INTEGRATED MULTI-CRITERIA DECISION MAKING – DATA ENVELOPMENT ANALYSIS MODELS IN EFFICIENCY ANALYSIS OF SPONSORED RESEARCH

by

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DEDICATIONS

To my mother, Norsiah Hashim
For always believing in me and my ability to endure this challenging journey

To my father, Nana Khurizan Abdullah
For showing me the importance of finishing what I have started and that giving up is not an option

To my husband, Abdul Salam Abdul Rahim
For the continuous support and encouragement during my most difficult time

To my children, Aisyah Safiya and Abdurrahman Naufal
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For just being there with me through this long arduous journey

To my family and in laws
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Our greatest weakness lies in giving up. The most certain way to succeed is always to try just one more time.
-Thomas Edison

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANOVA	Analysis of Variance
BCC	Banker, Charnes and Cooper
CCR	Charnes, Cooper and Rhodes
CRS	Constant Return to Scale
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DRS	Decreasing Return to Scale
EDA	Efficient DMU Analysis
IRPA	Intensification of Research in Priority Areas
IRS	Increasing Return to Scale
KPI	Key Performance Indicator
MACBETH	Measuring Attractiveness through a Category Based Evaluation Technique
PE	Pure Efficiency
PTE	Pure Technical Efficiency
RCMO	Research Creativity and Management Office
RTS	Return to Scale
SAGA	Scientific Advancement Grant Allocation
USM	Universiti Sains Malaysia

MODEL GABUNGAN PEMBUATAN KEPUTUSAN KRITERIA BERGANDA – ANALISIS PENYELIPUTAN DATA UNTUK ANALISIS KECEKAPAN PENYELIDIKAN BERTAJA

ABSTRAK

Dalam konteks pengurusan institusi pengajian tinggi khususnya untuk penyelidikan bertaja iaitu penyelidikan yang menerima tajaan geran, proses analisis kecekapan telah menjadi satu keutamaan bagi penaja dan penyelidik. Proses penilaian akan menyediakan maklumat berkenaan produktiviti penyelidikan dalam menggunakan sepenuhnya sumber untuk menghasilkan hasil yang wajar. Bagi menilai prestasi penyelidikan bertaja, adalah lebih mudah jika skor tunggal dihasilkan bagi mewakili kecekapannya. Pelbagai metodologi telah menyumbang dalam menilai prestasi penyelidikan bertaja. Antara yang popular ialah Pembuatan Keputusan Kriteria Berganda (MCDM) dan Analisis Penyeliputan Data (DEA). MCDM dan DEA berurusan dengan masalah berkaitan kepelbagaian input dan keluaran. Faktor ini penting dalam menganalisis kecekapan kerana dalam proses ini, kebanyakan kajian kes melibatkan lebih daripada satu sumber dan keluaran. Fokus utama kajian ini ialah untuk menilai kecekapan penyelidikan bertaja tertakluk kepada ketersediaan data dan bilangan unit pembuatan keputusan (DMU). Model gabungan MCDM dan DEA telah diperkenalkan untuk memenuhi kehendak proses penilaian berdasarkan keadaan data penyelidikan bertaja tersebut. Kajian awal melibatkan proses analisis bagi data yang lebih ringkas dengan bilangan data yang sedikit. Kajian kes pertama membentangkan cara baharu bagi menggabungkan tiga model MCDM dan DEA berbeza untuk menilai prestasi penyelidikan bertaja

dengan saiz data yang ringkas daripada geran yang sama. Model gabungan ini dapat menguruskan data subjektif dan data objektif dalam menghasilkan skor tunggal bagi setiap penyelidikan bertaja. Masalah kuasa diskriminasi rendah bagi DEA juga dapat diatasi oleh model tiga peringkat ini. Penemuan analisis telah membawa kepada analisis lanjutan terhadap data bersaiz lebih besar daripada satu geran yang sama dengan keperluan untuk menilai prestasi disiplin bagi penyelidikan bertaja. Ketika proses penilaian, telah timbul isu kewujudan karakter bukan homogen bagi Unit Pembuatan Keputusan (DMU). Analisis statistik telah dijalankan untuk menyokong penemuan tersebut dalam saiz data yang lebih besar. Maka penggunaan algoritma sedia ada yang telah diperhalusi telah dicadangkan untuk mengatasi masalah tersebut. Algoritma tersebut telah di takrifkan dalam enam langkah sistematik supaya ia dapat diaplikasikan dalam kajian kes yang serupa. Kewujudan karakter bukan homogen dalam analisis kecekapan mungkin meningkatkan keperluan bagi analisis sokongan berkenaan kesan kepelbagai pemboleh ubah persekitaran terhadap prestasi penyelidikan. Kewujudan pelbagai pembolehubah persekitaran juga dikaji bagi kes data yang melibatkan kepelbagaian jenis geran yang beroperasi dalam persekitaran yang berbeza. Sekali lagi, model gabungan MCDM dan DEA dicadangkan utuk menangani keperluan proses penilaian penyelidikan bertaja di bawah kewujudan pelbagai pemboleh ubah persekitaran. Kaedah yang dicadangkan juga dapat menyusun kedudukan pusat pengajian berdasarkan prestasi penyelidikan bertaja dibawahnya. Kekuatan akademik pusat pengajian dari segi kajian juga dapat dikenalpasti dan boleh digunakan untuk menilai prestasi keseluruhan pusat pengajian tersebut. Kajian yang dicadangkan di dalam tesis ini menyediakan platform bagi menganalisis kecekapan penyelidikan bertaja di bawah kondisi berbeza. Setiap model gabungan sesuai diaplikasikan

