} is the observed output of DMUj

Y_{rj}^{Pre} is the predicted output obtained from ANN

Using equation 3-2 for efficiency estimates are not bounded to be less than or equal to unity. After empirical test between DEA and ANN with the same panel data, Athanassopoulos & Curram (1996) found that DEA and ANN give similar results in terms of efficiency scores and identification of inefficiencies among the observations. According to their findings, ANN often gives lower score than the DEA results though the benchmarking and ranking remain almost same for all DMUs. Theoretically, DEA has some advantage over ANN. These are:

- The assessment of efficiency is based on the development of a non-parametric extreme and not an average production function.
- For each inefficient activity unit DEA identifies a number of benchmark efficient activity units that are used as comparators.
- DEA can decompose efficiency scores into allocative, technical, congestion and scale efficiency.
- DEA results are based on global optimum values as the problem has a linear structure.
- DEA can examine efficiency variation and technological progress across activity units and over time (panel data).

In summary, the differences between parametric and non-parametric approaches can be seen in the following Table 3.1:

Table 3.1: Parametric vs. non-parametric approaches

	Parametric test	**Non-parametric test**
Characteristics	Follows production theory of economics	Follow management science or operations management
	Use econometric estimations for efficiency calculation	Use mathematical programming for said calculation
Strengths	Can estimate errors and random noises	Calculates efficiency with multiple inputs and outputs.
	Can test hypothesis	Does not require distributional information.
	Does not require return to scale assumption to calculate efficiency scores	Does not need functional information either.
Weaknesses	Need distributional specifications. For example, truncated, half-normal etc.	Does not account any error or random noise.
	Need functional specifications; i.e., Cob-Douglas, translog etc.	Need specification for return to scale (constant or variable)
		Cannot be used for hypothesis testing.

In this chapter, sub-sections from 3.4 to 3.5 can be summarized into the above Figure 3.3.

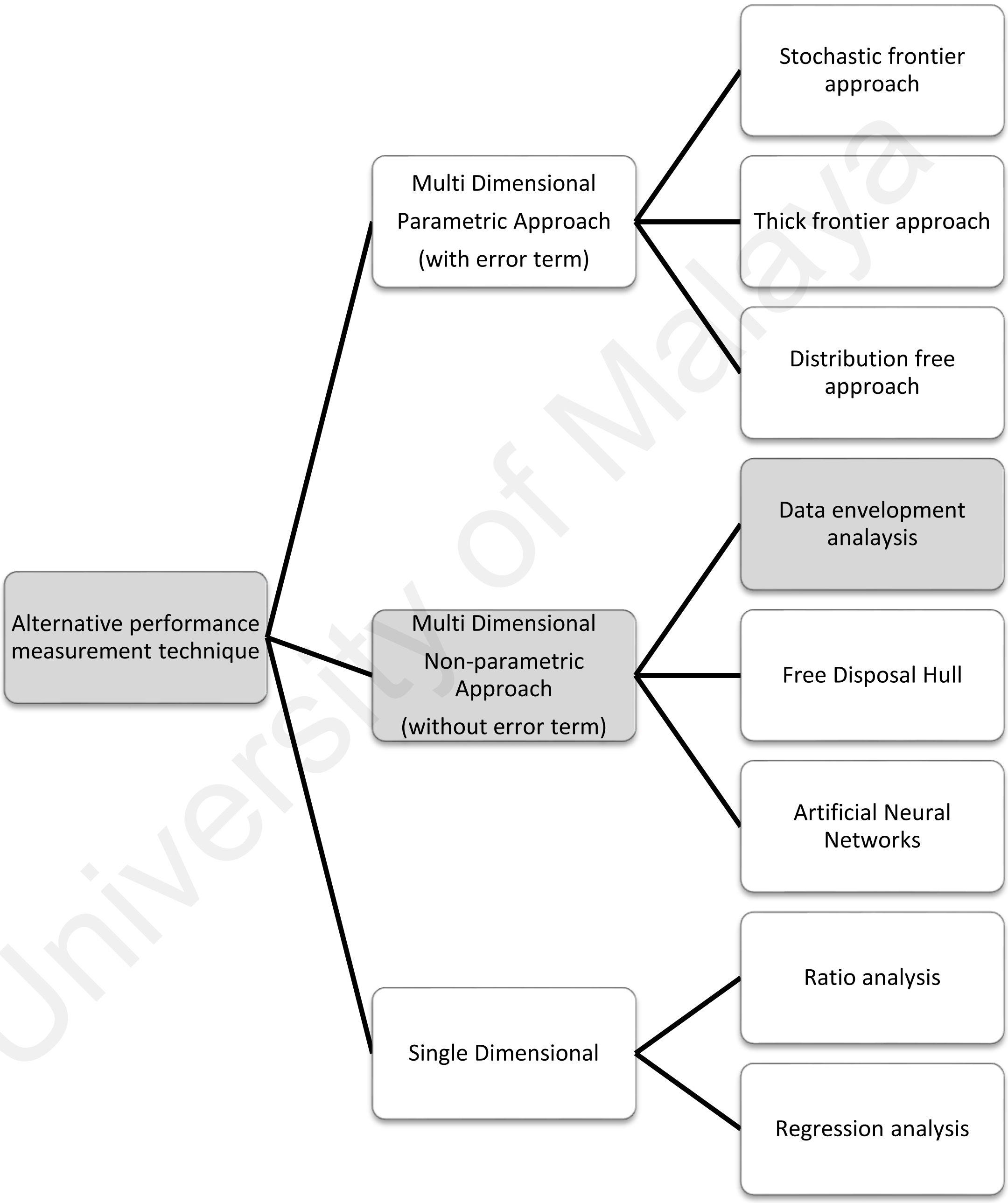

Figure 3.3: Alternative performance measurement technique

As shown in the diagram, the major categories of alternative performance techniques are shown. Since, bank operation is complex in nature, multidimensional measures are essential. Finally, data envelopment analysis can accommodate characteristics of banking operation better than other multidimensional performance measurement techniques as discussed in subsection 1.5.4 in this chapter and subsection 2.3 in chapter 2.

3.6 Data envelopment analysis: Theory, models and applications

After the brief discussion on different performance measurement techniques in section 3.4, the whole chapter will only focus on DEA measurement technique. The basis of DEA that its non-linearity and frontier concept distinguish it from the parametric nature of analysis. Figure 3.4 illustrates the difference between frontier (e.g., DEA) and parametric analyses (e.g., regression).

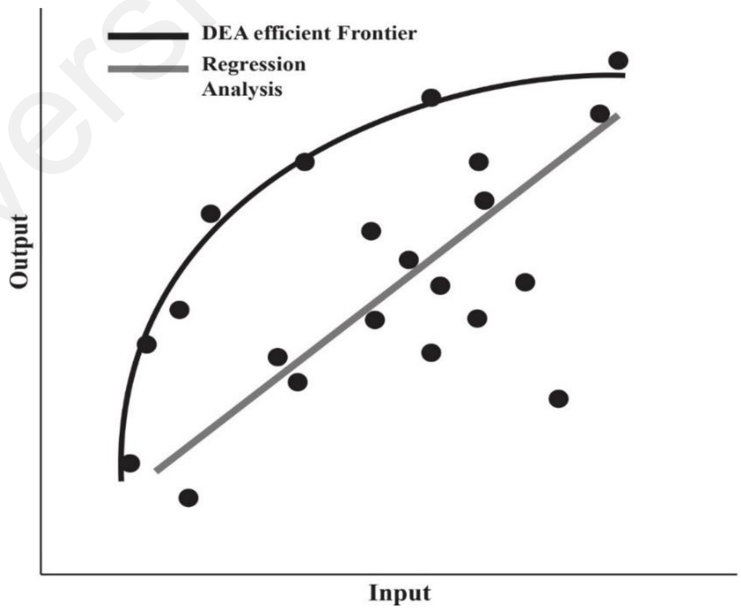

Figure 3.4: The basic concept of DEA

Unlike the regression analysis (parametric tests), DEA examines the maximal performances of selected DMUs by calculating relative performance of each DMU to all other DMUs. Thus, DEA covers all DMUs either on the best practiced frontier (the bold line) or below of it. Comparing with regression analysis, the most significant statistical difference between frontier and regression is the purpose of analysis. In one end, regression examines the average or central tendency of the selected DMUs. On the other end, frontier analysis (DEA) examines best performance frontier and calculates the deviation of other DMUs comparing to that frontier.

Considering banks as the DMUs, it is imperative to analyze the best performing banks and evaluate other banks' performance by comparing to the best ones. This can help to provide related information to all of its stakeholders (i.e., regulators, managers, stockholders, etc.) at a time. For instance, bank mangers of an inefficient DMU can target to improve by considering the performance of one or more DMUs within the frontier. This relative performance examination allows managers to determine how much inputs they can reduce or without reducing inputs, how much output they can target to produce. The regulators, too, can easily identify the best and less performing DMUs in a market. In addition, regulators can reexamine the performance of the best performer banks to emulate these performing banks' business inputs and outputs combination for their own future operations. For the less performing banks, regulators can closely examine the banks' limitations to reduce future distress. Nonetheless, the investors (stockholders) can easily compare the banks based on the performance to readjust their decision whenever necessary.

Another fundamental benefit of using DEA in bank performance issue is that the banks have multiple inputs and produce multiple outputs. DEA can easily calculate relative performance of the banks based on all of its input-output variables. Since DEA is a relative benchmarking tool, it calculates the best performance frontier based on the group of banks (DMUs) under study. Each time, a new bank is added, DEA will reexamines the frontier and recalculates efficiency scores for all the banks. The ability of using multiple inputs-outputs clearly distinguishes DEA from other one-dimensional techniques (ratio analysis and regression), where within the parametric approach requires predetermined functional form (regression) by defining dependent and independent variables. The technique also requires error terms backed with specific assumptions and other restrictions. But in DEA analysis, any specific non-performing or inefficient bank can target the frontier by projecting the best performing bank on the frontier or to a combination of reference banks. Below, Figure 3.5 illustrates how an inefficient bank can target the frontier to emulate the best performing DMUs.

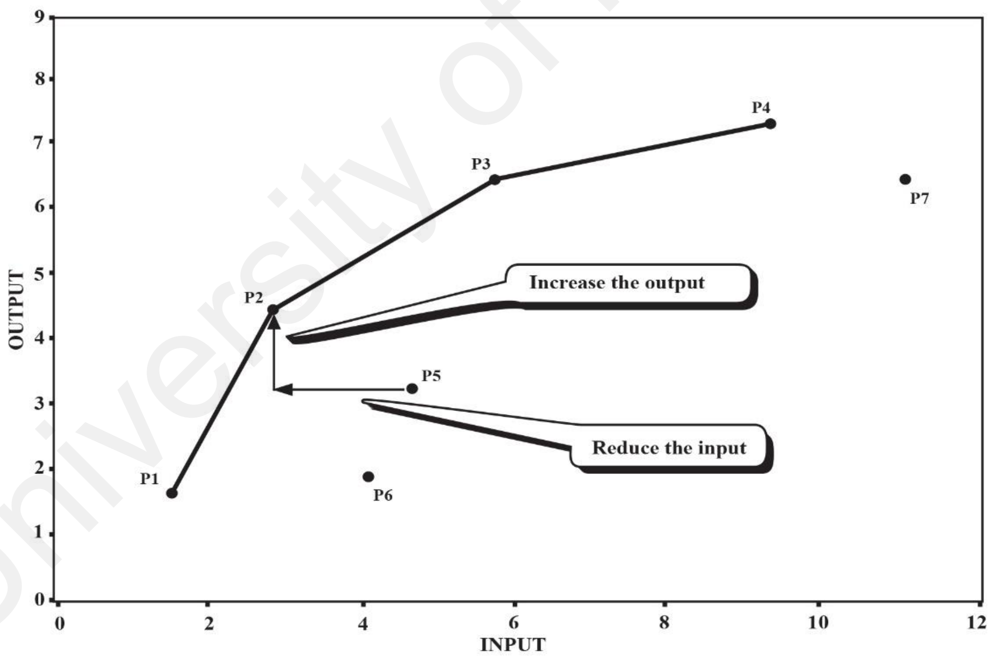

Figure 3.5: Targeting frontier by an inefficient DMU

Farrell (1957) defined overall efficiency as a product of technical efficiency and allocative efficiency. A system is considered to be technically efficient if it produces output with the lowest use of input. Again, to be an allocative efficient system, it must produce an output with a minimum cost. This breakthrough helped better understanding of efficiency and its practical use in benchmarking organization performance (Charnes et al., 1978). The major limitation of Farrell's efficiency measurement was that the number of input-output can only employ single input and single output.

The later effort was to include multiple inputs and multiple outputs in efficiency measurement technique which was initiated in Farrell & Fieldhouse (1962). Mathematically they initiated common weight to all inputs and outputs, and further compute the efficiency by dividing weighted sum of outputs by weighted sum of inputs.

$$Farrell\ and\ Fieldhouse's\ efficiency\ =\ \frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \qquad \textbf{3-3}$$

Where, X_{ij}= ith input to unit j

v_i= corresponding weight to ith input

Y_{rj}= rth output to unit j

u_r= corresponding weight to rth input

This model enables utilization of multiple inputs and outputs event though finding a common weight remain unfeasible and unpractical. Addressing this specific problem, Charnes et al. (1978) proposed a model that allows inputs and outputs to choose their own weights based on peer groups with an aim to maximize its efficiency. They developed a model examining the non-profitable organizations. Their proposed model is known as data envelopment analysis-DEA. DEA has specialty in analyzing complex business process involving multiple inputs and outputs. DEA is based on robust linear programming that examines efficiency in a relative term. Here, the most important assumption is that the DMUs are assumed to be operating in a similar environment (i.e., similar organizational system where the DEA technique is applied).

Unlike parametric techniques (i.e., regression analysis), DEA does not require pre-specification of functional form, meaning that the model can consist with its own frontier with the best practiced or best performed DMUs. This frontier is also known as production frontier that envelopes all underperformed DMUs; as such named after 'data envelopment analysis' technique. The efficient DMUs are joined in a set to construct frontier. So, the DMUs that are not in the frontier line are inefficient. The inefficiency scores are calculated using the distance from the closest frontier and benchmark accordingly. Managers, in light with the performance score, can strive to improve a DMU's performance by targeting/ referencing the closest efficient units. Figure 3.6 presents the basic model of DEA with single input and single output[10].

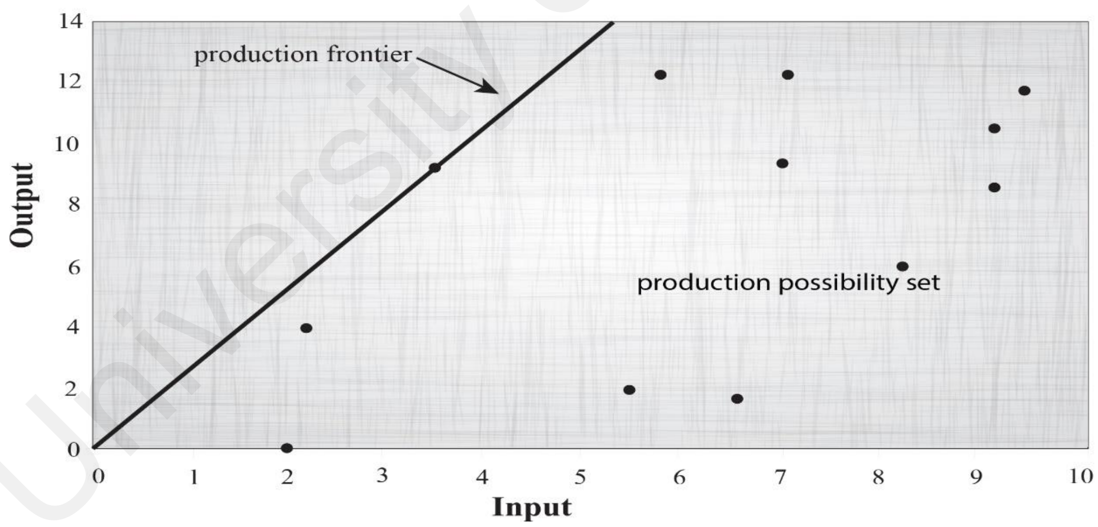

Figure 3.6: CCR model with single input and single output

[10] Graphically (usually 2 or 3 dimensions) it is not possible to present multiple inputs and multiple outputs in a figure. Hence, it is in practice that single input and single output is with the assumption that if everything remain constant.

According to Charnes et al. (1978), the production frontier constructs within the assumption of constant returns-to-scale (CRS) (Figure 3.6). This initial model is known as the CCR[11] model. Charnes et al. (1978) examined US public schools to facilitate the disadvantageous students; where the previous known techniques were unable to deal with unknown outputs. But, CCR solved the case by its inherent assumption that an increase to any input results in a proportionate and equal increase in output. Again, this might solve the problem but remain unfeasible for many business organizations. For instance, in bank business, an increase of deposits increases loan amount but not proportionately. Moreover, in some cases, banks simply increase deposits from equity only to increase market confidence. Thus, production function in CRS may not be always feasible. Finally, Banker, Charnes, & Cooper (1984) proposed a flexible frontier that allows variable returns-to-scale (VRS); the frontier is comprised with piecewise linear functions and it has convex characteristics (Figure 3.7). The model is known as BCC[12] model.

[11] The CCR model is named for their creators, Charnes, Cooper and Rhodes (CCR) (Charnes et al., 1978)

[12] The BCC model is named for their creators, Banker, Charnes, and Cooper (BCC) (Banker et al., 1984)

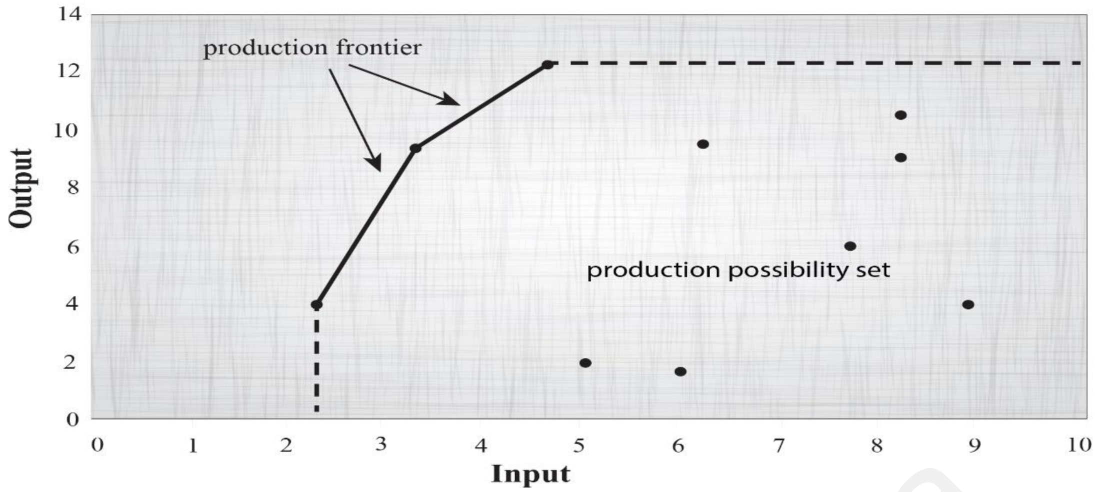

Figure 3.7: BCC model with single input and single output

3.6.1 Returns-to-scale

The concept of returns-to-scale was first incorporated into DEA in the BCC model. In the constant returns-to-scale, the slope of production frontier remains constant and hence, an increase in input increases the output proportionally. In contrast, the VRS model allows the slope to change in any of the following three states:

- Constant returns-to-scale (CRS)
- Increasing returns-to-scale (IRS): meaning that the average productivity of input-output ration is less than the marginal productivity.
- Decreasing returns-to-scale (DRS): when marginal productivity is less than average productivity of the slope. (see graphical discussions in Figure 3.8 below)

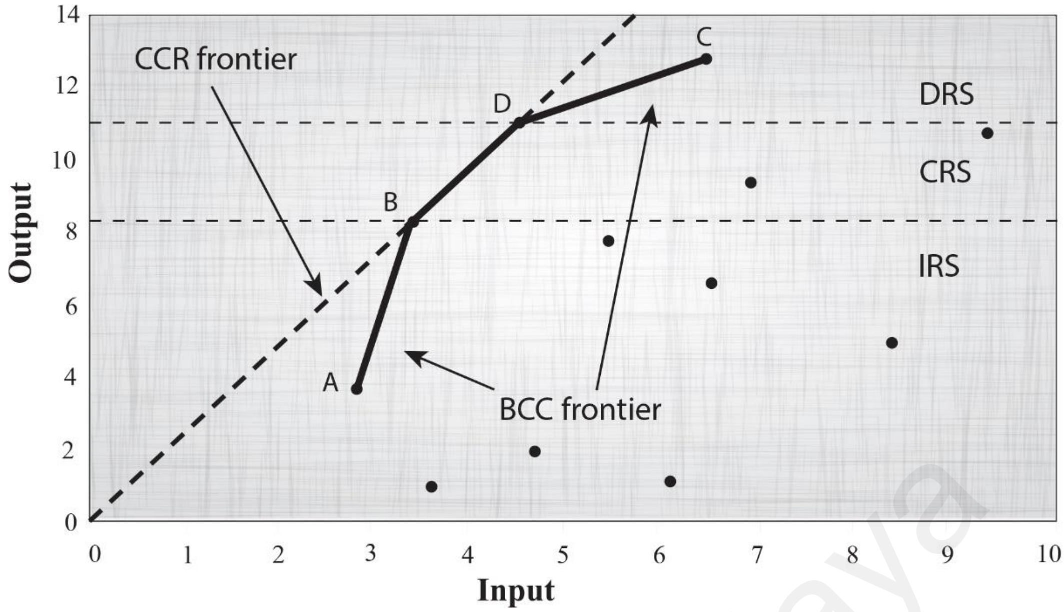

Figure 3.8: Returns-to-scale (IRS, DRS and CRS)

In Figure 3.8, the dotted line represents CCR frontier. The solid line represents BCC frontier. Here, DMU B and D are found in both CCR and BCC frontier. And, both of them are operating under CRS. DMU A is an efficient unit and operating with IRS whereas, DMU C is also an efficient unit that is operating with DRS. The discussions of returns-to-scale is presented here with rudimentary explanation. For additional understanding see Seiford & Zhu (1999).

3.6.2 The CCR model

The CCR model of efficiency calculation is the progression of earlier model (equation 3-1); this model allows DMUs to have their own set of weights. These weights (u,v) are added to the model and valid until the efficiency score (θ) for every DMU is within the range of 0 and 1.

$$Maximize\ \theta = \frac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{i=1}^{m} v_i X_{i0}} \qquad \textbf{3-4}$$

Subject to: $\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1$

For: $X_{ij} \geq 0$; i^th^ input to unit j

$v_i \geq 0$; Corresponding weight to i^th^ input

$Y_{rj} \geq 0$; r^th^ output to unit j

$u_r \geq 0$; corresponding weight to r^th^ input

In replacement of this CCR model, two linear programming forms can be used.

CCR multiplier (or primal) form

$$Maximize\ \theta = \sum_{r=1}^{s} u_r Y_{r0} \quad \textbf{3-5}$$

$$Subject\ to:$$

$$\sum_{r=1}^{s} u_r Y_{rj} \leq \sum_{i=1}^{m} v_i X_{ij}; j = 1, \dots, n$$

$$\sum_{i=1}^{m} v_i X_{i0} = 1$$

$$u_r, v_i \geq 0$$

CCR envelopment (or dual) form

$$Minimize\ \theta - \left[\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+\right] \quad \textbf{3-6}$$

$$Subject\ to:$$

$$\theta X_{i0} - \sum_{j=1}^{n} X_{ij}\lambda_j - S_i^- = 0$$

$$\sum_{j=1}^{n} Y_{rj}\lambda_j - S_r^+ = Y_{r0}$$

$$\lambda_j \geq 0;\ j = 1, \dots, n$$

$$S_i^- \geq 0; i = 1, \dots, m$$

$$S_r^+ \geq 0; r = 1, \dots, s$$

The primal Linear Program (LP) as shown in equation 3-5 above normalizes the constraints by setting the outputs as the objective function. The dual LP, as shown in equation 3-6, form is faster than the primal LP because of fewer constraints. It is formed by assigning a dual variable to each constraint. Here, θ represents the proportion of inputs required to produce the output of an efficient DMU. For example, if θ = 1, it is an efficient DMU. For θ=0.80, the DMU should be able to produce its outputs with just 80% using its inputs. In any efficiency calculation, the excess input or output shortage can be presented using input output slack; S_r^+ and S_i^- respectively. A DMU is supposed to be a fully efficient unit if θ=1 and both slacks are zero, meaning that there is no mix efficiency exists. Figure 3.9 represents the input minimization and output maximization of efficiency calculation.

For any DMU, if it has…	**the DMU is…**
$\theta = 1$ *and both slacks are zero,*	fully efficient.
$\theta = 1$ *and slacks are present,*	weakly efficient.
Efficiency score < 1 (input-oriented)	inefficient.
Efficiency score > 1 (output-oriented)	inefficient.

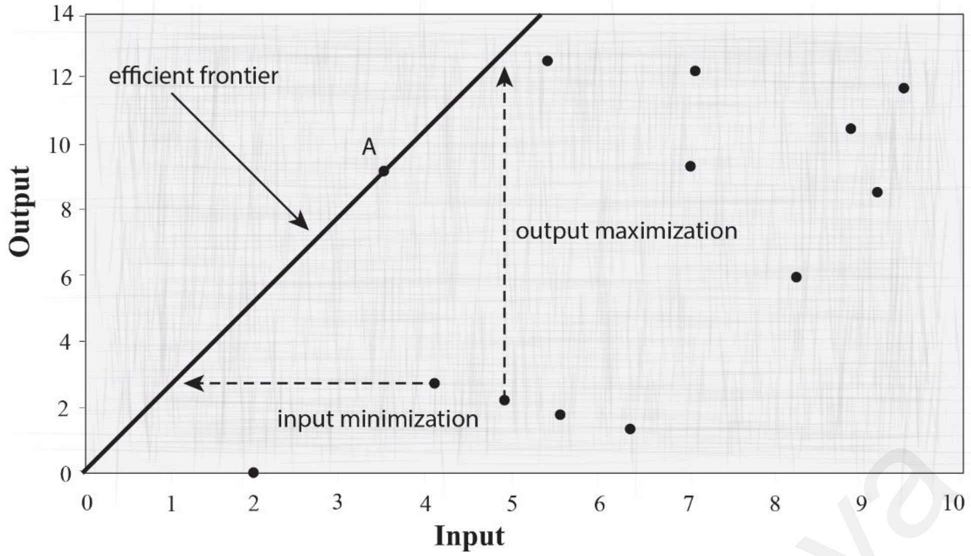

Figure 3.9: Efficiency with input-output orientation

Based on the orientation, CCR model is further classified in two groups: i) input oriented model; a DMU is not efficient if it is possible to decrease any input without decreasing output or without supplement to any other input; and ii) output oriented model; a DMU is not efficient if it is possible to increase output without increasing any input or without decreasing any output.

3.6.3 The BCC model

The BBC model allows a flexible construct for the DMUs and presents with piecewise linear function. Similar to CCR model, the BCC model reduces multiple input-output using a virtual input and a virtual output; as shown in equation 3-7 below.

$$Maximize\ \theta_{BCC} = \frac{\sum_{r=1}^{s} u_r Y_{r0} - \widetilde{u_0}}{\sum_{i=1}^{m} v_i X_{i0}} \quad \textbf{3-7}$$

$$Subject\ to: \frac{\sum_{r=1}^{s} u_r Y_{rj} - \widetilde{u_0}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1; j = 1, \dots, n$$

$$\theta_{BCC} = efficiency\ estimation\ under\ BCC\ model$$

$X_{ij} \geq 0$; i[th] input to unit j

$v_i \geq 0$; Corresponding weight to i[th] input

$Y_{rj} \geq 0$; r[th] output to unit j

$u_r \geq 0$; corresponding weight to r[th] input

$\widetilde{u_0}: unrestricted$

The new variable $\widetilde{u_0}$is included in order to estimate economics of scale. Where,

$\widetilde{u_0} = 0$, means θ_{BCC} is equivalent to the CCR model

$\widetilde{u_0} > 0$, means the DMU is operating under IRS

$\widetilde{u_0} < 0$, means the DMU is operating under DRS

As similar to CCR model, the BCC model can also be solved using two linear programming forms:

BCC multiplier (or primal) form

$$Maximize\ \theta_{BCC} = \sum_{r=1}^{s} u_r Y_{r0} - \widetilde{u_0} \qquad \textbf{3-8}$$

$$Subject\ to:$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} - \widetilde{u_0}\ ;\ j = 1, \dots, n$$

$$\sum_{i=1}^{m} v_i X_{i0} = 1$$

$$u_r, v_i \geq 0$$

$$\widetilde{u_0}: unrestricted$$

BCC envelopment (or dual) form

$$Minimize\ \theta_{BCC} - \left[\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+\right] \qquad \textbf{3-9}$$

$$Subject\ to:$$

$$\theta X_{i0} - \sum_{j=1}^{n} X_{ij}\lambda_j - S_i^- = 0$$

$$\sum_{j=1}^{n} Y_{rj}\lambda_j - S_r^+ = Y_{r0}$$

$$\sum_{j=1}^{n} \lambda_j = 1;\ j = 1, \dots, n$$

$$S_i^- \geq 0; i = 1, \dots, m$$

$$\boldsymbol{S_r^+ \geq 0; r = 1, \dots, s}$$

The basic difference between CCR and BCC dual (or envelopment) LPs is that the BCC model forces $\sum_{j=1}^{n} \lambda_j$ =0. Thus, the main constraint of CCR (i.e., DMUs must be scale efficient) is removed. Similar to Figure 3.8, in Figure 3.10 the input-output slacks are presented.

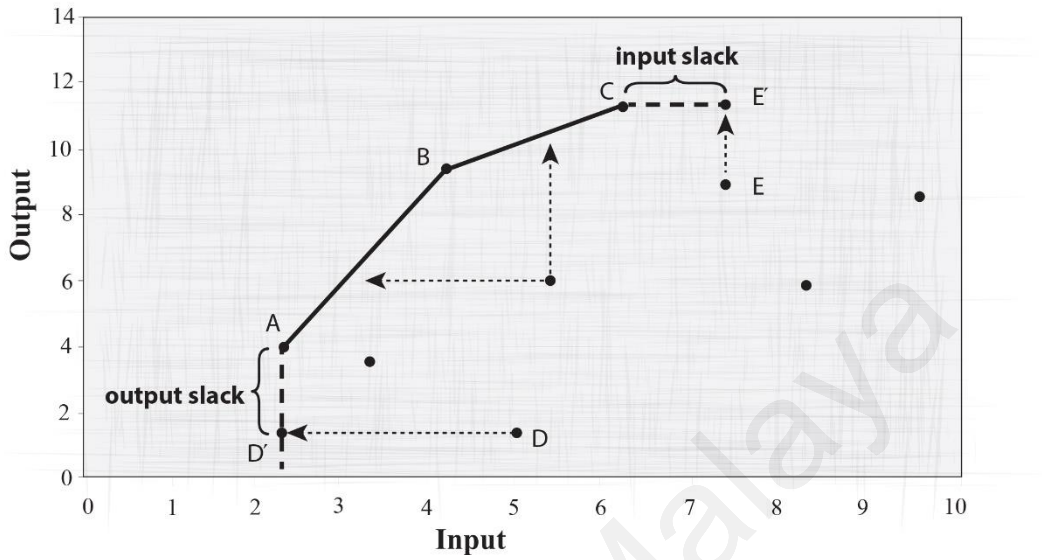

Figure 3.10: BCC model, input-output slack

3.7 Other progressive DEA models

There are various studies of more advanced DEA model which have evolving for the past few decades. These models have been developed to incorporate different nature of operating efficiency related-variables of the entity to be measured. Some of the most relevant to banking efficiency measurement studies are briefly discussed below.

3.7.1 Slack-based network DEA

A general slack based DEA model assumes that inputs and outputs do not change proportionately (Pastor et al., 1999; Tone, 2001). A study on slack based network DEA (NSBM-DEA) model was proposed by Tone & Tsutsui (2009) where the use of NSBM-DEA will decompose the overall efficiency into divisional efficiency (sub-process).

