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Comparative Evaluation of Public Universities in Malaysia Using Data Envelopment Analysis

By

Wan Rohaida Wan Husain

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

Operational Research and Management Sciences Group,

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GLOSSARY

ARES = Academic Reputation Survey

ARWU = Academic Ranking of World Universities

BCC = Banker, Charnes and Cooper

BCG = Boston Consulting Group

BSC = Balanced Scorecard

CCR = Charnes, Cooper and Rhodes

CRS = Constant returns to scale

DEA = Data Envelopment Analysis

DFA = Deterministic Frontier Approach

DMU = Decision making unit

DMU_0 = Decision making unit being evaluated

DRS = Decreasing returns to scale

EF = Efficient frontier

FDH = Full Disposal Hull

FT = Full time

FTE = Full time equivalent

GRANT = Monetary amount of research grant or research money

HEIs = Higher education institutions

HRS = Hybrid returns to scale

HRSTO = Hybrid returns to scale with trade-off

IRS = Increasing returns to scale

KPI = Key performance indicators

LP = Linear programming

MOE = Ministry of Education

MOHE = Ministry of Higher Education

MPSS = Most productive scale size

MQA = Malaysian Qualifications Agency

MQF = Malaysian Qualifications Framework

MRS = Marginal rates of substitution

MS = Number of Masters students enrolment

MYRA = Malaysia Research Assessment System

PhD = Number of PhD students enrolment

PMS = Performance measurement system

PPS = Production possibility set

PUB = Publication count

QMS = Quality management system

RTS = Returns to scale

RU = Research University

R&D&I = Research and development and innovation

R&D&C = Research and development and commercialisation

SETARA = Rating System for Malaysia Higher Education

SFA = Stochastic Frontier Approach

STAFF = Number of academic staff

THE = Times Higher Education World University Rankings

UDM = Universiti Darul Iman Malaysia

UG = Number of Undergraduate students enrolment

UIAM = Universiti Islam Antarabangsa Malaysia

UiTM = Universiti Teknologi Mara

UK = United Kingdom

UKM = Universiti Kebangsaan Malaysia

UM = Universiti Malaya

UMK = Universiti Malaysia Kelantan

UMP = Universiti Malaysia Pahang

UMS = Universiti Malaysia Sabah

UMT = Universiti Malaysia Terengganu

UniMAP = Universiti Malaysia Perlis

UNIMAS = Universiti Malaysia Sarawak

UPM = Universiti Putra Malaysia

UPNM = Universiti Pertahanan Nasional Malaysia

UPSI = Universiti Pendidikan Sultan Idris

US = United States of America

USIM = Universiti Sains Islam Malaysia

USM = Universiti Sains Malaysia

UTeM = Universiti Teknikal Malaysia Melaka

UTHM = Universiti Teknologi Tun Hussein Onn Malaysia

UTM = Universiti Teknologi Malaysia

UUM = Universiti Utara Malaysia

VRS = Variable returns to scale

VRSTO = Variable returns to scale with trade off

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Wan Rohaida Wan Husain

May 2012

DECLARATION

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ABSTRACT

Applications of Data Envelopment Analysis (DEA) for the assessment of performance of universities have been widely reported in the literature. Often the number of universities under the assessment is relatively small compared to the number of performance measures (inputs and outputs) used in the analysis, which leads to a low discriminating power of DEA models on efficiency scores. The main objective of this thesis is the development of improved DEA models that overcome the above difficulty, using a sample of public universities in Malaysia as an illustrative application. The proposed new approach combines the recently introduced Hybrid returns to scale (HRS) model with the use of additional information about the functioning of universities stated in the form of production trade-offs. The new model developed in this thesis, called Hybrid returns to scale model with trade-offs (HRSTO), is applied to a sample of eighteen universities, which is considered to be a very small sample for the DEA methodology. Our results show that, in contrast with standard DEA models, the new model is perfectly suitable for such samples and discriminates well between good and bad performers. The proposed combined use of HRS model with production trade-offs is a novel methodology that can be used in other applications of DEA. Overall, the thesis makes several contributions of the theory and practice of DEA. First, for the first time, it is shown that the higher education sector satisfies the assumptions and can be modelled using the proposed HRSTO model. Second, also for the first time, it is shown that production trade-offs can be assessed for such applications and the methodology of their assessment has been developed and used in the thesis. Third, it is demonstrated that the HRSTO model significantly improves the discriminating power of analysis compared to standard DEA models, which is particularly important for small data sets. Fourth, it is concluded that the HRS model is further improved if production trade-offs are used. Fifth, by experimenting with different specific values of production trade-offs, it is shown that even the most conservative estimates of trade-offs notably improve the model. Finally, our results contribute to the more general discussion of the performance of universities in Malaysia and identification of the best performers among them.

Keywords: University, Malaysia, DEA, Hybrid returns to scale (HRS), Trade-off, Small sample, Discriminatory power, Performance Measurement System (PMS)

CHAPTER 1

INTRODUCTION

1.1. Introduction

Since the independence of Malaysia in 1957, its education system has been continuously reformed and revised in response to changes in the national policies as well as the need of its current economic and technological developments. Today, the challenges faced by Higher Education Institutions (HEIs) are further intensified as they not only need to develop human competency, ensure high quality graduates, and increase research productivity, but they are expected to generate own funding, be globally competitive, and to contribute towards the society. The belief that knowledge is a fundamental need for the country's prosperity as well as social development has been an aspiration of the national policy, Vision 2020, which considers HEIs as a mechanism to transform Malaysia into a fully developed country by year 2020.

Starting from 27 March 2004, the Malaysian education administration has been divided into two ministries with separate jurisdiction. The Ministry of Education (MOE) governs early or basic education level such as pre-schools, primary schools and secondary schools while the Ministry of Higher Education (MOHE) governs tertiary or higher education levels[1].

[1]All information about the education system in Malaysia for this study has been obtained from http://www.mohe.gov.my/educationmsia/education.php?article=system

Primary and secondary schooling, which is mandatory for children aged seven until seventeen, is subsidised by the Government and generally takes eleven years to complete. On the other hand, tertiary education (which is optional) is offered at certain fees by public and private HEIs and the Government does provide sponsorships and loans to finance this education for qualified Malaysians in line with its human capital development policy.

Indeed MOHE plays an imperative role in developing, administering and monitoring tertiary education institutions in Malaysia. Today, MOHE has its own performance measurement system (PMS) namely the *Malaysia Research Assessment System* (MyRA) and the *Rating System for Malaysia Higher Education* (SETARA) which are being carried out once every three years beginning in 2007. In addition to these measurement systems, universities in Malaysia are being evaluated annually by various independent performance appraisal tools including the *Times Higher Education World University Rankings* (THE) and the *Academic Ranking of World University* (ARWU) internationally as well as by the *Academic Reputation Survey* (ARES) nationally. Although all of the above mentioned models have considered various aspects of performance and expectations on a particular university, they seemed to rely on subjective evaluations or surveys and ignore the efficiency of performance from an operational perspective.

Consequently, a more appropriate measurement technique to complement the existing PMS is crucial as any inappropriate evaluation can ruin or damage both the HEIs' reputation and the students' well-being in the long run. It is worrying that the quest for "quality recognition" by the public is weighed heavier than the value-added contributions of the universities in terms of quality teaching and research outcomes. To sum up, this study claims that efficient measurement based on a technological perspective is crucial. Moreover, a PMS should not focus solely on public expectations but also integrate institutional performance targets.

Assessment of teaching and research activities by universities need to concurrently account for multiple inputs and outputs which is the foremost attractiveness of the *Data Envelopment Analysis* (DEA). DEA is an activity analysis that could flexibly take into account intra-institution as well as inter-institution differences, making the resulting performance evaluation more meaningful and insightful. It empirically identifies benchmark institutions by segregating the best universities within a sample founded on relative efficiency of the inputs-outputs transformation process. In contrast to modelling based on average practices which are common in non-frontier approaches such as regression-based framework, more valuable information is captured using the DEA technique. This includes the causes of inefficiency (excessive input or low output level), genuine input-output substitution potentials and identification of university-specific operating scales (Thanassoulis, 1993; Daraio & Simar, 2007). Therefore, it enhances the understanding of the university operating environment.

Technically, the preference is motivated by the need for limited assumptions to employ DEA. It could naturally and conveniently make relative performance evaluation without requiring elaborative assumption to either depict functional form of relationship between inputs-outputs or describe the distribution of inefficiency components within a particular sample (Thanassoulis, 1993; Daraio & Simar, 2007). This is very useful considering that mistakes in choosing the appropriate functional form could lead to misspecification errors (Coelli, Prasada Rao, O'donnell, & Battese, 2005; Daraio & Simar, 2007; Fried, Lovell & Schmidt, 2008). Specification of the underlying functional form, however, is essential for applying any parametric approaches.

For the purpose of setting improvement targets for individual universities, the DEA calculates university-specific productive volumes based upon every university's resource availability. It generates individual output augmentation or input contraction levels instead of basing the measurement on a single average or an aggregated performance level (Thanassoulis, 1993, 2001; Ahn, Charnes & Cooper, 1988). Besides giving more accurate relative efficiency appraisal of universities, the DEA provides additional information for performance improvement, for instance identification of university-specific role models and realistic optimal targets (Thanassoulis, 1993, 2001). The information provided is mostly technical hence is constructive for facilitating implementation at operational levels. In short, it is considered timely for Malaysia to consider employing the DEA as a part of its official PMS.

1.2. Public Universities in Malaysia

Higher education providers in Malaysia comprise of 60% public and 40% private institutions. Specifically, they consist of 20 public universities, 24 polytechnics, 37 public community colleges, 33 private universities, 4 foreign university branch campuses and approximately 500 private colleges [2]. Public or government-funded tertiary institutions include public universities, polytechnics, community colleges and

[2]Information related to HEIs in Malaysia is mostly obtained via the Government's official webpage http://www.mohe.gov.my/educationmsia/education.php?article=system

teacher training institutes. Tertiary education is also being supplied by foreign institutions (including those universities that have home campuses in United Kingdom, United States of America, Australia, Canada, France, Germany and New Zealand) in the form of twinning and franchised degree programmes by way of joint venture with local private colleges and private universities. Today, there is at least one public university located in every state throughout Malaysia.