untuk pelbagai saiz data dan ketersediaan informasi data tersebut. Oleh itu, model yang paling sesuai boleh dipilih untuk memenuhi karakter data yang ingin dianalisis.

INTEGRATED MULTI-CRITERIA DECISION MAKING – DATA ENVELOPMENT ANALYSIS MODELS IN EFFICIENCY ANALYSIS OF SPONSORED RESEARCH

ABSTRACT

In the context of higher education administration, specifically for sponsored research, efficiency analysis has become an essential process for both sponsors and researchers. The evaluation process will provide the information on research productivity in fully utilising the resource to produce the desirable outcome. It is easier to evaluate the sponsored research' performance when its efficiency is represented by a single score. Over the years, many methodologies have contributed into assessing the performance of sponsored research. Among the most popular ones are Multi-Criteria Decision Making (MCDM) Method and Data Envelopment Analysis (DEA). MCDM and DEA method both deal with problems concerning multiple inputs and outputs. This factor is crucial in efficiency analysis as most case studies are presented with more than one resource and outcome. The main objective of this study is to evaluate the efficiency of sponsored research in a university subject to its data availability and number of Decision Making Units (DMUs). The integrated MCDM-DEA methods are presented in order to fulfill the requirement of the main objective. The first case study presents a novel way of integrating three different MCDM and DEA model to evaluate the performance of a sponsored research from a much simpler form of data in a small size under the same grant. The integrated model has managed to handle the subjective data and objective data in producing the single score for each sponsored research. The issue

of low discrimination power of DEA is also tackled using the three-stage model. This study continues to further investigate a data set containing larger number of DMUs from one grant for the purpose of investigating the sponsored research performance according to its discipline of study. During evaluation process, the issue of non-homogeneity characteristics of the sponsored research has also come to light especially regarding its research' discipline which is supported by two statistical analysis. Hence a refined algorithm, properly defined in six steps, is suggested to tackle the issue. The algorithm is refined such that it is applicable to similar case studies. The issue of non-homogeneity characteristics of sponsored research may raise the need into supplementary analysis on the effect of multiple environmental variables on the research' performance. The presence of multiple environmental variables are investigated when the data set is from different types of grants that operate under multiple environments. An integrated MCDM-DEA method is proposed to tackle the need of evaluating the sponsored research performance under the existence of multiple environmental variables. The method suggested also managed to rank the university's school based on the performance of its sponsored research. The school's academic strength on research can be identified and may be of use in evaluating its overall performance. Each distinctive integrated model presented in this study provides a platform to evaluate the sponsored research' efficiency in accordance to the sizes and information availability of its data. One may select the best model to accommodate the characteristics of the data.

CHAPTER 1

INTRODUCTION

This chapter presents an introduction to the study conducted in this thesis. The discussion includes the research interest and background of the case study. Following the brief discussion on the area of study, the objectives and outline of the thesis are also presented.

1.1 Research and Development (R&D)

The meaning of research is to conduct a systematic investigation in a certain areas or subjects that matters for the purpose of discovering new facts or even establish a new findings and conclusions. Development on the other hand, is a progress in which the subject of study grows and become more advance in its field. Research and development, better known as R&D represents the need of exploration in the area of study to improve and even better, to produce new outcomes for the benefit of many specifically the parties concerned.

In order for the R&D to commence, many factors have to be taken into consideration to assure its successfulness. Two most important factors are the experts in the field of study and financial support. Both factors complement each other as without the financial support, the experts will face limitation in conducting the research. The importance of R&D has resulted in an increase in the numbers of grants being allocated to encourage researchers to take part in improving their area of specialisation. Areas of R&D is mainly divided into two areas namely industrial R&D and educational R&D. While both areas focus their R&D in their competitive environment, the industrial R&D is usually dedicated to the firms' production and

sales whereas the educational R&D is focused on encouraging scientific growth of the current research and therefore enhancing its overall academic strength.