3.7.2 Malmquist Index

Among other techniques of productivity and efficiency measuring technique that involve more than a period of time, which have been applied, are ratio (Farrington, 2000); Fisher index (Kuosmanen & Sipilainen, 2009); Tornqvist index (Diewert & Fox, 2010), and Malmquist index (MI). Among all methods, Malmquist index (MI) is more often used (Bassem, 2014; Liu et al., 2013a, 2013b). The three major benefits of using MI comparing with Fisher and Tornqvist index are: i) MI does not require presumption of profit minimization or cost minimization, ii) does not require input/output prices, and iii) MI decomposes the results into efficiency changes (catching up- how a DMU has increased or decreased its efficiency comparing the last year) and technical changes (changes in the best practice). The imperative nature of MI examines the efficiency of a DMU using multiple inputs and outputs. Moreover, the capacity of comparing a DMU's efficiency between two consecutive periods makes MI as the most useful tool in efficiency measurement (Bassem, 2014; Coelli & Rao, 2005; Zofio, 2007).

3.7.3 Meta-frontier

The concept of meta-frontier was originated by Hayami (1969). He conceptualized that studying efficiency in comparison basis would become difficult due to different technological groups (i.e., local ownership vs. foreign ownership) which have been enjoying different set of production factors. More specific information on meta-production function is explained in a study by Binswanger & Ruttan (1978). They revealed that meta-production function envelops all sub functions and stands as the best efficient one assuming that all the groups have the access in meta-production technology (Battese & Rao, 2002). Oh & Lee (2010) introduced the three technologies in a global meta-frontier study- i) contemporaneous distance function, ii) inter-temporal distance function and iii) global distance function. With the help of above benchmark technologies, the component distance function is measured as required in meta-frontier technology. The concept of meta-frontier is explained in greater detail in the succeeding chapter.

Within the meta frontier analysis, technological gap ratio (TGR) was also introduced and empirically used by Battese et al. (2004). TGR identifies the gap between different technologies in sampling with the global technology set. The efficiency change ratio (EC) was named as pure technological catch-up by Chen & Yang (2011). A value larger than one implies the shrinkage of the technology gap (an increase in TGR). The technological change ratio (FC) is the meta-frontier shift relative to the Group-frontier shift. Chen & Yang (2011) named this as frontier catch-up. A value larger than 1 (FC>1) implies a larger progress in the meta-frontier than that in the Group-frontier. Finally, the Malmquist index is also known as technology gap ratio change (TGR) named by (Chen & Yang, 2011). This is also the product of Efficiency Change Ratio (EC) and Technological Change Ratio (FC).

3.8 Research direction of this study

Based on the empirical review of past bank efficiency measurement studies in Chapter 2 and the theoretical review on DEA methodology in this chapter, several conclusions can be put forth. Limitations in present efficiency models of banking efficiency measurement could lead banks operating in the long term financial problems. Moreover, the absence of statistical tools for analyzing banks heterogeneity and negligence of accurate identification of both internal and external factors in case of bank efficiency measurement will cause inaccurate flow of information to the banks' stakeholders.

The urge is made for a comprehensive understanding on the background of the bank industry particularly, the Malaysian banks. Bank heterogeneity (i.e., banks with different production technologies and different factors of production-land, labor, and capital) within the industry also need to be examined. . Additionally, there is crucial need for selecting the input-output variables comprising the “black box” of the particular banks which have been emphasized in the concluding part of chapter 2. Therefore, this study proposes bank efficiency measurement model based on a) slack based measure of benchmarking, b) meta-frontier DEA, and most importantly c) network DEA.

The following chapter explores three advanced DEA concepts; networked slack-based, Malmquist Indexed and meta frontier analysis and it can be incorporated in the proposed DEA model that fill the gap in establishing a more holistic approach to analyze a bank’s efficiency. The model not only measures the bank efficiency, but also combines managers’ insight and the banks specific condition, highlighting what a specific bank is considering as its performance for a complete scenario of bank efficiency, efficient benchmarking hence decision making is to be achieved.

CHAPTER 4: THE PROPOSED NETWORK DEA APPROACH

4.1 Introduction

This chapter fills the research gap which is found in the earlier Chapter 2 and Chapter 3. By summarizing previous chapters it is evident that, thus far, the approach undertaken by previous studies in measuring banking have overlooked the holistic view of a bank's operation and the nature of industry on which has been operating. This has resulted in only partial examination of the bank or group of banks' efficiency. To reveal bank total efficiency, the complete process of a bank's operation needs to be considered and examined holistically.

This chapter establishes a link between the earlier chapters and the following chapter. First, this chapter explicates the progressive application in the DEA techniques like slack-based networked DEA, Malmquist Index and meta-frontier analysis. Along with the explanation on the existing different approaches of bank efficiency examination, the deliberation of three progressive DEA approach proposes an adaptive network DEA efficiency examination approach which suits the Malaysian banking industry.

4.2 Slack Based Network DEA

The slack-based network DEA approach incorporates the concept of 'black box" in establishing the bank efficiency measurement model. The basic DEA application in bank merely calculates performance based on a "black-box" which receives input(s) and produces output(s). The concept of black-box in banking operation has been explained in detail under subsection 2.3.2.3 of Chapter 2. Färe & Grosskopf (2000) first delved into the application of network DEA specifically looking into what is actually happening within the "black-box".

For this purpose, a network DEA compartmentalize the black-box into several sub-processes (nodes) and link them with a number of intermediate variables within the systems. Within the black box, an intermediate variable is firstly treated as an output of a node or sub-process and would, then, be treated as an input to the following node or sub-process. Links from one node or sub-process to another forms a network which describes the nature of any DMU operation. Therefore, a network DEA calculates not only the DMU overall efficiency but separately compute the efficiency for each sub-process. Thus, the measurement of bank performance is no longer limited to a static conventional format.

So, the production possibility set of equation 3-1 of chapter 3 is updated as shown in equation 4-1 as shown below.

$$P(x) = \{(X^k, Y^k, Z^{(k,h)})\} \qquad \textbf{4-1}$$

Subject to;

$$X^k \geq \sum_{j=1}^{n} X_j^k \lambda_j^k \qquad (k = 1, \dots \dots, K),$$

$$Y^k \geq \sum_{j=1}^{n} Y_j^k \lambda_j^k \qquad (k = 1, \dots \dots, K),$$

$$Z^{(k,h)} \geq \sum_{j=1}^{n} Z_j^{(k,h)} \lambda_j^k \qquad (\forall (k,h) = outputs\ from\ k),$$

$$Z^{(k,h)} \geq \sum_{j=1}^{n} Z_j^{(k,h)} \lambda_j^k \qquad (\forall (k,h) = inputs\ to\ h),$$

$$\sum_{j=1}^{n} \lambda_j^k = 1(\forall k) \ , \qquad \lambda_j^k \geq 0 \ (\forall j, k)$$

Equation 4-1 presents K number of divisions i.e., nodes in the proposed network DEA model $(k = 1, \dots \dots, K)$ by upgrading the earlier production set in equation 3-1. Here, the number of DMUs is n (j=1,……,n) where $m_k \ and \ r_k$ be the numbers of inputs and outputs for any node k respectively. Now for the link between node k to node h be presented as (k, h) and L represents the set of links. So, the data set for the input set in node k is $\left\{X_j^k \ \in R_+^{m_k}\right\}(j = 1, \dots \dots, n; k = 1, \dots \dots, K)$, output set from node k is $\left\{Y_j^k \ \in R_+^{r_k}\right\}(j = 1, \dots \dots, n; k = 1, \dots \dots, K)$, and the intermediate set for a link between node k and node h is $\left\{Z_j^k \ \in R_+^{t_{(k,h)}}\right\}(j = 1, \dots \dots, n; (k, h) \in L)$ where $t_{(k,h)}$ is the number of items in the link. Finally, $\lambda^k \ \in R_+^{m_k}$ is the intensity vector which corresponding to node k $(k = 1, \dots \dots, K)$. This is to note that this is a variable return to scale model (VRS) suitable for explaining banking activities. The last constraint $\sum_{j=1}^{n} \lambda_j^k = 1(\forall k)$ is a VRS application.

Now, slack vectors $S^{K-}(S^{k+})$ for input (output) within the DMUs can be presented by

$$x_0^k = \mathrm{X}^{\mathrm{k}}\lambda^{\mathrm{k}} + S^{K-} \qquad (k = 1, \dots \dots, K), \qquad \textbf{4-2}$$

$$y_0^k = \mathrm{Y}^{\mathrm{k}}\lambda^{\mathrm{k}} - S^{K+} \qquad (k = 1, \dots \dots, K),$$

$$\lambda^{\mathrm{k}} = 1 \qquad (k = 1, \dots \dots, K),$$

$$\lambda^{\mathrm{k}} \geq 0, \ S^{K-} \geq 0, \ S^{K+} \geq 0, \ (\forall k),$$

Where,

$$X^k = \left(X_1^k, \dots \dots, X_n^k\right) \in R^{m_k \times n},$$

$$Y^k = \left(Y_1^k, \dots \dots, Y_n^k\right) \in R^{r_k \times n}$$

So, if the output-oriented efficiency is denoted by τ_0^*, and the linear equation is

$$1/\tau_0^* = \max_{\lambda^k, S^{K+}} \sum_{k=1}^{K} W^k \left[1 + \frac{1}{r_k}\left(\sum_{r=1}^{r_k} \frac{S_r^{k+}}{Y_{r0}^k}\right)\right]$$

Subject to

$$x_0^k = X^k \lambda^k + S^{K-} \qquad (k = 1, \dots \dots, K),$$

$$y_0^k = Y^k \lambda^k - S^{K+} \qquad (k = 1, \dots \dots, K), \qquad \textbf{4-3}$$

$$\lambda^k = 1 \qquad (k = 1, \dots \dots, K),$$

$$\lambda^k \geq 0, \; S^{K-} \geq 0, \; S^{K+} \geq 0, \; (\forall k),$$

$Z^{(k,h)}\lambda^h = Z^{(k,h)}\lambda^k, \left(\forall (k, h)\right)$ if link between nodes are free, OR

$Z_0^{(k,h)} = Z^{(k,h)}\lambda^h, \left(\forall (k, h)\right)$ if link between nodes are fixed, where $\sum_{k=1}^{K} W^k = 1, W^k \geq 0\ (\forall k),$ and W^k is the relative weight of node k which determined corresponding to it importance. So, the overall efficiency score for an output oriented production set (banking sector in this research) is the weighted harmonic mean of individual node's efficiency scores.

$$1/\tau_0^* = \sum_{k=1}^{K} \frac{W_k}{\tau_k} \quad \textbf{4-4}$$

For an optimal solution of equation 4-3, the projection onto the frontier as follows:

$$X_0^{k*} \leftarrow X_0^k - S^{K-*}\ (k = 1, \dots \dots, K), \quad \textbf{4-5}$$

$$Y_0^{k*} \leftarrow Y_0^k + S^{K+*}\ (k = 1, \dots \dots, K).$$

For a free type link between the nodes, the projection is as follows:

$$Z_0^{(k,h)*} \leftarrow Z^{(k,h)} \lambda^{h*}\ \left(\forall (k,h)\right) \quad \textbf{4-6}$$

To define a reference set of any node k for the DMUs as follows:

$$R_0^k = \left\{\mathrm{j} \middle| \lambda_\mathrm{j}^{\mathrm{k}*} > 0\right\}(\mathrm{j} \in \{1, \dots \dots, \mathrm{n}\}) \quad \textbf{4-7}$$

4.3 Malmquist Index (efficiency over time)

The basic MI model of Caves, Christensen, & Diewert (1982), a contemporaneous MI index would be;

$$MI^s(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D^s(x^{t+1}, y^{t+1})}{D^s(x^t, y^t)} \quad \textbf{4-8}$$

Here the production set is $P^s_{R_j}, s = t, t+1$ for R_j and the distance function$D^s(x, y) = \inf\{\phi > 0 | \frac{x,y}{\phi} \in P^s_{R_j}$. Färe, Grosskopf, Norris, & Zhang (1994) proposed that MI index as the geometric mean of MI of two periods since$MI^t(x^t, y^t, x^{t+1}, y^{t+1}) \neq MI^{t+1}(x^t, y^t, x^{t+1}, y^{t+1})$. With this connection, for an intertemporal benchmark technology, the distance function is;

$$MI^I(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D^I(x^{t+1}, y^{t+1})}{D^I(x^t, y^t)} \quad \textbf{4-9}$$

Here, the production set is $P^I_{R_j}, I = t$ for a group of R^I_j and the distance function $D^I(x, y) = \inf\{\phi > 0 | \frac{x,y}{\phi} \in P^I_{R_j}$. Based on the valued work of Pastor & Lovell (2005), any intertemporal distance function can be decomposed as follow;

$$MI^I(x^t, y^t, x^{t+1}, y^{t+1}) \quad \textbf{4-10}$$

$$= \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \left\{ \frac{D^I(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D^t(x^t, y^t)}{D^I(x^t, y^t)} \right\}$$

$$= \frac{TEff^{t+1}}{TEff^t} \times \frac{BPGp^{t+1}}{BPGp^t}$$

$$= EC \times BPG$$

Here, $TEff^s$ and $BPGp^s$ are the technical efficiency and best practice respectively. EC denotes measure in change of efficiency proposed by Färe et al. (1994). Here, BPG denotes the changes in best practice technology gap between the Contemporaneous and intertemporal production possibility frontier. $BPG > 1$ Refers that the contemporaneous frontier of $t + 1$ is closer than the intertemporal benchmark technology for the time t, and $BPG < 1$ is vice versa. Pastor & Lovell (2005) proposed this change as just the technical change a technology within a defined group. This is also the equivalent of technical progress or regress as presented by Caves et al. (1982).

4.4 Meta-frontier

Considering efficiency measurement of this study involves banks of local ownership vs. foreign ownerships adapting the concept of meta-frontier is the best approach. In addition, comparison on the basis of different ownership would be more meaningful since these two groups are likely to inherent different technological background. For instance, the local banks in Malaysia enjoy greater flexibility and government support to capture the market in lending public sector credit (Cook, 2009).

However, a large section of bank efficiency literature found higher level of efficiency among the foreign banks because of their expertise in risk adjustment and capitalization (Gardener et al., 2011; Jeon & Miller, 2005). After the economic crises of 1980s and in 1997, financial liberalization, and Malaysian reformation of 2001-2010, it is imperative to examine the efficiency of Malaysian banks keeping in mind that there is a number of technological groups in Malaysian banking sector (e.g., conventional banks-CBs, Islamic banks-IBs, foreign banks-FBs and local banks-LBs). More specific information on meta-production function is done by Binswanger & Ruttan (1978). They revealed that meta-production function envelops all sub functions and stands as the best efficient one assuming that all the groups have the access in meta-production technology (Battese & Rao, 2002). Thus, using meta-frontier for examining relative efficiency is justified for Malaysian banking sector.

Assuming three possible technologies in meta-frontier- i) contemporaneous distance function, ii) inter-temporal distance function and iii) global distance function (Oh & Lee, 2010). In benchmarking technologies, the component distance function can be measured for the Malaysian banks based on this meta-frontier technology. Let's assume that there are (J) different technologies within the selected DMUs, i.e. the banks. Figure 4.1 illustrates the meta-frontier technology in of the three contemporaneous technology sets in three periods.

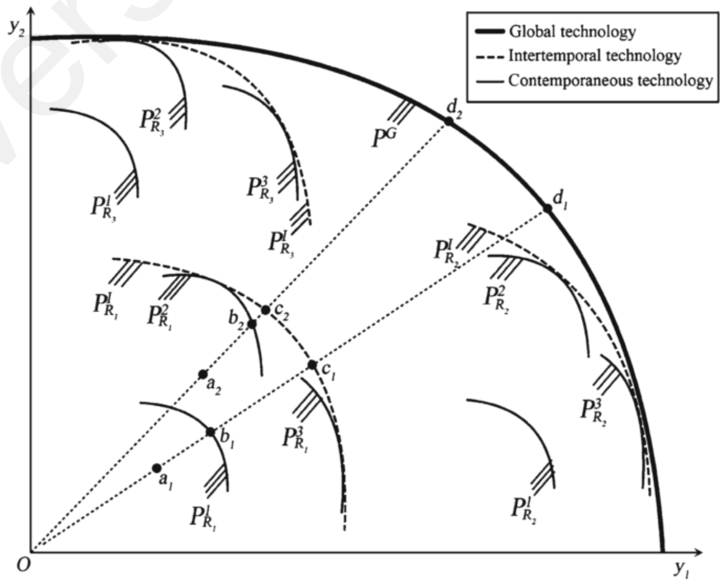

Figure 4.1: Meta-frontier in DEA
Source: Oh & Lee (2010, p. 49)

The superscript on P represents the time period and the subscript on P stands for the indicator of various groups. The interior solid lines are the contemporaneous technology sets, those with broken lines are intertemporal technology sets, and the thick solid line is the global technology set. As can be seen in Figure 4.1, the intertemporal benchmark technology of a specific group envelopes its contemporaneous benchmark technologies and the global benchmark technology envelopes all the intertemporal benchmark technologies.

Contemporaneous benchmark technology produces a reference set of (P) at any time period(t). For each group of technology (R_j), the production set is designed as $P_{R_j}^{t} = (X,Y)|X\ produces\ Y$ and $\lambda P^t = P^t, t = 1, \ldots, T, and\ \lambda > 0.$ This technology is based on the valued work of Pastor & Lovell (2005) and Tulkens & Vanden Eeckaut (1995). Tulkens & Vanden Eeckaut (1995) also guided the second technology- intertemporal benchmarking. This technology is a simple combination of all the proposed contemporaneous production sets and for all time period $P_{R_j}^{InterT} = conv(P_{R_j}^{1} \cup P_{R_j}^{2} \cup, \ldots, \cup P_{R_j}^{T})$ for a defined technology group$\left(R_j\right)$. So, for all the (J) different technologies within the selected DMUs, (J) different intertemporal benchmarks will be produced. Finally, global technology for all time period is $P_{R_j}^{Global} = conv(P_{R_1}^{InterT} \cup P_{R_2}^{InterT} \cup, \ldots, \cup P_{R_J}^{InterT})$.

Let's defined in production set of P^{Global} as;

$$MI^{Global}(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D^{Global}(x^{t+1}, y^{t+1})}{D^{Global}(x^t, y^t)} \qquad \textbf{4-11}$$

Here, the production set is $P_{R_j}^{Global}, I = t$ for all groups of R_J^s and the distance function $D^{Global}(x,y) = \inf\left\{\phi > 0 | \frac{x,y}{\phi} \in P^{Global}\right\}$ known as global technology set. For MI, decomposition of a global set can be shown as follows:

$$MI^{Global}(x^t, y^t, x^{t+1}, y^{t+1}) \quad \textbf{4-12}$$

$$= \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \left\{\frac{D^t(x^t, y^t)}{D^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D^{Global}(x^{t+1}, y^{t+1})}{D^{Global}(x^t, y^t)}\right\}$$

$$= \frac{TEff^{t+1}}{TEff^t} \times \frac{BPGp^{t+1}}{BPGp^t} \times \frac{TGpR^{t+1}}{TGpR^t}$$

$$= EC \times FCR \times TGR$$

Here $EC, FCR, and\ TGR,\ s = t, t+1,$ are the technical efficiency level, technology gap for the best practice and level of technological gap ratio respectively.

The distance function for $k' \in R_j$ for the period of $s = t, t+1,$

$$\left(D^s\left(x^{k',s}, y^{k',s}\right)\right)^{-1} = max\, \phi_c^{k',s} \quad \textbf{4-13}$$

Subject to;

$$\sum_{k \in R_j} z^{k,s} y_m^{k,s} \geq \phi_c^{k',s} y_m^{k',s}, \quad m = 1 \dots\dots\dots M$$

$$\sum_{k \in R_j} z^k x_n^{k,s} \leq x_n^{k',s}, \quad n = 1 \dots\dots\dots N$$

$z^{k,s} \geq 0$

Where $z^{k}$is the intensity variable of a DMU, in our case each bank is a unit. The intertemporal distance functions $D^{I}(x^{k',s}, y^{k',s}/D^{k',s}(x^{k',s}, y^{k',s}), s = t, t+1$ are calculated using the following calculation:

$$\left[D^{I}(x^{k',s}, y^{k',s}/D^{k',s}(x^{k',s}, y^{k',s})\right]^{-1} = max\phi_{I}^{k'} \quad \textbf{4-14}$$

Subject to;

$$\sum_{k \in R_{j}, s \in \tau} z^{k} y_{m}^{k} \geq \phi_{I}^{k'} \hat{\phi}_{c}^{k',s} y_{m}^{k',s}, \quad m = 1 \dots \dots \dots M$$

$$\sum_{k \in R_{j}, s \in \tau} z^{k,s} x_{n}^{k,s} \leq x_{n}^{k',s}, \quad n = 1 \dots \dots \dots N$$

$z^{k,s} \geq 0, \tau = (1,2, \dots., T)$

This equation examines all units of all time period for any specific group R_{j}. Now, the following objective function is responsible for calculating objective function for all units, all periods and for all groups in any study. Denoting the solution of equation, the global distance function $D^{Global}(x^{k',s}, y^{k',s}/D^{k',s}(x^{k',s}, y^{k',s}), s = t, t+1$ may calculate as follow:

$$\left[D^{Global}(x^{k',s}, y^{k',s}/D^{k',s}(x^{k',s}, y^{k',s})\right]^{-1} = max\phi_{Global}^{k'} \quad \textbf{4-15}$$

Subject to;

$$\sum_{k \in R_{j,} s \in \tau} z^k y_m^k \geq \phi_{Global}^{k'} \widehat{\phi}_I^{k',s} y_m^{k',s}, \quad m = 1 \dots \dots \dots M$$

$$\sum_{k \in R_{j,} s \in \tau} z^{k,s} x_n^{k,s} \leq x_n^{k',s}, \quad n = 1 \dots \dots \dots N$$

$$z^{k,s} \geq 0, R = R_1 \cup R_2 \cup, \dots., \cup R_J, \tau = (1,2, \dots., T)$$

The application of technological gap ratio (TGR), the product of Efficiency Change Ratio (EC) and Technological Change Ratio (FCR) are applied for the proposed DEA of this study.

4.5 Variable selection

Bank efficiency is actually a complex issue to comprehend since there are different groups (i.e., managers, shareholders, regulators, etc.) having similar legitimate interest in understanding the performance level of the banks. Ironically, there is no general agreement on what should be the prescribed inputs-outputs from the banking literature. Now, there are three alternative approaches outlined as the guidelines to bank efficiency calculations. Literature survey on application of different approaches are shown in subsection 2.4.2 in Chapter 2. A brief discussion on these approaches are presented below.

4.5.1 Production approach (Benston, 1965)

The production approach is pioneered by Benston (1965). This approach explains both financial and non-financial activities of a bank. According to the production approach customer service is treated as the key performance indicator for a bank. As such, banks are only producer of transactions for its customers. To support production approach of a bank, number of employees, amount of employee hour and physical capital are used as bank input to produce transactions (i.e., credit check, payment and other bank services) as the bank's output. According to production approach, inputs are best measured by physical units, and outputs are best measured by the number and type of transactions.

4.5.2 Intermediation approach (Sealey and Lindley, 1977)

The intermediation approach, proposed by Sealey & Lindley (1977) examines bank's capacity in transforming deposits into loans and advances. This approach treats a bank's operation as the set of work that intermediates depositors' funds into borrowers' loan. In this process, banks incur both operating and interest expenses to create bank assets (loans). For example, through intermediation approach, banks produce loan, investment and other bank products using the labor and capital as inputs.

4.5.3 Profitability approach (Paradi & Zhu, 2013)

Profitability approach considers banks as the producer of profits out of its business operation. This approach considers expenses as inputs and revenues as outputs. In contrast, Paradi & Zhu (2013) revealed that this approach examines bank's ability of "going concern". By the term "going concern", it assumes that a bank will function without the threat of liquidation for the likely future. Again, Fethi & Pasiouras (2010) found that major studies in bank DEA have used profitability model.

The aptness of each approach is largely dependent upon a number of internal factors such as operational background and external issues like economic environmental as well as the present circumstances (Sirvent, Ruiz, Borras, & Pastor, 2005; Wagner & Shimshak, 2007). Therefore, examining only an aspect of bank's ‘tasks’ would not, sufficiently, probe into bank efficiency. The best approach is to consider the interest of all the stakeholders in efficiency measurement.

4.6 The proposed adaptive network DEA approach

As revealed in literature review (chapter 2), during the core banking operations, bank first concentrate on capital and deposit (total liability) which allows a bank to determine how much growth it can afford in long-term business. From this, a bank produces earning assets which in turn became loans. In the final stage, from these loans bank creates profit and as a byproduct, bank also incurs bad loans (Loan loss provision). As an input for second and third stages, bank also uses interest expenses and non-interest expenses respectively. The list of all input and output variables for all the three approaches by the earlier research are shown in Chapter 2, subsection 2.4.2, Table 2.9.

It can be resolved that the existing DEA models have failed to explain bank’s efficiency adequately for a number of reasons. Firstly, the review on NDEA application on bank efficiency clearly revealed NDEA applications on bank efficiency is only limited to a few models and structures only. Studies on bank efficiency using NDEA only explores the internal process of banking system. Moreover, there is a clear literature gap of using undesirable output in NDEA applications. To the best of my knowledge, the first use of bad output in NDEA model was conducted by Kordrostami & Amirteimoori (2005) and there is only a limited number of studies were found compiling NDEA with bad outputs. Among those, Lozano (2016) applied NDEA along with bad outputs in examining bank efficiency His proposed model of slack based NDEA with bad outputs have further proven to produce unbiased and meaningful efficiency results. The application of slack based NDEA is actually found to be limited in bank applications (Cook et al., 2000; Kao, 2014; Lozano, 2016).

A conceptual presentation is demonstrated in Figure 4.2 below.

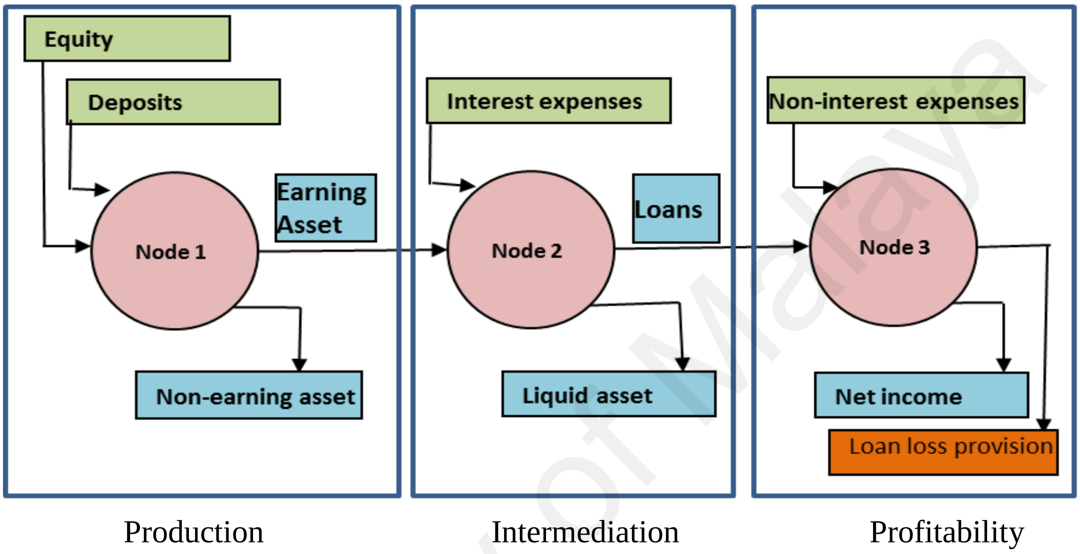

Figure 4.2: Proposed adaptive network DEA approach

The basic DEA application in bank business calculates performance based on a "black-box" which receives input(s) and produces output(s). This black-box concept has been explained in detail under subsection 2.3.2.3 of Chapter 2. Färe & Grosskopf (2000) examined into the application of network DEA specifically looking into what is actually happening within the "black-box". For this purpose, a network DEA can compartmentalize the black-box into several sub-processes (nodes) and link them with a number of intermediate variables within the systems. Within the black box, an intermediate variable is firstly treated as an output of a node or sub-process and would, then, treated as an input to the following node or sub-process. Links from one node or sub-process to other node forms a network which describes the nature of any DMU operation.

Based on the literature, the core operations of a bank are designed and lined in Figure 4.2. The first core represents the *production approach* of a bank by which a bank starts its operation. In this process, banks transform earning assets from the equity and debt (deposit and others instruments). This process is also call financing in Finance terminology. Collection of fund and transform it into loanable fund is critically important for any bank. Without gaining optimal efficiency in this core, a bank cannot turned out to be both profitable and viable (Berger & Humphrey, 1997). Within this process, another output produces by the bank which is non-earning assets. For example current asset, prepaid expenses, prepaid insurance etc. These outputs in this process does not produce any profit.

The second core is named as *intermediation approach*. After producing earning assets from equity and deposits, a bank produces loans and similar instruments which generates profit for the bank in long-run. In core 2, the earning asset which is an output of core one uses as carryover input. This approach convers loanable funds into loans and advances to the investors. In finance terminology this process is called investment. Now, long-term profitability and credit risk is critically involved with this core. How much bank clients are getting benefit with the bank transactions, can also be examined in this core. The final core of this proposed adaptive model is called *profitability approach*. In this core, the loan items of core-2 uses as input. The objective of this core is to examine profitability of a bank by explaining the how much a bank is efficient in producing profit out of its loans keeping in mind that loan loss provision is also attached to loans.

Therefore, this adaptive network DEA will calculate not only the overall bank efficiency but also the efficiency for each core (approaches). Thus, the measurement of bank efficiency is no longer limited to a static conventional format.

4.7 Application of the proposed model for examining bank efficiency

Application of the proposed model is expected to improve bank efficiency results in mainly three ways. Firstly, this approach is expected to increase accuracy of examining bank efficiency through the holistic scheme to incorporate the three approaches (production, intermediation and profitability) in a network. Thus, a bank's efficiency is going to be examined not only using the operational aspects of a bank but also using profitability assumption. Earlier studies have evidenced that examining bank efficiency based on only one of the approaches may lead to contradict findings and biased results[13].

Secondly, this proposed network enable to unveil the actual bank operation by explaining the linkage of inputs and outputs at different stages of bank operation. Figure 4.2 ādemonstrates the connections of different inputs and outputs thorough the process. This network successfully presents a flow of activities of banks' operation. As it reveals that bank starts its activities by collecting deposits and finishes the process with net income. During the selection of inputs and outputs, only most cited variables have been selected using the CAMELS rating theory. As it reveals that

[13] Published in ESCI (web of science TM) and Scopus indexed journal: Azad, M. A. K., Kian-Teng, K., & Talib, M. A. (2017). Unveiling black-box of bank efficiency: an adaptive network data envelopment analysis approach. International Journal of Islamic and Middle Eastern Finance and Management, 10(2), 149-169.

variables selection using CAMELS is most effective in banking studies[14]. Last but not least, majority of bank efficiency studies have failed to incorporate bad debt as undesirable output in banking studies. Especially in Malaysian context, the application of network DEA with undesirable output would be the first of its kind. It is expecting that application of this proposed adaptive network DEA approach would successfully evaluate bank efficiency in Malaysia with additional explanations and accuracy.

Number of DMUs to maintain sufficient degrees of freedom

Finally, about the minimum number of DMUs which a DEA test must have - a general rule to determine the minimum number of DMUs (n) - is:

$$n > max\,(m\,x\,s\,, 3\,(m + s))$$

Where,

n = minimum number of DMUs

m = number of inputs

s = number of outputs

In other words, a model needs to have as many DMUs as the greater of the result of number of input variables multiplied by the number of output variables, or three times the sum of the number of input variables plus the number of output variables. For example, if a model includes 4 input variables and 4 output variables, there should be at least max (4x4, 3(4+4)) = max (16, 24) = 24 DMUs.

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[14] Published in ESCI (web of science ™) and Scopus indexed journal: Azad, M. A. K., Munisamy, S., Masum, A. K. M., Saona, P., & Wanke, P. (2016). Bank efficiency in Malaysia: a use of malmquist meta-frontier analysis. Eurasian Business Review, 03 September 2016, 1-25.

4.8 Summary

Application of the proposed adaptive network DEA in banking sector of Malaysia is presented in the following chapter. This chapter proposes the model and explains various aspects of this model. Its empirical application and findings would make this model further acceptable which is to be explored to the following chapter.