Public universities can be further differentiated into three categories. The first is *Research University* (RU). As of 2011, there are five RUs namely the Malaya University (Universiti Malaya – UM), the Science University of Malaysia (Universiti Sains Malaysia – USM), the National University of Malaysia (Universiti Kebangsaan Malaysia - UKM), the Putra University of Malaysia (Universiti Putra Malaysia – UPM) and the Technology University of Malaysia (Universiti Teknologi Malaysia – UTM)[3]. The first four of the universities were designated as RUs on 11th October 2006 while the fifth received the award in June 2010 (Nordin, 2011). Unlike the following two categories, RU is a recognition of excellence. It is awarded based on eight selection criteria that focus on aspects of research and development as well as commercialization (R&D&C) activities. They share four common characteristics of (a) research-oriented subject areas; (b) competitive entry requirement; (c) highly-qualified lecturers; and (d) Undergraduate to Postgraduate ratio of 50:50.

The second category is *Comprehensive University* offering a wide range of courses and subject areas. The International Islamic University of Malaysia (Universiti Islam

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[3] Results of the analyses reported in this thesis is based on the data and information collected during the fieldwork in 2009 and at that time there were only four *Research Universities* in Malaysia

Antarabangsa Malaysia – UIAM), the Sabah University of Malaysia (Universiti Malaysia Sabah – UMS), the Sarawak University of Malaysia (Universiti Malaysia Sarawak – UNIMAS) and the Mara Technology University (Universiti Teknologi Mara – UiTM) are the four institutions under this *Comprehensive University* category. The four common characteristics among them are (a) wide range of subject areas; (b) competitive entry requirement; (c) highly-qualified lecturers; and (d) Undergraduate to Postgraduate ratio of 70:30.

Focused University is the third category and comprises eleven universities; the Northern University of Malaysia (Universiti Utara Malaysia – UUM), the Sultan Idris Education University (Universiti Pendidikan Sultan Idris – UPSI), the Tun Hussein Onn Technology University of Malaysia (Universiti Teknologi Tun Hussein Onn Malaysia – UTHM), the Melaka Technical University of Malaysia (Universiti Teknikal Malaysia Melaka – UTeM), the Perlis University of Malaysia (Universiti Malaysia Perlis – UniMAP), the Terengganu University of Malaysia (Universiti Malaysia Terengganu – UMT), the Pahang University of Malaysia (Universiti Malaysia Pahang – UMP), the Islamic Science University of Malaysia (Universiti Sains Islam Malaysia – USIM), the Darul Iman University of Malaysia (Universiti Darul Iman Malaysia – UDM), the Kelantan University of Malaysia (Universiti Malaysia Kelantan – UMK) and the National Defence University of Malaysia (Universiti Pertahanan Nasional Malaysia – UPNM). They focus on certain fields of knowledge related to the goals of their establishment including technical, education, management and defence. They have four common characteristics that are identical to RUs (a) research-oriented subject areas; (b) competitive entry requirement; (c) highly-qualified lecturers; and (d) Undergraduate to Postgraduate ratio of 50:50.

Table 1.1 gives the names of the public universities in Malaysia that have been established before 2010 and are reported in the Government databases during the data collection period conducted for this thesis in 2009. Some of them were initially established as an institute that targets a much focused student market. However, due to their exceptional performance, they have been upgraded by the Government as a public *Focused University* during the major national educational reform in 2006. They are USIM, UMT, UTHM, UTeM, UMP and UniMAP.

Table 1.1: List of All Public Universities in Malaysia as in 2009

PUBLIC UNIVERSITIES IN MALAYSIA	YEAR	
	Established	Upgraded
Universiti Malaya (UM)	1962	
Universiti Sains Malaysia (USM)	1969	
Universiti Kebangsaan Malaysia (UKM)	1970	
Universiti Putra Malaysia (UPM)	1971	
Universiti Teknologi Malaysia (UTM)	1975	
Universiti Islam Antarabangsa Malaysia (UIAM)	1983	
Universiti Utara Malaysia (UUM)	1984	
Universiti Malaysia Sarawak (UNIMAS)	1992	
Universiti Malaysia Sabah (UMS)	1994	
Universiti Pendidikan Sultan Idris (UPSI)	1997	
Universiti Teknologi Mara (UiTM)	1999	
Universiti Darul Iman Malaysia (UDM)	2005	
Universiti Sains Islam Malaysia (USIM)	1998	2006
Universiti Malaysia Terengganu (UMT)	1999	2006
Universiti Teknologi Tun Hussein Onn Malaysia (UTHM)	2000	2006
Universiti Teknikal Malaysia Melaka (UTeM)	2000	2006
Universiti Malaysia Pahang (UMP)	2001	2006
Universiti Malaysia Perlis (UniMAP)	2001	2006
Universiti Malaysia Kelantan (UMK)	2006	
Universiti Pertahanan Nasional Malaysia (UPNM)	2006	

The table indicates for every university, year of establishment and respective year (for certain institutions) of being upgraded to public university status

For the analyses reported in this thesis, only the first eighteen universities were evaluated. This was necessary to ensure the validity of the analyses and findings. It was decided in consideration of the homogeneity of universities as characterised by the focus of this research i.e. on joint activities of research and teaching. In particular, both of the eliminated universities were formed in the middle of 2006 and only began to offer Undergraduate degree programmes in 2007. Yet, the assessment conducted via the proposed *Hybrid Returns to Scale model with Trade-Offs* (HRSTO) is meant to evaluate teaching of both Undergraduate and Postgraduate degrees in addition to research activities. Although the UMK started offering Postgraduate programmes in 2008, it still does not have any research outcomes to be evaluated against the other universities. On the other hand, UPNM is a defence-university, focusing solely on Undergraduate programmes and exclusively catering to the needs of military students. Thus, it is totally different than any other universities that cater to public needs for tertiary education at all degree levels.

1.3. Research Motivations

Accordingly, there are two key motivations for the study that is pursued and reported in the current thesis. Firstly, the inspiration is to recommend a DEA framework that gives complementary mechanism for measuring the performance of Malaysian public universities. HRSTO is not offered as a substitute to MyRA and SETARA which are currently administered by MOHE to assess the performance of all HEIs in Malaysia. However, it offers a different perspective as well as an alternative means to look into HEIs' efficiency. MyRA evaluates a university's performance in terms of research only while SETARA evaluates a university's performance in terms of teaching only. This is believed to be an insufficient scope of performance appraisal on universities considering the fact that universities are using the same resources in order to jointly conduct research and teaching activities. Therefore, the proposed HRSTO works along with MyRA and SETARA in complementing the existing PMS by providing a more integrated analysis of university performance.

Furthermore, the majority of existing PMS seems to rely heavily on subjective evaluation of different stakeholders. Efficiency of performance from an operational perspective which is crucial for facilitating quality improvement initiatives has been ignored by many. Thus, improvement strategies for underperforming universities based on benchmark practice is very much needed to support MOHE's vision to transform Malaysia into a regional hub for higher education. These guarantee feasible and meaningful course of actions to improve performance as the improvement strategies can then be devised based on the achieved performance of universities operating within the same environment, culture and regulation.

Recently, there are an increasing number of universities in Malaysia using the *Balanced Scorecard* (BSC) as a strategy implementation instrument to align and meet the requirements of the PMS being administered by MOHE, or MyRA and SETARA in particular. The proposed HRSTO will also complement this increasingly popular strategy implementation tool. The DEA and BSC can be used as complementary tools to identify strength and weaknesses, evaluate performance and address the identified problems. This is because the DEA diagnoses a university's performance and identifies improvement strategies at a broader university level while BSC complements it by detailing the strategies at the lower operational levels. Whilst the BSC facilitates identification of critical inputs and outputs to be considered, the DEA helps identify efficient peers and optimal productivity levels (Avkiran, 2001). Such combination will enable a better understanding of a wider range of influential factors on academic efficiency.

Secondly, the enthusiasm is to propose a DEA framework that would give a better reflection of a unit's performance, i.e. a single model that could make a correct depiction of a unit's transformation process and acknowledge the preferences of the end users which are then translated into realistic and doable performance targets. In addition, the current study looks at a small population of only twenty public universities in Malaysia. This could lead to the curse of dimensionality associated with DEA applications on small samples. Despite the DEA being practically applicable on either small or large samples, applications involving large samples ensure greater accuracy of assessment (Daraio & Simar, 2007). It will later be proven in the *Analysis and Discussion* chapter that by adopting the proposed DEA framework, this issue will no longer be a major concern.

1.4. Research Contributions

Through the proposed integration of Hybrid returns to scale (HRS) and Trade-off approaches, called HRSTO model, as a DEA framework to evaluate the Malaysian public university, several contributions have been made to DEA as well as non-DEA literatures.

1.4.1. DEA Framework for Better Insight of Unit's Performance that Refines Definition of Benchmark Units

The foremost contribution made is a DEA framework that could provide a better and more integrated insight of a unit's transformation activities. It also refines the definition of benchmark units. Refined benchmark of performance is obtained when the proposed model explicitly inflicts via its formulation, the pattern of required synchronised change between assessment variables and delineates acceptable magnitude of change between relevant variables. This is achieved by incorporating relevant and reasonable information describing the transformation process being examined. It results in a more stringent expectation on performance to be considered as a technically efficient unit. Pertaining to role models or reference peers for inefficient units to emulate, HRSTO considers both efficient and inefficient universities to be regarded a role model or benchmark. Efficient benchmark universities are those institutions with the best overall performance, thus obtain an efficiency score of 100%. In contrast, inefficient benchmark universities, whose efficiency score is below 100%, are those institutions that have reasonably good practice to be emulated in consideration that its operating scale is of comparable size to the inefficient university being examined. Efficient universities certainly make better models of best practice yet HRS model also takes into account inefficient universities in devising optimal solutions for inefficient ones. In fact this is a unique feature of HRS as compared to the standard DEA models that only generate efficient units as the reference peers. The goal is accomplished in getting a good model of technology via a non-technically extensive procedure. Furthermore, it indirectly tackles the curse of the dimensionality problem associated with applying

DEA on small samples, such as the reported case study. Empirical evidence is later presented in support of the claim that the proposed methodological framework makes better assessments than the existing approaches founded on Variable Returns to Scale (VRS) or Constant Returns to Scale (CRS) technology.