Research allocated with grant or better known as sponsored research has also contributed to the rapid growth of research evaluation study. Research evaluation and performance measurement are needed in order to identify the efficient R&D that has succeeded in achieving its target. One of the most important aspect in research evaluation process is its multi-criteria requirement in assessing the research performance. The multiple resources that contributes into achieving multiple goals and targets of the research are to be considered during the evaluation process. Over the years, various methods have been developed and applied to assess the performance of R&D activities. This, among others, is due to the competitive environment in gaining financial support from either government or private sector. Many methodologies have contributed into such requirement in terms of both subjective and objective data.

1.1.1 Higher Education Administration Sponsored Research

Educational R&D is an important benchmark in determining the quality of a higher learning institutions. Past literature revealed that one of the important aspects in assessing the performance of an institutions is the outcome of a research conducted by the academicians or researchers working under its roof. These outcomes are best presented in the form of publications. The importance of R&D in higher learning institutions contribute to more allocation in terms of financial support. Particularly in Malaysia, the government and ministry have been working hand-in-hand in providing the sufficient amount of grants to encourage scientific advancement in higher learning institutions.

In empowering research development in higher education, research grant allocation has become essential in providing the necessary financial support for researchers. In the context of higher education administration specifically for sponsored research i.e. research awarded with grant, performance evaluation has become an essential process for both sponsors and researchers. Performance evaluation of sponsored research will answer the simple question of: Is the amount of grant allocated sufficient with the output produced? Or in the other way around; has the research produced enough output by fully utilising the given amount of input? Either way, both questions need to be answered by an evaluation process whereby the performance of each and every sponsored research can be compared to one another in the same characteristics of interest.

The efficiency analysis will assist the administration in investigating the sufficient amount of resource allocation in aiding the researchers to conduct the related study. By doing so, any form of overflowing resource may be identified to avoid any excessive spending especially in capital resource in order to achieve any designated target of research development.

1.2 Problem Statement

Multiple issues have come to light during the evaluation process. Initially, all research are allocated with resources to produce the outcomes during the assigned terms of time. For a data set that has small number of research to be evaluated, the problem may rise from data set available involving a large number of resources and outcomes. While all sponsored research will have nonzero value for its resources, large numbers of distinctive outcomes may result in too many zero

values as not all research can manage to produce the same type of outcome. This condition will result in having too many efficient units in an efficiency analysis.

For a data containing a large number of sponsored research from the same grant, apart from evaluating the research individually, there may be a need to see the performance of the related discipline as well. The performance of the research discipline may differ from one another due to external factor that influence its performance as well as publications opportunity, chances in producing a technology related outcome and the availability and need of equipment. By grouping the sponsored research into its related discipline, an inconsistency in the evaluation process may arise since the performance may differ when different types of analysis are conducted.

Such findings suggest the non-homogeneity characteristics of the sponsored research whereby a single analysis will not be enough to meet the requirement of the characteristics. When a problem of non-homogeneity characteristics arises, it is not fair for the research to be evaluated under a single rule and assumption. The presence of the heterogeneity characteristics require an extension to the existing analysis process in order to fairly evaluate all the research based on its capability of performing under different circumstances.

1.3 Research Objectives

The main objective of this study is to analyse the performance of a sponsored research based on the number of sponsored research and the available information on the resources and outcomes of the research. For each distinctive grant, the availability of the data varies from the number of research that receive the

grant allocations to the types of outcomes achieved by the research. The objectives are listed as below:

1) To rank individual research based on its performance. We aim to improve the evaluation process by tackling the issue of low discrimination power of DEA as well as to highlight the individual strength of the research in producing different types of outcomes.
2) To investigate the performance of the sponsored research based on its related discipline and to examine any difference in mean and median efficiencies of a classified group.
3) To tackle the issue of non-homogeneity characteristics of the sponsored research specifically on the discipline of the research.
4) To incorporate the presence of multiple environmental variables in a larger scale data from four distinctive grant and to rank the university's school based on the performance of the sponsored research.

Figure 1.1 summarize the development of research in this study.

Fundamental Research
• The application of MCDM methods to improve the discrimination power of DEA by reducing the number of output variable in sponsored research evaluation.
Research Development
• Ranking the sponsored research individually and based on relevant non-homogeneous group • The effect of environmental variable in sponsored research performance and efficiency score
Main Research
• Evaluating the performance of sponsored research by taking into account its heterogeneity characteristics. • Evaluating the efficiency score in accordance to the presence of single and multiple environmental variables. • Ranking the schools in university based on the sponsored research development

Figure 1.1 Research development

1.3.1 Rules and Assumptions

There are certain rules applied in this study that require multiple mentioning. Hence to simplify and in order to avoid multiple repetition on the same subject, some of the rules, information on the research approach and assumptions are described as follows:

i) Lee and Lee (2015) mentioned the rule of thumb previously discussed by Baker et al. (1989) and Boussofiane et al. (1991). The former stated that the number of DMUs should be at least three times larger than the sum of number of inputs and outputs. The latter stated that the number of DMUs should be larger than the product of the number of input and outputs. The rules of thumb are to be applied in case of overcoming the low discrimination power of DEA.

ii) Based on the data collected for the analysis, some sponsored research did not manage to produce any outcome from its study. For such research we assume the value of the efficiency score to be 0 since there is no achievement to be evaluated as the data available is only the input data.

iii) The maximum efficiency score of the DMU in the DEA analysis is 1 as to avoid confusion with the maximum value of standardised data which is 100.

iv) The DEA Analysis in this thesis is run using Banxia Frontier Analyst and DEAP Version 2.1: A DEA (Computer) Program.

v) The statistical analysis conducted in this thesis is aided by Minitab 17 software.