CHAPTER 5: RESULTS AND ANALYSES

5.1 Introduction

This chapter is comprised with the application of equations and models which have discussed in Chapter 4. Three sub-headings, as shown below, are designed to present results and analysis of this research. The first section presents the descriptive analysis of all collected bank level data of this study. Next, empirical results and their analyses are presented. Third sub-heading covers the robustness check of the results. Finally, a summary of these results is drawn at the end of this chapter.

5.2 Descriptive statistics

Table 5.1 as shown below presents a list of the selected banks from Malaysian banking sector and the respective codes are given for each bank together with the full names. The short codes and bank names are used, interchangeably, in this thesis. . The list comprises of the combination of foreign conventional banks (FC): foreign Islamic banks (FI), Local conventional (LC): and Local Islamic banks (LI).

Table 5.1: List of 43 banks in the Malaysian banking industry

Bank name	Code	Bank name	Code
Bangkok Bank Berhad	FC1	Al Rajhi Banking & Investment Corporation (Malaysia) Berhad	FI1
Bank of America Malaysia Berhad	FC2	Asian Finance Bank Berhad	FI2
Bank of China (Malaysia) Berhad	FC3	HSBC Amanah Malaysia Berhad	FI3
Bank of Tokyo-Mitsubishi UFJ (Malaysia) Berhad	FC4	Kuwait Finance House (Malaysia) Berhad	FI4
BNP Paribas Malaysia Berhad	FC5	OCBC Al-Amin Bank Berhad	FI5
Citibank Berhad	FC6	Standard Chartered Saadiq Berhad	FI6
Deutsche Bank (Malaysia) Berhad	FC7	Affin Bank Berhad	LC1
HSBC Bank Malaysia Berhad	FC8	Alliance Bank Malaysia Berhad	LC2
India International Bank (Malaysia) Berhad	FC9	AmBank (M) Berhad	LC3
Industrial and Commercial Bank of China (Malaysia) Berhad	FC10	CIMB Bank Berhad	LC4
J.P. Morgan Chase Bank Berhad	FC11	Hong Leong Bank Berhad	LC5
Mizuho Bank (Malaysia) Berhad	FC12	Malayan Banking Berhad	LC6
National Bank of Abu Dhabi Malaysia Berhad	FC13	Public Bank Berhad	LC7
OCBC Bank (Malaysia) Berhad	FC14	RHB Bank Berhad	LC8
Standard Chartered Bank Malaysia Berhad	FC15	Affin Islamic Bank Berhad	LI1
Sumitomo Mitsui Banking Corporation Malaysia Berhad	FC16	Alliance Islamic Bank Berhad	LI2
The Bank of Nova Scotia Berhad	FC17	AmIslamic Bank Berhad	LI3
The Royal Bank of Scotland Berhad	FC18	Bank Islam Malaysia Berhad	LI4
United Overseas Bank (Malaysia) Bhd.	FC19	Bank Muamalat Malaysia Berhad	LI5
		Public Islamic Bank Berhad	LI6
		CIMB Islamic Bank Berhad	LI7
		RHB Islamic Bank Berhad	LI8
		Hong Leong Islamic Bank Berhad	LI9
		Maybank Islamic Berhad	LI10

Notes: FC: foreign conventional banks, FI: foreign Islamic banks, LC: Local conventional, LI: Local Islamic banks

Table 5.2 presents the descriptive statistics of the bank level data from sample banks which is examined in this study. For each variable, minimum value of data, median value and maximum value is presented.

Table 5.2 : Descriptive summary of collected data

Variable Type		Ordinary inputs				Undesirable carry-over output	Desired output	Undesirable outcome	Desired output	Intermediary	
CAMELS Model		A= Asset	C= Capital	M= Management	M= Management	L= Liquidity	L= Liquidit	M= Manageme	E= Earning	S= sensitivit	S= sensitivit
Variable Name		Deposits	Equity	Interest Expenses	Non-interest Expenses	Non-Earning Asset	Liquid Assets	Loan loss provisions	Net income	Earning Assets	Loan
Short form of Variable		X1	X2	X3	X4	Y1	Y2	Y3	Y4	Z1	Z2
2009	Mi	179.8	210.3	0.97	-6.83	-840.1	-467.5	-21.97	2340.33	161	29.1
	1st	5887.6	667.4	89.73	79.15	2015.4	3105.8	20.16	41.74	4616	3796.9
	M	25499.6	2567	382.23	458.7	7552.5	8713.5	85.3	268.8	23174	17262.1
	M	175139.	61340.7	3615.1	9697.14	104398.7	159519.	1230.29	3930.24	163068	95297.6
	3r	65770.9	8847.9	1318.66	1147.87	17654.9	26299	180.88	1298.22	76924	51680.6
	M	2071366	623230.3	74125.33	257138.33	1597526.3	1987407	20360	1298.22	3622790	1105661
2010	Mi	145.7	294.5	0.7	8.2	12.6	-48.8	-1864	-6637.3	267	24.6
	1st	6110.3	747.7	111.7	98.97	2023.8	3051.8	10.6	37.9	5804	3729.5
	M	26209.4	2807.8	508	496.2	7314	8789.4	58.4	288.5	26838	18224.5
	M	216054.	64869	4623.2	8622.65	101771.5	158652.	930.9	2711.8	199308	107119.7
	3r	67558.5	9626.4	1416.8	1328.8	18076.3	27042.5	166.2	1015.2	83540	46903.6
	M	2350015	:3193857	65482	216357	1348432	2256560	12596.2	40021	1348432	1423184
2011	Mi	145.7	329.2	-1429.7	21.2	12.6	355.3	-2864	-8283	267	24.6
	1st	6464.9	817.4	105.3	114.8	2430.8	3020.1	2.9	32.2	6555	3824
	M	27209.4	2807.8	496.5	533.7	6839.3	8620.1	63	152.8	27620	19224.5
	M	250806.	66835.2	5820.8	8814.3	91662.3	146279.	402.5	2204.7	267720	136780.3
	3r	68374.8	10279.5	1802.9	1462	15682.9	26465.4	151.3	805.6	94171	54300.1
	M	2505966	606719	65482	216357	1348432	2256560	11276.4	40021	3193857	1740707
2012	Mi	1050	349.8	12.6	32.7	68.5	23.8	-1118	-24132	651	17.9
	1st	6487	907.8	160.2	120.5	2138.7	2535.9	-0.4	49.15	6647	4292.8
	M	31844	3103	654.2	588.8	5044.8	8431.1	63	155.9	34290	20168.1
	M	331868	74696.7	7915.4	8131.9	95591.6	183068.	763.3	1144	348885	175615.8
	3r	77030	11870.8	2035.8	1858.7	20852.5	34991.7	148.2	906.65	116481	58899.7
	M	4047303	581952	98601	155185	2024862	2660289	10855	42113	4357643	2058230

		X1	X2	X3	X4	Y1	Y2	Y3	Y4	Z1	Z2
2013	Min.	1556	367.1	23.2	36.1	-41254	234	-108.1	-6317	806	112.7
	1st Qu.	8058	1004.9	186.8	132.3	1456	3194	1.35	62.25	7432	5984.5
	Median :	38034	3326.8	848.6	625.1	4219	8497	56.1	357	37598	24445
	Mean	445677	85748.8	9407.4	6246.2	78739	254255	993.47	2556.75	491653	225493.2
	3rd Qu.	141117	13224.4	3191.2	1983.8	11198	32437	337.9	1202.1	162508	106661.4
	Max.	8279063	707484	157323	55630	1299404	5810787	15361	56860	8287876	2796973
2014	Min.	1866	386.3	16.5	32.1	-66830	409	-1082	-3217	956	235
	1st Qu.	9221	1101.1	201.9	148.8	1078	2133	1.05	68.55	9049	7534
	Median :	41310	3729.6	901.3	584.6	3866	6320	68.6	391.3	40911	29525
	Mean	516094	108418.7	12408.8	7154.8	86336	232817	1651.73	4362.66	576998	314505
	3rd Qu.	138860	14982.5	3783.7	2102.1	11174	26393	257.7	1679.25	197299	121062
	Max.	8627648	1079200	261324	76352	1605119	4065681	52790	106303	9117247	5052027
2015	Min.	1866	386.3	24.1	32.1	-66830	574	-1082	-3705	1126	198
	1st Qu.	10098	1254.1	243.6	150.7	1173	1973	5.3	87.05	9908	8496
	Median :	43846	4132.4	1122	604	3149	5469	75.83	377.45	44224	35308
	Mean	543822	114910.7	13236.5	7478.7	83606	229276	1943.58	4660.51	602998	337186
	3rd Qu.	169298	16782.4	4013.2	2217.9	9111	20706	349.5	1517.45	207121	131478
	Max.	8627648	1079200	261324	76352	1580605	4065681	60335.5	106303	9117247	5052027
Total	Min.	146	210.3	-1429.7	-6.83	-66830	-467	-2864	-24132	161	18
	1st Qu.	7264	846.2	131.5	124.6	1556	2783	2.89	52.2	7192	4428
	Median :	31928	3084	667.6	565.2	4847	8431	68.6	288.5	34250	23741
	Mean	354209	82402.8	8146.7	8020.81	91729	194838	1130.83	3081.5	378662	198857
	3rd Qu.	103334	11704.2	2405.2	1766.45	15414	29507	217.8	1135.7	123201	74189
	Max.	8627648	1079200	261324	257138.3	2024862	5810787	60335.5	106303	9117247	5052027

Handling outlier data in any sample is a requirement for data validity. Unlike a parametric test such as regression, non-parametric method such as DEA requires outliers in the data sample for determining the frontier. Robust regression seems to be a good strategy for handling the outliers since it is a compromise between excluding these points entirely from the analysis and including all the data points and treating all them equally in OLS regression. For this purpose, robust regression is utilized. Robust regression is a form of weighted and reweighted least squares regression. In this study, robust regression is applied to weigh the observations differently. The graphical presentation of robust regression of the data of this study is presented in Figure 5.1.

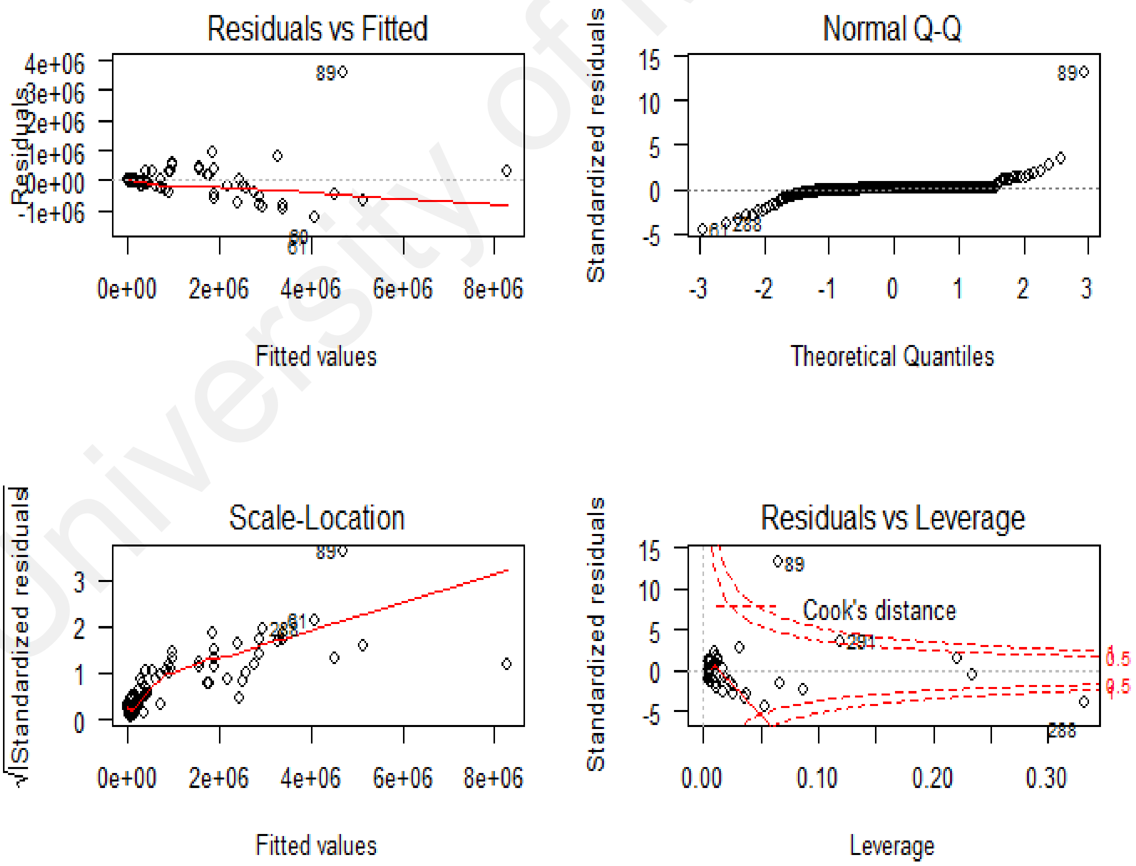

Figure 5.1: The outcome of robustness test of data used in this study

Figure 5.1 depicts the outcomes for fitted values (Residuals vs fitted; share location), Normal Q-Q plot and leverage. All four sub-figures have visually revealed some outliers among the data. Thus, examining bank efficiency based on the assumption that there prevails a frontier in bank efficiency among the Malaysian banks is appropriate (Sufian et al., 2016). Though most of the banks' data have been seen in closer position to the center of this study, a number of outliers are clearly shown in all four sub figures.

Due to having significant difference in values, two separate figures are presented in Figure 5.2 portrays the general annual trend of the variables (inputs and outputs) based on the average amount. The figure on the left part presents the trend for deposits and short term funding, earning assets, liquid assets, loans, equity and non-earning asset, while the right hand side presents yearly changes on average of interest expenses, loan loss provisions, net-income and non-interest expenses.

Figure 5.2 has some key elements to highlight. The interest expenses and deposits both shows upward movement throughout the years that could indicate positive relationship between these two. Interestingly, non-earning assets did not show any increment while earning assets have grown significantly. This gives an indication of better management skills which prevails among the bank managers. This improvement in management skill could be due to the forced merger and acquisition among the commercial banks in Malaysia (Sufian, 2007b). In consequence, a huge downfall in liquid asset is also observed during this study period.

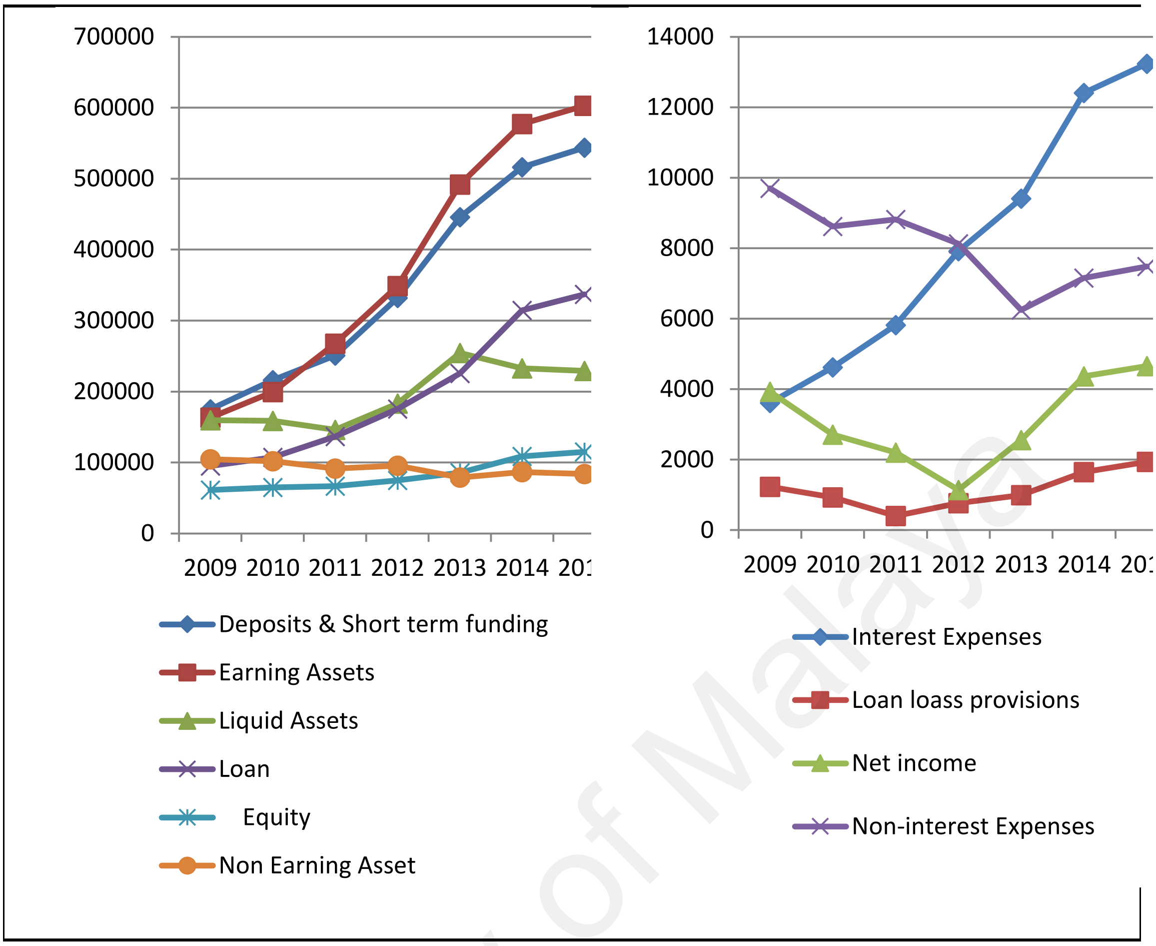

Figure 5.2 : Yearly changes in the variables stated in Table 5.2

(Sufian et al., 2016) (for the year 2009-2015)

Figure 5.2 also indicates that, during the years, Malaysian banks have successfully reduced their non-interest expenses. This might also have a link to the above-mentioned fact that of improvement in management skill among the merged banks in Malaysia. Though the earning assets have increased over the study time, the net-income has experienced a gradual shortfall until 2012 and started to level up for the next three years. Thus, a significant indication remains that Malaysian banks have been facing issues related to profitability while loan creation and deposits collection remain intact. Besides, loan loss provision has shown slight increase over the course of time.

The variations of data among the variables in all the four different types of banks in Malaysia can be illustrated in a spider diagram. Figure 5.3 depicts the spider diagram which include the average values of key variables for different types of banks.

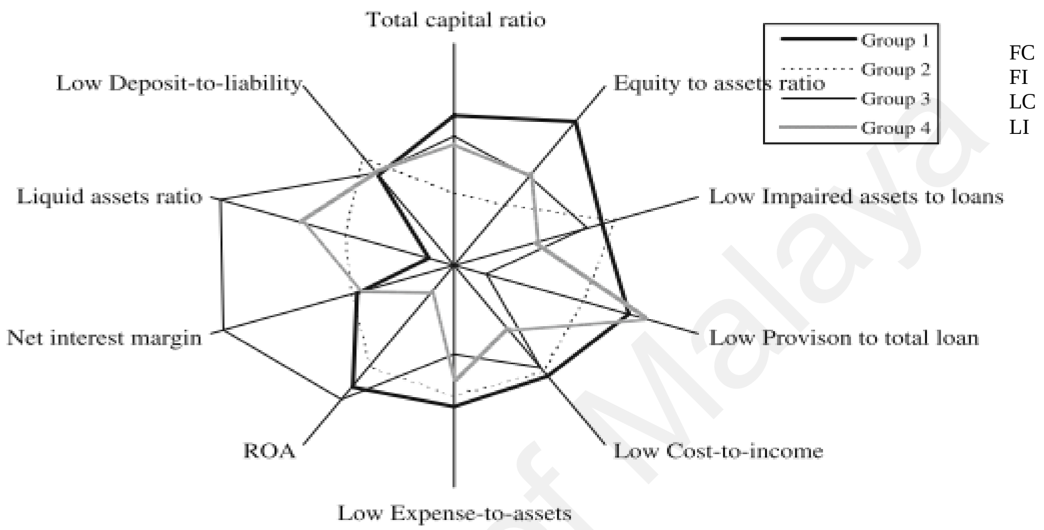

Figure 5.3: Spider diagram of different variables

It is visibly seen from Figure 5.3 that banks have significant different constituents in terms of their operating variables. Thus, it is worth to explore which bank performs more efficiently than others based on such differences do. Moreover, it is also important to explore how these differences would affect the banks' efficiency or inefficiency.

Since nonparametric tests like DEA use the frontier to examine benchmark, the presence of outlier in a sample data helps to discriminate the benchmark value with other sample data. In order to examine the presence of outliers among the selected variables in this study, the following density tests (from Figure 5.4 to Figure 5.10) are shown. Density tests helps to identify the nature of a sample data and presence of outliers. Figure 5.4 below depicts the density test of loan loss provision of the selected banks in Malaysia.

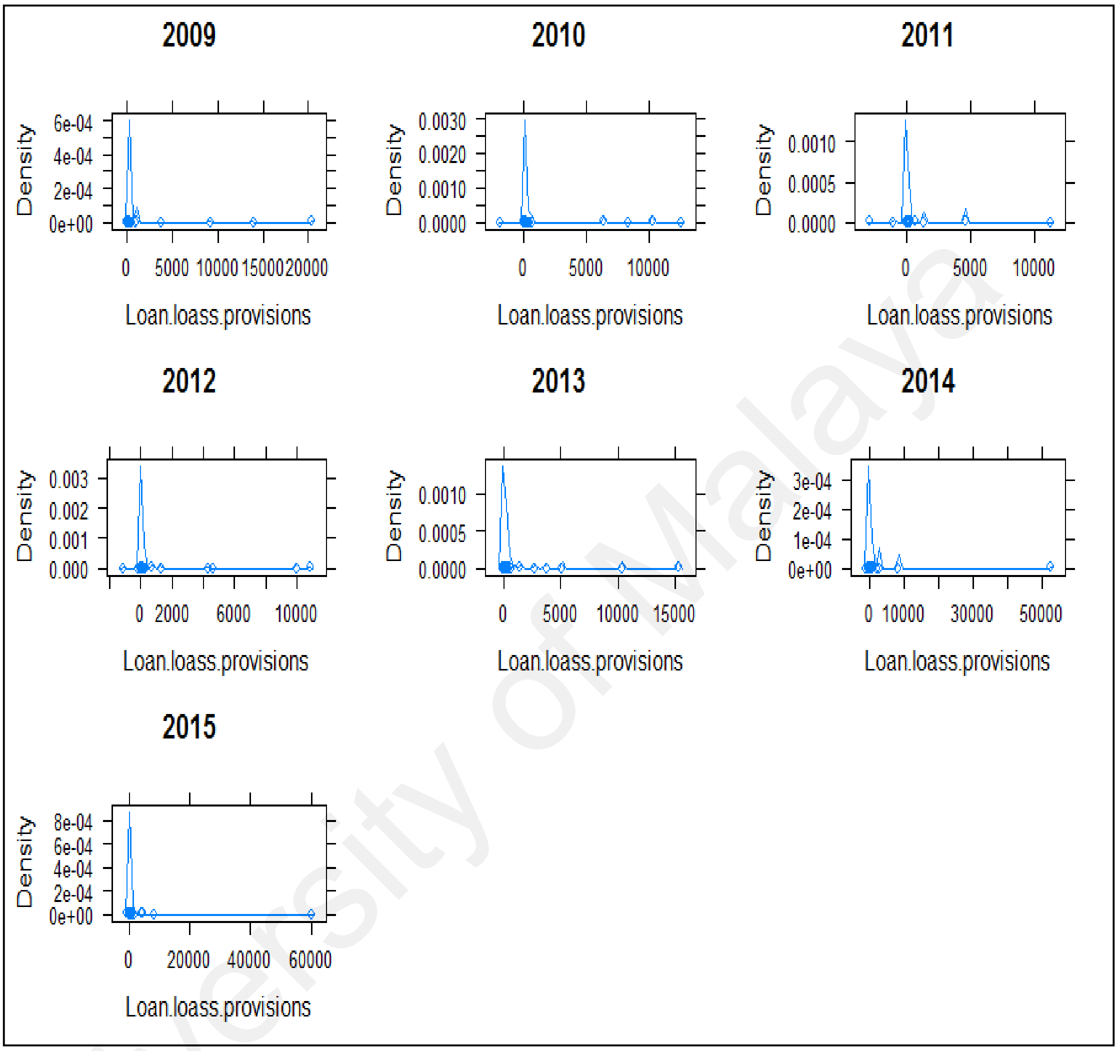

Figure 5.4 : Density test 2009-2015 (loan loss provision)

Figure 5.4 depicts the density of data for loan loss provision of banks on yearly basis. This is an additional examination on the trend presented in Figure 5.2. By examining the density of each variable at yearly basis would assist to examine the presence of outliers among the variables. Since, these outliers will help to determine the benchmark and to evaluate its peer group (Conover, 1980). Interestingly, during the years 2013-2015, some banks are found to have negative loan loss provision. In addition to negative loan loss provision, comparatively low dispersions among the values are observed for these years. Figure 5.4 depicts some outliers detected for all years under this study.

Figure 5.5 presents density of non-earning assets for banks in Malaysia during 2009 to 2015. Some clear outliers are present in all year's data set. This figure also reveals that only a few banks have extreme value in their non-earning assets. High density and low dispersion in non-earning assets value could indicate that only a few banks that have failed to manage their investment fund (Cook, 2009).

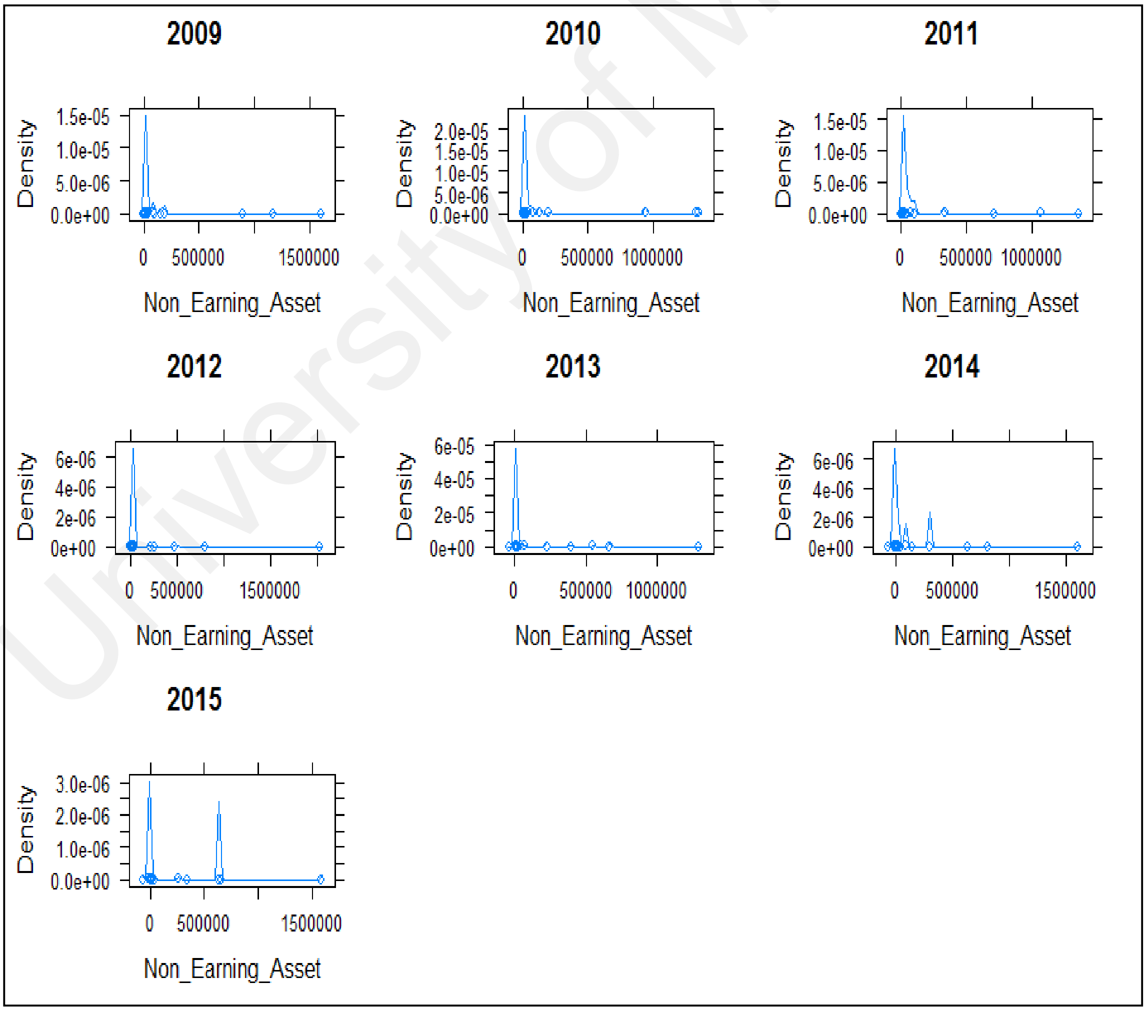

Figure 5.5 : Density test 2009-2015 (Non-earning asset)

Figure 5.6 presents a density plot for the data of liquid assets of all the banks in Malaysia on yearly basis. During the initial years i.e., 2009-2012, most of the banks have almost similar liquid assets position. Only a few banks have high liquidity status. This high liquidity might be a result of earlier mergers among the banks. The pattern of density among the banks, however, have changed during 2013-2014. Most of the banks have low liquidity positions where the density become more scattered.

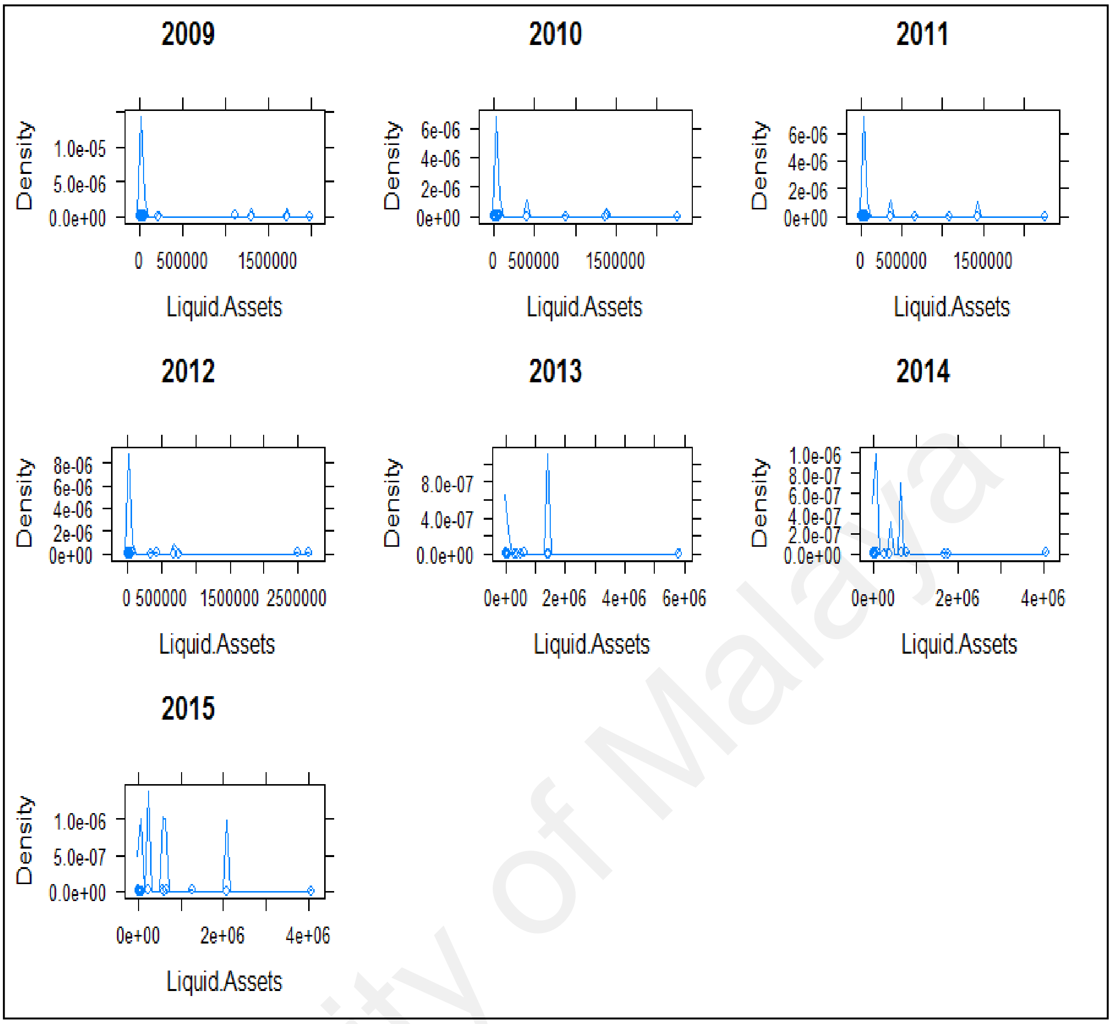

Figure 5.6 : Density test 2009-2015 (Liquid asset)

From figure 5.7, in 2015, there are several data points showing high density of banks' liquidity assets.