In reality, for a group of assessment variables, often some will have proportional whilst some non-proportional change-relationships, which is selective proportionality relationship. For those with proportional relationships, expected range of change should also be defined. By “explicit” it is meant to deliberately articulate in DEA formulation acceptable yet undemanding range of compromises for the assessment. HRS is the preferred technology to acknowledge the partial proportionality relationship which is believed to have the best resemblance of relationship between variables in reality. Technologically realistic performance expectations and targets are guaranteed by employing the Trade-off approach. It also enables integration of country-specific targets and standard practice into DEA evaluation. Such concurrent proposed modifications to the standard DEA formulation will reflect a better, and more integrated insight of a unit’s performance and indirectly improve the discriminatory power of DEA assessment. The underlying notion is that a correct model will provide meaningful and relevant analysis to the end users, in this case MOHE and the affected public universities.

1.4.2. Novel Approach to DEA Combining Hybrid Returns to Scale Technology and Trade-off Restriction (Proposed as HRSTO model)

The proposed integration of HRS and Trade-off as a DEA framework is novel. HRSTO is introduced and tested on real-life data for the first time in this thesis. The fact that

HRSTO could sustain the technological gist of DEA assessment can further be regarded as a modelling contribution to the DEA literature. More importantly, it is a very flexible framework that could easily suit prevailing relationships between assessment variables being examined in an evaluation exercise. Subsequently, either full-proportional (underlying CRS technology), partial-proportional (underlying HRS technology) or non-proportional (underlying VRS technology) relationships that actually exist within a group of variables could effectively be accommodated into the proposed HRSTO model with trivial adjustment. The fact that it is being tested on real data gives empirical contribution to DEA literature as well.

It will later be demonstrated in the *Analysis and Discussion* chapter that the discriminatory power of the DEA assessment has been increased by employing HRSTO, even on small samples of 17 and 18 universities. This is ascertained by looking at the number of universities identified as efficient as well as the efficiency scores (individual and average) being awarded to the universities. It has been empirically proven to outperform CRS and VRS both with and without trade-offs as well as HRS without trade-offs.

1.4.3. Bridging Focus Gap of MyRA and SETARA; HRSTO Integrates Existing Evaluation Aims on Measuring Malaysian Public Universities

HRSTO is being proposed as a complementary PMS to assess the performance of HEIs in Malaysia instead of a substitute to the currently in-use MyRA and SETARA. It offers a more integrated outlook of HEIs' efficiency by combining the evaluation focuses of both MyRA and SETARA into a single model. It is apparent that the Government, particularly MOHE, does acknowledge the need to measure universities' performance by looking into their efficiency in research and teaching activities. This is evident based on the current policy of administering MyRA to evaluate research and SETARA to evaluate teaching of all HEIs, public and private institutions, operating in Malaysia. Nonetheless, the current approach of distinguishing a university's performance into independent viewpoints of efficiency in terms of research and efficiency in terms of teaching is deemed inappropriate. This is because every academic staff in Malaysia is assigned and assessed in accordance with both research and teaching responsibilities. All the other resources of a university are then dedicated to provide, support and enhance these two primary activities of a university as expected by the public. Hence, a review of performance that jointly evaluates university efficiency in research and teaching is claimed in this study to be necessary for a correct portrayal of an academic excellence.

By adopting the proposed HRSTO, a new vision of university performance is revealed which could provide a more realistic review of performance. In particular, HRSTO complements MyRA by measuring research efficiency from an operational perspective when MyRA only evaluates research efficiency from an administrative perspective. Moreover, HRSTO complements SETARA by looking deeper into the effectiveness of teaching activity in terms of university capability to optimize its teaching outputs from existing teaching inputs. In fact, HRSTO supplements the information provided by each MyRA and SETARA when, as a single model, it can be used to determine a university's efficiency in managing resources for research and teaching, both Undergraduate and Postgraduate programmes.

1.4.4. Operational Perspective as Complementary Viewpoint for Measuring Malaysian Public Universities

The HRSTO model also makes contributions to non-DEA methodologies. Existing PMS models being applied in Malaysia seem to ignore university efficiency from an operational perspective. An operational perspective of performance evaluation is regarded as crucial for a developing country like Malaysia if it were to become a self-improvement tool for universities. Therefore, the proposed HRSTO approach is very relevant and will contribute to the pool of other (non-DEA) methodologies used in the assessment of Malaysian HEIs.

By giving a technological perspective of evaluation, practical and straight forward improvement strategies are being advocated hence facilitates implementation and encourages acceptance by the end users. Unique to existing models that focus solely on university outputs in their appraisal, HRSTO analyses performance by looking at resource utilization in producing reported outputs, and against benchmark performance levels in the evaluation process. In contrast to existing international ranking models, the optimal levels given by HRSTO are founded on actual achievements of institutions in the country operating in the same environment, culture and regulation. Consequently, the optimal targets being put forward take into consideration feasibility and practicality aspects of implementation. For managerial purposes, it makes it possible to integrate preference and expected targets into assessment while for implementation purposes it ensures the expected improvement goals are always producible and feasible.

The fact that SETARA evaluates Undergraduate teaching efficiency of universities by measuring criteria belonging to input, process and output components of teaching activity signifies MOHE does recognises that operational perspective of evaluating the activity provides superior review of the HEIs' performance. Meaning that SETARA resonates the evaluation concept of HRSTO. Although both SETARA and HRSTO quantify performance from an operational standpoint, performance excellence for SETARA confines scoring certain percentage on assessment criteria attributed to inputs, process and outputs of teaching process. HRSTO goes beyond reaching critical levels but additionally is concerned with the effectiveness of universities in transforming inputs into outputs of the teaching process.

In addition, HRSTO also provides an examination of inefficiency of university performance. Inefficiency is analysed by identifying its sources and estimating its amounts as observed in input and output transformation activities of the universities (Charnes, Cooper & Thrall, 1986). Examination of inefficient performance levels disclose different feature, and thus gives different understanding, of excellent performance (Fried et al., 2008). It could be used, for example, in identifying success indicators for refining educational policies (Fried et al., 2008). It also alerts the need to manage inefficiency when efficiency improvement is temporarily infeasible especially for short term remedy of an identified problem or performance deficiency, for instance, to devise immediate solutions so as not to make it worse.

1.4.5. Extending the Context of DEA Empirical Applications

Although it is not very significant, it is an empirical contribution to the DEA literature in terms of broadening its application context. Firstly, it contributes to DEA literature on higher education and secondly, it contributes to DEA literature on developing countries. Thus HRSTO further enhances the usefulness of DEA as a PMS. For the former, HRSTO enriches the choice of DEA models for evaluating academic institutions that it adds to the many existing frameworks that have been recommended to address the identified difficulties and limitations of DEA in evaluating the performance of HEIs worldwide. Particularly concerns that are associated with incorporating the needs of local environment, policy and system into the DEA appraisals.

For the latter, there are various DEA studies conducted related to the performance of schools, colleges and universities worldwide, but similar studies on academic institutions in developing Asian countries such as Malaysia is scanty. Of those few DEA studies on Malaysia, most of them analysed the banking industry, few examined ports management but only two studied HEIs. This research will therefore contribute to the DEA application made on developing Asian countries, particularly Malaysia. For Malaysia, DEA will provide very practical improvement strategies as they are derived from the observed practice in the country. This includes performance targets and university-specific benchmark institutions for those universities regarded as underperforming. Given the proven success of its implementation and advantages of using this data driven benchmarking technique worldwide, it is deemed useful and feasible to apply it on Malaysia that consider HEIs as the country’s economic transformation mechanism.

1.5. Structure of the Thesis

The thesis is organized into five chapters. Chapter 1 has given a general overview on organisations being examined and has introduced the analysis instrument that inspired the thesis. It provides the research motivations and research contributions in attempting to contribute to DEA literature as well as to the Malaysian higher education system.

Chapter 2 presents a non-technical review of the theoretical background, which informs the research motivations. It discusses literature on performance measurement of Malaysian HEIs and applicable PMS on Malaysian public universities. The subsequent discussion is on frontier techniques commonly employed to evaluate HEIs. Emphasis is finally given on the applications of DEA on universities worldwide.

Chapter 3 discusses the technical side of DEA and introduces the proposed performance measurement framework adopted in this research. The HRSTO model is proposed as a potentially useful method to evaluate the performance of Malaysian public universities via the DEA framework. It provides an integrated review of performance in research and teaching activities; complementing the currently in-use instruments MyRA and SETARA.

Chapter 4 presents the formulation of the HRSTO model to evaluate public universities in Malaysia. It explains the construction of the important components of HRSTO formulation in stages. Data analysis and empirical findings are then presented. Subsequently, it provides empirical evidence on the advantages of employing the proposed HRSTO model compared to the DEA framework under CRS and VRS technologies.

Chapter 5 provides a summary of the thesis and its key contributions. The key findings are recapitulated and suggestions for future research are offered.

1.6. Conclusion

This thesis is motivated by the interest to recommend a DEA framework that could reveal a better and more integrated insight of a unit's performance, and to propose an assessment model that would complement existing PMS on public universities in Malaysia. In truth, assessing the same entity from different angles will give different aspects of understanding of the same entity. Similarly, when evaluating the same institutions from a different viewpoint as the suggested HRSTO model is formulated and founded on technological perspective.

The DEA is a non-parametric function estimator for approximating the unknown efficient educational technology. The function is basically a mathematical expression of the implicitly assumed technical relationship between inputs and outputs. In this regard, framework conceptualization is a critical stage to obtain correct replica of a transformation process being examined. Therefore, correct account of the prevailing relationship between variables is essential to obtain a better, more integrated and comprehensive insight of performance. Moreover, a review of performance is often meant to devise improvement strategies instead of merely quantifying current efficiency levels. When a PMS could provide assessment which is considered as relevant, meaningful and implementable by the end users, then such evaluation could be considered as a true performance review. The proposed HRSTO model addresses these issues of which this study claims to be capable of giving a better and more integrated insight of performance through DEA framework. This will then be a very constructive yet comprehensive PMS readily to be adopted in evaluating Malaysian public universities' performance.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This chapter provides non-technical background for the study pursued and presented in this thesis. The first part gives an overview of the existing literature on performance measurement related to Higher Education Institutions (HEIs) in Malaysia. The second part focuses on the models of performance measurement currently applicable to universities in Malaysia, including those administered by the government and those conducted by independent bodies. The discussion subsequently focuses on the applications of Data Envelopment Analysis (DEA) on universities worldwide, after a brief examination of frontier techniques commonly applied to HEIs. The chapter concludes, highlighting the identified gap in the literature and motivation for pursuing this study, from which the research contributions are deduced.