1.4 Research Data

This section will provide information about the data used for analysis in this thesis. There are four types of grants involved in this thesis. While three of the grants are allocated by the government and are eligible for applicants throughout the country, this thesis will only consider the selected applicants from Universiti Sains Malaysia (USM). The data used in this thesis are collected by USM Research Creativity and Management Office (RCMO). This study will be the platform for RCMO's future planning on funded research. The result of this study may benefit in many ways such as assessing the research performance for a possible most efficient research award, encouragement to future funded researcher and to predict the output from sponsored research in the future. All information on the background of the grants are obtained from the Office of Prime Minister Malaysia (SAGA Grant) and USM website. Summary on the details of each grant is presented in Table 1.1.

Table 1.1

Summary of Grants allocated to USM

Grants	**Sponsors**	**Number of Receiver from USM**
SAGA	MOSTI Academy of Science Malaysia	21
IRPA	MOSTI	152
Science Fund	MOSTI	192
Short-term	USM	152

1) **Scientific Advancement Grant Allocation (SAGA)**

This grant is part of the 8th Malaysia Plan's Nobel Prize Programme to support scientific advancement in fundamental sciences. The long-term objective of this grant is to finally have a Malaysian win a Nobel Prize Award. This grant is under the supervision of Ministry of Science and Technology (MOSTI) and Academy of Science Malaysia. From the collected data, a total number of 21 research from USM are selected to receive the grant.

2) **Intensification of Research in Priority Areas (IRPA)**

Also part of the Malaysia Plan, IRPA supports diversity in research areas from selected applicants throughout Malaysia. The grant allocation is monitored by MOSTI Malaysia in order to encourage growth in research and development area concurrently with the objective of producing an advanced society in science and technology. 152 research from USM are selected to receive this grant.

3) **Science Fund**

A total number of 192 research from USM are eligible for this grant funded again by MOSTI. Similar to the previous two grants, this monetary allocation aims

to promote research advancement in generating new scientific knowledge by supporting the development in productivity and commercialization.

4) **Short-term Grant**

Funded by USM for its academic staff, this grant aims to support short term research activities that will able to spark the advancement of research environment in the university. The data collected for this study is from 152 selected short-term receivers.

1.5 Thesis Outline

This thesis is divided into chapters based on the characteristics of the data to be analysed. Consisting of eight chapters, the brief outline of each chapters is discussed below.

Chapter 2 discussed the literature review. A brief summary of relevant past study is presented. The literature review provides an insight on the case study to be tackled n this thesis by understanding the research gap.

In Chapter 3, we present and discuss all the methods used in this study. There are three main methodology namely Analytic Hierarchy Process (AHP), Measuring Attractiveness through a Category based Evaluation Technique (MACBETH) and Data Envelopment Analysis (DEA). The method of DEA based preferential voting will also be discussed. Following discussion on all the methods is the discussion on the non-homogeneous DEA.

The model presented in this Chapter 4 is a three level multi-criteria model using AHP-DEA and DEA based preferential voting. AHP methodology is employed in the variable reduction process in order to overcome the problem of low

discrimination power of DEA and too many zero output values in the data. The DEA methodology is applied next to investigate the effect of duration on efficiency score. The same method is also used to test the efficiency score based on multiple output combinations. The ranking of an individual sponsored research is presented following the execution of preferential voting method.

Chapter 5 discusses the application of MACBETH and DEA in investigating the research performance based on its discipline. MACBETH methodology is put into practice in exchange to AHP to accommodate a much more straightforward process of judgment. A statistical analysis is also conducted to find any evidence of mean and median differences. Two statistical tests were employed, the ANOVA for the mean differences and the Kruskal Wallis test for the median differences.

A refined algorithm is presented in Chapter 6 to evaluate the performance of same data used in Chapter 5, only this time it includes the non-homogeneity findings from statistical analysis in Chapter 5.

The case study presented in Chapter 7 deals with data set containing more DMUs from four distinctive grants. The analysis done in this chapter considers the presence of multiple environmental characteristics in order to rank university's school according to the performance of the sponsored research.