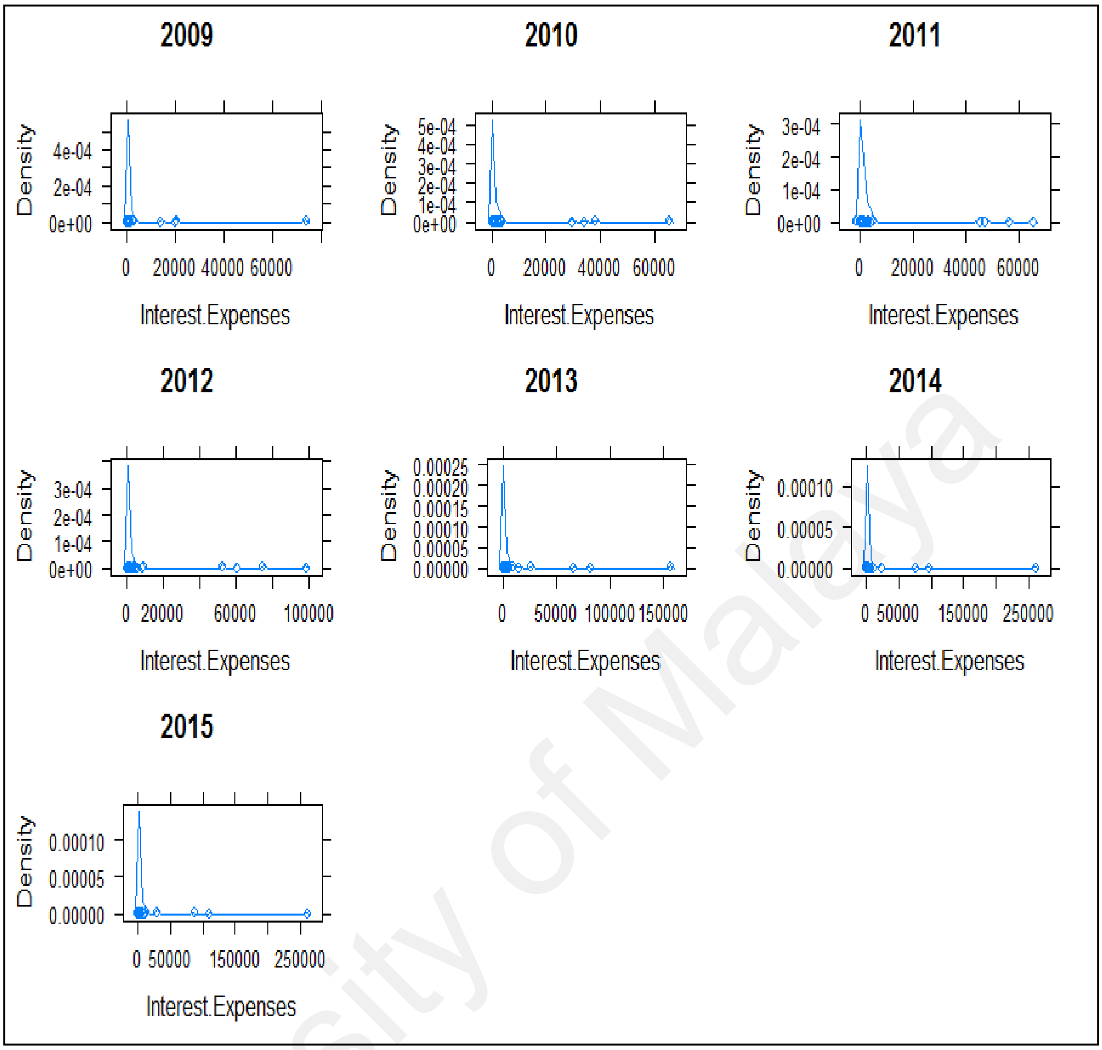

Figure 5.7 : Density test 2009-2015 (Interest expenses)

Figure 5.7 also depicts the status of banks. Based on the density plot pattern, it is clear that most of the banks have similar interest expenses pattern. However, only a few banks show high interest expenses. High interest expenses could be due to high volume of deposits or liabilities (Suffian, Sanusi, Osman, & Azhari, 2015). For example, large banks typically have high volume of interest expenses. This dispersion of density signifies that, in the Malaysian context, some banks are performing high volume of transactions. However, for some years (especially in 2014 and 2015) the dispersion of interest expenses data increased by almost four times for few banks.

Similar to density tests as shown above, boxplots can also be used for detecting outliers in a sample dataset (Conover, 1980). Figure 5.8 presents boxplots of net-income earned by the banks in Malaysia in different years. In general, from 2009 to 2015, at least a few banks were reported having net-loss. The reported net-income is, however, more dispersed than the net loss. This could be due to a number of good performers (in terms of net-income) were reported to attain high level of net-income. While during 2014 to 2015, longer tail of the outliers are evident.

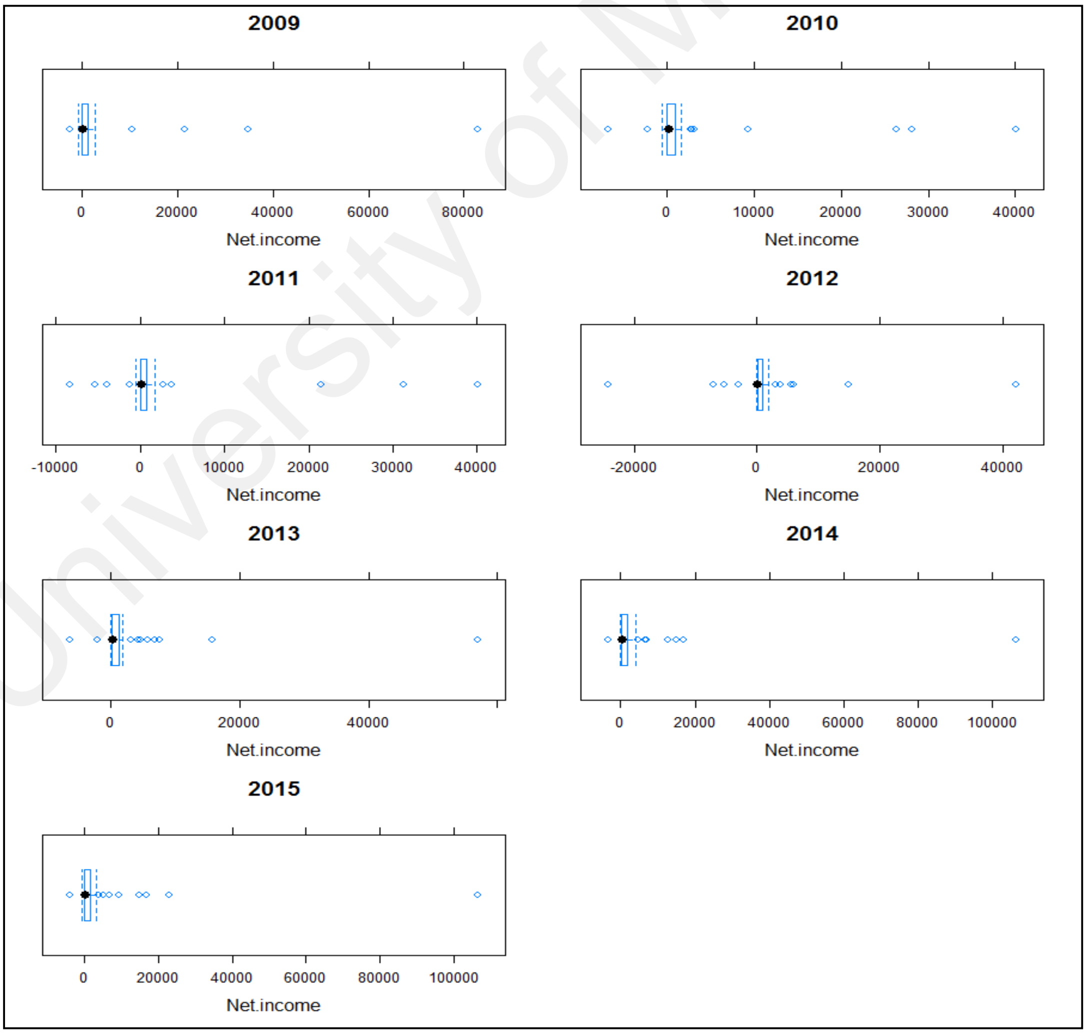

Figure 5.8 : Density test 2009-2015 (Net income)

The density of non-interest expenses among the banks in Malaysia are presented with boxplot in **Figure 5.9.** Non-interest expenses are mostly related to salary expenses and services which are directly not related to core expenses for a bank (Sufian, 2015). The above figure depicts that several banks are scattered away from the density center. It could be that a number of banks are experiencing high operating costs (Cook, 2009). It could also indicate a possibility of management incompetency (Cook, 2009).

Figure 5.9 : Density test 2009-2015 (Non-interest expenses)

Figure 5.10 depicts boxplots on the density of loans. The figure shows a pattern of increasing loan volume in yearly basis. This signifies that the Malaysian banking sector has been successful in creating loans from their deposits. However, one vital question to put forth and is yet to be answered is whether this growth of loans were supported by creating liability or by raising owners capital. Because, without increasing capital composition, the increase of loans usually put a bank in higher capital risk position as well as profitability increases and vice versa.

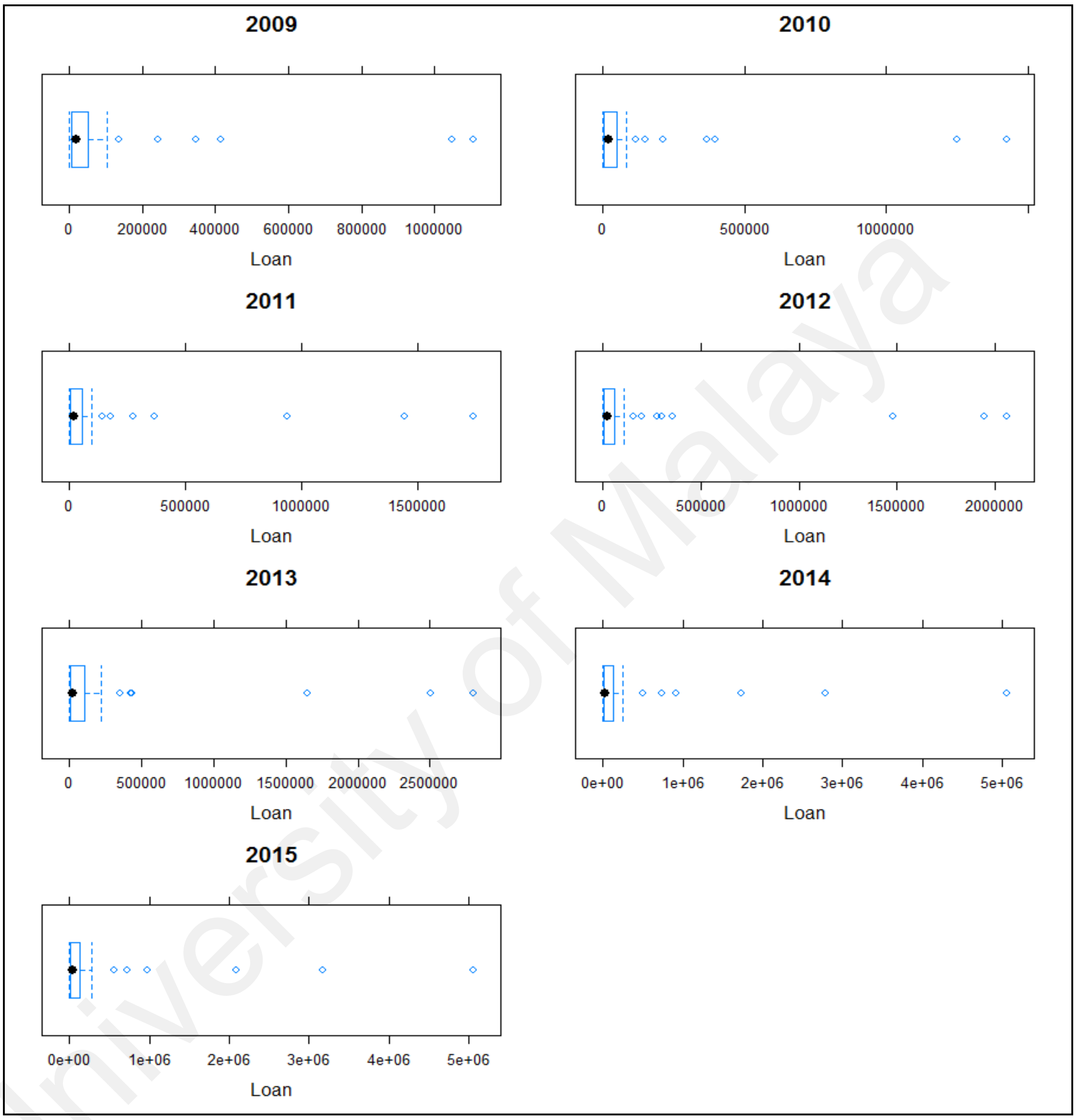

Figure 5.10 : Density test 2009-2015 (Loans)

Again, examining efficiency of banks in Malaysia is of worthy so as to explore why some banks are performing better while some are not while all of them have been operating in the similar economic environment. The above discussion and presentation of density test for the variables on yearly basis will assist to examine the discrimination of efficiency values among the banks. The following section will critically evaluate the efficiency values among the banks in Malaysia.

5.3 Empirical results and analysis

Table 5.3 gives a brief summary of the model used in this study. An output oriented model consists of 3 network nodes, 43 banks' data for 7 years, 4 inputs, 4 outputs (both desirable and undesirable), and two intermediate variables. MaxDEA software is used for calculation.

Table 5.3 : Model summary

Property	Value
Model Type	Envelopment Model
Number of Nodes	3
Number of Periods	7
Number of DMUs	43
Number of Inputs	4
Number of Outputs	4
Number of Intermediates	2
Distance	Non-radial (SBM)
Orientation	Output-oriented
Returns to Scale	Variable
Extended Options	Undesirable-Malmquist(Adjacent Mean of 2 TFP Indices Multiplicative and Geometric Mean)-Network(Free Intermediate Type)-Meta-frontier
Elapsed Time	1 Minutes 7 Seconds

5.3.1 Efficiency among the 43 commercial banks in Malaysia

The outcomes from the model run are the efficiency scores of all 43 banks in Malaysia for three different nodes: production approach, intermediation approach, and profitability approach. Therefore, the efficiency scores of different banks are recorded separately for all three nodes and are presented by Table 5.4, 5.5 and 5.6 respectively. This section specifically analyze the deviations (both among the banks and within every bank among the three nodes) among the banks in terms of banks' ability to convert inputs into outputs at the three proposed nodes of the proposed model. Here, meta-frontier is also applied. Based on the literature, by applying network DEA and meta-frontier analysis, not only the analysis are made on the efficiency differences but differences in efficiency which are due to changes in nature of banks are also explored.

5.3.1.1 Efficiency on Node 1- Production approach

Table 5.4 shows efficiency scores of 43 banks for Node-1 of the proposed model. There is a number of discrimination in results which signify that though these banks have been operating in the same region, efficiency of these banks vary from one to another. In the proposed network model, node-1 explains a bank's capacity to convert its liabilities and owners' equity into earning assets.

Table 5.4 : Efficiency scores from Network DEA with meta-frontier (Node-1)

DMU	Efficiency (2009)	Efficiency (2010)	Efficiency (2011)	Efficiency (2012)	Efficiency (2013)	Efficiency (2014)	Efficiency (2015)
FC1	0.866	0.842	0.639	0.432	0.506	0.850	0.822
FC2	1.000	1.000	1.000	0.816	1.000	1.000	1.000
FC3	0.340	0.243	1.000	1.000	1.000	1.000	1.000
FC4	0.720	0.887	0.940	1.000	1.000	1.000	1.000
FC5	1.000	1.000	1.000	1.000	1.000	0.833	0.843
FC6	0.895	0.954	0.915	0.887	0.115	0.183	0.179
FC7	0.184	0.356	0.367	0.307	0.282	0.559	0.441
FC8	0.482	0.583	0.546	0.712	0.402	0.459	0.263
FC9	0.604	0.381	0.690	1.000	1.000	1.000	1.000
FC10	0.843	1.000	1.000	1.000	1.000	1.000	1.000
FC11	0.371	0.210	0.221	1.000	0.921	1.000	1.000
FC12	1.000	1.000	1.000	0.252	1.000	0.149	1.000
FC13	1.000	1.000	1.000	1.567	0.038	0.013	0.059
FC14	0.531	0.691	0.947	0.959	0.976	1.000	1.000
FC15	0.731	0.763	0.976	0.968	0.989	0.981	0.946
FC16	1.000	0.900	0.740	1.000	1.000	0.022	0.553
FC17	0.088	1.000	1.000	1.000	1.000	1.000	1.000
FC18	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FC19	0.923	1.000	0.967	0.659	0.374	0.417	0.397
FI1	0.707	0.612	0.824	0.896	0.905	0.936	0.584
FI2	1.000	1.000	1.000	0.653	0.697	0.570	0.715
FI3	0.696	0.621	0.885	0.931	0.234	0.972	0.684
FI4	0.775	0.702	0.816	0.811	0.832	0.861	0.770
FI5	1.000	1.000	1.000	1.000	1.000	1.000	0.974
FI6	1.000	0.740	1.000	1.000	1.000	1.000	1.000
LC1	0.877	0.844	0.936	0.935	0.959	0.937	0.877
LC2	0.556	0.435	0.701	0.933	0.937	0.940	0.891
LC3	0.502	0.670	1.000	1.000	1.000	0.992	0.978
LC4	0.838	0.878	0.964	0.994	1.000	1.000	1.000
LC5	0.915	1.000	1.000	0.990	0.987	0.983	0.760
LC6	1.000	1.056	1.039	0.405	0.092	0.216	0.233
LC7	0.279	0.473	1.000	1.000	0.582	0.565	0.962
LC8	0.629	0.738	0.963	0.989	0.976	1.000	1.000
LI1	1.000	1.000	1.000	1.000	1.000	1.000	0.910
LI2	0.648	0.416	0.823	0.949	0.496	0.962	0.947
LI3	0.428	0.535	1.000	1.000	1.000	1.000	1.000
LI4	0.699	0.517	0.907	0.945	0.937	0.931	0.869
LI5	0.865	0.694	0.944	0.958	0.946	0.923	1.000
LI6	0.841	0.718	0.921	0.918	0.955	0.819	0.937
LI7	1.000	1.000	1.000	1.000	1.000	0.994	0.910
LI8	0.757	1.000	0.955	0.964	0.237	0.445	0.328
LI9	0.849	0.663	0.752	1.000	0.205	0.309	0.332
LI10	0.946	0.931	0.995	1.000	1.000	1.000	1.000

The results presented in Table 5.4 provide several critical issues. Out of the total of 43 banks, for every year under study, more than one bank are found to achieve unit efficiency score (score equals to 1). This particular result signifies that every year (2009-2015) a few banks in Malaysia are performing at their optimal level and score at the frontier. Since meta-frontier has been applied in the analysis, the discussion on efficiency scores would take into account different ownership categories of the banks (i.e. foreign conventional, foreign Islamic, local conventional and local Islamic) and the discussion is as follow.

First, analysis on the 19 foreign conventional banks, only one bank, namely FC18: the Royal Bank of Scotland Berhad, is found to be unit efficient throughout all the examined years. This result signifies that the Royal Bank of Scotland Berhad has been at the optimal level of converting its total source of fund into total earning assets. For each of the year under study, 2009 to 2015 in sequence , there are 6, 8, 8, 8, 9, 10, 10, and 10 banks respectively were located on the frontier (i.e. unit efficient) in respectively. Thus, on an average, half of the total foreign conventional banks were found as the unit efficient. Among the explanations for this results is the expectation of high competition among the foreign conventional banks in Malaysia.

During the study period, 5 banks are listed with high efficiency levels (i.e. more than 90%). These banks are FC2, FC4, FC5, FC10, and FC15 with annual average efficiency of 97%, 94%, 95%, 98% and 91% respectively. Two banks with lowest efficiency are FC7 and FC8 with 36% and 49% average annual efficiency respectively. Results in Table 5.4 indicates FC7 (Deutsche Bank Malaysia Berhad) has been consistently performing at inefficient capacity in converting capital into earning assets. This also means that most of its capital remained as the nonearning assets. Nonetheless, it is interesting to learn that , even though FC7 (Deutsche Bank Malaysia Berhad) has produced poor efficiency scores, indicating the least capacity for converting capital into earning assets throughout all the estimated years, relative to the best performers like FC18: The Royal Bank of Scotland Berhad, it has secured profit in almost every years.

Secondly, analysis on 6 foreign Islamic banks, all banks are found to score annual average efficiency of more than 71%. The highest efficiency is recorded for FI5: OCBC Al-Amin Bank Berhad with 99.6% and FI6: Standard Chartered Saadiq Berhad with 96.3%. Within this group, at least two banks were consistently found to be unit efficient in each year. It could also indicate the condition of high competition among group members. Also, this may be an indication that Islamic foreign banks are efficient than that of foreign conventional banks in Malaysian context. Among the 18 local banks (8 local conventional banks and 10 Local Islamic banks), only 7 banks (3 local conventional and 4 local Islamic) were found with high efficiency scores. In both groups, the least bank performers have been recorded with only 57% efficiency. In addition, it is important to note that none of banks was found with consistent unit efficiency throughout the study years.

5.3.1.2 Efficiency on Node 2- Intermediation approach

Table 5.5 presents the efficiency scores from the Node-2 of the proposed adaptive network DEA model. In this proposed model, the assumption made at this point banks create loans out of their earning assets (intermediate input) from node-1. In addition, expenses on interest is considered as input. However, liquidity requirement is excluded from this node. Thus, examining node-2 explains a fundamental operation of a bank- how efficiently bank can create loans from its earning assets with special attachment of interest expenses for financing the liability.

Table 5.5 : Efficiency from Network DEA with Malmquist meta-frontier (Node2)

DMU	Efficiency (2009)	Efficiency (2010)	Efficiency (2011)	Efficiency (2012)	Efficiency (2013)	Efficiency (2014)	Efficiency (2015)
FC1	1.000	1.000	0.642	0.417	0.247	0.515	0.429
FC2	1.000	1.000	1.000	0.448	1.000	1.000	1.000
FC3	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FC4	0.278	0.516	0.332	1.000	1.000	1.000	0.680
FC5	1.000	1.000	0.064	1.000	0.655	0.630	0.483
FC6	0.312	0.712	0.312	0.332	0.807	0.904	0.585
FC7	0.044	0.407	0.178	0.295	0.812	0.370	0.624
FC8	0.354	0.556	0.381	0.286	0.706	0.526	0.314
FC9	0.153	0.402	1.000	1.000	1.000	1.000	1.000
FC10	1.000	0.878	0.764	0.520	0.988	0.815	0.716
FC11	0.016	0.031	0.015	0.050	0.176	0.254	0.312
FC12	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FC13	1.000	1.000	1.000	0.890	1.000	0.901	1.000
FC14	0.095	0.171	0.145	0.152	0.300	0.308	0.240
FC15	0.135	0.247	0.195	0.152	0.372	0.341	0.273
FC16	0.092	0.725	0.283	1.000	1.000	1.065	0.658
FC17	0.058	0.016	0.074	0.214	0.395	0.517	0.421
FC18	1.000	1.000	1.000	1.000	0.807	1.000	1.000
FC19	0.142	0.358	0.245	0.117	0.597	0.377	0.289
FI1	0.139	0.170	0.137	0.145	0.072	0.130	0.131
FI2	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FI3	0.263	0.229	0.142	0.096	0.441	0.080	0.060
FI4	0.153	0.254	0.214	0.104	0.230	0.341	0.228
FI5	0.201	0.169	0.069	0.002	0.115	0.145	0.074
FI6	0.336	0.218	0.397	0.186	0.315	0.198	0.193
LC1	0.217	0.307	0.207	0.183	0.398	0.270	0.096
LC2	0.067	0.108	0.078	0.081	0.121	0.125	0.075
LC3	0.103	0.262	0.194	0.204	0.618	0.632	0.438
LC4	0.190	0.304	0.242	0.378	0.414	0.404	0.300
LC5	0.234	0.449	0.616	0.444	0.585	0.523	0.294
LC6	0.443	0.272	0.493	0.440	0.617	1.231	0.314
LC7	0.243	0.533	0.234	0.595	0.738	0.724	0.183
LC8	0.083	0.141	0.143	0.195	0.145	0.242	0.140
LI1	0.357	0.852	0.491	0.467	0.731	0.647	0.206
LI2	0.075	0.112	0.064	0.033	0.037	0.080	0.080
LI3	0.227	0.272	0.192	0.132	0.157	0.224	0.215
LI4	0.163	0.180	0.133	0.053	0.212	0.178	0.091
LI5	0.198	0.536	0.206	0.156	0.266	0.068	0.057
LI6	0.189	0.289	0.239	0.258	0.464	0.259	0.147
LI7	0.147	0.403	0.298	0.178	0.322	0.355	0.196
LI8	0.283	0.338	0.281	0.133	0.250	0.255	0.179
LI9	0.251	0.400	0.327	0.213	0.846	0.575	0.130
LI10	0.610	0.205	0.175	1.000	0.154	0.152	0.135

Among the 19 foreign conventional banks, two banks namely FC3: Bank of China (Malaysia) Berhad and FC12: Mizuho Bank (Malaysia) Berhad have found to be unit efficient during the study years. On an average, the better performer with more than 90% efficiency banks are FC2: Bank of America Malaysia Berhad, FC13:

National Bank of Abu Dhabi Malaysia Berhad and FC18: The Royal Bank of Scotland Berhad. 7 banks were found to perform with below 50% efficiency. The lowest efficiency score is recorded for FC11: J.P. Morgan Chase Bank Berhad with only 12% efficiency. Foreign conventional banks have been keeping many liquid assets into their volts. It could possibly be due to legislative reasons, management incapacity, lack of home ground benefit, economic turmoil into their home country etc. as suggested (Suffian et al., 2015).

In case of foreign Islamic banks, out of six banks, only FI2: Asian Finance Bank Berhad is found to be unit efficient throughout the years. Remaining 5 banks' efficiency have scored less than 20%, while FI5 is the least performing bank with efficiency score at 11% in converting earning assets into loans comparing to the unit efficient bank FI2- the most efficient among the foreign Islamic banks. Overall, the average efficiency of foreign Islamic banks is lower than that of foreign conventional banks during the study period.

In the results of Node-2, the efficiency levels of 18 local commercial banks for the year 2009-2015 presented in Table 5.5 depicts most of the banks are performing less than 40%. Among these banks, only two banks have scored more than 50% namely LC6: Malayan Banking Berhad and LI1: Affin Islamic Bank Berhad. The least performing among the local banks are LI2: Asian Finance Bank Berhad with only 6.9% and LC2: Alliance Bank Malaysia Berhad with 9.4% efficiency level. These low performing among all types of banks confirms that these banks are lagging behind in converting the earning assets into loans. This also signify that in comparison to the higher efficient banks (FC2, FC13, FC18 and FI2), the remaining 39 banks in Malaysia have less capacity to convert earning assets into loans and liquidity. It could also be the case that interest expenses and liquidity of these banks are high (Cook, 2009).

5.3.1.3 Efficiency on Node 3- Profitability approach

Table 5.6 presents results from node 3. Examining node 3 in this proposed NDEA model is the most crucial because the index of this node explains a bank's capacity in transforming the loans into net income. This proposed model also includes personal expenses as an input and non-performing loans as bad output. Thus, results from node-3 not only describes a bank's efficiency in converting loans into profit but also examines minimizing capacity of bad output (non-performing loans) from production process. This node also describes banks' involvement in operating costs.

Table 5.6 : Efficiency from Network DEA with Malmquist meta-frontier (Node3)

DMU	Efficiency (2009)	Efficiency (2010)	Efficiency (2011)	Efficiency (2012)	Efficiency (2013)	Efficiency (2014)	Efficiency (2015)
FC1	1.000	1.000	0.228	0.701	0.620	0.225	0.270
FC2	0.461	0.488	1.000	0.411	1.000	1.000	1.000
FC3	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FC4	0.952	0.098	0.228	1.000	1.000	0.048	0.114
FC5	1.000	1.000	0.027	1.000	1.000	1.000	0.886
FC6	0.689	0.170	0.379	1.000	0.850	0.599	0.559
FC7	0.033	0.043	0.021	0.147	0.284	0.146	0.053
FC8	0.705	0.215	0.510	1.000	1.000	0.497	0.559
FC9	0.740	1.000	1.000	1.000	0.450	0.454	0.453
FC10	1.000	1.000	1.000	0.598	0.283	0.399	0.362
FC11	0.018	0.005	0.006	0.031	0.010	0.119	0.487
FC12	0.382	0.241	0.298	0.800	0.537	0.536	0.547
FC13	0.490	0.497	0.497	0.495	0.445	0.481	0.519
FC14	0.746	0.173	0.300	1.000	0.784	0.615	0.615
FC15	0.817	0.186	0.315	0.963	0.736	0.656	0.635
FC16	1.000	1.000	0.287	0.380	1.000	0.404	0.318
FC17	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FC18	1.000	1.000	1.000	0.454	0.618	1.000	1.000
FC19	0.801	0.142	0.376	0.793	0.733	0.589	0.625
FI1	0.341	0.233	0.020	0.234	0.050	0.055	0.051
FI2	0.544	0.587	0.289	0.421	0.477	0.568	0.610
FI3	0.482	0.444	0.451	0.674	0.691	0.612	0.406
FI4	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FI5	0.204	0.116	0.236	0.511	0.672	0.475	0.556
FI6	0.153	0.425	0.311	0.578	0.541	0.141	0.296
LC1	0.501	0.107	0.057	1.000	1.000	0.310	0.297
LC2	0.745	0.028	0.015	0.761	1.000	0.417	0.398
LC3	1.000	0.522	0.672	0.895	1.000	1.000	1.000
LC4	1.000	0.082	0.468	1.000	1.000	0.606	0.628
LC5	1.000	0.049	0.068	1.000	1.000	0.130	1.000
LC6	0.657	0.250	0.228	1.000	0.988	0.570	0.651
LC7	1.000	1.000	1.000	1.000	1.000	1.000	1.000
LC8	1.000	0.202	0.737	1.000	0.841	0.537	0.619
LI1	0.199	0.046	0.146	1.000	0.016	0.156	0.293
LI2	0.673	0.627	0.343	0.666	0.575	0.490	0.503
LI3	0.603	0.354	0.419	0.697	0.695	0.651	0.576
LI4	0.812	0.040	0.061	1.000	0.397	0.558	0.511
LI5	0.020	0.012	0.200	0.453	0.225	1.000	0.341
LI6	1.000	1.000	1.000	0.925	0.720	0.656	0.527
LI7	0.392	0.116	0.170	0.733	0.812	0.606	0.543
LI8	0.406	0.101	0.184	0.617	0.690	0.570	0.388
LI9	0.159	0.222	0.432	0.580	1.000	1.000	0.408
LI10	1.000	0.256	0.539	1.000	0.177	0.459	0.528

First, the results of foreign conventional banks shows that the overall bank efficiency scores are relatively higher than the efficiency results at node-2 of the respective banks. Throughout the study years, the best performing among the foreign conventional banks with unit efficiency are FC3: Bank of China (Malaysia) Berhad and FC17: The Bank of Nova Scotia Berhad among these 19 banks. Most of the banks' efficiency scores range from 50% to 80%. The least performing banks were FC11: J.P. Morgan Chase Bank Berhad with 9.7% and FC7: Deutsche Bank (Malaysia) Berhad with 10.4% efficiency scores only.