2.2. Background of HEIs Performance Measurement in Malaysia

The vision of Malaysia is to become a regional and international hub of education, and to become a developed country by the year 2020. HEIs[4]play critical roles in supporting the country's transformation vision by producing high quality, educated, skilled and innovative human capital. It is believed that the ability to become a developed country

[4] HEI as defined by MOHE is a corporate body, organization or other body of persons which conducts higher education or training programmes including skills training programmes leading to the award of a higher qualification or which award a higher education qualification and includes the public and private higher education providers, examination or certification bodies or their representatives

and to sustain it does not hinge on financial strength per se, but rather, on continuous research and development and innovation (R&D&I; Nordin, 2011). This is because innovations and creative breakthroughs supporting knowledge and economic developments will enable a country to prosper with stable growth in order to compete with the outside world. Nowadays, besides being held accountable for providing high quality education and producing skilled manpower, HEIs are expected to be more entrepreneurial in generating funds, in attracting worldwide students and academics, and in giving value-added to the local community.

According to a report of a twelve-month quality survey carried out by the Government between August 2006 and July 2007, most public universities in Malaysia were found to be underperforming in the sense that their performance was below the public expectation (Yu, Hamid, Ijab, & Soo, 2009). It prompted the management of the affected institutions to look into the causes of their poor performance which consequently increase public awareness on the need to continuously monitor university performance (Yu, *et al.*, 2009). However, most existing Performance Measurement Systems (PMS)[5] are adopted from well-acknowledged international ranking or rating agencies. The benefit of adopting such models is that they are well accepted and established rating systems. The hitch is that they do not consider country specific policies and focus more on measures that would enhance performance from stakeholders' perspective instead of operational perspective (Yu, *et al.*, 2009). In light of this issue, the current study offers a complementary perspective of measuring the

[5]Performance measurement system (PMS); is referring to any techniques or methods used to evaluate the performance of or to rank the standing of HEIs

performance of HEIs in Malaysia. The evaluation model to be put forward will judge performance by considering university-specific internal capabilities as well as prevailing local policies. In addition, a systematic tool to devise improvement strategies for enhancing a university's performance from an operational point of view is offered.

It is not straightforward to measure the performance of non-profit organisations like HEIs when compared to measuring the performance of profit organisations. This is because HEIs generate a very special kind of services that affects everybody in the society namely education. As pointed out by Jalali, Islam, and Ku Ariffin (2011, p. 182), education is "physically intangible, it is an activity not a thing, and its production and consumption are simultaneous in some manner". Education is an intangible output that only the effect of teaching could be seen and hence assessed. Education engages various components including instructor, students and visual aids that the quality of their interaction affects the quality of its effectiveness. Finally, education is simultaneously produced and consumed such that its progression is also affected by external environment including the classroom. Still, given the intensifying competition to retain and attract students, funding and academicians from a borderless world market, there is growing interest and need to measure the quality of education being provided, and hence the performance of education providers or HEIs.

There exists a global acceptance of popular league tables such as *Times Higher Education World University Rankings* (THE) and *Academic Ranking of World Universities* (ARWU). But these rankings agencies have drawbacks (Campbell, 2009). First, they can be subjective with inclination to quantify reputation. Second, they fail to satisfactorily acknowledge teaching and learning activities. Third, they replicate *Anglo-*

American research-intensive universities and favour well established institutions to the detriment of new ones in their assessments (Campbell, 2009). Besides, Campbell (2009) alleged that *THE* gives unreasonably volatile rankings, focuses the evaluation on reputation, and shows bias towards international status. Responding to the new methodology employed by *THE* starting 2010, Willetts (2010) gave a more supportive remark by advocating that reputation is given lesser importance whilst greater weights are accorded to teaching and learning activities. Willetts (2010) expressed his preference on the new concept of using “scaled data and research productivity relative to size” that gives advantages to smaller universities. On the other hand, ARWU was favourably described by Campbell (2009) as evaluating output but too restricted to research and publications that they ignore intangible value-added contributions to the community. Other criticisms were in the form of cautionary note, that, league tables provide an incomplete synopsis of universities’ performance and there are other aspects of success to be considered to get an accurate picture of universities’ performance (Smith, 2010).

In addition, other popular performance indicators, such as student demographic, staff demographic, academic staff qualification, student intake size, graduation rate, and availability of high-tech amenities, are example of external indicators that would enhance the reputation and popularity of a particular institution (Yu, *et al.*, 2009). External indicators do provide a good measurement of quality in the interest of external stakeholders, in particular, students, parents, education ministry and potential sponsors (Yu, *et al.*, 2009). The indicators do not, however, reflect the internal performance of a university in terms of its productivity and efficiency in creating value for public money, which is also critical aspect of performance measurement. This subsequently gives an inaccurate reflection of HEIs' true performance from an operational perspective. Operational perspective provides tactical solutions that will be useful in devising and implementing improvement strategies. This is necessary as HEIs now need to compete for highly competitive source of educational funding and face an increasing global competition that require them to become entrepreneurial and be able to attract good students worldwide.

2.3. Evidence on HEIs Performance Measurement in Malaysia

Within the Malaysian context, there are a small number of published studies on performance measurement of universities. However, it does not mean to say that academic institutions do not measure and monitor their performance. The existing performance assessment approaches tend to compute simple productivity ratios and mostly conduct surveys for internal periodical reports. Most of the published studies concentrate on measuring the satisfaction and performance of students (Arfan & Othman, 2005; Omar & Chiam, 2009; Ali & Nordin, 2010). The existing studies appear to focus on Undergraduate students and their academic excellence on a particular course or programme at an institution instead of analysis on a broader spectrum. This is true for articles written both in English and Malaysian languages. It is also worth noting that the effectiveness of other aspects of HEIs in Malaysia has also received limited attention. The examples are:

a) The performance and working satisfaction of lecturers (Zainab & Meadows, 1999; Wong & Heng, 2009; Yusrizal & Halim, 2009)

b) The performance of university at institutional level (Wilkinson & Yussof, 2005; Munisamy & Abdul Talib, 2007, 2008)
c) The implementation of Balanced Scorecard (BSC; Othman, Ahmad Domil, CheSenik, Abdullah & Hamzah Othman, 2006; Yu, *et al.*, 2009)
d) The quality of internal management processes (Tayib & Amir Hussin, 2005; Mohayidin, Azirawani, Kamaruddin & Margono, 2007)
e) The services provided by university libraries (Ming, 1996; Johari & Zainab, 2007)
f) The quality of Information, Communication and Technology services (ICT; Nor, Alias & Abdul Rahman, 2008), and
g) The implementation of Total Quality Management (TQM; Ali, Zairi & Mahat, 2008)

Of the above areas of studies, that of university performance is gaining momentum and is expected to have a big leap in the near future considering the greater emphasis and expectations of the Government and the public on the roles played by HEIs in support of national developmental reforms. Also worth noting is the fact that for most of the existing studies, questionnaire and interviews have been the popular method for obtaining the required data for the analysis.

With regards to students' satisfaction level, evaluations have been made based on criteria such as cost, teaching/learning support facilities, lecturers, medium of instruction, course offering, class size, course structure, study duration, demographic factors, and academic factors (Sohail & Saeed, 2003; Jalali, *et al*., 2011). A research work undertaken by Sohail and Saeed (2003), for example, is more concerned with increasing the attractiveness, and improving the quality of services provided by private HEIs offering twinning programmes as an alternative means to study outside Malaysia from marketing perspective. Sohail and Saeed (2003) looked for factors that would contribute to students' satisfaction and identified study duration as the most critical factor for their sampled respondents. A different study conducted by Jalali, *et al*. (2011) was more concerned with increasing students' satisfaction in order to boost the image of public universities. The authors argued that, emphasis should be placed on improving the quality standards of all aspects of services related to students' academic life. They remarked that by enhancing student satisfaction and reducing student dissatisfaction, sustainable competitive advantage could be created for securing existing and new students locally and internationally. They analysed a more representative sample on university as their respondents consisted of full-time and part-time, local and international students, who were pursuing Bachelors, Masters and Doctoral programmes. Concerning the above two study examples, questionnaire was the primary source of information.

One study that measured the performance of universities as an institution was by Wilkinson and Yussof (2005). It was a comparative study on public and private HEIs in Malaysia in terms of enrolments, costs, facilities and service quality. The study aimed at exploring the contribution of the two types of HEIs in providing tertiary education opportunity to the public. The study was motivated by the highly debated policy on the need for private HEIs to improve the performance of public HEIs. They found that private colleges did play complementary roles in providing education opportunities to the public, especially for courses such as Information Technology, Engineering, Economic and Business Studies, and Medicine and Dentistry whose public demand was too high for public HEIs to accommodate. However, for courses such as Education, Applied and Pure Sciences, and Arts and Social Sciences, public HEIs could conveniently accommodate their low demand. Wilkinson and Yussof (2005) observed that private institutions were selective in terms of course offerings in order to minimize their operating cost, to quickly recover their capital outlays, and to optimize resource utilization. But, to some degree, the policy on the allocation of government funding did affect the course offerings at an institution. For example, the Government provides monetary support to purchase high-priced teaching equipment for selected courses. This was necessary to ensure that the country's need for more Science and Technology based course offerings were not compromised by the HEIs' concern for cost minimization or economic efficiency. In contrast to common perception, their finding indicated that public universities were better in providing quality education that met public expectation.

Data used by Wilkinson and Yussof (2005) was gathered using postal questionnaire and follow up interviews. Analysis was then made by comparing percentages observed at both public and private universities according to field of studies for each of their selected key indicators of efficiency and quality. They had a very limited observation in terms of period of assessment (i.e. from July to September 1998) and number of institutions (i.e. two public and three private universities). Nevertheless, they argued that their sample was representative of higher education sector in Malaysia because the selected institutions were homogeneous in all aspects, identical with respect to composition of faculties and course offerings, and constituted one-fifth of the total enrolments at HEIs in Malaysia.

Tayib and Amir Hussin (2005) also evaluated universities at institutional level, but they were more interested in assessing university's internal process of budgeting. They observed budgeting practices at public universities in Malaysia in terms of the presence of the characteristics of *good budgeting practices* as commonly implemented by private organizations. They discovered the presence of characteristics of good budgeting practices among their sample of eight universities. Consequently they proposed that budgeting practice was to be a useful control mechanism as part of university PMS. They did not however make any assessment on the quality of the system currently in place, but rather suggested this as an area for further research.