Finally, in Chapter 8, we discuss on the thesis contributions, conclusions and discussion for possible future research.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the literature review on all the methodologies used in this thesis and discussed relevant past studies on the application of Data Envelopment Analysis (DEA) in higher education administrations. This review also includes study on efficiency analysis of R&D and sponsored research. Section 2.1 provides the selected relevant literature review on the developments of Analytic Hierarchy Process (AHP) method. Section 2.2 discussed the findings in Measuring Attractiveness through a Category based Evaluation Technique (MACBETH) while Section 2.3 focus on the application of DEA. The literature review on integrated AHP-DEA model were discussed in Section 2.4. The DEA-based preferential voting method and non-homogeneous DEA related papers were presented in Section 2.5 and 2.6 accordingly. Finally, Section 2.7 present the data and variables selection on R&D efficiency analysis.

2.1 Developments of AHP Methodology in Higher Education Administration Efficiency Evaluation

AHP, orginally developed by Thomas A. Saaty in 1977, is a well-established multi-criteria decision making method that takes into account the judgment of decision makers. It has gained many interests in the field of complex decision making problem in various research areas.

Islam and Anis (2015) provides a comprehensive literature review on the application of AHP in higher learning institutions. The literature review critically analysed 33 papers dated from 1997 to 2013, on the application of AHP as a single tool and integrated models. Among the 33 papers included in the literature review,

18 papers applied the AHP methodology as a single tool. However, none of the paper discussed includes the integrated model of AHP and DEA. They identified 13 areas of application in higher learning institutions. The areas with most applications are faculty evaluation and measuring the quality education in higher learning institutions.

Some of the papers discussed were written by Liberatore and Nydick (1997) whereby an evaluation on research performance has been demonstrated by using an AHP methodology to rank research papers based on group decision making. Badri and Abdulla (2004) developed an AHP model for university's award system. Not included in the literature review by Islam and Anis (2015) is study by Lin and Chiang (2007) in which they used the same method as in Liberatore and Nydick (1997) to evaluate the performance of a sponsored research using the expert opinion of nine decision makers. Both of the application calculates the priority score of each criterion to evaluate the research performance. Recently a study on a new AHP extended method was presented by Zong and Wang (2017) to evaluate the university scientific research ability based on the sci-tech papers. The study proposed a substitution for the pairwise comparison matrix with the D matrix, developed from new models of handling uncertain information, the D numbers. The method is thus called D-AHP.

2.2 Developments of MACBETH Methodology in Higher Education Administration Efficiency Evaluation

The application of both MACBETH and DEA in higher education administration can be considered relatively new and rare as there is only limited

literature found on this topic. Furthermore, there are also no application found on MACBETH as a tool for determining the priority score for environmental variables.

In 2002, Soares De Mello et al. described the application of MACBETH in evaluating the performance of calculus class by using its weight restriction function to assist the DEA analysis. Later in 2012, Bana e Costa and Oliveira demonstrated a faculty evaluation model based on MACBETH by conducting a two-level hierarchical additive structure. MACBETH featured the flexibility on weightage bound by providing the decision makers (DM) with a summary of upper and lower bound of the weightage which can be adjusted according to the DM's preference.

2.3 Developments of DEA Methodology in Higher Education Administration Efficiency Evaluation

One of the earliest studies on DEA in higher education was done in 1997 by Mcmullen to assessed the performance of Master's of Business Administration (MBA) programme using DEA with weight restriction. Published in the same year, Rousseau and Rosseau (1997) constructed performance indicators using DEA by analysing the R&D expenditure of several countries. Their research provides a reference for the government on the performance of R&D based on monetary allocation, population and publications. Later in 2000, Colber et al. measured the relative efficiency of MBA programmes by applying the BCC model using three different output sets whereas Agrell and Steuer (2000) presented a multi-criteria decision support system to review the performance of individual faculty named ACADEA.

Three relevant literature review were found in 2001. Kocher et al. (2001) measured the productivity of economics research using both output oriented CCR

and BCC models by discussing further on the effect of uncontrolled variable. Korhonen et al. (2001) on the other hand, applied the output-oriented BCC model into assessing the performance of academic research from one particular academic school. Their study focus mainly on the quality of the research. Avkiran (2001) applied DEA in three performance model each representing the overall performance, educational delivery performance and success rate of attracting fee-paying students. The study aims to investigate the efficiencies of universities in Australia.

Lopes and Lanzer (2002) used DEA to modeled a fuzzy numbers to be aggregated through a weighted ordered aggregator. The DEA methodology is performed multiple times in which the performance indicators was later adapted into fuzzy sets to be integrated into single fuzzy performance measure. The case study is applied to assess the performance of academic departments. Meanwhile Abbott and Doucouliagos (2003) used DEA to perform the evaluation process of Australian universities and investigate its technical and scale efficiency to group the universities into the lowest and highest-ranking universities. Taylor and Harris (2004) evaluated the efficiency of 21 South African universities using seven different input combinations in DEA model to investigate the stability and consistency of the models. The chosen model was then applied to further analyse the relative efficiency over time.