The most efficient banks not only have been able to convert loans into net income but also in loan recovery (nonperforming loans). Considering the foreign Islamic banks, only FI4: Kuwait Finance House (Malaysia) Berhad is found to maintain unit efficiency throughout the study period. The remaining banks have found to score efficiency level with a range from 30% to 50%. The least performing is recorded for FI1: Al Rajhi Banking & Investment Corporation (Malaysia) Berhad with only 14.1% efficiency for that duration.

Analysis on the 18 local banks, only one bank is found to be unit efficient during the study period, namely LC7: Public Bank Berhad. Majority of the banks have scored efficiency level between 40% and 80%. The least efficiency performers among these banks were LI1: Affin Islamic Bank Berhad with only 26.5% efficiency followed by LI5: Bank Muamalat Malaysia Berhad with efficiency score of 32.2% only. These results indicates only a number local Malaysian-based banks that have been performing efficiently in converting loans into profit as well as minimizing loan loss provisions.

Figure 5.11 below summarizes the different efficiency scores for the three nodes from Table 5.4, 5.5 and 5.6. A number of issues can be highlighted in comparing the average efficiency of four different ownership of banks in this study.

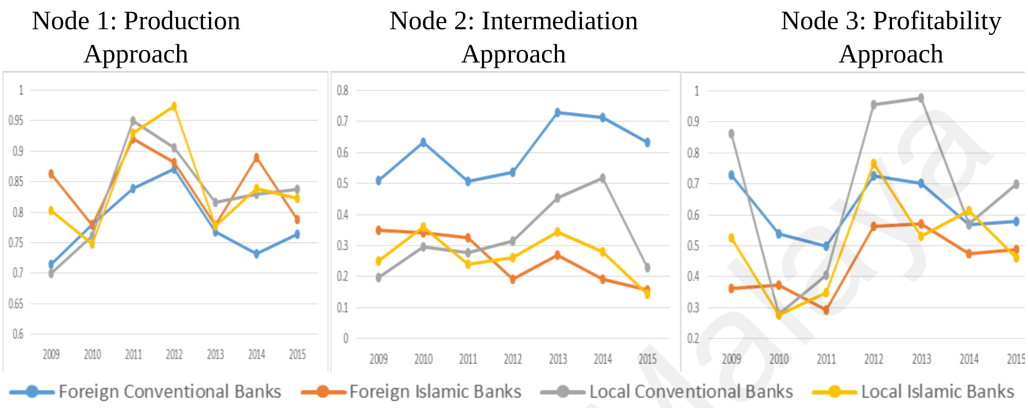

Figure 5.11: Comparative analysis of the results at three different nodes

The average efficiency scores are seen to be higher at node-1 as compared to node 2 and node 3 indicating that most of the banks are performing better while converting liabilities and owners' equity into earning assets. At Node-1 the local conventional bank have performed better than the foreign conventional banks. Similarly, local Islamic banks have performed higher on an average compared to that of foreign Islamic banks. **Figure 5.11** also shows similar efficiency trend during the period for all four bank categories: average efficiency rising from a lower level to a higher level during the year of 2009-2011. After 2011 the efficiency scores for all types of banks dropped during 2013 to 2015. Node-2 and Node-3 in Figure 5.11, also depict similar pattern over the study period.

While examining the average performance of selected groups of banks at node-2, it is shown that the least average efficiency is recorded for foreign Islamic banks. Again, the highest average efficiency score is recorded for foreign conventional banks. Similar to the pattern at node-1, all banks, regardless of bank ownership, are found to be least efficient in the year 2015 at Node 2. On an average, only the foreign conventional banks scored high efficiency level of 70% during 2013. Rest of the groups are observed to score average efficiency between 20% and 40%. Poor performance by all banks in Malaysia regardless of groups could suggest these bank are actually less efficient in converting earning assets into loans during those periods.

Lastly, the results of efficiency scores at Node-3 highlight a number of important issues. The ups and downs of efficiency scores at this node, particularly for local banks are obvious while the foreign banks' efficiency growth or decline of are a little flatter compared to that of local banks. This particular scenario reflects the issue that could happen following the direct effect of the "Master Plan" of Malaysian government on force merger and financial restructuring of local banks. Whereas, foreign banks' efficiency upward or downward trend could be due to its operative performances. In 2013, the average efficiency of local conventional banks was found to be almost 100%. This provides a clear indication of success of the Master Plan (financial restructuring and forced merger and acquisition) in Malaysian local banking sector since through obligatory mergers and acquisitions among the public banks and private banks increase efficiency among public banks in later periods (Fadzlan Sufian, 2011b; Sufian & Habibullah, 2009).

5.3.2 Efficiency change ratio

Efficiency change ratio (commonly represent with TGR) describes how much improvement is observed between the group-frontiers while comparing to the meta-frontier. Results in this section helps to define whether an individual bank has improved in its efficiency while the total group frontier is changing over a course of consecutive years. From a number of perspectives, the results from Table 5.7 is significant in capturing the relative performance of the banks in Malaysia. These results explain a bank's capacity to outperform its peer groups in respect to move towards the meta-frontier keeping in mind that both the frontiers are changing over the time. The value of efficiency change ratio equals to the efficiency change measured with meta-frontier divided by efficiency change measured with group-frontier: A value larger than 1 implies the shrinkage of the technology gap (an increase in TGR). Table 5.7 below presents the efficiency change ratio (TGR) of node-1 for the 43 commercial banks in Malaysia.

Table 5.7 : Efficiency change ratio (Node-1)

DMU	Efficiency Change (2009-10)	Efficiency Change (2010-11)	Efficiency Change (2011-12)	Efficiency Change (2012-13)	Efficiency Change (2013-14)	Efficiency Change (2014-15)
FC1	0.971	0.759	0.675	1.173	1.679	0.967
FC2	1.000	1.000	0.816	1.225	1.000	1.000
FC3	0.713	4.119	1.000	1.000	1.000	1.000
FC4	1.232	1.060	1.064	1.000	1.000	1.000
FC5	1.000	1.000	1.000	1.000	0.833	1.012
FC6	1.066	0.960	0.969	0.130	1.588	0.981
FC7	1.933	1.030	0.838	0.918	3.546	0.441
FC8	1.210	0.937	1.304	0.565	1.140	0.572
FC9	0.630	1.814	1.449	1.000	1.000	1.000
FC10	1.187	1.000	1.000	1.000	1.000	1.000
FC11	0.568	1.051	4.520	0.921	1.085	1.000
FC12	1.000	1.000	0.252	3.975	0.149	6.721
FC13	1.000	1.000	1.567	0.025	0.345	4.403
FC14	1.301	1.370	1.013	1.018	1.024	1.000
FC15	1.044	1.280	0.992	1.021	0.992	0.964
FC16	0.900	0.822	1.352	1.000	0.022	4.800
FC17	11.354	1.000	1.000	1.000	1.000	1.000
FC18	1.000	1.000	1.000	1.000	1.000	1.000
FC19	1.083	0.967	0.682	0.568	1.115	0.951
FI1	0.866	1.345	1.088	1.010	1.034	0.623
FI2	1.000	1.000	0.653	1.069	0.818	1.254
FI3	0.891	1.426	1.052	0.251	4.158	0.704
FI4	0.905	1.163	0.994	1.027	1.035	0.894
FI5	1.000	1.000	1.000	1.000	1.000	0.975
FI6	0.740	1.352	1.000	1.000	1.000	1.000
LC1	0.962	1.109	1.000	1.025	0.977	0.936
LC2	0.783	1.611	1.331	1.003	1.004	0.948
LC3	1.337	1.492	1.000	1.000	0.992	0.986
LC4	1.047	1.098	1.031	1.006	1.000	1.000
LC5	1.093	1.000	0.990	0.997	0.997	0.773
LC6	1.056	0.984	0.390	0.226	2.356	1.081
LC7	1.694	2.115	1.000	0.582	0.971	1.704
LC8	1.173	1.304	1.028	0.986	1.025	1.000
LI1	1.000	1.000	1.000	1.000	1.000	0.910
LI2	0.642	1.978	1.153	0.523	1.938	0.985
LI3	1.250	1.869	1.000	1.000	1.000	1.000
LI4	0.739	1.756	1.042	0.992	0.993	0.933
LI5	0.802	1.360	1.015	0.988	0.976	1.083
LI6	0.854	1.283	0.997	1.040	0.858	1.144
LI7	1.000	1.000	1.000	1.000	0.994	0.915
LI8	1.321	0.955	1.009	0.246	1.873	0.737
LI9	0.781	1.135	1.329	0.205	1.509	1.074
LI10	0.984	1.069	1.005	1.000	1.000	1.000

The results for node-1 in Table 5.7 demonstrate that all banks have difficulties in their efficiency change ratios. Particularly, efficiency change ratio from 2009 to 2010, most of the foreign conventional banks as well as local conventional banks were found to have an increase in TGR. It is reported that out of 19 foreign conventional banks, only 5 banks are reported for decrease in TGR. Similarly, out of 8 local conventional banks, only 2 banks were reported with decreasing TGR. On the contrary, majority of both foreign Islamic and local Islamic banks were reported with decreasing TGR (4 out of 6 and 6 out of 10 respectively). A similar trend is observed for all the years of study.

A substantially large shift of group-frontier compared to the meta-frontier is observable during the study period. For instance, FC17 is reported with TGR score of 11.354 in 2009-2010; TGR of FC3 and LC7 were scored at 4.119 and 2.115 respectively. Another abnormal TGR value is observed for FC16 during 2014-2015. Following decreasing TGR during the initial years is an unusual increase in the later year. Such phenomena reveals that foreign reinforcement or national regulation put them in such urgency to improve their performance.

With the results in node-1, it can be summarized that all 43 banks in Malaysia have been performing at a satisfactory level while continuing to improve their efficiency. Additionally, even though the banks have different individual efficiency results, these banks, generally, have been improving in a similar pattern. Moreover, a few foreign conventional banks also found to have almost no TGR changes around the years which signify that some banks remains at the group frontier or meta-frontier during the study period.

Table 5.8 presents the TGR values of node-2 for all 43 banks in Malaysia over the study period. As discussed earlier, node-2 describes a bank's capacity in producing loans out of its earning assets.

Table 5.8 : Efficiency change ratio (Node-2)

	Efficiency Change (2009-10)	Efficiency Change (2010-11)	Efficiency Change (2011-12)	Efficiency Change (2012-13)	Efficiency Change (2013-14)	Efficiency Change (2014-15)
FC1	1.000	0.642	0.650	0.591	2.088	0.834
FC2	1.000	1.000	0.448	2.234	1.000	1.000
FC3	1.000	1.000	1.000	1.000	1.000	1.000
FC4	1.855	0.642	3.016	1.000	1.000	0.680
FC5	1.000	0.064	5.547	0.655	0.962	0.768
FC6	2.281	0.438	1.065	2.430	1.121	0.647
FC7	9.253	0.438	1.653	2.756	0.456	1.687
FC8	1.572	0.685	0.752	2.466	0.745	0.597
FC9	2.620	2.488	1.000	1.000	1.000	1.000
FC10	0.878	0.871	0.681	1.898	0.826	0.878
FC11	1.991	0.493	3.202	3.544	1.446	1.226
FC12	1.000	1.000	1.063	0.941	1.018	0.983
FC13	1.000	1.000	0.142	7.040	0.901	1.109
FC14	1.803	0.851	1.050	1.967	1.027	0.779
FC15	1.829	0.791	0.776	2.450	0.918	0.799
FC16	7.856	0.391	3.532	1.000	1.065	0.618
FC17	0.275	4.646	2.890	1.848	1.308	0.815
FC18	1.000	1.000	1.000	0.807	1.239	1.000
FC19	2.526	0.683	0.477	5.115	0.632	0.767
FI1	1.220	0.804	1.060	0.500	1.796	1.008
FI2	1.000	1.000	0.622	0.708	0.573	1.009
FI3	0.872	0.621	0.673	4.610	0.181	0.746
FI4	1.665	0.844	0.486	2.209	1.482	0.669
FI5	0.841	0.409	0.032	1.880	1.262	0.511
FI6	0.648	1.822	0.469	1.694	0.627	0.978
LC1	1.412	0.674	0.883	2.178	0.678	0.354
LC2	1.623	0.723	1.032	1.500	1.035	0.600
LC3	2.552	0.742	1.051	3.022	1.024	0.693
LC4	1.598	0.796	1.563	1.096	0.976	0.742
LC5	1.914	1.374	0.720	1.319	0.895	0.562
LC6	0.613	1.817	0.893	1.402	1.993	0.255
LC7	2.193	0.439	2.541	1.241	0.981	0.253
LC8	1.696	1.014	1.362	0.745	1.667	0.576
LI1	2.390	0.576	0.951	1.564	0.885	0.318
LI2	1.498	0.567	0.515	1.138	2.143	0.997
LI3	1.201	0.704	0.689	1.189	1.426	0.961
LI4	1.101	0.740	0.400	3.990	0.837	0.509
LI5	2.708	0.384	0.759	1.700	0.256	0.831
LI6	1.528	0.826	1.081	1.797	0.558	0.566
LI7	2.746	0.738	0.599	1.804	1.104	0.552
LI8	1.195	0.831	0.476	1.870	1.020	0.702
LI9	1.592	0.817	0.650	3.982	0.679	0.226
LI10	0.336	0.851	5.729	0.154	0.984	0.889

The results during 2009-2010 reveal that most of banks have performed well which means they TGR have increased. Only 6 banks show declining scores in TGR for most of the two-year periods (2010-11 and 2011-12) and in 20014-15. Again these findings reveal foreign conventional banks have outperformed the other bank categories. There is one possible rationale to such situation which is recent devaluation of foreign currency exchange rate (Ching, Munir, & Bahron, 2016). Foreign banks in Malaysia might have taken advantage of their foreign deposits to offset the exchange rate risk since excluding foreign banks, other type pf banks would not have such opportunity (Ching et al., 2016; Ghroubi & Abaoub, 2016).

Table 5.9 presents TGR for the 43 banks in Malaysia for Node-3 of the proposed NDEA model. As, node-3 defines a bank's capacity in producing net income from its loans. During this, non-performing loans are also created and thus helps this proposed model to define a bank's true efficiency.

Table 5.9 : Efficiency change ratio (Node-3)

DMU	Efficiency Change (2009-10)	Efficiency Change (2010-11)	Efficiency Change (2011-12)	Efficiency Change (2012-13)	Efficiency Change (2013-14)	Efficiency Change (2014-15)
FC1	1.000	0.228	3.073	0.885	0.363	1.197
FC2	1.060	2.048	0.411	2.435	1.000	1.000
FC3	1.000	1.000	1.000	1.000	1.000	1.000
FC4	0.103	2.323	4.392	1.000	0.048	2.368
FC5	1.000	0.027	7.506	1.000	1.000	0.886
FC6	0.246	2.231	2.640	0.850	0.706	0.933
FC7	1.318	0.473	7.161	1.937	0.514	0.360
FC8	0.306	2.366	1.963	1.000	0.497	1.125
FC9	1.351	1.000	1.000	0.450	1.007	0.998
FC10	1.000	1.000	0.598	0.473	1.413	0.906
FC11	0.293	1.176	5.014	0.320	1.919	4.096
FC12	0.631	1.238	2.685	0.671	0.998	1.022
FC13	1.013	1.001	0.996	0.898	1.081	1.079
FC14	0.233	1.727	3.338	0.784	0.785	1.000
FC15	0.228	1.688	3.061	0.765	0.892	0.968
FC16	1.000	0.287	1.327	2.628	0.404	0.786
FC17	1.000	1.000	1.000	1.000	1.000	1.000
FC18	1.000	1.000	0.454	1.362	1.619	1.000
FC19	0.177	2.655	2.107	0.924	0.803	1.061
FI1	0.683	0.087	1.605	0.215	1.092	0.922
FI2	1.080	0.492	1.457	1.132	1.191	1.075
FI3	0.922	1.016	1.493	1.025	0.886	0.664
FI4	0.950	1.058	2.120	1.036	1.000	1.000
FI5	0.568	2.033	2.165	1.315	0.706	1.171
FI6	2.783	0.732	1.856	0.937	0.261	2.094
LC1	0.214	0.529	7.642	1.000	0.310	0.956
LC2	0.037	0.526	2.297	1.313	0.417	0.955
LC3	0.522	1.289	1.331	1.117	1.000	1.000
LC4	0.082	5.730	2.137	1.000	0.606	1.036
LC5	0.049	1.389	4.783	1.000	0.130	7.711
LC6	0.381	0.909	4.391	0.988	0.577	1.141
LC7	1.000	1.000	1.000	1.000	1.000	1.000
LC8	0.202	3.652	1.357	0.841	0.639	1.152
LI1	0.229	3.211	6.834	0.016	1.049	1.875
LI2	0.931	0.547	1.945	0.863	0.852	1.026
LI3	0.587	1.182	1.664	0.998	0.936	0.885
LI4	0.049	1.532	6.280	0.397	1.406	0.916
LI5	0.612	1.116	2.268	0.496	4.446	0.341
LI6	1.000	1.000	0.925	0.779	0.911	0.803
LI7	0.295	1.471	4.310	1.108	0.747	0.896
LI8	0.248	1.823	3.360	1.119	0.826	0.681
LI9	1.400	1.944	1.343	1.725	1.000	0.408
LI10	0.256	2.109	1.855	0.177	2.590	1.150

Table 5.9 here presents TGR ratio which defines how a frontier has performed comparing to meta-frontier. Similar to earlier findings, foreign conventional banks have found to be the best performer comparing to remaining three groups on an average basis. However, during 2011-2012, the TGR progress is comparatively higher than other years for almost every bank. External variables like GDP, inflation or regulatory issue might simultaneously affected every bank during this year. Likewise,

to the results of node-1 and node-2, foreign conventional banks have found to be progressed with TGR.

5.3.3 Technological change ratio

The technological change ratio is ratio of technological change measured with meta-frontier and technological change measured with group frontier. It also means that the meta-frontier shift relative to the group frontier shift. Here the 'catch-up' of a meta-frontier is examined compared to the group frontier. A value higher than 1 in technological change ratio implies a larger progress in the meta-frontier than that in the group-frontier. Thus, a bank might have performed better compared to its peers but may not have performed as much at the meta-frontier shifted aggregately. The technological change ratio measures the comparative performance between group-frontier shift and meta-frontier shift. Results from Table 5.10 reveals that on particular, no individual bank has reported to have consistence progress or regress over the study period.

Table 5.10 : Technological changes ratio (Node-1)

DMU	Technological Change (2009-10)	Technological Change (2010-11)	Technological Change (2011-12)	Technological Change (2012-13)	Technological Change (2013-14)	Technological Change (2014-15)
FC1	1.412	1.206	0.920	0.726	0.876	0.957
FC2	0.897	1.000	0.899	0.578	0.793	1.169
FC3	1.112	0.607	0.953	1.164	1.021	1.000
FC4	0.987	0.944	1.183	0.970	0.946	1.083
FC5	1.169	1.000	1.169	0.899	0.578	0.793
FC6	0.938	0.928	0.988	0.848	0.861	1.019
FC7	0.852	0.904	1.194	1.046	0.592	2.430
FC8	0.719	0.982	0.633	1.056	0.807	1.016
FC9	0.981	0.578	0.793	0.615	1.103	1.120
FC10	0.843	0.899	0.578	0.793	1.169	1.000
FC11	0.968	0.951	0.513	0.940	1.009	1.095
FC12	0.970	0.776	2.443	1.654	6.548	0.581
FC13	1.100	0.972	0.638	3.111	4.167	0.227
FC14	0.892	0.730	0.993	0.985	0.959	1.000
FC15	0.920	0.757	0.995	0.986	0.952	1.038
FC16	1.201	0.676	0.971	1.216	0.914	1.420
FC17	0.239	0.368	0.899	0.578	0.793	1.000
FC18	1.305	1.000	1.031	0.623	1.112	0.796
FC19	0.923	0.935	0.637	1.080	0.803	1.000
FI1	1.180	0.748	0.947	0.991	0.994	1.554
FI2	2.271	1.111	1.270	0.783	0.804	0.972
FI3	1.201	0.676	0.971	1.216	0.914	1.420
FI4	1.079	0.851	0.963	0.992	0.963	1.031
FI5	0.899	0.578	0.793	1.705	1.006	0.994
FI6	1.089	0.819	0.956	0.999	1.008	0.954
LC1	0.945	0.868	0.994	0.983	0.866	1.041
LC2	1.172	0.579	0.751	1.005	0.998	1.075
LC3	0.772	0.670	0.958	0.993	1.017	1.019
LC4	0.910	0.891	0.986	0.998	0.939	0.991
LC5	0.710	1.000	0.982	0.951	0.962	0.925
LC6	0.748	0.879	0.978	0.900	2.072	0.749
LC7	1.220	0.697	0.883	1.319	1.179	0.936
LC8	1.047	0.827	0.992	0.909	0.990	0.989
LI1	1.080	0.840	0.772	0.984	0.928	0.789
LI2	1.356	0.440	0.828	1.822	0.670	1.211
LI3	1.050	0.520	1.009	0.970	1.014	1.099
LI4	1.169	0.570	0.875	1.003	1.005	1.070
LI5	1.211	0.702	0.985	0.981	0.970	0.941
LI6	0.963	0.761	0.988	0.968	0.955	0.972
LI7	0.539	0.789	0.829	0.777	0.800	1.042
LI8	1.186	0.750	0.974	1.178	0.746	1.046
LI9	1.175	0.668	0.752	2.694	0.837	0.617
LI10	1.169	0.936	1.053	0.671	0.941	1.000

Results from foreign conventional banks reveal that out of 19 foreign conventional banks, 6 banks were reported with higher progress in meta-frontier than in group frontier during 2009-2010. Likewise; 4 banks in 2010-11, 5 banks in 2011-12, 7 banks in both 2012-13 & 2013-14 and 14 banks in 2014-15 were found having similar results. In this case, the less number of banks with progress in technological change ratio means that progress of meta-frontier did not slow down the growth of these banks. Thus, the existing technology progress of foreign conventional banks is higher than the progress in total meta-frontier. Similarly, out of 6 foreign Islamic banks, 5 banks were found having more progress in meta-frontier than that of group frontier for the year 2009-10 and 2014-15. However, for the remaining years, foreign Islamic banks have more progress than that of meta-frontier since only one bank was found to have progress in meta-frontier than that of group frontier. Overall, foreign banks' group-frontier progress often found less than the progress of meta-frontier.

During 2009-10, local banks in Malaysia indicating better progress in meta-frontier than the progress in group-frontier. More specifically, three local conventional banks out of 8 banks and 8 local Islamic banks out of 10 banks depict comparatively lower progress within the group-frontier. However, for the remaining years, (2010-2015) local banks are mostly found having higher progress in group-frontier than in meta-frontier. Only one or two banks were found having exception. Thus, it can be concluded here that local banks in Malaysia are progressing faster toward the frontier than the progress in meta-frontier.

Thus, considering efficiency at Node-1- converting deposits and equity into earning assets- it can be said that local banks in Malaysia have been progressing better than that of foreign banks in Malaysia. Even though the efficiency of foreign banks was found to be higher than the local banks. In other words, in terms of yearly progress local banks have outperformed the foreign banks. Analysis of node-2 in

Table 5.11 reveals that no individual bank has reported to have consistence progress/ regress over the study period. Taking account of all banks during 2009-2010 (40 banks out of total 43), the progress in group-frontier is observed to be higher than that of meta-frontier. The remaining three banks are the foreign conventional banks on which almost similar result is revealed during 2012-2014.

Table 5.11 : Technological changes ratio (Node 2)

DMU	Technological Change (2009-10)	Technological Change (2010-11)	Technologica l Change (2011-12)	Technologica l Change (2012-13)	Technologica l Change (2013-14)	Technologica l Change (2014-15)
FC1	0.870	1.550	0.636	1.074	0.874	0.931
FC2	0.508	1.000	0.850	2.075	0.306	0.912
FC3	0.912	1.195	1.019	1.422	1.130	1.000
FC4	0.657	1.558	0.571	1.038	1.033	1.968
FC5	0.912	5.547	0.850	2.075	0.306	0.912
FC6	0.438	1.018	0.690	0.578	0.793	1.546
FC7	0.574	2.154	0.605	0.687	1.571	0.784
FC8	0.618	1.256	1.024	0.437	0.936	1.524
FC9	0.663	0.578	0.793	0.401	1.289	0.956
FC10	1.139	0.912	0.850	2.075	0.306	1.139
FC11	0.630	2.029	0.635	0.752	1.389	1.401
FC12	0.663	0.983	1.203	1.336	1.217	1.019
FC13	1.172	0.364	7.040	0.627	1.468	0.901
FC14	0.588	1.175	1.115	0.433	0.680	1.283
FC15	0.505	1.221	1.107	0.403	0.645	1.256
FC16	0.777	1.015	1.374	0.850	2.075	0.306
FC17	0.132	0.203	0.528	0.578	0.793	1.227
FC18	1.196	1.000	1.125	0.768	1.413	0.930
FC19	0.396	0.582	1.028	0.445	0.931	1.404
FI1	0.719	1.568	1.132	0.572	0.617	1.112
FI2	0.705	0.727	1.119	0.975	0.951	0.883
FI3	0.777	1.015	1.374	0.427	0.815	1.340
FI4	0.539	1.082	1.300	1.443	0.370	1.098
FI5	0.850	2.075	0.306	0.527	0.735	1.110
FI6	0.417	1.223	0.670	0.623	0.728	0.934
LC1	0.317	0.572	0.998	1.159	0.484	1.403
LC2	0.537	1.190	0.969	0.540	0.892	1.523
LC3	0.357	1.227	0.750	0.792	1.255	1.148
LC4	0.963	0.681	1.073	0.487	0.657	1.257
LC5	0.366	0.728	0.920	0.493	1.138	1.435
LC6	0.504	0.501	1.067	1.104	0.751	3.803
LC7	0.850	2.075	0.306	0.914	1.061	3.350
LC8	0.479	1.223	0.800	0.300	0.730	1.240
LI1	0.351	1.087	0.557	1.004	0.699	0.714
LI2	0.426	1.276	1.290	0.521	0.756	1.191
LI3	0.546	1.111	1.452	0.477	0.772	1.376
LI4	0.651	1.351	1.292	0.466	0.785	1.497
LI5	0.341	1.571	1.317	0.472	0.847	1.387
LI6	0.303	1.174	0.427	0.324	0.532	1.368
LI7	0.220	0.588	0.561	0.232	0.387	1.316
LI8	0.414	0.550	1.293	0.470	0.883	1.143
LI9	0.582	1.036	1.539	0.706	1.270	2.522
LI10	0.808	1.175	1.345	1.367	0.840	1.125

During 2010- 2012, there is no specific trend observed in the results of all three groups of banks. However, during 2014-15, 33 banks were observed to show lower progress within the group-frontier than that of meta-frontier. This particular result reveals that technological context has forced the banks to be regressed in efficiency results while meta-frontier moved in greater speed. In simpler form, any frontier has progressed in terms of efficiency with lower speed than that of the meta-frontier. This could be a result of recent slowdown of economy in Malaysian context and impact of foreign trade uncertainty.

Node-2 explains a bank's capacity of creating loans out of earning assets. Thus, the summary of Table 5.11 portrays somewhat positive findings. Most of the banks in Malaysia have been competing in distribution of loans during the study year excepting 2014-2015.

Table 5.11 indicates that local banks, on an average, again have outperformed the foreign banks in creating loans. Table 5.12 presents technological change ratio of commercial banks in Malaysia for node-3: how banks are efficient in producing net-income out of its loans. Irrespective to any groups, all banks were found to be scored less progress in group-frontier compared to that of meta-frontier for the years 2009-10, 2012-2013, 2013-14 and 2014-15. However, almost all banks were found having higher progress in group-frontier compared to that of meta-frontier during 2010-11 and 2011-12.

Table 5.12 : Technological changes ratio (Node 3)

DMU	Technological Change (2009-10)	Technological Change (2010-11)	Technological Change (2011-12)	Technological Change (2012-13)	Technological Change (2013-14)	Technological Change (2014-15)
FC1	0.831	2.381	0.388	1.100	1.290	1.022
FC2	0.555	0.488	0.140	1.531	4.658	5.215
FC3	1.002	1.471	0.743	1.104	1.170	1.000
FC4	2.244	0.430	0.461	0.959	2.084	3.133
FC5	3.212	7.506	0.140	1.531	4.658	5.215
FC6	4.059	0.271	0.336	1.101	1.414	1.072
FC7	4.284	0.918	0.140	1.531	4.658	5.215
FC8	3.212	0.322	0.610	1.056	1.888	0.924
FC9	1.161	1.000	1.134	0.720	0.997	1.489
FC10	1.000	0.289	0.507	1.099	1.227	1.104
FC11	2.637	0.850	0.136	1.849	1.133	0.494
FC12	1.259	0.899	0.610	1.397	1.643	1.364
FC13	0.993	0.670	1.004	1.055	1.651	0.926
FC14	3.958	0.579	0.284	1.129	1.512	1.000
FC15	3.670	0.478	0.349	1.040	1.108	1.041
FC16	1.009	0.837	0.140	1.531	4.658	5.215
FC17	0.715	0.486	0.842	1.007	1.291	1.000
FC18	0.861	1.000	1.134	0.604	1.188	1.000
FC19	5.654	0.289	0.507	1.099	1.227	0.955
FI1	0.937	1.601	0.286	1.022	1.578	1.524
FI2	0.693	0.778	0.685	1.378	1.202	1.056
FI3	1.009	0.837	0.753	1.007	1.090	1.507
FI4	1.014	0.941	0.298	1.548	0.926	1.104
FI5	1.081	2.716	0.928	0.999	1.132	0.979
FI6	0.382	0.982	0.461	0.972	1.190	1.256
LC1	1.748	0.241	0.079	1.490	1.291	1.050
LC2	9.776	0.516	0.019	3.031	1.188	1.296
LC3	1.480	0.638	0.731	1.081	2.716	0.928
LC4	9.061	0.828	0.231	0.987	1.547	0.962
LC5	4.531	0.720	0.062	0.748	5.847	0.763
LC6	1.405	1.172	0.374	1.024	1.786	0.957
LC7	1.606	1.095	0.987	0.993	1.212	1.151
LC8	3.677	0.218	0.616	1.005	1.630	0.917
LI1	0.851	0.204	0.194	8.013	0.112	0.468
LI2	0.816	1.074	0.296	0.935	1.129	1.022
LI3	1.478	0.819	0.565	0.939	1.078	1.135
LI4	3.316	0.653	0.098	1.594	1.638	1.164
LI5	0.808	0.956	0.441	1.998	0.600	1.434
LI6	0.926	1.000	0.669	1.011	0.891	1.168
LI7	1.167	0.283	0.207	0.815	1.050	1.117
LI8	1.350	0.252	0.329	0.868	1.144	1.720
LI9	0.725	0.916	0.744	1.204	1.009	1.604
LI10	0.808	0.474	0.903	0.779	4.343	0.870

In aggregate term, it can be said that banks having group-frontier shift higher than the meta-frontier might be an indication of banks are improving their frontier shift closer to meta-frontier. However, in the following years, banks' group frontier progress were less than the meta-frontier shift. Recent economic slowdown can be a fact behind such frontier catch-up.

5.4 Sources of bank inefficiency

In order to identify the most influential external factors that have been contributing towards inefficiency of the banks in the Malaysian banking sector, the following regression model is estimated:

$$Efficiency_j = \beta_0 + \beta_1 \sum Bank\ specific_j + \beta_2 \sum Macroeconomic_j + \beta_3 \sum Ownership_j + \beta_4 \sum Nature_j + \varepsilon_{jt}$$

5-1

Here, $Efficiency_j$ is the Farrell's bias-corrected efficiency score of the j th bank that derived from meta-frontier DEA analysis in the earlier section. Also, *Bank specific, Macroeconomic, Ownership and Nature* represents bank specific variables, macroeconomic variables, bank ownership (foreign vs. local) and bank nature (conventional vs. Islamic) respectively as presented in **Table 2.10**. To capture the governance issue in both the foreign owned banks and local banks in Malaysia using binary dummy variable are included in the regression estimates.

The Simar & Wilson (2007) is calculated using the double bootstrap in FEAR package of R software pioneered by Wilson (2008). First "trunk.reg" command is applied to run a truncated normal regression with the maximum likelihood method. Second, command 'rnorm.trunc" is executed in FEAR to achieve the random deviations. Next, bias-corrected efficiency scores is run with the results from bootstrap. Then, a second stage regression using the bias-corrected efficiency results is tested. Fifth, another (double) bootstrap regression based on the achieved efficient results in earlier stage is run. Finally, marginal effect of contextual variables a bootstrap with 95% confidence intervals is constructed.