2.4. Literature Review of DEA Applications on Universities in Malaysia

Since possibly the first DEA paper by Mohd Yunos and Hawdon (1997), and the first HEIs DEA study on Malaysia by Hussain, Abdullah and Agus (2000), DEA has captured the interest of an increasing number of scholars to study Malaysia. At present, its deployment is most popular in the banking sector and port management. Despite the growing number of empirical DEA studies on academic institutions and universities worldwide, only a handful of studies exist in the context of Malaysia, to the best of the author's knowledge. A review of DEA literature on HEIs worldwide will be discussed in Section 2.7.

Munisamy and Abdul Talib (2007) used DEA to measure the performance of Malaysian public universities, motivated by the growing public interest to evaluate and rank the performance of academic institutions. It was also motivated by the need for a uniform rating system for Malaysian HEIs as led by the former Prime Minister of Malaysia. The authors studied 15 HEIs in Malaysia that were established by the year 2001. In particular, the sample consisted of 11 universities and 4 college universities[6] using 2001/02 academic year data when the complete required information was claimed to be available. There were altogether five variables chosen for the assessment. These were one input (*Operating expenditure*) and four outputs (*Number of Undergraduate enrolment, Number of graduate enrolment, Number of publication* and *Research income*) variables. The input variable *Operating expenditure* was made up of five cost categories including *Emoluments, Supply & services, Assets, Allowance & fixed charges*, and *other expenditure*. Both teaching outputs focused on count of full-time student enrolments, ignoring part-time student population. The third output *Publication* was reported to represent the average of three-year data set to account for time lag in publication. Variable *Research income* was the average figures of, and sourced from, 2000 and 2002 reports on the National Survey of Research and Development. The preferred underlying technology was Constant returns to scale (CRS) due to their assumption that university's productivity is not affected by its operating scale.

According to the authors, the average efficiency score for those institutions was 64.17%. Five of them were rated to be 100% efficient and of the inefficient ones, seven were identified to perform below the average. Further analysis of the weights attached

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[6]College University is usually a private HEI, which is a relatively new institution that functions like universities conducting teaching and research activities with limited autonomy granted by the Government. They could apply for an upgrade to university status (public or private) after at least 5 years of establishment upon satisfying the required criteria as outlined by the MOHE.

to the variables revealed that nine institutions (of which only two were fully efficient) could be regarded as giving a balanced focus on teaching and research while the remaining six institutions had either focused more on teaching or more on research only. Based on the generated weight again, only one university could be regarded as genuinely fully efficient because it most frequently became a referent peer for inefficient units and placed equal importance on both HEIs' core activities as expected by the public.

Munisamy and Abdul Talib (2008) modified their earlier study (Munisamy & Abdul Talib, 2007) using exactly the same data set to evaluate the same set of public HEIs in Malaysia [7]. They used four variables to evaluate teaching and research activities consisting of one input and three outputs. They are *Operating expenditure, Total student enrolment, Publication count* and *Research income,* respectively. In addition, *Age of university* was treated as a non-discretionary input variable. With regards to variable *Total student enrolment*, the authors in this replication study treated both number of full-time Undergraduate and full-time Postgraduate student enrolments as one instead of two output variables. They argued that the evaluation of universities has been biased since older and HEIs that are more prominent were given ratings that are more favourable when in actuality some newer HEIs were much better.

[7] According to the authors, as of 2003, there were seventeen public universities in Malaysia consisting of eleven universities and six college universities. They used the term "public universities" to refer to both universities and college universities. However, according to MOHE, HEIs with the status of "College University" is different from the status of "University". The six college universities had been upgraded to "public universities" only in 2006. Therefore, in their study, the seventeen institutions should be referred to as "public HEIs" instead.

In order to obtain empirical support for their argument, the authors employed input-oriented Constant returns to scale DEA model to compute cost efficiency scores. The length of establishment of a university was considered as environmental factor and treated as non-discretionary input variable. This is because age indirectly influenced university's performance even though it was not part of universities' primary activities. DEA evaluation was carried out in three stages and presented as three DEA models, which varied in terms of number of variables evaluated to see the influence of the variable, *Age of university*. Further examination was then made by focusing on the resulting scores for Model 2 (one input and three outputs without considering *Age of university*) and Model 3 (one input and three outputs by considering *Age of university*). They concluded that age did significantly influence university's rating based on the results obtained; indicating significant change in the scores of four institutions and adjustment in ranking among one-third of the institutions. Their finding is reproduced as Table 2.1, which was given as the justification for their conclusion. Information in the second and third columns of the table is the given information in their article whilst information in the last three columns is the review made on their analysis.

A look at the reported results for Model 2 and Model 3, in terms of efficiency scores (*mean*, *count above average* and *count below average*) as well as the names of benchmark universities, indicates that both models gave identical results except for the slightly lower mean efficiency for Model 3 than Model 2, or 60.11% and 62.12%, respectively.

Table 2.1: Summary of Results for DEA Analysis Conducted by Munisamy & Abdul Talib (2008)

15 DMUs	Model 2	Model 3	*Review on Authors' Findings*		
	Eff Score	Eff Score	*Yr Establish*	*Score Chg*	*Rank Chg*
UM	100	100	*1962*	*0.00*	*Same*
USM	100	100	*1969*	*0.00*	*Same*
UKM	63.97	65.15	*1970*	***1.18***	*Same*
UPM	69.55	78.77	*1971*	***9.22***	*Same*
UTM	100	100	*1975*	*0.00*	*Same*
UUM	91.80	97.40	*1984*	***5.60***	*Same*
UiAM	21.50	23.08	*1983*	***1.58***	*Better (Old)*
UNIMAS	30.34	3.03	*1992*	***-27.31***	*Worse? (Old)*
UMS	47.73	4.82	*1994*	***-42.91***	*Worse (New)*
UPSI	52.29	59.26	*1997*	***6.97***	*Same*
UiTM	100	100	*1999*	*0.00*	*Same*
KUSTEM (UMT)	100	100	*1999 (2006)*	*0.00*	*Same*
KUIM (USIM)	19.02	19.02	*1998 (2006)*	*0.00*	*Better? (New)*
KUiTTHO (UTHM)	33.71	49.12	*2000 (2006)*	***15.41***	*Better? (New)*
KUTKM (UTeM)	1.96	1.96	*2000 (2006)*	*0.00*	*Same*
Mean	**62.12**	**60.11**		***-2.01***	
SD	35.2	40.18			
Count Eff	**5**	**5**			

HEI already established for at least 10 years in 2001

Summary of results for DEA analysis conducted by Munisamy & Abdul Talib (2008) is reproduced on the left side and observation of the authors' results is given on the right side

It is believed that *Age of university* should be concluded as having influence instead of significant influence (as suggested) on the performance. Further, information on *Age of university* was not provided for every university and it was not indicated what age could be considered as *old university* in their analysis. Therefore, it is assumed that at least ten years of establishment by the year 2001 was the university age to be considered as an *old university*. Accordingly, it could be seen that all of the three inefficient universities with score higher than average were as expected to be *old universities* but there was a new college university - established in 1999 and upgraded to university only in 2006 (KUSTEM) - that was consistently rated as fully efficient by the presented DEA models. KUSTEM has also been identified as the most popular referent peer by inefficient institutions; by 8 compared to only 4 institutions for UM. UM is the oldest and most prominent Malaysian university that was established in 1962. It is also believed that the revised scores for the 4 institutions did not strongly support the authors' claim. This is because, by considering university's age, Model 3 has resulted in the most significant increase in score for a new institution namely UTHM by 15.4% but biggest score increase among old universities was only by 9.22% i.e. UPM. Further, the favourable decrease in scores of 2 new universities (UNIMAS by 27.31% and UMS by 42.91%) was experienced by new but fairly old universities; they were established in 1992 and 1994, respectively. It is expected that a more significant increase in the scores for old universities and remarkable decrease for more new universities were given as the authors' empirical evidence for their conclusion on significant influence of the *Age of university*. Pertaining to the university ranking, Model 3 also gave unexpected ratings for relatively newer institutions.

Last but not the least, there has recently been a conference paper on DEA that was led by Abdullah Yusof (Abdullah Yusof, Mohd Amin, Haneef & Omar, 2011). The study examines the efficiency of a university faculty or school. Their study was limited to only one particular academic faculty at a particular university using the official record of the public university concerned. The objectives of their study were to appraise the change in performance, from 2000 to 2009, associated with the faculty's expansion, and to identify *best year performance* of the faculty to be emulated for further improvement. Annual information on two inputs as well as four outputs was collected for 2000 until 2009 and the years were the DMUs of the analysis.

For the inputs, they considered *Operating costs* and *Number of academic/administrative staff*. The quantitative output indicators were *Students* (total number of Undergraduate enrolment and Postgraduate graduated), and *Research* (various types of publication counts) while qualitative output indicators were *Internationalization* (represented by count of international publications, percentage of international students and percentage of international staff), and *Islamization* (represented by count of Islamic-based publications and percentage of Islamic content in courses offered). They employed both input-oriented and output-oriented DEA assessments to determine technical and scale efficiencies of the faculty. They chose Variable returns to scale (VRS) technology owing to their interest to calculate both scale and technical efficiencies. Due to their small sample size, eleven DEA assessments (11 combinations of 2-input and 1-output sets) were needed and tested by changing the output variable to derive the efficiency scores. They observed a decline in publication activities of the staff and then discussed possible reasons causing such deficiency in the performance. These included, among others, significant number of senior and productive lecturers leaving the institution as well as publication incentives and promotion policies favouring publications in reputable journals at the expense of its *Islamization* niche institution vision. In their recommendations, the authors advocated strategies to curtail the identified problems.

2.5. Current Performance Measurement Systems on HEI in Malaysia

In order to boost the development and competitiveness of its higher education sector, the Malaysian government has instigated several remarkable reforms into its education system. Such policy transformation is most pronounced at the beginning of the 21st century and periodically reviewed until today. Amongst the significant implications of this transformation are revolutions in university governance, proliferation of life-long learning, dependability on private sectors, and emphasis on measuring university performance (Omar & Chiam, 2009). Frequently referenced PMS in Malaysia can be classified into official[8] and unofficial[9] reviews on HEIs. Official PMS include *Malaysia Research Assessment System* (MyRA) and *Rating System for Malaysia Higher Education* (SETARA) whilst popular unofficial assessments include *Times Higher Education World University Rankings* (THE) and *Academic Ranking of World University* (ARWU). Official PMS is administered by the Government and the adherence is made a requirement. Unofficial PMS is administered by external independent bodies and frequently adopted by universities at own initiative to monitor their reputation and achievement.