Johnes (2005) employed DEA to measure the higher education teaching performance. The study found that DEA analysis using aggregate data is misleading compared to the study using individual efficiency analysis of teaching institutions. Emrouznejad and Thanassoulis (2005) explored the application of DEA in a condition whereby the input-output levels are inter-temporally dependent. They measured the efficiency of an assessment path determined by the period of which

the input and output coincident. Lozano and Salmeron (2005) applied two inputs and two outputs DEA model in evaluating the performance of operations research and management science journal. They considered the time measures for first editorial review and publications as inputs and submission and acceptance rate as outputs. They further investigate the efficiency analysis of the journal impact versus the article length.

Johnes (2006a) applied DEA in higher education efficiency measurement to more than 100 higher education institutions. Again, a different combination of inputs and outputs is used in eight DEA models. Meanwhile Johnes (2006b) compared the efficiency of university based on student achievement obtained from DEA and multi-level modelling using the same data set. Koksal and Nalcaci (2006) evaluate the performance of engineering college using two types of dual CCR output-oriented model, the CCR-Assurance Region method and Multi-criteria DEA-CCR method. The weightage of all criteria was first evaluated using AHP. Soares de Mello et al. compared the performance of engineering post-graduate programme using both CCR model and CCR with weight restriction model. Bougnol and Dula (2006) applied DEA and Tiered DEA (TDEA) to compare the efficiency score calculated for university's performance to the one published in an annual report. They managed to prove DEA ability to act as a ranking tool despite being a performance measurement tool. On the other hand, the performance of university departments was evaluated by Martin (2006). The study executed four DEA models by removing one different output variable each from three of these four models. This was to test the sensitivity on the input-output specification. The study, however only discussed the performance based on each model without producing a single rank for the departments.

Both CCR and BCC methods were applied by Leitner et al. (2007) in evaluating the performance of university departments by using multiple input and output combinations. In assistance to DEA methodology, the determination of the inputs and outputs were done beforehand by using correlation analyses and ordinary least square (OLS) regression. A three-stage approach using DEA and tobit regression model were introduced by Wang and Huang (2007) in assessing the performance of 30 countries in R&D. DEA was applied in the first and third stage while tobit regression model is applied in the second stage for controlling the external environmental effects. The tobit regression estimated coefficient is used for prediction of input slacks in the calculation of new adjusted data. Castano and Cabanda (2007) to assess the performance of private higher education institute. They further investigated the affecting factor using stochastic frontier model. Johnes (2007) applied DEA to study the productivity change in higher education institution by deriving the Malmquist indexes over some period of time. This study investigated the growth of the sector over time.

In 2008 Kao and Hung adapted the assurance region method to assign the non-homogeneous weight restriction to the efficiency analysis of university departments using DEA. Also, in 2008, Johnes and Yu discussed the effect of using various combinations of inputs and outputs to test the sensitivity of DEA analysis of Chinese higher education institutions. Meanwhile Sharma and Thomas (2008) applied both CCR and BCC model in studying the efficiency analysis in inter-country R&D of 22 countries.

In 2009, Cullman et al. studied the impact of regulatory environmental factors on R&D efficiency by applying DEA for the evaluation process and a single bootstrap procedure to compensate the environmental factors study. Jeong at. al

(2010) investigated the effect of environmental variable on R&D efficiency by conducting both parametric and non-parametric statistical analysis following the application of super-efficiency DEA model in evaluating the R&D performance. Their findings suggested that multiple environmental factors affect the R&D performance. Sarkis and Seol (2010) evaluated university course performance using DEA by incorporating the student's judgment into the data variables. Input and output variables are determined by the student in the form of numerical scale to be analysed using both CCR and BCC models. Similarly, Tzemeres and Halkos (2010) used both CCR and BCC models to evaluate university's department's efficiency. They later employed a bootstrap method to test the CCR results against the BCC results.

Abramo et al. (2011) applied the input-oriented DEA model in their study of 28 universities based on the strength of bibliometrics data over some period of time as an output. Agasisti et al. (2011) investigated the research efficiency of academic departments by employing the DEA and assisted by Malmquist indexes method to measure any change in efficiency scores They further analyse the effect of certain factors on the efficiency score by conducting a non-parametric statistical test. Alwadood et al. (2011) evaluated the performance of six university departments separately using DEA model and later compared their performance. Arisovnik and Obadic (2011) also applied multiple combination of input and output on a DEA model to evaluate the efficiency of higher education institution. On the other hand, Kuah and Wong (2011) investigated the teaching and research efficiency of hypothetical university data using joint DEA maximisation model.

Agasisti and Pohl (2012) studied on the comparison of Germany and Italian public universities employed DEA methodology to derive the efficiency score for

two reference years for further investigation using Tobit analysis. In 2013, a research conducted by Johnes employed a network DEA methodology using two nodes to produce one final efficiency score to compare the efficiency of higher education institutions in England.