The estimation based on equation 5-1 is reported in **Table 5.13**. The bias-corrected coefficients are presented in second column. The associated 95% confidence bands are also listed.

Table 5.13: Results from double-bootstrap estimation

Item	Bias-adjusted	95% Bootstrap confidence interval	
	Coefficient	lower	Upper
ROA	0.0361*	0.0161	0.0661
MSHAR	-0.0014*	-0.0071	-0.0001
SIZE	0.0098	0.0017	0.0104
LIQ	-0.0040	-0.0103	0.0152
DIVERSI	0.0212*	0.0114	0.0319
CAPADQ	-0.0171	-0.0701	-0.0247
MGTQ	0.0329	0.0117	0.0622
ASSQ	0.0091	0.0031	0.0196
IB	-0.0783	-0.0944	-0.0621
FB	0.0417*	-0.0268	0.0597
CB	0.0458	0.0124	0.0616
IB	0.0081*	0.0061	0.0078
GDP	0.0019*	0.0012	0.0027
GDPG	0.0023*	0.0003	0.0043
INF	-0.0414	-0.0717	0.0196

* Significance at the 5% level.

The coefficients of first four variables can be directly interpreted as shifts in percentage efficiency scores. Details of these variables are given in sub-section 2.5 in Table 2.10. A total 7 out of 15 independent variables are statistically significant at 5% levels. The profitability indicator of Malaysian banks (ROA) is found to have positive impact on efficiency at the 5% level of significance. A similar and noteworthy finding of this study is that Malaysian bank efficiency is positively associated to income diversification (DIVERSI). This particular result signifies that

Malaysian banks are endowed with earning management, as such interest sensitivity of Malaysian banks reduces. Market share (MSHAR) of Malaysian banks is also found to be significantly associated to variables among the bank specific variables. The negative relationship between efficiency and total deposit indicates that customers are prone to higher return from their deposits and thus, banks are dealing with higher cost involvement in deposit collection.

The coefficient of foreign ownership remains positive and significant indicating that foreign banks benefit from higher efficiency. This finding is consistent with Lensink et al. (2008). In contrast, although the coefficient of local ownership is positive, it is not significant indicating that local ownership has no influence on the efficiency of banks within the group. This particular finding is consistent with the earlier studies of Athanasoglou et al. (2008).

The conventional bank nature is also found to be not significant indicating that being conventional bank, there is no influence on bank efficiency. Whereas, the coefficient of Islamic bank nature is positive and found to be significant. Thus, this result indicates that the nature of Islamic bank in Malaysia can have additive feature on bank efficiency. Such finding is contradictory (i.e., cost inefficient) with the earlier result of Beck et al. (2013). This can be an effect of social values and customer orientation with home field advantage particularly in Malaysian settings (Sufian & Kamarudin, 2015; Sufian, Mohamad, & Muhamed-Zulkhibri, 2008). The coefficient of GDP is positive and significant indicating that having a favorable economic growth can lead to an efficiency progress among the banks which is consistent with the earlier results (Gardener et al., 2011). Finally, the regression results support that inflation has negative influence on bank efficiency, since the coefficient is found negative but not significant indicating that even if the economy suffers inflation, bank managers can still operate efficiently by taking the appropriate measure at an earlier stage. This result is also consistent with the earlier results (Dietrich & Wanzenried, 2014; Perry, 1992).

5.5 Summary

In brief, it can be said that the application of this adaptive network DEA model allows benchmarking a bank's efficiency, not only from its own operation perspectives but also from its peer groups' perspectives. Analysis of efficiency of different nodes of a bank reveals that banks' efficiency varies due to the selection of variables and external context. With the proposed NDEA model, efficiency of a bank could be assessed from the efficiency point of view which is creating earning assets out of its capital (node-1); efficiency in terms of loan creation (node-2) and finally form the aspect of efficiency in making profit (node-3). These are the banks' efficiency from the perspectives of its own operation. Additionally, a bank's efficiency not only could be measured relative to its own peer group performance but also can be made across different groups. The following chapter provides an interactive discussion on the core findings and the obtained results from the proposed adaptive network DEA model.

CHAPTER 6: DISCUSSIONS

6.1 Introduction

This study examines efficiency index based on each of the three approaches (production, intermediation and profitability) within an adaptive network model in capturing the efficiency of whole bank's operations. The aptness of considering each of the approaches is largely dependent on a number of external variables as well (Wagner & Shimshak, 2007). For example, efficiency of commercial banks will be significantly deviate if governmental foreign policy or domestic tax policy change irrespective of banks' individual credentials. The technique of estimating bank efficiency from three different aspects of operational-related (production, intermediation and profitability) activities and tasks are deemed as most suitable for all bank operations generally involved performed all the related tasks simultaneously. Again, the input and output variables are listed in Table 2.9 of chapter 2 and the selection of each variables has literature significance that variables have been used in earlier studies (Paradi & Zhu, 2013). The descriptive statistics of these variables are shown in Table 5.2 of the preceding chapter.

In chapter 5, results were presented and analyzed. In this chapter, discussions on these results are made to draw findings and conclusions from this study. This chapter further examines the results to provide a comparative analysis. Robustness tests of this study are also presented.

6.2 Robustness of variable selection using CAMELS theory

This section illustrates the rationale of using CAMELS related variables for benchmarking bank efficiency as proposed in the Network Adaptive DEA model for this study. As explained in the earlier chapters, CAMELS measure the internal aspects of bank's function to measure the overall banks' efficiency by delving into the condition of: capital adequacy (C), asset quality (A), management quality (M), earnings (E), liquidity (L), and sensitivity to interest rate risk (S). In doing so, productivity index for all 43 banks are determined by estimating the efficiency of each aspect of banks' function: (1) Production (with equity and deposits as input, earning asset and non-earning assets as output); (2) Intermediation (with earning assets and interest expenses as inputs, liquid assets and loans as output); and Productivity (with loans and non-interest expenses as inputs, net income and loan loss provisions as output). The performance of each bank function measured separately is more practical as the tasks involved for each aspect are performed separately by all banks. The measurement index of the three aspects for each bank are enlisted in Table 6.1.

Table 6.1: Deviation in efficiency results because of approach selection

	Production approach			Intermediation approach			Profitability approach		
Category	MI	EC	TGR	MI	EC	TGR	MI	EC	TGR
LI1	0.691	0.984	1.029	0.595	0.898	1.003	0.959	0.969	1.051
LI2	0.711	1.013	1.041	0.155	1.210	0.959	0.493	1.147	1.246
LI3	1.000	1.000	1.018	0.930	0.914	1.091	0.808	1.109	1.006
LI4	0.904	1.005	0.714	0.700	1.056	1.023	0.978	0.985	0.994
LI5	0.842	1.050	1.074	0.347	1.082	1.021	0.807	1.094	1.073
LI6	1.000	1.000	1.158	1.000	1.000	1.320	1.000	1.000	1.474
LI7	0.921	1.028	1.004	0.398	0.843	0.914	0.895	0.962	1.017
LI8	0.698	1.066	1.009	0.384	0.975	1.010	0.902	0.967	1.001
LI9	1.000	1.000	1.138	0.899	0.966	1.000	0.972	0.985	1.030
LI10	0.929	0.994	1.025	0.600	0.917	0.944	0.992	0.996	0.995
LC1	0.940	0.999	0.986	0.209	0.951	1.124	0.774	1.083	1.069
LC2	0.914	0.962	1.133	0.309	0.839	0.837	0.905	0.942	0.741
LC3	0.952	0.979	1.001	0.305	0.924	1.060	0.838	1.008	1.014
LC4	0.725	1.030	1.058	0.107	0.920	1.057	0.661	1.087	1.133
LC5	0.924	1.007	1.004	0.314	0.843	1.006	0.807	1.037	1.054
LC6	0.763	1.013	1.074	0.378	0.863	1.048	0.822	1.092	1.092
LC7	0.945	1.018	0.998	0.264	0.873	0.992	0.757	1.055	1.054
LC8	1.000	1.000	0.970	0.336	0.842	0.988	0.883	0.978	0.978
FI1	0.308	1.750	0.944	0.737	0.844	0.822	0.987	0.983	0.397
FI2	1.000	1.000	0.870	0.149	1.311	1.050	1.000	1.000	0.966
FI3	0.728	1.070	1.126	0.563	1.324	0.949	0.712	1.184	0.745
FI4	0.543	0.967	0.971	0.426	0.793	0.881	0.653	0.827	1.007
FI5	0.952	0.940	0.994	0.341	1.066	0.961	0.721	1.009	1.134
FI6	1.000	1.000	0.855	1.000	1.000	0.987	1.000	1.000	0.997
FC1	0.973	1.021	1.008	1.000	1.000	1.000	1.000	1.000	1.003
FC2	1.000	1.000	1.000	0.921	1.039	1.031	1.000	1.000	1.000
FC3	0.677	0.939	0.983	0.949	1.007	1.000	0.890	0.989	0.992
FC4	1.000	1.000	0.967	0.971	0.977	0.957	0.980	1.000	0.911
FC5	1.000	1.000	1.070	0.997	1.000	1.028	1.000	1.000	0.957
FC6	0.934	1.049	0.978	1.000	1.000	1.002	0.987	1.000	0.941
FC7	0.975	0.997	1.328	1.000	1.000	1.000	1.000	1.000	1.000
FC8	0.983	1.021	0.883	1.000	1.000	1.000	0.739	1.075	0.813
FC9	1.000	1.000	1.000	0.993	1.003	1.002	0.988	1.000	0.881
FC10	0.764	1.064	0.974	0.962	1.014	1.001	0.628	1.043	0.951
FC11	0.699	1.001	1.041	0.904	0.975	1.014	0.913	0.972	0.969
FC12	0.666	1.186	1.058	0.964	1.035	1.029	0.716	1.067	1.072
FC13	0.747	1.004	0.970	0.833	0.999	0.989	0.783	1.081	0.997
FC14	0.883	1.064	0.990	0.999	1.000	0.994	0.999	1.000	0.981
FC15	0.970	1.038	0.951	1.000	1.000	1.000	0.725	1.132	0.948
FC16	0.819	1.033	0.977	0.923	1.019	1.018	0.824	1.027	0.974
FC17	0.515	1.044	1.096	0.809	1.072	1.027	0.716	1.103	1.064
FC18	0.940	1.063	0.998	1.000	1.000	0.993	1.000	1.000	0.961
FC19	0.814	1.046	0.969	0.999	1.001	1.012	0.895	1.052	0.972
Mean									
FIBs	0.861	1.030	1.092	0.959	1.007	1.005	0.883	1.028	0.967
FCBs	0.706	1.345	0.977	0.613	1.105	0.920	0.814	1.042	0.856
LIBs	0.895	1.040	1.028	0.277	1.081	1.014	0.805	1.035	1.016
LCBs	0.881	1.012	1.007	0.559	1.015	1.030	0.891	1.029	1.077

MI: Malmquist index; EC: efficiency changes; TGR: technology gap ratio; LIBs: Local Islamic Banks; LCBs: Local conventional banks; FIBs: Foreign Islamic banks; FCBs: Foreign conventional banks

Table 6.1 reveals that results from all Malmquist index scores, efficiency change ratios and technological ratio changes for all 43 commercial banks in Malaysia based on the three operational aspects have significant deviation. By examining the results, it reveals that the local banks are productive banks in all aspects of operations. The average highest productivity for local banks has observed in case of production approach by 0.895 and 0.881 for LIBs and LCBs respectively. Based on intermediation aspect, however, the productivity scores among the local banks have scored the lowest by 0.277 and 0.559 for LIBs and LCBs respectively. From all aspects, there is no significant differences in efficiency scores among the local banks operating in Malaysia.

Another interesting finding is that the efficiency scores of local banks (both Islamic and conventional) and are found to be progressed over the period. In particular, the local Islamic banks' Malmquist index are found to be higher than local conventional banks for all three aspects. On the other hand, the Malmquist index scores among the foreign banks are found less than unity (value of 100%) indicating that foreign banks are progressing their operations in Malaysia compared to the counter local banks. However, in all approaches, the average Malmquist index results (Production approach: 0.861, Intermediation approach: 0.959, Profitability approach: 0.883) of foreign Islamic banks' are higher than that of the foreign conventional banks (Production approach: 0.706, Intermediation approach: 0.613, Profitability approach: 0.814).

The average Malmquist index for foreign Islamic banks is found to be higher with 95.9%. For all aspects, the average efficiency scores of foreign conventional banks are higher than that of foreign Islamic banks. The highest average efficiency progress is observed for the case of production approach.

By definition, TGR measures of how much a DMU (i.e., a bank) gets closer to or farther away from the meta-frontier. It is found that on an average local conventional banks have higher change in both profitability and intermediation approach with a value of 1.077 and 1.030 respectively. However, local Islamic banks have found with higher level of progress in production approach by 1.028. The highest TGR is evident in case of local conventional banks in profitability approach by 1.077. The results from foreign Islamic banks reveal that, on an average, TGR is higher than those of foreign conventional banks (Production approach: 1.092, Intermediation approach: 1.005, Profitability approach: 0.967).

In summary, the above results in Table 6.2 depict differences in efficiency scores among different bank categories and there are also significant deviation among the results for all three approaches.

Table 6.2: Summary of efficiency scores among different groups of banks

	Foreign Islamic banks	**Local conventional banks**	**Foreign Islamic banks**	**Foreign conventional banks**
Average efficiency				
Production approach	1.040	1.012	1.030	1.345
Profitability approach	1.035	1.029	1.028	1.042
intermediation approach	1.081	1.015	1.007	1.105
No. of Efficient Banks				
Production approach	8	5	4	17
Profitability approach	1	6	4	17
Intermediation approach	4	0	4	16
Total number of banks	10	8	6	19

For each banks operation, the number efficient DMU has also deviate. This are clear evident of significant changes in the efficiency scores among the banks. Hence, by using any single approach to explain the bank efficiency may lead to a biased results and could lead to biased benchmarking. The application of CAMELS as the guidelines in selecting variables in examining the bank efficiency is more effective.

6.3 Robustness of the proposed NDEA model

Several robustness tests are performed to check on the appropriateness and significance of the proposed model for benchmarking efficiency of banks in Malaysia can be seen in Figure 6.1. Comparative line diagrams are shown for all banks in three different methods: Malmquist DEA, Malmquist meta-frontier DEA and the proposed adaptive NDEA model.

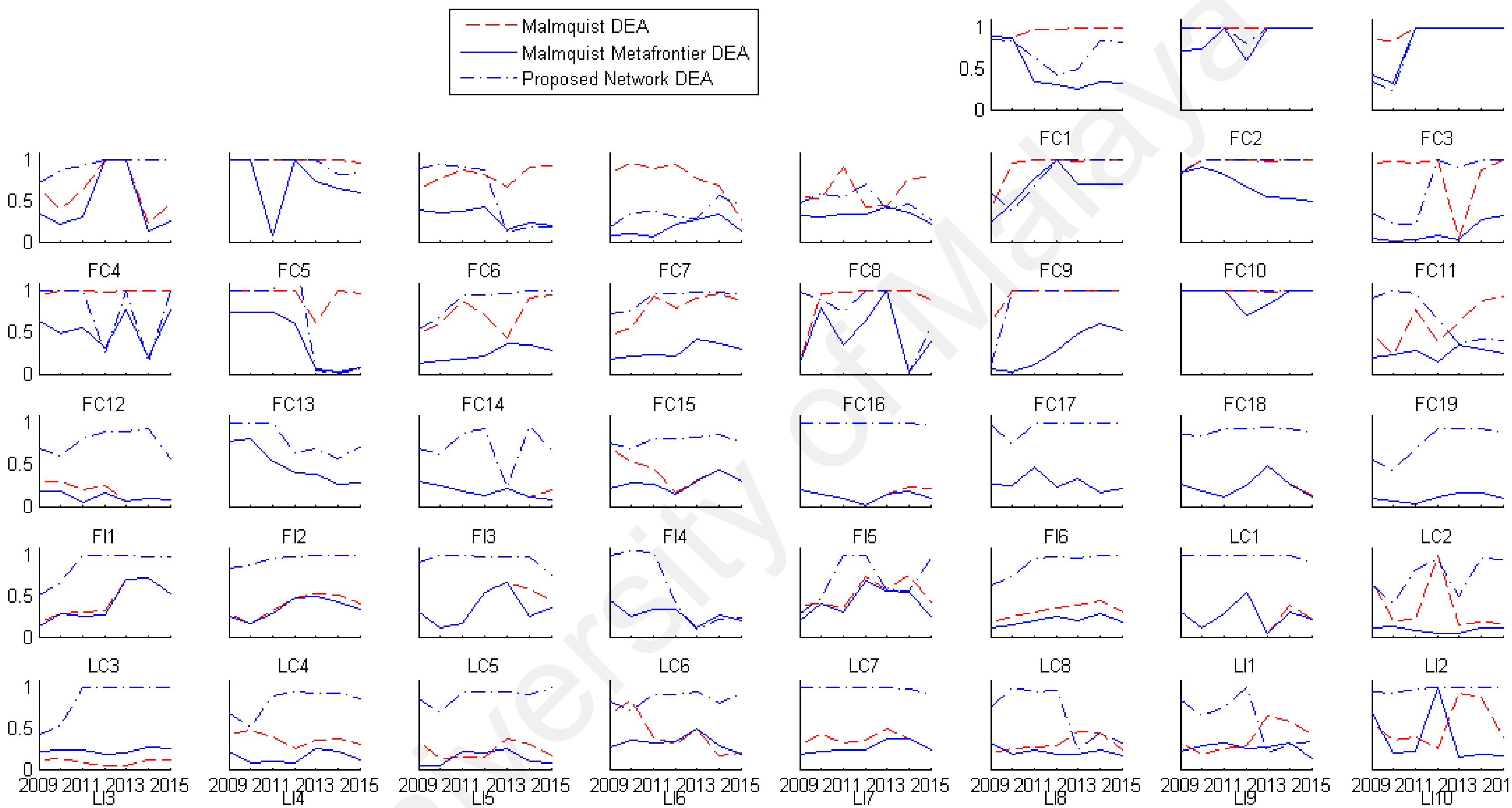

Figure 6.1: Robustness of bank efficiency with the proposed NDEA model.

Notes: Unlike traditional approaches, this proposed model encompasses the entire process of a bank. Hence, the results are robust.

It is evident from the Figure 6.1 that there are obvious differences in terms of bank efficiency among the banks based on the proposed NDEA model used for this study. Different efficiency scores (production, intermediation and profitability) for each DMU are presented.

By comparing the trends of line diagrams, several some major findings are revealed by this study. In general, the results of Malmquist index and Malmquist meta-frontier DEA index depict lower efficiency scores compared to the efficiency scores of the proposed NDEA model (e.g. LI1-LI10, FC12-FC19). Only for few banks, for example FC1-FC3, FC6-FC7 and FC19, higher efficiency results have observed only for Malmquist index compared to the results of proposed NDEA model. This is clearly evident that the proposed adaptive NDEA model which employs meta-frontier DEA is more meaningful since both banks' internal black box and external factors have been considered during efficiency calculation.

More specifically, not only the banks' variables but also the proper definition of a bank's operation is considered and examined using this proposed NDEA model. Hence, estimating the efficiency by only using the Malmquist DEA or Malmquist meta-frontier DEA, could underestimate the efficiency scores of different bank categories. Additionally, the trends shown by the proposed NDEA adaptive model clearly suggest that there are actually steady movement of efficiency scores during the period under study. Figure 6.2 depicts a comparative analysis of line diagrams for each bank from the perspective of bank operations: Node 1, Node 2 and Node 3 of the proposed adaptive NDEA model.

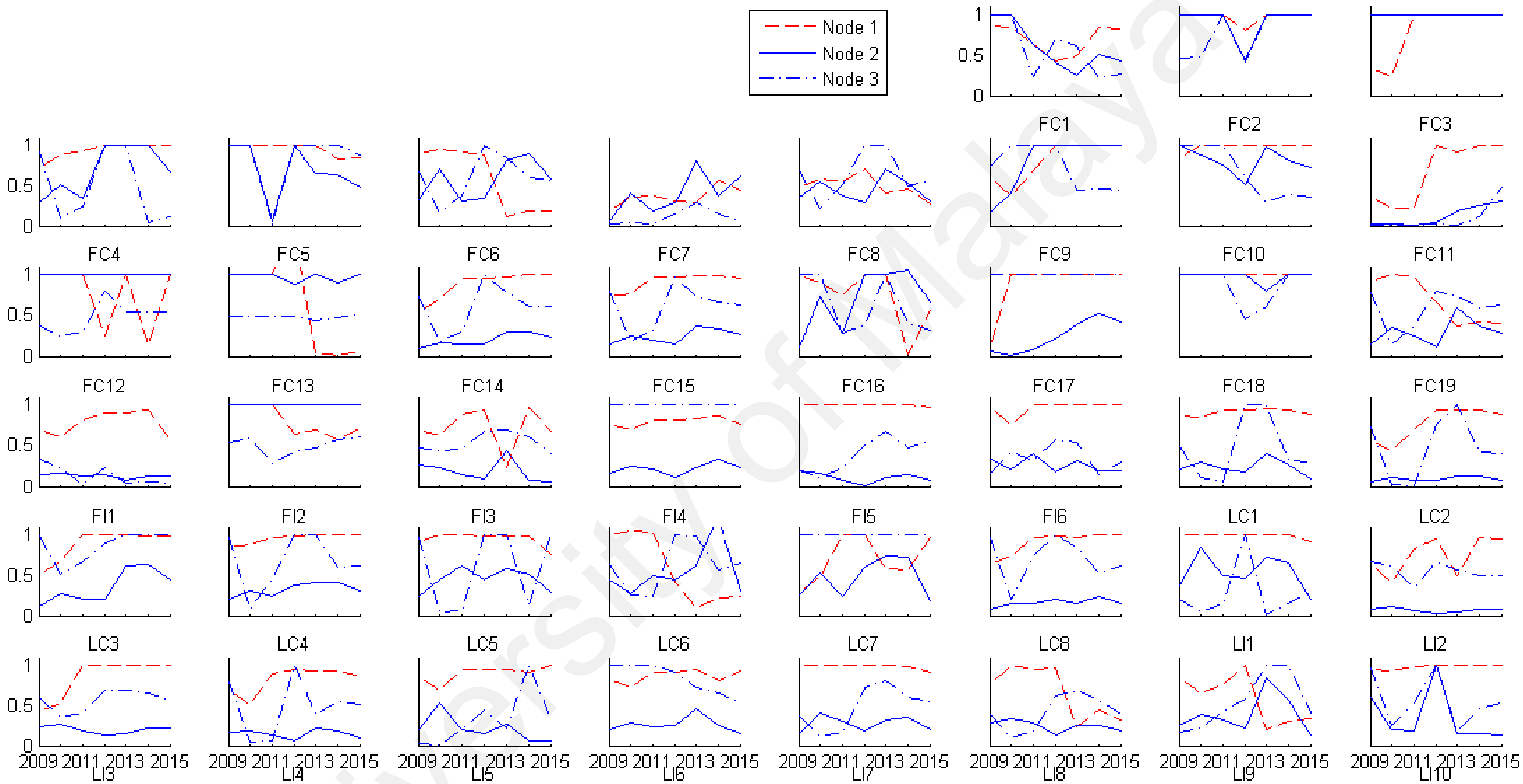

Figure 6.2: Bank efficiency based on proposed approaches

Notes: Unlike traditional approaches, this proposed model encompasses the entire process of a bank. Hence, the results are robust. (Production– Node 1; Intermediation– Node 2; Profitability– Node 3)

Generally, that the figures illustrates different efficiency scores among the banks of the same category are estimated at different nodes. These diagrams are crucial in describing the performance of specific banks. On average, majority of the banks score higher level of efficiency at Node-1 (production). Several banks also portray high efficiency scores at Node-3 (profitability) over the study period. Finally, node-3: profitability performance of banks are found lower than that of other two nodes. These particular findings could suggest for some urgency for the policy makers to examine certain individual banks and insists future development of the banks and more importantly to avoid bank failure in advance.

6.4 Robustness test of bank efficiency at the three nodes

This section tests the rationale of using meta-frontier technology in the proposed adaptive network model while examining bank efficiency. Both parametric (t-test) and non-parametric (Mann-Whitney U test and Kruskall-Wallis test) tests are utilized to examine the robustness of efficiency scores based on bank heterogeneity (either bank ownership or bank orientation). Application of the "Mann-Whitney U" test for examining robustness of the comparative results has now becoming more common (Fuentes, 2011; Sufian & Kamarudin, 2015). Mann-Whitney U test is a non-parametric test which examines if a randomly selected value from one sample is likely to be less than or greater than that of a randomly selected value from the other sample.

Unlike a t-test, a non-parametric approaches like Mann-Whitney and Kruskal Wallis tests do not assume the sample data are normally distributed. Additionally, the Mann-Whitney U test is more powerful compared to the other non-parametric alternative tests, i.e., the Sign Test (Conover, 1980; Fuentes, 2011). For this purpose, Mann-Whitney U and Kruskal Wallis test are applied to check the robustness of efficiency scores between conventional and Islamic banks.

The Mann-Whitney U test results in Table 6.3 reveal that the proposed adaptive network model efficaciously estimate the bank efficiency scores based on its operations .

Table 6.3: Robustness with Mann-Whitney U test (conventional vs. Islamic)

Test statistics	Mann-Whitney U (Wilcoxon Rank-Sum) test z (Prb>z)		Kruskall-Wallis Equality of Populations test X^2 (Prb > X^2)		*t*-test T(Prb>t)	
	Mean rank	z	Mean rank	X^2	Mean	t
Node 1						
Islamic banks	86	-3.41***	86	19.86***	0.869	6.34***
Conventional banks	79		79		0.532	
Node 2						
Islamic banks	62	-2.54**	62	3.58**	0.637	4.51**
Conventional banks	78		78		0.744	
Node 3						
Islamic banks	71	-5.05**	71	17.24**	0.727	5.37***
Conventional banks	83		83		0.861	

** and *** indicate significance level at the 5% and 1% levels respectively.

Notes: Both non-parametric (Mann-Whitney U test and Kruskall-Wallis test) and parametric (t-test) tests are utilized to examine the robustness of efficiency between Islamic and conventional banks. Sample size is total 43 (Islamic 16 banks and conventional banks 27 banks).

The results in Table 6.3 concludes that Islamic banks in Malaysia have outperformed the conventional banks at Node-1 (production function). In other words, the Islamic banks are performing better in terms of financing their capital. On the other hand, the conventional banks show higher efficiency in loan creation (at Node 2) and profit creation (at Node 3). Similar results are shown as significant at either 1% or 5% level of significance in both t-test and Kruskall-Walls test. The Mann-Whitney U test results in Table 6.4 reveal that the proposed NDEA explains that relationship between bank ownership in Malaysia and their efficiency scores.

Table 6.4: Robustness test (local vs. foreign)

Test statistics	Mann-Whitney U (Wilcoxon Rank-Sum) test z (Prb>z)		Kruskall-Wallis Equality of Populations test X^2 (Prb > X^2)		*t*-test T(Prb>t)	
	Mean rank	z	Mean rank	X^2	Mean	t
Node 1						
Local banks	92	-2.37***	92	18.32***	0.821	4.01***
Foreign banks	63		63		0.638	
Node 2						
Local banks	95	-1.01**	95	16.25**	0.751	3.17**
Foreign banks	89		89		0.699	
Node 3						
Local banks	65	-0.98**	65	5.67*	0.913	6.24***
Foreign banks	75		75		0.955	

** and *** indicate significance level at the 5% and 1% levels respectively.

Notes: Both non-parametric (Mann-Whitney U test and Kruskall-Wallis test) and parametric (t-test) tests are utilized to examine the robustness of efficiency between local and foreign banks. Sample size is total 43 (local 18 banks and foreign banks 25 banks).

From the results in Table 6.4, it can be concluded here that local banks in Malaysia have better performance compared to the foreign banks at both Node-1 and Node-2. That is, local banks are performing better in financing their capital as well as in converting loans from its earning assets. However, foreign banks are found to be more efficient in profit creation from its loans (Node-3). These results are found significant at both 1% and 5% level of significance. Similar results are also produced by the other two tests at the three nodes. The Kruskal–Wallis test by ranking the One-way ANOVA is tested and shown in Table 6.5.

Table 6.5: Robustness test (Node)

Kruskall-Wallis [Equality of Populations Test] - X^2 (Prb > X^2)		
	Mean rank	X^2
Node 1	94	15.72***
Node 2	83	
Node 3	67	

*** indicate significance level at 1% level

The Kruskal–Wallis test by ranking the One-way ANOVA on ranks is a non-parametric method which is used for comparing two or more independent samples of equal or different sample sizes. It extends the Mann–Whitney U test when there are more than two groups. It is seen from Table 6.5 that the rank of nodes in efficiency scores from this proposed adaptive network model is Node 1, Node 2 and Node 3 with mean rank value of 94, 83 and 67 respectively. This result is found significant at 1% level of significance.

6.5 Sources of bank inefficiency

By examining the effect of contextual variables on bank efficiency in Malaysian context in Table 5.13, this study finds that being local and conventional banks in nature have no influence in the banking efficiency along with inflation. The examination of external variables in Table 5.13 also reveals that the Islamic bank nature, foreign bank ownership and GDP have significant positive impact on Malaysian banking sector. The merit attention is observed for bank nature (Islamic banking), GDP and foreign ownership of banking. These findings supports the earlier findings (Gardener et al., 2011; Sufian & Kamarudin, 2015). Among the bank specific variables, bank profitability and income diversification are found positively linked with Malaysian bank efficiency while market share (total deposit) is found have negative influence in efficiency (c.f. Table 5.13). These results are significant at 5% level of significance.

6.6 Key findings

The key findings of this thesis can be summarized as follows:

- The proposed adaptive network DEA model explains bank's total efficiency.

- Application of variables (inputs and outputs) based on only traditional approaches (profitability, production and intermediation) reveal biased results. Thus, variables based on CAMELS can provide holistic results.
- Studying the effect of contextual variables, this study finds that local banks in Malaysia failed to receive 'home ground benefit'.
- However, Islamic bank nature, foreign bank ownership and GDP have significant positive impact on Malaysian banking sector.
- Among the bank specific variables, bank profitability and income diversification are found to be positively significant while market share is found to be otherwise.

6.7 Summary

This chapter exclusively summarizes and discusses the major findings of this study. Firstly, robustness test of variables selected for this study based on CAMELS in the Malaysian banking context is presented. Secondly, assessing the appropriateness of estimating efficiency of the 'black box' at three separate nodes based on bank operational functions (production, intermediation and profitability) – by proposing an adaptive network DEA model. A robustness tests also has been performed to justify the selection of variables. Finally, both parametric (t-test) and non-parametric (Mann-Whitney U test and Kruskall-Wallis test) tests are employed to examine the robustness of efficiency scores based on bank heterogeneity (either bank ownership or bank orientation). The next chapter probe into the concluding part of the study.

CHAPTER 7: CONCLUSION

7.1 Summary

This study proposes an adaptive network data envelopment analysis (DEA) model which measures the bank efficiency by incorporating all the three mainstream bank operation functions with special focus on loan-loss provision (bad output). To the best of my knowledge, this is the first of its kind that gives a holistic approach to estimate the efficiency of all banks operating in Malaysia. The conceptual framework of this study illustrates the roadmap on the application of nonparametric DEA methods. By considering efficiency measurement at each of the bank's operation, namely production, intermediation and profitability. Pointing to the inability of the basic DEA model to probe into measuring different aspects of bank efficiency, exploiting the proposed adaptive network model delve into the black-box concept in examining the different aspects of bank efficiency. The adaptive model has effectively revealed the characteristics of bank process and subsequently assisted in examining the standard performance.

The issue of unfavorable (bad) output when applied to efficiency examination has been well addressed by incorporating loan-loss provision in the proposed model to construct a more robust estimator. When applied to the same data, the adaptive network DEA model has been proven to be more robust than the standard normal DEA or metafrontier DEA (c.f., Chapter 6, Subsection 6.2, Table 6.1). As a whole, the objectives of this research have been achieved fruitfully and the research questions have been answered throughout the process of constructing and applying the proposed adaptive network DEA model; and in the process of developing, the model incorporates all the approaches of bank efficiency measurement as well as unfavorable output. In due course, it is expected that this study would shed some light on the banking sector of Malaysia and abroad and the potential benefits offered by the proposed adaptive model.