2.5.1. Official Performance Measurement System

The Malaysian government on education, or specifically Ministry of Higher Education (MOHE), continuously monitor and improve the quality of its higher education by establishing its own Quality Management System (QMS) and PMS. This is administered by an independent subsidiary entity called Malaysian Qualifications Agency (MQA). To obtain the required information, MOHE has created several types of databases to periodically gather information on different aspects of HEIs in Malaysia including MyMOHES[10], MyRA and ePMO in addition to Tracer Study system[11], COPIA[12], Employers' Survey (conducted by SETARA team) and HEIs self-

[8] Term "official" is used in this study to refer to PMS being recognized and administered by the Government on public HEIs
[9] Term "unofficial" is used in this study to refer to PMS being conducted on HEIs at the national and international levels but not required and not administered by the Government
[10]MyMohes is a data collection system related to all public HEIs
[11] Tracer Study is an online system that collects information about the graduates (a) 6 months before convocation and (b) 6–12 months after convocation; to monitor employability of graduates of a particular university at certain points after graduation
[12] COPIA is a rating system based on the Academic Performance Audit conducted by MQA

administered data entry. Actually, QMS has been formulated based on ISO 9000 certification and Malaysian Qualifications Framework (MQF)[13].

2.5.1.1. Malaysian Qualifications Framework (MQF)

At present, MQF[14] is the core reference instrument for defining guidelines, standard requirements and qualification nomenclature for courses and academic programmes at certificate, diploma and degree levels, offered by both public and private HEIs. MQF has been adapted from major international qualification frameworks and the practice of renowned HEIs around the globe. It guarantees consistency of qualification awarded by every HEI thereby integrating the entire national qualifications being conferred by any awarding institutions. Therefore, in addition to enhancing public confidence and international recognition, it also amplifies students' marketability in seeking employment and furthering education. When MQF was introduced in 2005, HEIs were expected to get MQA's accreditation prior to offering new courses only. However, starting from 2011, when MQF has been fully implemented, all institutions are required to undertake review on accredited courses and to get accreditation for new courses to be offered (Nordin, 2011).

2.5.1.2. Malaysia Research Assessment System (MyRA)

The prominent focus on R&D&I activities as a mechanism to support the national transformation vision can also be seen in the ninth Malaysia Plan for 2006–2010 and

[13]MQF as defined in MQF document is an explanation or description of the national education system that is understood at the international level, which clarifies all qualifications and academic achievement in higher education (post-secondary) and how these qualifications are meaningfully linked
[14]Information on Malaysian Qualification Framework (MQF) has been obtained from www.mqa.gov.my/dokumen/MALAYSIAN%20QUALIFICATION%20FRAMEWORK_2011.pdf

tenth Malaysia Plan for 2011-2015. In both short-term national development plans, numerous policies have been devised to promote and boost research activities including greater supports for research centres, additional types of discipline-based research grants[15] and *Research University* (RU) status award of research excellence (Nordin, 2011).

Research University is an official national recognition of excellent performance as well as a rating instrument to monitor and acknowledge research and development and commercialisation (R&D&C) activities at university level. The objectives of the Government awarding RU status are (a) to increase number of Postgraduate students, (b) to increase number of lecturers with PhD qualification, (c) to increase number of international students, (d) to strengthen research centres, and (e) to boost the rating of local HEIs at international level[16]. In 2011, there are five public universities already given the status and the national target is to have six RUs by 2015 (Nordin, 2010b, 2011). The first four universities were awarded RU accreditation in 2006. They include the oldest public universities; Universiti Sains Malaysia (USM), Universiti Putra Malaysia (UPM), Universiti Kebangsaan Malaysia (UKM) and Universiti Malaya (UM). The most recent recognition award was granted to Universiti Teknologi Malaysia (UTM) in 2010. These RUs are regarded as exemplary institutions and hence, expected to focus their resources on activities related to R&D&C initiatives.

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[15] Examples of additional research grants recently awarded to promote R&D: Long Term Research Grant Scheme (LRGS), Exploratory Research Grant Scheme (ERGS) and Prototype Research Grant Scheme (PRGS)
[16]Information on Malaysia Research Assessment System (MyRA) has been obtained from jpt.mohe.gov.my/ru.php

Consequently, *Research University Assessment System* or MyRA has been implemented as a rating instrument to evaluate HEIs' (public and private universities or university colleges) performance but only in research related aspects or R&D&C activities. Specifically, MyRA appraises HEIs' top management supervision on research agenda, monitors the performance of existing RUs, and assesses research commitment and performance of the other universities and university colleges. MyRA is also used by MOHE as an instrument to gather information on R&D&C activities undertaken by HEIs. Further, it works as a filtering instrument on applications made for Fundamental Research Grant Scheme (FRGS) - a type of research funding offered by the Government- by all private HEIs. Information on annual basis is collected for MyRA but the evaluation exercise is conducted once every three years. Assessment of RU is based on eight criteria that can be summarized in Table 2.2. Further, to facilitate and encourage research enthusiasm and culture among the academia, in 2009, online self-administered MyRA was launched. It enables any institution to employ it as an instrument to monitor or evaluate current performance and to verify if an institution has satisfied the criteria to be nominated as a candidate for RU status award.

Table 2.2: Assessment Criteria for Malaysia Research Assessment System (MyRA)

	Categories of Criteria for Research University	Weight (in %)
1	Quantity and quality of researchers	25
2	Quantity and quality of research	30
3	Quantity of postgraduates	10
4	Quality of postgraduates	5
5	Innovation	10
6	Professional services and gifts	7
7	Networking and linkages	8
8	Support facilities	5

Source: Ministry of Higher Education (MoHE), Malaysia

2.5.1.3. Rating System for Malaysia Higher Education (SETARA)

At the more comprehensive level, performance of all universities is evaluated by using SETARA, but the assessment scope is restricted to teaching activity only. SETARA was first introduced in 2007 (SETARA 2007) as an official rating instrument in order to determine the ranking and calculate key performance indicators (KPI[17]) for public universities[18]. It has been significantly revised in 2009 (SETARA 2009) and its second implementation was conducted between October 2008 and June 2010 using data collected for 2009. SETARA 2009 now includes private universities, making it an appraisal system for all universities in Malaysia.

SETARA measures the effectiveness of Undergraduate teaching and learning activities from an operational perspective, but only to limited extent. In other words, teaching and learning activities are seen as a process of transforming learning resources into educational outcomes. The appraisal system considers indicators belonging to three components, viz., resources, process and outcomes. Each indictor needs to reach a certain percentage to be regarded as an outstanding university. However, SETARA only measures performance based on criteria belonging to the three components of transformation activity independently. That is to say that each indicator is weighed independent of each other so it does not consider the efficiency of the transformation activity itself in quantifying efficiency level as in DEA. Since SETARA focuses on Undergraduate programmes, it is therefore important to emphasize that results of

[17]Key Performance Indicators is internally administered by MOHE and reported in the form of simple ratios on selected features of students and academic staff demographics at all types of HEIs in Malaysia
[18] Information on SETARA has been obtained fromhttp://www.mqa.gov.my/SETARA09/index.cfm

SETARA appraisal is not directly comparable to the DEA framework to be proposed in this thesis, namely, Hybrid returns to scale model with trade-offs (HRSTO). HRSTO focuses on the efficiency of public universities performance in teaching both Undergraduate and Postgraduate programmes.

Although the information for SETARA is collected on annual basis, the appraisal is conducted once in three years. This is to say that every SETARA evaluation is made by considering a university's performance in three consecutive years. There are 82 indicators being evaluated via SETARA 2009 in order to capture 25 performance criteria. The criteria are broadly categorised into five domains. The following Table 2.3 gives the assessment criteria being considered by SETARA 2009.

Table 2.3: Assessment Criteria for SETARA 2009

DIMENSION	DOMAIN	CRITERIA
INPUT (20%)	GOVERNANCE (12%)	1. Governing Body (Board of Directors, Governors, Council, etc.)
		2. Academic Governance
		3. Leadership and Staff
		4. Strategic Plannin
		5. Academic Autonomy
		6. Clearly Defined Lines of Responsibility & Decision-Making
		7. Students' Representation
		8. Organisational Climate
	PHYSICAL & FINANCIAL RESOURCES (3%)	1. Infrastructure (Physical)
		2. Financial
		3. Support services
	TALENT (5%)	1. Faculty: Adequacy
		2. Faculty: Capability
		3. Faculty: Experience
		4. Student Quality
		5. International Student
PROCESS (40%)	CURRICULUM (40%)	1. Curriculum Content
		2. Quality Delivery / Pedagogy
		3. Quality Assessment
		4. Monitoring
		5. Ancillary Activities
OUTPUT (40%)	QUALITY OF GRADUATES (40%)	1. Student Marketability
		2. Students' Satisfaction
		3. Employers' Satisfaction
		4. Generic Student Attributes

Source: Malaysian Qualification Agency (MQA)[19]

[19]http://www.mqa.gov.my/SETARA09/pdf/DIMENSI%20DOMAIN%20KRITERIA%20%20INDIKATOR%20SETARA%20%2709.pdf

In 2011, the instrument was extended to include assessments on public and private university colleges as well as non-conventional institutions that offer open and distance learning education. At the same time, a *Discipline Based Rating* (called D'SETARA), has also been introduced but limited to six niche disciplines[20] that are considered as *National Key Economic Areas* (NKEA). Note that while SETARA measures a university's performance, D'SETARA measures a university departmental performance. The same concept of quality assessment as SETARA has also been established in 2011 to measure private colleges (MyQUEST[21]) and polytechnics institutions (PolyRate[22]; Nordin, 2011).

[20] Six niche disciplines (NKEAs): Islamic Banking and Finance; Science of Health; Advanced Engineering, Science and Innovation; Tourism and Hospitality

[21] Private College Quality and Rating Management System (Sistem Pengukuran Kualiti dan Kesetaraan Kolej Swasta)

[22] Polytechnic Rating System (Sistem Penarafan Politeknik)

Table 2.4: 2006 Performance of Public Universities in Malaysia Based on SETARA 2007

HEIs	SETARA 2007	
	2006	
UM	0.87	Excellent
USM	0.58	Good
UKM	0.63	Good
UPM	0.68	Excellent
UTM	0.52	Good
UUM	0.39	Good
UIAM	0.63	Good
UNIMAS	0.46	Good
UMS	0.47	Good
UPSI	0.43	Good
UiTM	0.63	Good
UDM	0.08	Satisfactory
UMT	0.40	Good
USIM	0.35	Good
UTHM	0.44	Good
UTeM	0.32	Satisfactory
Efficient		**2**
Average	**0.49**	

Source: Corporate Strategy & Quality Assurance Unit of International Islamic University Malaysia

A point worth emphasizing is that both MYRA and SETARA models have been developed by the Malaysian Government to measure the performance of universities in local framework. However, in their respective evaluation context, the performance of a university in their primary activities of research and teaching are treated as two independent perspectives of performance when essentially they are jointly carried out using the same bundles of resources. Thus, this is a less representative concept of university evaluation. In order to have a meaningful and a more accurate reflection of a university performance, a university is to be jointly assessed in terms of efficiency in research and teaching. Further, current models would be more constructive if they could also offer solutions to enhance performance such as the proposed DEA framework. In other words, instead of only evaluating the performance of a university the models should also be able to recommend the prospective or improvement potentials of a university.