Afzal and Lawrey (2014) compared the performance of ASEAN region R&D using both CCR and BCC DEA models. Meanwhile, Munoz and Lopez (2014) employed DEA to study on R&D efficiency and productivity between regions and further identifying the R&D clusters according to the region. However, their study only includes a limited number of input and outputs which may affect the final outcome. Li and Hu study the efficiency of R&D resource allocation by applying DEA super efficiency model to its data analysis. On the other hand, Hao and Yanhui (2014) studied the growth of R&D research institute in China by using multiple input and output combinations in the DEA analysis.

Munoz (2016) analysed the efficiency of higher education institutions in Chile using four models of different input-output combination using DEA BCC method. However, the study only produced four different efficiency score based on each model. Such finding is not conclusive when it comes to producing a single ranking for the universities.

Recently, Sharifian et al. (2017) investigated the performance of university's colleges within time constraint of five years using window DEA and double frontier DEA. Window DEA method has found to be useful in the assessment of a time-based evaluation analysis.

2.4 Developments of Integrated AHP-DEA Methodology in Higher Education Administration Efficiency Evaluation

Feng et al. (2004) employed both AHP and DEA methods in their study of university's R&D management. AHP is used to find the weight restriction value for the variables in the DEA analysis to find the relation between the university's research management and its growth in efficiency. In 2005, Saen et al. compensate the case of missing variables value in a slightly non-homogeneous DEA efficiency analysis of research organization by applying the series mean technique. This paper also employed the AHP methodology for weight restriction.

In applying AHP for data transformation to improve the low discrimination power of DEA, Meng et al. (2008) constructed a three levels hierarchy before conducting AHP analysis to calculate the priorities of all the indicators for grouping the data. The data were later analysed using two-level DEA approach; one of them is BCC model, to evaluate the research performance. Jyoti, Banwet and Deshmukh (2008) integrate AHP-DEA methodology to derive the weight of all outputs variable in measuring the efficiency of national R&D organizations. Lee et al. (2009) overcame the issue of non-homogeneity in national R&D programme by assigning a relative weight calculated using AHP and Assurance Region (AR) model to the variables in the DEA analysis.

In 2011, Lee et al. presented the R&D management system analysis in monitoring and evaluation process. They employed the method of AHP to calculate the weight of variables and an input-oriented CCR model for efficiency analysis. Similarly, Kong and Fu (2012) applied AHP for the same purpose of weight generation before proceeding into Assurance region-DEA method for empirical

analysis of business school. Later in 2016, Jablonsky integrated the AHP and DEA methodology to assess the higher education teaching performance. AHP was applied to interpret the student's evaluation of the tutor and the result is then used for the DEA analysis.

2.5 DEA based Preferential Voting

This section presents some literature review on the preferential voting method. Since only few findings can be found on the application of the method on sponsored research assessment process, we discussed the development of the method instead.

Cook and Kress (1990) defined a discrimination intensity function to build the assurance region (AR) constraint to restrict the weight difference for each place/position in which the weight of $j+1$ th position should not be equal nor exceed the weight of j th position. Ever since then, the proposed method has sparked interest in various research many of which trying to improve the existing method.

By retaining the intention of Cook and Kress, Green et al. (1996), in selecting R&D projects for R&D programmes, employed the used of cross evaluation method in solving the preference voting problem by considering the weakest form of discrimination intensity function which is 0.

In 1997, Hashimoto substituted the original DEA/AR model in Cook and Kress (1990) with the DEA/AR exclusion model which discriminated the DMU being evaluated from the comparison set.

Meanwhile, Obata and Ishii (2003) proposed a method to correct the discrimination intensity function dependency on inefficient DMU so that the position of efficient DMU stay the same regardless the presence of inefficient DMU.

One of the most recent studies on preferential voting using DEA, Angiz et al. (2012) incorporated the DEA methodology with cross-efficiency evaluation method into a modified Cook and Kress original model to produce six stages of new proposed approach. On the other hand, Angiz et al. (2013) introduced a new way of ranking alternatives using preferential voting by incorporating the need to handle crisp data using fuzzy concept. This method is proved to be the efficient in producing the final ranking.

2.6 Non-homogeneous DEA

In addition to the non-homogeneous characteristics of research evaluation presented in classical DEA model in Section 2.3, we will further discuss the development of study in non-homogeneous DEA. However, no applications of non-homogeneous DEA were found in the area of sponsored research.

The assumption of homogeneous DMU in the original DEA model may result in bias of relative efficiency score (Tao 2013). Since early 2000, researchers have begun discussing on the non-homogeneous characteristics of the DMU. Dyson (2001) discussed the homogeneous assumption of the DEA model that the DMUs operate under three similarities; activities to produce comparable outputs, range of available resources and environments.

By referring to the findings on Dyson (2001), Brown (2006) demonstrated the pitfalls and protocols of using DEA in credit unions sector. In 2001, Castelli et

al. presented a new approach which assesses the performance of non-homogeneous decision-making sub-units that lies within a larger DMU.