7.2 Conclusion

The main and general conclusions of this research are discussed in this subsection. This study has developed an adaptive network DEA model to address the present limitation of explaining a bank's total operation while examining bank efficiency. This framework sets out to answer the research questions dictated in Chapter 1. The first research question specifically aimed at obtaining more insights on the definition of banking process. This investigates into several aspects of the banking process; selection of variables; explaining the black-box; and identifying sources of bank inefficiency.

In realization of multiple aspects of banking process, a three stage network model is recommended as a technique to monitor the quality of the banking process. The presence of undesirable output in the banking process initiates the importance of incorporating bad output in the proposed network DEA model. Examining bank efficiency overtime by using metafrontier DEA further explains efficiency of Malaysian banking system. By focusing on different of banking ownership and bank orientation, the metafrontier DEA provides more informative benchmarking recommendation for both the policymakers and bank managers.

This study examines efficiency of all 43 commercial banks operating in Malaysia by unveiling the traditional efficiency concept "black-box" with a proposed adaptive three-stage network model. Bank efficiency examinations applying any of the three traditional approaches (intermediation, production and profitability) produce biased result. Because, when bank efficiency is examined based on its profitability, a complete ignorance of banks long term sustainability (capital ratio) can see a profitable bank into a bankrupt one. Earlier studies have proposed CAMELS rating for selecting bank efficiency variables. But, their studies have failed to explain how these variables are linked to each other. The question which may arise is, whether all inputs are simultaneously used to produce all outputs. Hence, this research has proposed an adaptive network DEA model (c.f. Figure 1.2) that explains not only the overall efficiency of banks but also the functional efficiency of banks. It is also explained here that bank functions are mainly threefold (specific function of a bank i.e., Node 1: production, Node 2: intermediation and Node 3: profitability). Thus, three nodes are included in our proposed NDEA model. In addition to this, bank operations in all stage is considered to be non-radial. Non-radial means, banks' inputs and outputs are variably related to each other. In other words, simply by increasing banks' input, a proportionate output cannot be expected.

A number of issues can be highlighted when comparing the average efficiency of two groups of banks in this study. Results for Node-1 present that on an average the local conventional banks have performed better than that of foreign conventional banks. Similarly, local Islamic banks have higher efficiency, on an average, compared to that of foreign Islamic banks. While examining the average efficiency of selected groups of banks in Malaysian context for node-2, it is seen that the least average efficiency is recorded for foreign Islamic banks. Again, the highest average efficiency is recorded for foreign conventional banks. Similar to the pattern in node-1, all types of banks have found least efficient in the year 2015. Nevertheless, this poor performance by all groups signify that Malaysian banks, irrespective of all groups, are less efficient in converting earning assets into loans.

This chapter summarizes the key points of this study including empirical contribution, theoretical contribution and managerial implications. In addition, possible future studies based on this study are also discussed. Limitations of this thesis is also indicated at the end of this chapter.

7.3 Empirical contributions

The empirical contributions of this study are threefold. Firstly, this study explains why traditional black-box has failed to probe into bank's functional efficiency and to solve this limitation, this study proposes a three-stage adaptive network DEA model to measure bank efficiency. The findings of this research suggest that efficiency scores could vary with respect to specific operation function of a bank like production, intermediation, and profitability. In the proposed adaptive model, the specific functions are represented by stages of nodes. The process at the three nodes operates in sequence that some outputs from one node transform as inputs to another node. During banking operations, both non-performing loans (undesirable output) and net income (desirable output) generates in the banking process.

Secondly, this study addresses the effect of undesirable output to bank efficiency. This study has shown that benchmarking of a bank only based on net income may not be accurate and even could lead to a bankruptcy although bank had high efficiency score in the earlier years. In recent years, Malaysia has successfully strengthen its banking sector through mergers and acquisitions (Krishnasamy et al., 2004; Lai et al., 2015; Sufian, 2007b). Thus, considering bad outputs in estimating bank efficiency in Malaysia is very crucial. Results of the proposed model also provide a comparative efficiency score of Islamic vs. conventional banks in the Malaysian context.

Finally, this study explains and empirically presents the importance of using various approaches (production, profitability and intermediation) to describe bank efficiency. The findings of this study suggests that efficiency scores varies with respect to variable selection approach. In considering the effect of business cycle, profitability approach should be worthwhile. Therefore, in case of any event of national or international financial crisis, using profitability approach can better explain the bank performance. On the other hand, intermediation approach would be more appropriate in examining the bank performance with time series data since the concept of intermediation lies into the “going concern” concept (Paradi & Zhu, 2013). Going concern refers to the ability of a bank to convert deposits into loans. Finally, the production approach gives a holistic idea of the bank’s ability to serve the society by producing both financial and nonfinancial activities. Hence, to gauge the ability of a bank to serve its economy, production approach is more appropriate. Finally, banks’ heterogeneity is considered and the meta-frontier method is employed to each approach in measuring bank efficiency.

The empirical findings of this research reveal that foreign Islamic banks are leading group based on all the three approaches. Such results signifies the advanced capacity of foreign banks in risk mitigation, investment portfolio and its capacity of adjusting liquidity (Lensink et al., 2008; Fadzlan Sufian, 2011a). Even, on the basis of profitability and intermediation approaches, the local conventional banks are not the performing group. In the context of Malaysian bank regulations where presumably exists discriminations and government restrictions on foreign bank ownership, the results reveal that even under the favorable business condition (Jeon & Miller, 2005), Malaysian local conventional banks still did not show good performance. Another noteworthy finding of this study is that Islamic banks in Malaysia are found to be more efficient than the local conventional banks. Based on the three different approaches, the Islamic banks have outperformed the conventional banks. This could explain the Islamic banks’ ability of taking higher risk, higher capitalization and profitability (Johnes, Izzeldin, & Pappas, 2014; Sufian & Kamarudin, 2015; Sufian et al., 2014).

7.4 Theoretical contributions

Theoretical contributions of this study can be categorized in three major areas. First, the complexity of bank operation is proven in this study. Here, complexity means banks are operating in a complex manner in which a bank's performance cannot be estimated only based on its one year performance. Rather, performance should be measured in a sequence of years. Only by exploring the profit of one particular year, any conclusive remark on banks' operation would be less accurate. Second, this study reveals that banks operation actually involves in three major separate activities at a time: Thus, examining a bank by considering the basic black-box concept would not provide much information regarding bank's efficiency or inefficiency.

This study theoretically closes the research gap providing an additive network model with the three nodes of production, intermediation, and profitability. However, examination of banks' operation without considering the bad output could only provide biased results. Last but not least, theoretically it is proved that both bank's specific and macroeconomic variables are the major sources of a bank's efficiency. Additionally, banks heterogeneity i.e., bank ownership (local vs. foreign) and bank nature (conventional vs. Islamic) have significant impacts on bank efficiency.

7.5 Managerial implications

From the managerial perspectives, this study contributes by examining bank efficiency through a network DEA approach. This technique serves as the ground breaking benchmarking tool in explaining the diverse aspects of bank operation. This study suggests that in measuring bank efficiency, managers should be able to incorporate the theories behind of how banks are actually operating i.e. what are the sub-processes. A bank might be efficient in the overall aspects; however, it may not be efficient in each sub-process of its operation.

This study also suggests that for attaining bank efficiency managers should focus not only to their peer groups but also to business approaches. A bank might be efficient in profit approach but may not be efficient in the other two or has less capacity in intermediation through attaining scale of economics or in production of loan. A significant finding of this study is that the managers can benchmark bank efficiency comparing it to both the peer banks in different study groups and within banks operational approaches.

7.6 Future studies

For future studies, findings of this study can be used as the guidelines. The concept of "black-box" DEA has been investigated in different theoretical context of bank efficiency measurements: bank profitability, bank risk mitigation, banks' ability as a financial intermediation etc. While the application of meta-frontier can provide benchmark based on both within the individual bank efficiency in a group and among the groups by applying the proposed adaptive network model in multi criteria decision making (MCDC) i.e., Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), game theory, better results can be explained based on group-based performance of bank efficiency. Lastly, the impact of different macroeconomic variables on bank efficiency can be examined by applying cross country examination to this proposed adaptive network model. Finally, this study can be applied for future risk management studies especially examining the data of a crisis period for any specific banking sector.

7.7 Limitations of this research

Limitations of the present study can be highlighted in two major areas. First, commercial banks in Malaysia have just experienced a major change in deregulation through mergers and acquisition in recent times. A steady market analysis would have given additional meaningful results and insights from applying the proposed model since benchmarking of banks' operation using efficiency scores is assumed to be connected with market condition and stability (Soedarmono et al., 2013). Second, application of primary data (through structured questionnaire) to examine bank efficiency could provide an internal assessment of the stated results.

REFERENCES

Abdul-Majid, M., Saal, D. S., and Battisti, G. (2010). Efficiency in Islamic and conventional banking: an international comparison. *Journal of Productivity Analysis, 34*(1): 25-43

Abdul-Majid, M., Saal, D. S., and Battisti, G. (2011a). Efficiency and total factor productivity change of Malaysian commercial banks. *The Service Industries Journal, 31*(13): 2117-2143

Abdul-Majid, M., Saal, D. S., and Battisti, G. (2011b). The impact of Islamic banking on the cost efficiency and productivity change of Malaysian commercial banks. *Applied Economics, 43*(16): 2033-2054

Adler, N., and Yazhemsky, E. (2010). Improving discrimination in data envelopment analysis: PCA-DEA or variable reduction. *European Journal of Operational Research, 202*(1): 273-284

Ahmad, S., and Rahman, A. R. A. (2012). The efficiency of Islamic and conventional commercial banks in Malaysia. *International Journal of Islamic and Middle Eastern Finance and Management, 5*(3): 241-263

Aigner, D., Lovell, C. A. K., and Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics, 6*(1): 21-37

Akther, S., Fukuyama, H., and Weber, W. L. (2013). Estimating two-stage network Slacks-based inefficiency: An application to Bangladesh banking. *Omega-International Journal of Management Science, 41*(1): 88-96

Angulo-Meza, L., and Lins, M. P. E. (2002). Review of methods for increasing discrimination in Data Envelopment Analysis. *Annals of Operations Research, 116*(1-4): 225-242

Apergis, N., and Polemis, M. L. (2016). Competition and efficiency in the MENA banking region: a non-structural DEA approach. *Applied Economics, 48*(54): 5276-5291

Arena, M. (2008). Bank failures and bank fundamentals: A comparative analysis of Latin America and East Asia during the nineties using bank-level data. *Journal of Banking & Finance, 32*(2): 299-310

Ashrafi, A., and Jaafar, A. (2011). Performance Measurement of Two-Stage Production Systems with Undesirable Factors by Data Envelopment Analysis. *Journal of Applied Sciences, 11*: 3515-3519

Athanasoglou, P. P., Brissimis, S. N., and Delis, M. D. (2008). Bank-specific, industry-specific and macroeconomic determinants of bank profitability. *Journal of International Financial Markets, Institutions and Money, 18*(2): 121-136

Athanassopoulos, A. D. (2000). An optimization framework of the triad: service capabilities, customer satisfaction and performance. In P. T. Harker & C. V. Zenios (Eds.), *Performance of financial institutions: efficiency, innovation and regulation* (pp. 312-335). Cambridge, United Kingdom: Cambridge University Press.

Athanassopoulos, A. D., and Curram, S. P. (1996). A comparison of data envelopment analysis and artificial neural networks as tools for assessing the efficiency of decision making units. *Journal of the Operational Research Society, 47*(8): 1000-1016

Avkiran, N. K. (1997). Models of retail performance for bank branches: predicting the level of key business drivers. *International Journal of Bank Marketing, 15*(6): 224-237

Avkiran, N. K. (2009). Opening the black box of efficiency analysis: An illustration with UAE banks. *Omega-International Journal of Management Science, 37*(4): 930-941

Avkiran, N. K. (2011). Association of DEA super-efficiency estimates with financial ratios: Investigating the case for Chinese banks. *Omega-International Journal of Management Science*, *39*(3): 323-334

Avkiran, N. K. (2015). An illustration of dynamic network DEA in commercial banking including robustness tests. *Omega-International Journal of Management Science, 55*: 141-150

Avkiran, N. K., and McCrystal, A. (2012). Sensitivity analysis of network DEA: NSBM versus NRAM. *Applied Mathematics and Computation, 218*(22): 11226-11239

Avkiran, N. K., and Morita, H. (2010). Benchmarking firm performance from a multiple-stakeholder perspective with an application to Chinese banking. *Omega-International Journal of Management Science, 38*(6): 501-508

Aysan, A. F., and Ceyhan, Ş. P. (2008). What determines the banking sector performance in globalized financial markets? The case of Turkey. *Physica A: Statistical Mechanics and its Applications, 387*(7): 1593-1602

Banker, R. D., Charnes, A., and Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science, 30*(9): 1078-1092

Banks, R., and Wheelwright, S. (1979). Operations versus strategy-trading tomorrow for today. *Harvard Business Review, 57*(3): 112-120

Barker, D., and Holdsworth, D. (1993). *The causes of bank failures in the 1980s*. Retrieved from USA:

Bassem, B. S. (2014). Total factor productivity change of MENA microfinance institutions: A Malmquist productivity index approach. *Economic Modelling, 39*: 182-189

Battese, G. E., and Rao, D. P. (2002). Technology gap, efficiency, and a stochastic metafrontier function. *International Journal of Business and Economics, 1*(2): 87-93

Battese, G. E., Rao, D. P., and O'Donnell, C. J. (2004). A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. *Journal of Productivity Analysis, 21*(1): 91-103

Bauer, P. W., Berger, A. N., Ferrier, G. D., and Humphrey, D. B. (1998). Consistency Conditions for Regulatory Analysis of Financial Institutions: A Comparison of Frontier Efficiency Methods. *Journal of Economics and Business, 50*(2): 85-114

Becht, M., Bolton, P., and Röell, A. (2003). Chapter 1 - Corporate Governance and Control. In M. H. George M. Constantinides & M. S. René (Eds.), *Handbook of the Economics of Finance* (Vol. 1, pp. 1-109). US: Elsevier.

Beck, T., Demirgüç-Kunt, A., and Merrouche, O. (2013). Islamic vs. conventional banking: Business model, efficiency and stability. *Journal of Banking & Finance, 37*(2): 433-447

Benston, G. J. (1965). Branch banking and economies of scale. *The Journal of Finance, 20*(2): 312-331

Berg, S. A., Forsund, F. R., Hjalmarsson, L., and Suominen, M. (1993). Banking Efficiency in the Nordic Countries. *Journal of Banking & Finance, 17*(2-3): 371-388

Berg, S. A., Forsund, F. R., and Jansen, E. S. (1992). Malmquist Indexes of Productivity Growth during the Deregulation of Norwegian Banking, 1980-89. *Scandinavian Journal of Economics, 94*: 211-228

Berger, A. N. (2007). International Comparisons of Banking Efficiency. *Financial Markets, Institutions & Instruments, 16*(3): 119-144

Berger, A. N., DeYoung, R., Genay, H., and Udell, G. F. (2000). Globalization of financial institutions: Evidence from cross-border banking performance. *Brookings-Wharton Papers on Financial Services, 20*(1): 23-120

Berger, A. N., Hancock, D., and Humphrey, D. B. (1993). Bank efficiency derived from the profit function. *Journal of Banking & Finance, 17*(2–3): 317-347

Berger, A. N., and Humphrey, D. B. (1997). Efficiency of financial institutions: International survey and directions for future research. *European Journal of Operational Research, 98*(2): 175-212

Betz, F., Opricǎ, S., Peltonen, T. A., and Sarlin, P. (2014). Predicting distress in European banks. *Journal of Banking & Finance, 45*: 225-241

Bhatia, V., Basu, S., Mitra, S. K., and Dash, P. (2018). A review of bank efficiency and productivity. *OPSEARCH*

BinMahfouz, S., and Hassan, M. K. (2013). Sustainable and socially responsible investing: does Islamic investing make a difference? *Humanomics, 29*(3): 164-186

Binswanger, H. P., and Ruttan, V. W. (1978). *Induced innovation: technology, institutions, and development*. Baltimore: Johns Hopkins University Press

Bititci, U., Garengo, P., Dörfler, V., and Nudurupati, S. (2012). Performance Measurement: Challenges for Tomorrow. *International Journal of Management Reviews, 14*(3): 305-327

Blum, J. M. (2008). Why 'Basel II' may need a leverage ratio restriction. *Journal of Banking & Finance, 32*(8): 1699-1707

BNM. (2016). List of Licensed Financial Institutions.

Bos, J. W., and Schmiedel, H. (2003). Comparing efficiency in European banking: a meta frontier approach. *De Nederlandsche Bank Research Paper, 57*(1): 213-245

Boyd, J. H., Levine, R., and Smith, B. D. (2001). The impact of inflation on financial sector performance. *Journal of Monetary Economics, 47*(2): 221-248

Brewer, G. A., Choi, Y., and Walker, R. M. (2007). Accountability, corruption and government effectiveness in Asia: An exploration of World Bank Governance Indicators. *International Public Management Review, 8*(2): 200-217

Caves, D., Christensen, L., and Diewert, W. (1982). The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica, 6*: 1393-1414

Chambers, R. G. (1988). *Applied production analysis: a dual approach*. US: Cambridge University Press.

Chan, S.-G., Koh, E. H. Y., Zainir, F., and Yong, C.-C. (2015). Market structure, institutional framework and bank efficiency in ASEAN 5. *Journal of Economics and Business, 82*: 84-112

Chang, D.-S., Kuo, L.-c. R., and Chen, Y.-t. (2013). Industrial changes in corporate sustainability performance – an empirical overview using data envelopment analysis. *Journal of Cleaner Production, 56*(1): 147-155

Charnes, A., Cooper, W. W., Golany, B., Halek, R., Klopp, G., Schmitz, E., and Thomas, D. (1986). Two phase data envelopment analysis approaches to policy evaluation and management of army recruiting activities: Tradeoffs between joint services and army advertising. Austin, Tex, USA: Center for Cybernetic Studies. University of Texas-Austin

Charnes, A., Cooper, W. W., Lewin, A., and Seiford, L. (1994). Basic DEA Models. In A. Charnes, W. Cooper, A. Lewin, & L. Seiford (Eds.), *Data Envelopment Analysis: Theory, Methodology, and Applications* (pp. 23-47): Springer Netherlands.

Charnes, A., Cooper, W. W., Lewin, A. Y., and Seiford, L. M. (1997). Data envelopment analysis theory, methodology and applications. *Journal of the Operational Research Society, 48*(3): 332-333

Charnes, A., Cooper, W. W., and Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*(6): 429-444

Chen, Chiu, Y. H., Huang, C. W., and Tu, C. H. (2013). The analysis of bank business performance and market risk-Applying Fuzzy DEA. *Economic Modelling, 32*: 225-232

Chen, Lu, C.-J., Lee, T.-S., and Lee, C.-T. (2009). Behavioral Scoring Model for Bank Customers Using Data Envelopment Analysis. In B.-C. Chien & T.-P. Hong (Eds.), *Opportunities and Challenges for Next-Generation Applied Intelligence* (Vol. 214, pp. 99-104): Springer Berlin Heidelberg.

Chen, and Yang, H.-Y. (2011). A cross-country comparison of productivity growth using the generalised metafrontier Malmquist productivity index: with application to banking industries in Taiwan and China. *Journal of Productivity Analysis, 35*(3): 197-212

Chen, Z., Matousek, R., and Wanke, P. (2018). Chinese bank efficiency during the global financial crisis: A combined approach using satisficing DEA and Support Vector Machines☆. *The North American Journal of Economics and Finance, 43*: 71-86

Chenhall, R. H., and Langfield-Smith, K. (2007). Multiple Perspectives of Performance Measures. *European Management Journal, 25*(4): 266-282

Ching, K. S., Munir, Q., and Bahron, A. (2016). Malaysian Banking Sector Efficiency, Structural Breaks and Cross-Sectional Dependence: Empirical Evidence. *Journal of Economic Cooperation and Development, 37*(1): 41-68

Chiu, Y. H., and Chen. (2009). The analysis of Taiwanese bank efficiency: Incorporating both external environment risk and internal risk. *Economic Modelling, 26*(2): 456-463

Chiu, Y. H., Chen, and Bai, X. J. (2011). Efficiency and risk in Taiwan banking: SBM super-DEA estimation. *Applied Economics, 43*(5): 587-602

Chiu, Y. H., Jan, C., Shen, D. B., and Wang, W. K. (2008). Efficiency and capital adequacy in Taiwan banking: BCC and super-DEA estimation. *Service Industries Journal, 28*(4): 479-496

Claessens, S. (2006). Corporate Governance and Development. *The World Bank Research Observer, 21*(1): 91-122

Claessens, S., Demirgüç-Kunt, A., and Huizinga, H. (2001). How does foreign entry affect domestic banking markets? *Journal of Banking & Finance, 25*(5): 891-911

Coelli, T. J., and Rao, D. S. P. (2005). Total factor productivity growth in agriculture: a Malmquist index analysis of 93 countries, 1980-2000. *Agricultural Economics, 32*: 115-134

Cole, R. A., and Gunther, J. W. (1995). A CAMEL rating's shelf life. *Federal Reserve Bank of Dallas Review, 9*: 13-20

Cole, R. A., and Gunther, J. W. (1998). Predicting bank failures: A comparison of on- and off-site monitoring systems. *Journal of Financial Services Research, 13*(2): 103-117

Cole, R. A., and White, L. (2012). Déjà Vu All Over Again: The Causes of U.S. Commercial Bank Failures This Time Around. *Journal of Financial Services Research, 42*(1-2): 5-29

Colwell, R. J., and Davis, E. P. (1992). Output and Productivity in Banking. *Scandinavian Journal of Economics, 94*: 111-129

Conover, W. J. (1980). *Practical nonparametric statistics*. UK: John Wiley & Sons.

Cook, M. (2008). *Banking Reform in Southern Asia: The Region's Decisive Decade* (Vol. XI). London and New York: Routledge.

Cook, M. (2009). *Banking reform in Southeast Asia: the region's decisive decade*. Oxon, United Kingdom: Routledge.

Cook, M., Hababou, M., and Liang, L. (2005). Financial liberalization and efficiency in Tunisian banking industry: DEA test. *International Journal of Information Technology & Decision Making, 4*(3): 455-475

Cook, M., Hababou, M., and Tuenter, H. J. H. (2000). Multicomponent efficiency measurement and shared inputs in data envelopment analysis: An application to sales and service performance in bank branches. *Journal of Productivity Analysis, 14*(3): 209-224

Cooper, W. W. (2014). Origin and Development of Data Envelopment Analysis: Challenges and Opportunities. *Data Envelopment Analysis Journal, 1*(1): 3-10

Cooper, W. W., Seiford, L., and Tone, K. (2006). *Introduction to data envelopment analysis and its uses: with DEA-solver software and references*. US: Springer Science & Business Media.

Cooper, W. W., Seiford, L. M., Tone, K., and Zhu, J. (2007). Some models and measures for evaluating performances with DEA: past accomplishments and future prospects. *Journal of Productivity Analysis, 28*(3): 151-163

Corrigan, E. G. (1982). *Are banks special?* : Federal Reserve Bank of Minneapolis, United States.

DCIBF Annual Report. (2014). *Islamic Banking Growth, Efficiency And Stability*. Retrieved from UAE:

Demirbag, M., Tatoglu, E., Glaister, K. W., and Zaim, S. (2010). Measuring strategic decision making efficiency in different country contexts: A comparison of British and Turkish firms. *Omega-International Journal of Management Science, 38*(1-2): 95-104

DeYoung, R., Flannery, M. J., Lang, W. W., and Sorescu, S. M. (1998). *The informational advantage of specialized monitors: The case of bank examiners*. Retrieved from Chicago:

Diallo, B. (2018). Bank efficiency and industry growth during financial crises. *Economic Modelling, 68*: 11-22

Dietrich, A., and Wanzenried, G. (2014). The determinants of commercial banking profitability in low-, middle-, and high-income countries. *The Quarterly Review of Economics and Finance, 54*(3): 337-354

Diewert, W. E., and Fox, K. J. (2010). Malmquist and Törnqvist productivity indexes: returns to scale and technical progress with imperfect competition. *Journal of Economics, 101*(1): 73-95

Dima, B., Dincă, M. S., and Spulbăr, C. (2014). Financial nexus: Efficiency and soundness in banking and capital markets. *Journal of International Money and Finance, 47*: 100-124

Doan, A.-T., Lin, K.-L., and Doong, S.-C. (2018). What drives bank efficiency? The interaction of bank income diversification and ownership. *International Review of Economics & Finance, 55*: 203-219

Doumpos, M., and Zopounidis, C. (2010). A multicriteria decision support system for bank rating. *Decision Support Systems, 50*(1): 55-63

Du, K., Duan, W. C., and Han, C. (2012). Group Decision Making Model under Risk Based on Bounded Rationality. *Management, Manufacturing and Materials Engineering, Pts 1 and 2, 452-453*: 533-537

Du, K., and Sim, N. (2016). Mergers, acquisitions, and bank efficiency: Cross-country evidence from emerging markets. *Research in International Business and Finance, 36*: 499-510

Dyson, R. G., Allen, R., Camanho, A. S., Podinovski, V. V., Sarrico, C. S., and Shale, E. A. (2001). Pitfalls and protocols in DEA. *European Journal of Operational Research, 132*(2): 245-259

Ebrahimnejad, A., Tavana, M., Lotfi, F. H., Shahverdi, R., and Yousefpour, M. (2014). A three-stage Data Envelopment Analysis model with application to banking industry. *Measurement, 49*: 308-319

Elyasiani, E., and Mehdian, S. (1990). A nonparametric approach to measurement of efficiency and technological change: The case of large U.S. commercial banks. *Journal of Financial Services Research, 4*(2): 157-168

Erkens, D. H., Hung, M., and Matos, P. (2012). Corporate governance in the 2007–2008 financial crisis: Evidence from financial institutions worldwide. *Journal of Corporate Finance*, *18*(2): 389-411

Erol, C., Hasan, F. B., Berna, A., and Gökçe, T. (2014). Performance comparison of Islamic (participation) banks and commercial banks in Turkish banking sector. *EuroMed Journal of Business, 9*(2): 114-128

Evans, J. R. (2004). An exploratory study of performance measurement systems and relationships with performance results. *Journal of Operations Management, 22*(3): 219-232

Fama, E. F. (1980). Banking in the theory of finance. *Journal of Monetary Economics, 6*(1): 39-57

Färe, R., and Grosskopf, S. (2000). Network DEA. *Socio-Economic Planning Sciences, 34*(1): 35-49

Färe, R., Grosskopf, S., Norris, M., and Zhang, Z. (1994). Productivity growth, technical progress and efficiency changes in industrial countries. *American Economic Review, 84*: 66-83

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A, 120*(30): 253-290

Farrell, M. J., and Fieldhouse, M. (1962). Estimating efficient production functions under increasing returns to scale. *Journal of the Royal Statistical Society. Series A (General), 125*(2): 252-267

Farrington, T. (2000). Efficiency in microfinance institutions. *Microbanking Bulletin, 4*: 18-23

Fernandez-Montes, A., Velasco, F., and Ortega, J. A. (2012). Evaluating decision-making performance in a grid-computing environment using DEA. *Expert Systems with Applications, 39*(15): 12061-12070

Fernández, A. I., González, F., and Suárez, N. (2013). How do bank competition, regulation, and institutions shape the real effect of banking crises? International evidence. *Journal of International Money and Finance, 33*: 19-40

Fethi, M. D., and Pasiouras, F. (2010). Assessing bank efficiency and performance with operational research and artificial intelligence techniques: A survey. *European Journal of Operational Research, 204*(2): 189-198

Franco-Santos, M., Kennerley, M., Micheli, P., Martinez, V., Mason, S., Marr, B., . . . Neely, A. (2007). Towards a definition of a business performance measurement system. *International Journal of Operations & Production Management, 27*(8): 784-801

Fuentes, R. (2011). Efficiency of travel agencies: A case study of Alicante, Spain. *Tourism Management, 32*(1): 75-87

Fukuyama, H., and Matousek, R. (2011). Efficiency of Turkish banking: Two-stage network system. Variable returns to scale model. *Journal of International Financial Markets, Institutions and Money, 21*(1): 75-91

Fukuyama, H., and Weber, W. L. (2010). A slacks-based inefficiency measure for a two-stage system with bad outputs. *Omega-International Journal of Management Science, 38*(5): 398-409

Fukuyama, H., and Weber, W. L. (2013). A dynamic network DEA model with an application to Japanese Shinkin banks *Efficiency and Productivity Growth* (pp. 193-213): John Wiley & Sons, Ltd.

Fukuyama, H., and Weber, W. L. (2015). Measuring Japanese bank performance: a dynamic network DEA approach. *Journal of Productivity Analysis, 44*(3): 249-264

Gardener, E., Molyneux, P., and Hoai, N. L. (2011). Determinants of efficiency in South East Asian banking. *Service Industries Journal, 31*(16): 2693-2719

Gattoufi, S., Oral, M., Kumar, A., and Reisman, A. (2004). Epistemology of data envelopment analysis and comparison with other fields of OR/MS for relevance to applications. *Socio-Economic Planning Sciences*, *38*(2): 123-140

Gattoufi, S., Oral, M., and Reisman, A. (2004). Data envelopment analysis literature: A bibliography update (1951–2001). *Journal of Socio-Economic Planning Sciences, 38*(2-3): 159-229

Ghroubi, M., and Abaoub, E. (2016). A Meta-Frontier Function for the Estimation of Islamic and Conventional Banks' Cost and Revenue Efficiency: The Case of Malaysia from 2006 to 2012. *International Journal of Business and Management, 11*(5): 254

Giuffrida, A., and Gravelle, H. (2001). Measuring performance in primary care: econometric analysis and DEA. *Applied Economics, 33*(2): 163-175

Golany, B., and Storbeck, J. E. (1999). A data envelopment analysis of the operational efficiency of bank branches. *Interfaces, 29*(3): 14-26

Gorman, J. A. (1969). Alternative measures of the real output and productivity of commercial banks. In V. R. Fuchs (Ed.), *Production and Productivity in the Service Industries* (Vol. Research in income and wealth, pp. 155 - 200). New Yark, United State: UMI, National Bureau of Economic Research.

Grigoroudis, E., Tsitsiridi, E., and Zopounidis, C. (2013). Linking customer satisfaction, employee appraisal, and business performance: an evaluation methodology in the banking sector. *Annals of Operations Research, 205*(1): 5-27

Gunay, E. N. O. (2012). Risk Incorporation and Efficiency in Emerging Market Banks During the Global Crisis: Evidence from Turkey, 2002-2009. *Emerging Markets Finance and Trade, 48*: 91-102

Haque, F., and Brown, K. (2017). Bank ownership, regulation and efficiency: Perspectives from the Middle East and North Africa (MENA) Region. *International Review of Economics & Finance, 47*: 273-293

Hasan, M. Z., and Kamil, A. A. (2015). Evaluation of the domestic banks'technical efficiency in Malaysia. *Bulletin of Mathematics, 7*(1): 65-79

Hayami, Y. (1969). Sources of agricultural productivity gap among selected countries. *American Journal of Agricultural Economics, 51*(3): 564-575

Hayes, R. H., and Abernathy, W. J. (1980). Managing our way to economic decline. *Harvard Business Review, 58*(4): 95-101

Hays, F. H., De Lurgio, S. A., and Gilbert, A. (2009). Efficiency ratios and community bank performance. *Journal of Finance and Accountancy, 1*: 1-15

Hensel, N. D. (2003). Strategic Management of Cost Efficiencies in Networks: Cross-country Evidence on European Branch Banking. *European Financial Management, 9*(3): 333-360

Hirtle, B. J., and Lopez, J. A. (1999). Supervisory information and the frequency of bank examinations. *Economic Policy Review, 9*(Apr): 1-20

Huang, J. (2014). *The Rising of Asian Values and the Financial Crisis: The Cases of Hong Kong, Malaysia and Singapore*. *When orient and occident meet (moneta, wetteren 2014), 52*(12): 141-157

Huang, J., Chen, J., and Yin, Z. (2014). A Network DEA Model with Super Efficiency and Undesirable Outputs: An Application to Bank Efficiency in China. *Mathematical Problems in Engineering, 63*(2): 14-26

Hwang, S. N., Chen, C. L., Chen, Y., Lee, H. S., and Shen, P. D. (2013). Sustainable design performance evaluation with applications in the automobile industry: Focusing on inefficiency by undesirable factors. *Omega-International Journal of Management Science, 41*(3): 553-558

Islam, S., and Kassim, S. (2015). Efficiency of Islamic and Conventional Banks in Bangladesh: Comparative Study using DEA Approach. *Journal of Islamic Economics, Banking and Finance, 11*(3): 83-110

Ismail, F., and Ab Rahim, R. (2013). Productivity of Islamic and conventional banks of Malaysia: an empirical analysis. *IUP Journal of Bank Management*, *12*(3): 7-19

Jalali Naini, S. G., Moini, A., and Jahangoshai Rezaee, M. (2013). Nash bargaining game model for two parallel stages process evaluation with shared inputs. *The International Journal of Advanced Manufacturing Technology, 67*(1): 475-484

Jeon, Y., and Miller, S. M. (2005). Performance of Domestic and Foreign Banks: The Case of Korea and the Asian Financial Crisis. *Global Economic Review, 34*(2): 145-165

Jin, J. Y., Kanagaretnam, K., and Lobo, G. J. (2011). Ability of accounting and audit quality variables to predict bank failure during the financial crisis. *Journal of Banking & Finance, 35*(11): 2811-2819

Johnes, J., Izzeldin, M., and Pappas, V. (2014). A comparison of performance of Islamic and conventional banks 2004–2009. *Journal of Economic Behavior & Organization, 103*: S93-S107

Kaffash, S., and Marra, M. (2016). Data envelopment analysis in financial services: a citations network analysis of banks, insurance companies and money market funds. *Annals of Operations Research, 68*(12): 1-38

Kamarudin, F., Safab, M. S., and Mohd, R. (2008). Assessing production efficiency of Islamic banks and conventional bank Islamic windows in Malaysia. *International Journal of Business and Management, 1*(1): 31

Kamarudin, F., Sufian, F., and Nassir, A. M. (2016). Global financial crisis, ownership and bank profit efficiency in the Bangladesh's State owned and private commercial banks. *Contaduría y Administración, 61*(4): 705-745

Kao, C. (2014). Network data envelopment analysis: A review. *European Journal of Operational Research, 239*(1): 1-16

Kaplan, R. S. (1986). Accounting lag: The obsolescence of cost accounting systems. *California Management Review, 28*(2): 174-199

Kareken, J. H. (1985). *Ensuring financial stability*. Paper presented at the Federal Reserve Bank of San Francisco Proceedings, San Francisco, United States.