Other enticements from the Government in support of country's developmental vision via R&D&C policy include *APEX University* status award given to university that has satisfied the criteria for World University ranking; *National Professor* award given to outstanding researcher; *Higher Institution Centre of Excellence* (HiCOE) award[23] given to outstanding research centres or known as Centre of Excellence in a particular field of studies; and *MyBrain 15* programme that awards scholarship to any individual who is interested in pursuing higher education at Masters and PhD levels.

2.5.2. Unofficial Performance Measurement System

Unofficial PMS are frequently referenced by HEIs for knowing their current standing and benchmark against good practice on voluntary basis. Usually, the widely accepted KPIs on universities have been established based upon the performance or rather studies made on universities in developed countries such United Kingdom and United States of America (Beerkens, 2009). Hence, some may not be accurately applicable, or they cannot address certain factors that are unique but necessary, to a developing country like Malaysia. Hence, alternative measures to aggregated or generalized KPIs are warranted for Malaysian universities given their different cultural environment and developing economy in which they operate. The fact is, in practice, suitable set of assessment

[23]As in 2010, there are six centers awarded with HiCOE status award: Renewable Energy at UMPEDAC; Cancer Biomarkers at UMBI; Diagnostics Platform at INFORMM; Animal Vaccines and Therapeutics at ISB; Behavioral Research in Addiction at CDR; Islamic Finance Criminology at ARI (Source Ministry of Higher Education, MOHE)

criteria for a performance analysis, including in establishing university ranking, is very much depending on the objectives of the analysis conducted. This makes it very difficult to define specific categories for the same variables. The criteria most commonly employed in various assessments of Malaysian HEIs could be summarized as the following Table 2.5.

Table 2.5: Criteria Commonly Adopted in the Assessment on HEIs in Malaysia

CRITERIA	STANDARD INDICATORS
RESEARCH	* Amount of research grants received
	* Number of research products/recognitions
	conferred by national and international bodies
	* Number of papers refereed and cited in refereed journals
	* Number of articles,books and publications per staff
	* Number of patents attained
	* Number of products commercialized
	* Number of postdoctoral students
TEACHING	* Ratio of academic staff to students
	* Number of programmes accredited by professional bodies
INFRASTRUCTURE	* Percentage of equipment fully operational and calibrated
	or physical facilities that meet safety and quality standards
	* Number of book titles in the library
HUMAN RESOURCE	* Number of academic staff with PhD or equivalent
	* Percentage of results from "Peer Review"
CONSULTANCY	* Income generated from consultancy activities
INTERNATIONALIZATION	* Number of international academic staff
	* Number of international students
STUDENTS	* CGPA of students admitted into the University
	* Percentage of graduates employed after graduation
	* Percentage of results from Employer Survey
	* Number of University Alumni awarded "Nobel Prizes and
	Fields Medals"
	* Number of PhD students
SERVICE DELIVERY	* Compliance to International Quality Standard
	(ISO9000 QMS)
	* Percentage of Customer Satisfaction Index

Source: Corporate Strategy & Assurance Unit of International Islamic University Malaysia

2.5.2.1. Times Higher Education World University Rankings (*THE*)

Among the most acknowledged unofficial PMS for HEIs in Malaysia is *Times Higher Education World University Rankings* (*THE*) or formerly known as *The Times Higher Education Supplement* (THES-QS). It was initiated by QS, a prominent international career and education network based in London and specialises in higher education related reviews[24]. It produces annual rankings founded on the information obtained from participating institutions, by conducting extensive worldwide *Academic Reputation Surveys*, and by referring to well established databases (such as Web of Science, The World Scientific, International Book Information Service, SCOPUS). There are four types of university rankings annually produced by QS; *THE* World University Rankings, regional Top University Rankings (Europe, Asia, North America, South America, Oceania and Africa), Top 50 Universities by subjects and also *THE* World Reputation Rankings. *THE* ranking system has been revised several times and the latest methodology begun to be implemented in 2010. It is proclaimed that the new methodology is superior to the former methodology (2004-2009) given that its assessment draws on "evidence-based indicators" instead of "reputational measures" as described by some critics. In other words, they are now using more robust and systematic indicators.

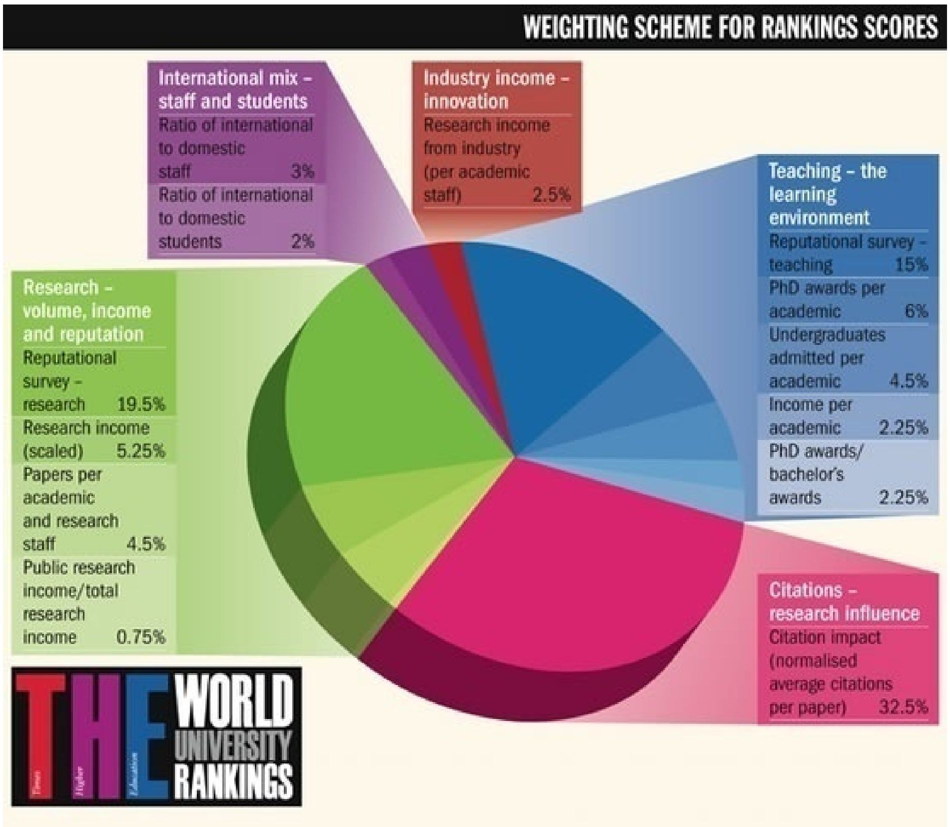
At present, *THE* league tables rank a university based upon five categories consisting of thirteen indicators with different weightings of importance depending on the usefulness

[24] Information for discussion on *THE* has been obtained from http://www.timeshighereducation.co.uk/world-university-rankings/2011-2012/analysis-rankings-methodology.html

of an element as the proxy, if not actual, indicator for the selected criteria. The five categories are *teaching* (*the learning environment*) worth 30%, *research* (*volume, income and reputation)* worth 30%, *citations* (*research influence*) worth 32.5%, *industry income* (*innovation*) worth 2.5%, and *international mix* (*staff and students*) worth 5%. The new combination of *THE* assessment criteria is asserted to account for a broader range of universities' activities associated with teaching, research and knowledge transfer. However, the priority given by this worldly renowned league tables is still on research that makes up 62.5% of the final ranking score instead of formerly only 60%, and in *teaching* category, PhD students' population is given the highest consideration[25]. The weighting scheme employed by *THE* World University Rankings in generating their annual league tables is reproduced as Figure 2.1 below.

[25] The former *THE* methodology had only four broad categories with six indicators; research quality (60%), teaching quality (20%), graduate employability (10%) and internalisation (10%)

Figure 2.1: Assessment Criteria Employed by Times Higher Education World University Rankings



Source: http://www.timeshighereducation.co.uk/world-university-rankings/2011-2012/analysis-rankings-methodology.html

2.5.2.2. Academic Ranking of World Universities (ARWU)

Concurrently, HEIs in Malaysia have also been quoting *Academic Ranking of World Universities* (ARWU) for quantifying their international competitiveness. ARWU was first published in June 2003 under the name *Shanghai Jiao Tong World University Ranking*[26]. Initially, it was launched as an initiative of Centre for World-Class Universities and the Institute of Higher Education of Shanghai Jiao Tong University, China, to determine the reputation of outstanding universities in China. Since its

[26]Information for discussion on ARWU has been obtained from http://www.shanghairanking.com/aboutarwu.html

publication, ARWU annual ranking so much caught the interest of global academe, governments and media that today it has become an influential international league table frequently cited for various official decisions. The weights accorded to the indicators currently used in generating ARWU is reproduced as Table 2.6 next.

Table 2.6: Indicators Employed by Academic Ranking of World Universities

	CRITERIA	INDICATORs	CODE	WEIGHT
1	Quality of Education	Alumni of an institution winning Nobel prizes & Fields medals	Alumni	10%
2	Quality of Faculty	a) Staff of an institution winning Nobel prizes & Fields medals	Award	20%
		b) Highly cited researchers in 21 broad subject categories	HiCi	20%
3	Research Output	a) Papers published in Nature & Science	N&S	20%
		b) Papers indexed in ... Science Citation Index-expanded & Social Science Citation Index	PUB	20%
4	Per Capita Performance	Per capita academic performance of an institution	PCP	10%

Source: http://www.shanghairanking.com/ARWU-Methodology-2011.html#2

Among those who favour ARWU, preferences have been expressed on its systematic, robust, transparent, and rigorous approach in generating the ranking with particular aim in becoming excellent research universities. In order to provide a more meaningful and relevant global rankings, the same practice as adopted by *THE,* ARWU is also being published in multiple versions, namely according to *Broad Subject Fields* (ARWU-FIELD) since 2007 and according to *Subject Fields* (ARWU-SUBJECT) since 2009.