The investigation performed by Haas and Murphy (2003) on three techniques to adjust the non-homogeneity presented in DMUs lead to the finding whereby none of the techniques is superior to the original CCR. The case of missing input or output that often contributes into the non-homogeneity of DMUs is presented in Saen et al. (2005). They overcame such problem by inserting the value of series mean into the missing values instead of simply appointing the value of zero.

The method differs from the same case discussed by Cook et al. (2012) and Cook et al. (2013) that focuses on the possibility of separable inputs. Samoilenko and Bryson (2008) demonstrated the process of improving the discrimination power of DEA to deal with the presence of non-homogeneous DMU by using cluster analysis and decision tree method. Two similar but different algorithm presented by Angulo Meza et al. (2011) and Gomes et al. (2012) to tackle the non-homogeneity characteristics of DMU which we will improve in this study will be highlighted more in chapter 5.

2.7 Data and Variables Selection on R&D Efficiency Analysis

This section discusses the data and variables selection for R&D efficiency analysis. A brief summary on chosen previous study choice of input and output is presented in Table 2.1.

The variable selection for the DEA analysis depends on the need of the evaluator and also available data. Some data maybe suitable for both input and output and it is up to the requirement of the study to allocate which data goes to

which type of variables. Some data may be required for the analysis but not available for the evaluation process due to certain reasons.

Meng et al. (2006) described the two main input factors for research evaluation as researchers and investment. Researchers are considered as the labor input and monetary allocation better known as investment is considered as the capital input. Also, according to Lee et al. (2009), the amount of money allocated for each research is basically determined in proportional to duration (time measures).

The findings from literature highlighted two main input variables for R&D performance measurement namely the labor input and capital input.

In contrast to input variables, the output variables may vary depending the evaluation process requirement. Martin (1996) reported that more than 60% of the case study used publications as an indicator to assess the performance of basic research, individually or supported by other indicator(s). Publications seems to be the most used output performance indicators. Publications include journal publications, conference proceedings, chapter in books and also citation impact. Kostoff (1996) mentioned the use of bibliometric indicators as to measure scientific accomplishment of government sponsored research.

Guena and Nesta (2006) investigated the effect of university patenting on academic research. Patent contributes to university productivity as well as trademark, copyright and industrial design. These outcomes may not be as significant as publications but still contribute to the research productivity and proves the technological innovation. Thomas et al. (2011) mentioned on the acceptance of patent as the indicators in R&D process.

Table 2.1

Inputs and outputs of previous study

Paper	Inputs	Outputs	Output classification	DEA Model
Kocher, Luptacik, sutter 2001	• (I1)Population • (I2)R&D expenditures • (I3)No of universities	• (O1)Papers published	-	CCR O-O
Korhonen, Tainio, Wallenius 2001	• (I1) Monetary allocations	• (O1) Quality of research • (O2) Research activity • (O3) Impact of research • (O4) Activity in educating doctoral students	• International journal publications • International scientific book and chapter in international book • Citations • Publications • Conference papers • Conference presentation • Citations • Invited talks • Foreign co-authors • Phd student produced • Phd student supervised	BCC O-O
Saen et al. 2005	• (I1) Construction Budget • (I2) Pilot plant budget • (I3) Current budget	• (O1) Completed applied research by internal researchers • (O2) Completed applied research by external researchers • (O3) Completed developmental research by internal researchers • (O4) Completed developmental research by external researchers • (O5) Confirmed research • (O6) Seminars • (O7) Internal papers • (O8) External papers • (O9) Compiled books • (O10) Translated books	-	Chance-constrained DEA

Table 2.1

Continued

Paper	Inputs	Outputs	Output classifications	DEA Model
Meng, Hu, Liu 2006	• (I1)Research staff • (I2)Total investment	• (O1) SCI publications • (O2) Postgraduate enrolment • (O3) Total citations	-	CCR I-O, CCR O-O, super efficiency
Meng et al. 2008	• (I1)Staff • (I2)Equipments • (I3)Research expenditures	• (O1)Direct research outputs • (O2)External funding • (O3)Scientist cultivation	• Publications • Awards • Invited talks • Invention patents • Consultant reports • Excellent leaders • Graduates education	BCC O-O
Sharma, Thomas 2008	• (I1) R&D expenditure • (I2) Researchers • (I3) Gross domestic product	• (O1) Papers published	-	BCC I-O
Lee, Park, Choi 2009	• (I1) Funds • (I2) Researchers	• (O1)) Domestic SCI papers • (O2) Domestic nonSCI papers • (O3) International SCI papers • (O4) International non-SCI papers • (O5) Domestic applied patents • (O6) Domestic granted patents • (O7) Foreign applied patents • (O8) Foreign granted patents • (O9) Master's students • (O10) Phd students	-	BCC O-O