Karim, M. Z. A. (2001). Comparative Bank Efficiency across Select ASEAN Countries. *ASEAN Economic Bulletin, 18*(3): 289-304

Kennerley, M., and Neely, A. (2002). A framework of the factors affecting the evolution of performance measurement systems. *International Journal of Operations & Production Management, 22*(11): 1222-1245

Ketokivi, M. A., and Schroeder, R. G. (2004). Perceptual measures of performance: fact or fiction? *Journal of Operations Management, 22*(3): 247-264

Khan, S. I. M. (2015). Bank Efficiency in Southeast Asian Countries. *International Business Management, 9*(3): 239-250

Khan, S. I. M., Shamzaeffa, S., and Rabiul, I. (2017). Efficiency of banks in Southeast Asia: Indonesia, Malaysia, Philippines and Thailand. *International Journal of Social Economics, 44*(12): 2302-2312

Khiyar, K. A. (2012). Malaysia: 30 years of Islamic banking experience (1983-2012). *The International Business & Economics Research Journal, 11*(10): 1133-1156

Kinsella, R. P. (1980). The measurement of bank output. *Journal of the Institute of Bankers in Ireland, 82*(Part 3): 173-182

Kinsella, R. P. (1981). The measurement of market concentration in Irish banking. *Journal of the Statistical and Social Inquiry Society of Ireland, 24*(3): 31-69

Kordrostami, S., and Amirteimoori, A. (2005). Un-desirable factors in multi-component performance measurement. *Applied Mathematics and Computation, 171*(2): 721-729

Kounetas, K., and Tsekouras, K. (2007). Measuring Scale Efficiency Change Using a Translog Distance Function. *International Journal of Business and Economics, 69*(1): 63-69

Krishnasamy, G., Ridzwa, A. H., and Perumal, V. (2004). Malaysian post merger banks' productivity: application of Malmquist productivity index. *Managerial Finance, 30*(4): 63-74

Krivonozhko, V. E., Piskunov, A. A., and Lychev, A. V. (2011). On comparison of ratio analysis and data envelopment analysis as performance assessment tools. *IMA Journal of Management Mathematics, 22*(4): 357-370

Kuosmanen, T., and Sipilainen, T. (2009). Exact decomposition of the Fisher ideal total factor productivity index. *Journal of Productivity Analysis, 31*(3): 137-150

Kwon, H.-B., and Lee, J. (2015). Two-stage production modeling of large U.S. banks: A DEA-neural network approach. *Expert Systems with Applications, 42*(19): 6758-6766

Lai, M. C., Ling, T. P., Eng, T. K., Cheng, L. S., and Ting, L. F. (2015). Financial Performance of Malaysia Local Banks: During Periods of Pre-Merger and Post-Merger. *Journal of Economics, Business and Management, 3*(9): 826-831

Lampe, H. W., and Hilgers, D. (2015). Trajectories of efficiency measurement: A bibliometric analysis of DEA and SFA. *European Journal of Operational Research, 240*(1): 1-21

Lauras, M., Marques, G., and Gourc, D. (2010). Towards a multi-dimensional project Performance Measurement System. *Decision Support Systems, 48*(2): 342-353

Lensink, R., Meesters, A., and Naaborg, I. (2008). Bank efficiency and foreign ownership: Do good institutions matter? *Journal of Banking & Finance, 32*(5): 834-844

Lev, B. (1989). On the usefulness of earnings and earnings research: Lessons and directions from two decades of empirical research. *Journal of Accounting Research, 8*(6): 153-192

Lin, T. T., and Chiu, S. H. (2013). Using independent component analysis and network DEA to improve bank performance evaluation. *Economic Modelling, 32*: 608-616

Lin, T. T., Doan, A. T., and Doong, S.-C. (2016). Changes in ownership structure and bank efficiency in Asian developing countries: The role of financial freedom. *International Review of Economics & Finance, 43*: 19-34

Lin, T. T., Lee, C. C., and Chiu, T. F. (2009). Application of DEA in analyzing a bank's operating performance. *Expert Systems with Applications, 36*(5): 8883-8891

Liu, J. S., Lu, L. Y. Y., Lu, W.-M., and Lin, B. J. Y. (2013a). Data envelopment analysis 1978–2010: A citation-based literature survey. *Omega-International Journal of Management Science, 41*(1): 3-15

Liu, J. S., Lu, L. Y. Y., Lu, W.-M., and Lin, B. J. Y. (2013b). A survey of DEA applications. *Omega-International Journal of Management Science, 41*(5): 893-902

Lo, S. F. (2010). Performance Evaluation for Sustainable Business: A Profitability and Marketability Framework. *Corporate Social Responsibility and Environmental Management, 17*(6): 311-319

Lo, S. F., and Lu, W. M. (2006). Does size matter? Finding the profitability and marketability benchmark of financial holding companies. *Asia-Pacific Journal of Operational Research, 23*(2): 229-246

Lozano, S. (2016). Slacks-based inefficiency approach for general networks with bad outputs: An application to the banking sector. *Omega-International Journal of Management Science, 60*(3): 73-84

Luo, X. (2003). Evaluating the profitability and marketability efficiency of large banks: An application of data envelopment analysis. *Journal of Business Research, 56*(8): 627-635

Luo, X., Bi, G. B., and Liang, L. (2012). Input/output indicator selection for DEA efficiency evaluation: An empirical study of Chinese commercial banks. *Expert Systems with Applications, 39*(1): 1118-1123

Ma, C., Liu, D., Zhou, Z., Zhao, W., and Liu, W. (2014). Game Cross Efficiency for Systems with Two-Stage Structures. *Journal of Applied Mathematics, 14*(6): 8-19

Maghyereh, A. I., and Awartani, B. (2014). Bank distress prediction: Empirical evidence from the Gulf Cooperation Council countries. *Research in International Business and Finance, 30*: 126-147

Malina, M. A., and Selto, F. H. (2004). Choice and change of measures in performance measurement models. *Management Accounting Research, 15*(4): 441-469

Malyarchuk, K. S. (2010). Methods of Assessing the Efficiency of a Bank Branch Network. *Actual Problems of Economics, 110*: 265-269

Manzoni, A., and Islam, S. N. (2009). DEA of corporate governance: the model and its application *Performance measurement in corporate governance* (pp. 103-124). Melbourne, Australia: Physica-Verlag.

Marimuthu, M., and Arokiasamy, L. (2011). Conventional banks and productivity level: The Malaysian perspective. *African Journal of Business Management, 5*(6): 2493-2500

Matthews, K. (2013). Risk management and managerial efficiency in Chinese banks: A network DEA framework. *Omega-International Journal of Management Science, 41*(2): 207-215

Matthews, K., and Ismail, M. (2006). *Efficiency and productivity growth of domestic and foreign commercial banks in Malaysia*. Retrieved from UK: econpapers.repec.org/RePEc:cdf:wpaper:2006/2

Meeusen, W., and Van den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review, 18*(2): 435-444

Melnyk, S. A., Bititci, U., Platts, K., Tobias, J., and Andersen, B. (2014). Is performance measurement and management fit for the future? *Management Accounting Research, 25*(2): 173-186

Miller, J., and Vollmann, T. (1985). The Hidden Factory. *Harvard Business Review, 63*(5): 142–150

Min, B. S., and Smyth, R. (2014). Corporate governance, globalization and firm productivity. *Journal of World Business, 49*(3): 372-385

Mokhtar, H. S. A., Abdullah, N., and Al-Habshi, S. M. (2006). Efficiency of Islamic banking in Malaysia: A stochastic frontier approach. *Journal of Economic Cooperation, 27*(2): 37-70

Mokhtar, H. S. A., Abdullah, N., and Alhabshi, S. M. (2008). Efficiency and competition of Islamic banking in Malaysia. *Humanomics, 24*(1): 28-48

Moshirian, F. (2008). Financial services in an increasingly integrated global financial market. *Journal of Banking & Finance, 32*(11): 2288-2292

Muda, M., Shaharuddin, A., and Embaya, A. (2013). Comparative analysis of profitability determinants of domestic and foreign Islamic banks in Malaysia. *International Journal of Economics and Financial Issues, 3*(3): 559-569

Muhmad, S. N., and Hashim, H. A. (2015). *Using the camel framework in assessing bank performance in Malaysia*. Retrieved from UK:

Narasimhan, R., Talluri, S., and Das, A. (2004). Exploring flexibility and execution competencies of manufacturing firms. *Journal of Operations Management, 22*(1): 91-106

Neely, A. (2002). *Business performance measurement: theory and practice* (A. Neely Ed.). Cambridge, United Kingdom: Cambridge University Press.

Ng, K. H., Wong, S. C., Yap, P. K., and Khezrimotlagh, D. (2014). A Survey on Malaysia's Banks Efficiency: Using Data Envelopment Analysis. *Scholars Journal of Economics Business and Management, 1*(11): 586-592

Nudurupati, S. S., Bititci, U. S., Kumar, V., and Chan, F. T. S. (2011). State of the art literature review on performance measurement. *Computers & Industrial Engineering, 60*(2): 279-290

Oh, D.-h., and Lee, J.-d. (2010). A metafrontier approach for measuring Malmquist productivity index. *Empirical Economics, 38*(1): 47-64

Olsen, L. M., and Lord, J. D. (1979). Market area characteristics and branch bank performance. *Journal of Bank Research, 10*(2): 102-110

Omar, M. A., Rahman, A. R. A., Yusof, R. M., Majid, M. S. A., and Rasid, M. (2006). Efficiency of commercial banks in Malaysia. *Asian Academy of Management Journal of Accounting and Finance, 2*(2): 19-42

Otley, D. (2002). Measuring performance: The accounting perspective. In A. Neely (Ed.), *Business performance measurement: Theory and practice* (pp. 3-21). Cambridge, United Kingdom: Camnridge University Press.

Ozdincer, B., and Ozyildirim, C. (2008, March 24-26). *Determining the factors of bank performance with a focus on risk and technical efficiency.* Paper presented at the The 2nd WSEAS International Conference on Management, Marketing and Finances, Harvard, Massachusetts, USA.

Paradi, J. C., Yang, Z., and Zhu, H. (2011). Assessing bank and bank branch performance. In W. W. Cooper, L. M. Seiford, & j. Zhu (Eds.), *Handbook on data envelopment analysis* (2nd edition ed., pp. 315-361). US: Springer.

Paradi, J. C., and Zhu, H. Y. (2013). A survey on bank branch efficiency and performance research with data envelopment analysis. *Omega-International Journal of Management Science, 41*(1): 61-79

Parkan, C. (1987). Measuring the efficiency of service operations: An application to bank branches. *Engineering Costs and Production Economics, 12*(1–4): 237-242

Pastor, J. T., and Lovell, C. A. K. (2005). A global Malmquist productivity index. *Economics Letters, 88*(2): 266-271

Pastor, J. T., Perez, F., and Quesada, J. (1997). Efficiency analysis in banking firms: An international comparison. *European Journal of Operational Research, 98*(2): 395-407

Pastor, J. T., Ruiz, J. L., and Sirvent, I. (1999). An enhanced DEA Russell graph efficiency measure. *European Journal of Operational Research, 115*(3): 596-607

Peng, M. W., Bhagat, R. S., and Chang, S.-J. (2010). Asia and global business. *Journal of International Business Studies, 41*(3): 373-376

Perry, P. (1992). Do banks gain or lose from inflation. *Journal of Retail Banking, 14*(2): 25-30

Petroni, A., and Bevilacqua, M. (2002). Identifying manufacturing flexibility best practices in small and medium enterprises. *International Journal of Operations & Production Management, 22*(7-8): 929-947

Phillips, F., and Tuladhar, S. D. (2000). Measuring organizational flexibility: An exploration and general model. *Technological Forecasting and Social Change, 64*(1): 23-38

Piot-Lepetit, I., and Nzongang, J. (2014). Financial sustainability and poverty outreach within a network of village banks in Cameroon: A multi-DEA approach. *European Journal of Operational Research, 234*(1): 319-330

Poghosyan, T., and Čihak, M. (2011). Determinants of Bank Distress in Europe: Evidence from a New Data Set. *Journal of Financial Services Research, 40*(3): 163-184

Rangan, N., Grabowski, R., Aly, H. Y., and Pasurka, C. (1988). The technical efficiency of US banks. *Economics Letters, 28*(2): 169-175

Ray, S. C. (2004). *Data envelopment analysis: theory and techniques for economics and operations research*. UK: Cambridge university press.

Rayner, S. (2003). Democracy in the age of assessment: reflections on the roles of expertise and democracy in public-sector decision making. *Science and public policy, 30*(3): 163-170

Resti, A. (1999). How Should We Measure Bank Efficiency? A Comparison of Classic and Recent Techniques Based on Simulated Data. In E. Canestrelli (Ed.), *Current Topics in Quantitative Finance* (pp. 109-126). Heidelberg: Physica.

Rouse, P. P., and Tripe, D. (2016). Allocative and technical efficiency of New Zealand Banks. *Meditari Accountancy Research, 24*(4): 574 - 587

Rydval, J. (2012). Decision Efficiency Analysis Selected by Decision Makers with Different Points of View on Education Using Dea Models. *Efficiency and Responsibility in Education, 42*(5): 498-507

Sachs, J. D., and Woo, W. T. (2000). *Understanding the Asian financial crisis*. US: MIT Press.

Salami, O. L., and Adeyemi, A. A. (2015). Malaysian islamic banks'efficiency: An intra-bank comparative analysis of islamic windows and full-fledged subsidiaries. *International Journal of Business and Society, 16*(1): 19-44

Sealey, C. W., and Lindley, J. T. (1977). Inputs, outputs, and a theory of production and cost at depository financial institutions. *The Journal of Finance, 32*(4): 1251-1266

Secme, N. Y., Bayrakdaroglu, A., and Kahraman, C. (2009). Fuzzy performance evaluation in Turkish Banking Sector using Analytic Hierarchy Process and TOPSIS. *Expert Systems with Applications, 36*(9): 11699-11709

Seiford, L. M. (1990). Models, Extensions, and Applications of Data Envelopment Analysis - a Selected Reference Set. *Computers Environment and Urban Systems, 14*(2): 171-175

Seiford, L. M. (1996). Data envelopment analysis: The evolution of the state of the art (1978-1995). *Journal of Productivity Analysis*, *7*(2-3): 99-137

Seiford, L. M. (1997). A bibliography for Data Envelopment Analysis (1978-1996). *Annals of Operations Research, 73*: 393-438

Seiford, L. M., and Zhu, J. (1999). An investigation of returns to scale in data envelopment analysis. *Omega-International Journal of Management Science, 27*(1): 1-11

Seydel, J. (2006). Data envelopment analysis for decision support. *Industrial Management & Data Systems, 106*(1-2): 81-95

Sherman, H. D., and Gold, F. (1985). Bank Branch Operating Efficiency - Evaluation with Data Envelopment Analysis. *Journal of Banking & Finance*, *9*(2): 297-315

Sherman, H. D., and Zhu, J. (2006). Benchmarking with quality-adjusted DEA (Q-DEA) to seek lower-cost high-quality service: Evidence from a US bank application. *Annals of Operations Research*, *145*(3): 301-319

Shi, X. L. B.-z., and Zou, X. (2016). A Study on Risk Factors Impact on the Efficiency of Commercial Banks in China—Based on Fuzzy DEA Model. In B.-Y. Cao, P.-Z. Wang, Z.-L. Liu, & Y.-B. Zhong (Eds.), *International Conference on Oriental Thinking and Fuzzy Logic: Celebration of the 50th Anniversary in the era of Complex Systems and Big Data* (pp. 329-347). Cham: Springer International Publishing.

Shyu, J., and Chiang, T. (2012). Measuring the true managerial efficiency of bank branches in Taiwan: A three-stage DEA analysis. *Expert Systems with Applications, 39*(13): 11494-11502

Simar, L., and Wilson, P. W. (2007). Estimation and inference in two-stage, semi-parametric models of production processes. *Journal of Econometrics, 136*(1): 31-64

Simpson, J. L. (2009). Were there warning signals from banking sectors for the 2008/2009 global financial crisis? *Applied Financial Economics, 20*(1-2): 45-61

Sirvent, I., Ruiz, J. L., Borras, F., and Pastor, J. T. (2005). A Monte Carlo evaluation of several tests for the selection of variables in DEA models. *International Journal of Information Technology & Decision Making, 4*(3): 325-343

Soedarmono, W., Machrouh, F., and Tarazi, A. (2011). Bank market power, economic growth and financial stability: Evidence from Asian banks. *Journal of Asian Economics*, *22*(6): 460-470

Soedarmono, W., Machrouh, F., and Tarazi, A. (2013). Bank competition, crisis and risk taking: Evidence from emerging markets in Asia. *Journal of International Financial Markets, Institutions and Money, 23*: 196-221

Soteriou, A. C., and Stavrinides, Y. (1997). An internal customer service quality data envelopment analysis model for bank branches. *International Journal of Operations & Production Management, 17*(7-8): 780-796

Soteriou, A. C., and Zenios, S. A. (1999). Operations, quality, and profitability in the provision of banking services. *Management Science, 45*(9): 1221-1238

Staub, R. B., Souza, G. D. E., and Tabak, B. M. (2010). Evolution of bank efficiency in Brazil: A DEA approach. *European Journal of Operational Research, 202*(1): 204-213

Stewart, C., Matousek, R., and Nguyen, T. N. (2016). Efficiency in the Vietnamese banking system: A DEA double bootstrap approach. *Research in International Business and Finance, 36*: 96-111

Suffian, M. T. M., Sanusi, Z. M., Osman, A. H., and Azhari, M. I. M. (2015). Manipulation of Earnings: The Pressure of Opportunistic Behavior and Monitoring Mechanisms in Malaysian Shariah-compliant Companies. *Procedia Economics and Finance, 31*: 213-227

Sufian, F. (2005). Sources of productivity changes of commercial banks in developing economy: Evidence from Malaysia, 1998-2003. *International Journal of Applied Econometrics and Quantitative Studies, 2*(3): 87-100

Sufian, F. (2007a). The efficiency of Islamic banking industry in Malaysia. *Humanomics, 23*(3): 174-192

Sufian, F. (2007b). Mergers and acquisitions in the Malaysian banking industry: technical and scale efficiency effects. *International Journal of Financial Services Management, 2*(4): 304-326

Sufian, F. (2009a). Determinants of bank efficiency during unstable macroeconomic environment: Empirical evidence from Malaysia. *Research in International Business and Finance, 23*(1): 54-77

Sufian, F. (2009b). Factors Influencing Bank Profitability in a Developing Economy Empirical Evidence from Malaysia. *Global Business Review, 10*(2): 225-241

Sufian, F. (2010). The Impact of the Asian Financial Crisis on Bank Efficiency: The 1997 Experience of Malaysia and Thailand. *Journal of International Development, 22*(7): 866-889

Sufian, F. (2011a). Banks total factor productivity change in a developing economy: Does ownership and origins matter? *Journal of Asian Economics, 22*(1): 84-98

Sufian, F. (2011). The evolution of Malaysian banking sector's efficiency during financial duress: consequences, concerns, and policy implications. *International Journal of Applied Decision Sciences, 3*(4): 366-389

Sufian, F. (2011b). Financial repression, liberalization and bank total factor productivity: Empirical evidence from the Thailand banking sector. *Economic Computation and Economic Cybernetics Studies and Research, 45*(4): 31-52

Sufian, F. (2011c). The nexus between financial sector consolidation, competition and efficiency: empirical evidence from the malaysian banking sector. *IMA Journal of Management Mathematics, 22*(4): 419-444

Sufian, F. (2015). Determinants of Malaysian bank efficiency: evidence from bootstrap data envelopment analysis. *International Journal of Applied Nonlinear Science, 2*(1-2): 100-119

Sufian, F., and Chong, R. R. (2008). Determinants of bank profitability in a developing economy: Empirical evidence from the philippines. *Asian Academy of Management Journal of Accounting & Finance, 4*(2): 91-112

Sufian, F., and Habibullah, M. S. (2009). Do mergers and acquisitions leads to a higher technical and scale efficiency? A counter evidence from Malaysia. *African Journal of Business Management, 3*(8): 340-349

Sufian, F., and Habibullah, M. S. (2010a). Bank-specific, Industry-specific and Macroeconomic Determinants of Bank Efficiency Empirical Evidence from the Thai Banking Sector. *Margin: The Journal of Applied Economic Research, 4*(4): 427-461

Sufian, F., and Habibullah, M. S. (2010b). Does economic freedom fosters banks' performance? Panel evidence from Malaysia. *Journal of Contemporary Accounting & Economics, 6*(2): 77-91

Sufian, F., and Habibullah, M. S. (2012a). Developments in the efficiency of the Malaysian banking sector: the impacts of financial disruptions and exchange rate regimes. *Progress in Development Studies, 12*(1): 19-46

Sufian, F., and Habibullah, M. S. (2012b). Globalization and bank efficiency nexus: Symbiosis or parasites? *Review of Development Finance, 2*(3–4): 139-155

Sufian, F., and Habibullah, M. S. (2013). The impact of forced mergers and acquisitions on banks' total factor productivity: empirical evidence from Malaysia. *Journal of the Asia Pacific Economy, 19*(1): 151-185

Sufian, F., and Habibullah, M. S. (2015). Does Foreign Banks Entry Fosters Bank Efficiency? Empirical Evidence from Malaysia. *Engineering Economics, 21*(5): 464-474

Sufian, F., and Kamarudin, F. (2015). Determinants of revenue efficiency of Islamic banks: empirical evidence from the Southeast Asian countries. *International Journal of Islamic and Middle Eastern Finance and Management, 8*(1): 1-30

Sufian, F., Kamarudin, F., and Nassir, A. m. (2016). Determinants of efficiency in the Malaysian banking sector: Does bank origins matter? *Intellectual Economics, 10*(1): 38-54

Sufian, F., Kamarudin, F., and Noor, N. H. H. M. (2014). Revenue efficiency and returns to scale in Islamic banks: Empirical evidence from Malaysia. *Journal of Economic Cooperation and Development*, *35*(1): 47-80

Sufian, F., and Majid, M.-Z. A. (2007). Banks' Efficiency and Stock Prices in Emerging Markets: Evidence from Malaysia. *Journal of Asia-Pacific Business, 7*(4): 35-53

Sufian, F., Mohamad, A., and Muhamed-Zulkhibri, A. M. (2008). The efficiency of Islamic Banks: empirical evidence from the MENA and Asian countries Islamic banking sectors. *The Middle East Business and Economic Review, 20*(1): 1-19

Sufian, F., Muhamad, J., Bany-Ariffin, A., Yahya, M. H., and Kamarudin, F. (2012). Assessing the effect of mergers and acquisitions on revenue efficiency: Evidence from Malaysian banking sector. *Vision: The Journal of Business Perspective, 16*(1): 1-11

Tan, Y. (2014). Corporate governance in the banking sector. In Y. Tan (Ed.), *Performance, Risk and Competition in the Chinese Banking Industry* (pp. 39-64): Chandos Publishing.

Taylor, W. M., Thompson, R. G., Thrall, R. M., and Dharmapala, P. S. (1997). DEA/AR efficiency and profitability of Mexican banks - A total income model. *European Journal of Operational Research*, *98*(2): 346-363

Thanassoulis, E. (1999). Data envelopment analysis and its use in banking. *Interfaces, 29*(3): 1-13

Thanassoulis, E. (2001). Definitions of Efficiency and Related Measures *Introduction to the Theory and Application of Data Envelopment Analysis: A Foundation Text with Integrated Software* (pp. 21-35). Boston, MA: Springer US.

Thanassoulis, E., Boussofiane, A., and Dyson, R. G. (1996). A comparison of data envelopment analysis and ratio analysis as tools for performance assessment. *Omega-International Journal of Management Science, 24*(3): 229-244

Thi, M. P. H., Daly, K., and Akhter, S. (2016). Bank efficiency in emerging Asian countries. *Research in International Business and Finance*, *38*: 517-530

Thompson, R. G., Dharmapala, P. S., Humphrey, D. B., Taylor, W. M., and Thrall, R. M. (1996). Computing DEA/AR efficiency and profit ratio measures with an illustrative bank application. *Annals of Operations Research, 68*: 303-327

Thomson, J. B. (1991). Predicting bank failures in the 1980s. *Economic Review, 27*(1): 9-20

Thoraneenitiyan, N., and Avkiran, N. K. (2009). Measuring the impact of restructuring and country-specific factors on the efficiency of post-crisis East Asian banking systems: Integrating DEA with SFA. *Socio-Economic Planning Sciences, 43*(4): 240-252

Titko, J., and Jureviciene, D. (2014). DEA Application at Cross-country Benchmarking: Latvian vs Lithuanian Banking Sector. *Procedia - Social and Behavioral Sciences, 110*(0): 1124-1135

Titko, J., Stankevičienė, J., and Lāce, N. (2014). Measuring bank efficiency: DEA application. *Technological and Economic Development of Economy, 20*(4): 739-757

Tobin, J. (1964). *Commercial banks as creators of" money"*. Connecticut: Cowles Foundation for Research in Economics, Yale University.

Tone, K. (2001). A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research, 130*(3): 498-509

Tone, K., and Tsutsui, M. (2009). Network DEA: A slacks-based measure approach. *European Journal of Operational Research, 197*(1): 243-252

Triki, T., Kouki, I., Dhaou, M. B., and Calice, P. (2017). Bank regulation and efficiency: What works for Africa? *Research in International Business and Finance, 39, Part A*: 183-205

Tulkens, H. (1993). On FDH efficiency analysis: Some methodological issues and applications to retail banking, courts, and urban transit. *Journal of Productivity Analysis, 4*(1-2): 183-210

Tulkens, H., and Vanden Eeckaut, P. (1995). Non-frontier measures of efficiency, progress and regress for time series data. *International Journal of Production Economics, 39*(1-2): 83-97

Turney, P. B., and Anderson, B. (1989). Accounting for continuous improvement. *Sloan Management Review, 30*(2): 37-47

Wagner, J. M., and Shimshak, D. G. (2007). Stepwise selection of variables in data envelopment analysis: Procedures and managerial perspectives. *European Journal of Operational Research, 180*(1): 57-67

Wang, W. K., Huang, W., Wu, J., and Liu, Y.-N. (2014). Efficiency measures of the Chinese commercial banking system using an additive two-stage DEA. *Omega-International Journal of Management Science, 44*: 5-20

Wang, W. K., Lu, W. M., and Lin, Y. L. (2012). Does corporate governance play an important role in BHC performance? Evidence from the US. *Economic Modelling, 29*(3): 751-760

Wang, W. K., Lu, W. M., and Liu, P.-Y. (2014). A fuzzy multi-objective two-stage DEA model for evaluating the performance of US bank holding companies. *Expert Systems with Applications, 41*(9): 4290-4297

Wang, W. K., Lu, W. M., and Wang, Y. H. (2013). The relationship between bank performance and intellectual capital in East Asia. *Quality & Quantity, 47*(2): 1041-1062

Wanke, P., and Barros, C. P. (2014). Two-stage DEA: An application to major Brazilian banks. *Expert Systems with Applications, 41*(5): 2337-2344

Wanke, P., Barros, C. P., and Emrouznejad, A. (2015). Assessing Productive Efficiency of Banks Using Integrated Fuzzy-DEA and Bootstrapping: A Case of Mozambican Banks. *European Journal of Operational Research, 249*(1): 378-389

Wanke, P., Barros, C. P., and Faria, J. R. (2015). Financial distress drivers in Brazilian banks: A dynamic slacks approach. *European Journal of Operational Research, 240*(1): 258-268

Williams, B. (2003). Domestic and international determinants of bank profits: Foreign banks in Australia. *Journal of Banking & Finance, 27*(6): 1185-1210

Wilson, P. W. (2008). FEAR: A software package for frontier efficiency analysis with R. *Socio-Economic Planning Sciences, 42*(4): 247-254

Wu, D. S. (2000). Is China's economic growth sustainable? A productivity analysis. *China Economic Review, 11*(3): 278-296

Wu, D. S., Yang, Z. J., and Liang, L. A. (2006). Using DEA-neural network approach to evaluate branch efficiency of a large Canadian bank. *Expert Systems with Applications, 31*(1): 108-115

Yahya, M. H., Muhammad, J., and Hadi, A. R. A. (2012). A comparative study on the level of efficiency between Islamic and conventional banking systems in Malaysia. *International Journal of Islamic and Middle Eastern Finance and Management, 5*(1): 48-62

Yang, C., and Liu, H.-M. (2012). Managerial efficiency in Taiwan bank branches: A network DEA. *Economic Modelling, 29*(2): 450-461

Yousefi, A., and Hadi-Vencheh, A. (2010). An integrated group decision making model and its evaluation by DEA for automobile industry. *Expert Systems with Applications, 37*(12): 8543-8556

Zeff, S. A. (1978). The rise of economic consequences. *The Journal of Accountancy, 5*(4): 56-63

Zha, Y., and Liang, L. (2010). Two-stage cooperation model with input freely distributed among the stages. *European Journal of Operational Research, 205*(2): 332-338

Zhao, H., Sinha, A. P., and Ge, W. (2009). Effects of feature construction on classification performance: An empirical study in bank failure prediction. *Expert Systems with Applications, 36*(2): 2633-2644

Zofio, J. L. (2007). Malmquist productivity index decompositions: a unifying framework. *Applied Economics, 39*(18): 2371-2387

LIST OF PUBLICATIONS AND PAPERS PRESENTED

1. Wanke, P., Azad, M. A. K. & Barros, C. P. (2016), "Financial distress and the Malaysian dual baking system: A dynamic slacks approach", *Journal of Banking & Finance*, 66 (May), 1-18.
2. Azad, M. A. K., Munisamy, S., Masum, A. K. M., Saona, P. & Wanke, P. (2017), "Bank efficiency in Malaysia: a use of Malmquist meta-frontier analysis", *Eurasian Business Review*, 7 (2), 1-25.
3. Azad, M. A. K., Kian-Teng, K. & Talib, M. A. (2017), "Unveiling black-box of bank efficiency: an adaptive network data envelopment analysis approach", *International Journal of Islamic and Middle Eastern Finance and Management*, 10 (2), 149-169.
4. Azad, M. A. K., Muzalwana, A.T. & Kwek, K.T. (2018), “Revisiting DEA Techniques in Measuring Bank Efficiency: The Case of Malaysian Banking Industry” in JSG book chapter under *Operations Research*, Department of Applied Statistics, University of Malaya Press (accepted).