2.5.2.3. Balanced Scorecard (BSC)

At the university specific management level, Balanced Scorecard (BSC) is the PMS currently employed by an increasing number of universities in Malaysia. The method is adopted as mechanism to align university-wide strategies and monitor the implementation of KPIs in accordance with the national educational policies and regulations. The growing interest to use BSC at institutions' own initiative is primarily motivated by its multiple perspective concepts of diagnosing a problem, formulating a strategy, and systematically aligning strategies via top-bottom approach (Yu, *et al.*, 2009; Othman, *et al.*, 2006) in the effort to create sustainable success. BSC consists of two components, namely, *Strategy Map* and *Scorecard* (Othman, *et al.*, 2006). The *Strategy Map* gives synopsis of all action plans in a single page that facilitates understanding of the master plan. The *Scorecard* describes performance and systematically aligns institutional resources with its courses of action. For every staff member, the individual BSC outlines and prioritizes critical activities according to their job specifications that it helps them to comprehend expectations and recognize their responsibilities in support of the organizational mission.

2.5.2.4. Other Performance Measurement Systems

In addition to those PMS discussed above, there are other models used by some institutions to quantify their achievement. They include *World Class Research University*, *Australian University Ranking*, and *Newsweek International*. The availability of these methods shows that, despite the limited published studies on universities' performance, these universities continuously monitor and evaluate their performance and achievements. Also, in practice, there is no one PMS that could give complete synopsis of a university's performance and that a combination of assessment models is necessary to account for various aspects of success. It should be noted that, for the performance assessment tool to be holistic, it should flexibly accommodate the institution's specific characteristics, concerns, and priorities. In other words, the academia is in need for an evaluation model that could be easily customised by the unit of assessment itself. This important gap and public need is what our research aims to address and contribute.

2.6. Frontier Approaches for Assessing HEIs Performance

Development in PMS on HEIs worldwide could be described as a gradual migration from reliance on purely statistical methods (such as regression analysis) and performance indicators (such as ratios and rates) to econometrics techniques (such as cost functions) and consequently, preference on sophisticated frontier analysis methodologies (Athanassopoulos & Shale, 1997). The second part of this chapter provides a selected review on previous studies of efficiency in higher education via frontier approaches with particular emphasis on DEA. The aim is to provide a non-technical background description of the proposed research methodology for the current thesis.

Economic efficiency measurement in education has been commonly undertaken via frontier analysis framework (Worthington, 2001; Abbott & Doucouliagos, 2003; Murillo-Zamorano, 2004). Within this framework, universities being evaluated are regarded as producers of educational benefits by converting learning resources into intellectual outcomes. Hence, technical relationship is essentially assumed to prevail between the components of such educational process (Worthington, 2001). The focus of earlier empirical studies has been on measuring HEIs' technical efficiency. This could be due to the postulation that the components of transformation activity are technically related and performance of HEIs is determined by the efficiency of the activity. To conduct frontier analysis, the underlying "efficient production technology frontier" for sampled institutions is first constructed (McMillan & Chan, 2006). Then the efficiency of all observations in the sample is measured relative to the constructed efficient frontier (EF). Also, improvement strategies for inefficient units are identified. There are three primary types of efficiency measures in economics, technical, allocative and total economic efficiencies. The reader is referred to example Worthington (2001), Murillo-Zamorano (2004), and Fried, Lovell and Schmidt (2008) for further details. A university is regarded as technically efficient by utilising its resources in the technologically most effective way such that the highest attainable productivity level is achieved. In contrast, a university is considered as allocatively efficient by prioritising between different technologically effective production mixes based upon associated prices and underlying production technology. A university is then said to achieve total economic efficiency or a productively efficient unit when it is both allocatively and technically efficient in its operation (Worthington, 2001).

With regards to earlier studies on educational efficiency, Worthington (2001) ascribed the popular techniques in empirical studies reported by the year 2000 as having difficulty to accurately construct educational production functions that could depict prevailing relationship between key policy variables and educational achievement. Four reasons have been suggested. The first reason was the mistake in choosing production function to model education system and assessment variables for the chosen function. It is important to remember that different production function models "address different questions, serve different purposes, and have different informational requirements"

(Worthington, 2001, p. 249). The second reason can be considered as related to the first reason. The chosen variables were not able to meaningfully evaluate public policy issues via the assessment model. The third reason, the chosen function was not able to accurately model the production function for education industry from an econometric perspective. That is, difficulties to use customary estimation techniques via single equation to understand relationship between educational inputs and outputs. The fourth reason, the chosen function had difficulty to model performance deficiency that actually exists in educational process. This is because of the traditional function assumption that every unit has the same transformation rate.

Nevertheless, the concern about inefficiency of academic institutions has been accounted for by more sophisticated frontier approaches for measuring economic efficiency, including SFA and DEA (Worthington, 2001). Consequently, not only frontier methods are apparently "more stable" than non-frontier technique. They have also been empirically proven to better accommodate the fundamentals of economic theory of efficiency measurement and hence exemplify the reality of academia better (Worthington, 2001).

Frontier analysis derives the efficiency score for a university in terms of its distance from the estimated EF. In other words, they calculate the gap between the achieved university performance level and the equivalent best observed performance in a sample. In reality, the production function is unknown. Therefore, efficient isoquant or frontier need to be empirically approximated based on the available data. Two broad categories of estimators have been advanced by Farrell, M.J. (1957) to empirically approximate the unknown production technology. These techniques are parametric and nonparametric frontier methodologies. Each varies in terms of the assumptions they make on the production frontier, specification of inefficiency component, and flexibility of production function in terms of the error term (Worthington, 2001).

Parametric envelopment estimators include Deterministic Frontier Approach (DFA) and Stochastic Frontier Approach (SFA; see Worthington, 2001 and Murillo-Zamorano, 2004 for more detailed discussions). In comparison to goal programming techniques, these econometric techniques give better projection of production frontiers from economics perspectives. The projection is better because goal programming techniques calculate the parameters for production function by solving *deterministic optimization problems* without any statistical logic. Thus, they forbid interpretation of results in statistically meaningful way to render any hypothesis testing (Murillo-Zamorano, 2004). However, the econometric techniques estimate the parameters of the production function based upon economic theories of efficiency and productivity.

Parametric estimators are further distinguished between deterministic and stochastic approaches. They differ in terms of the account made on inefficiency component to explain the observed performance deficiency among universities (Murillo-Zamorano, 2004). DFA has the same “technological framework” as mathematical programming models in that, it makes no account for technical errors - inaccuracy of observations and outputs measurement- such that every observed production mix is presumed to be producible (Simar & Wilson, 2000; Murillo-Zamorano, 2004, p. 47-48). Like SFA, DFA function incorporates inefficiency component but unlike SFA, it does not incorporate possible effects of random events on performance (Murillo-Zamorano, 2004). To estimate frontier parameters via DFA, parametric expressions such as

Modified Ordinary Least Squares, Corrected Ordinary Least Squares and Maximum Likelihood Estimation are frequently employed (Murillo-Zamorano, 2004).

In comparison to other parametric frontier methods, SFA is the most popular approach employed in studies related to measuring economic efficiency. This is because, besides the ability to incorporate economic principles of efficiency to explain variations in productivity, it is also capable of decomposing components of external factors to describe performance deficiency instead of simply attributing it to inefficiency alone (Worthington, 2001; Murillo-Zamorano, 2004). The external factors are uncontrollable events such as "operating environments", modelling errors, and "measurement errors" that result in inefficiency (Worthington, 2001, p. 250). As also indicated by Worthington (2001) and Murillo-Zamorano (2004), measurement errors in SFA model is not limited to inaccuracy of observations and outputs measurement but mistakes associated with prices and costs figures which are also considered in SFA analysis. Therefore, despite the fact that SFA gives correct measurement of productive efficiency from economic perspective, it necessitates substantial assumptions for constructing the production function and describing the distribution of the inefficiency.

Like the non-parametric DEA, SFA requires all units of assessment to be homogeneous. Homogeneity is characterised by the chosen input-output variables and identical operating technology. The latter is recognized based upon the fact that they are all operating in the same industry. Both techniques are capable of making evaluation based on multiple inputs multiple outputs specification. Within the broad scope of education, at present, SFA application on HEIs is less popular compared to DEA application for the reasons to be explained later. An example is a comparative investigation undertaken by McMillan and Chan (2006) that compared the performance of 45 Canadian universities by using DEA and SFA. The aim was to compare and contrast the efficiency and consistency of rating generated by both methods. McMillan and Chan (2006) subsequently concluded that there was significant inconsistency of results given by the two models. In fact, to determine an appropriate approach for a particular analysis, one should consider “theoretical and empirical” requirements of each based on evaluation objectives, data availability and “the intrinsic characteristics of the industry” to ensure accurate and successful analysis (Worthington, 2001; Murillo-Zamorano, 2004, p.63).

The widely applied nonparametric frontier estimators are Free Disposal Hull (FDH) and DEA. Worthington (2001), Murillo-Zamorano (2004), Daraio and Simar (2007), Fried, *et al.* (2008), Simar and Wilson (2008) as well as Thanassoulis, Portela and Despic (2008) give very good discussions on these estimators. Although non-statistical frontier estimators do not need parametric expressions, it is still possible to make statistical inferences on the generated results (Simar & Wilson, 2000). FDH is less restrictive than DEA in delineating frontier’s contour. This is because FDH assumes only the free disposability of inputs and outputs[27] but DEA assumes both the free disposability as well as the convexity[28] in depicting the envelopment surface (Simar & Wilson, 2000; Daraio & Simar, 2007). In other words, FDH estimates the frontier based solely on observed DMUs in the sample, excluding the linear or convex combinations of observed

[27]Daraio and Simar, 2007, p. 2: *Free disposability of inputs and outputs* is the possibility of not using or destroying goods -inputs, outputs- without costs
[28]Daraio and Simar, 2007, p. 3: *Convexity* implies that if two observations are possible, then all the linear combinations that lie between them are also possible

units as in the case of DEA (Cook & Seiford, 2009). In fact, FDH depict the efficient frontier using VRS orientation of DEA but with added integral constraint requiring λ_j values to be either 0 or one i.e. $\lambda_j \epsilon \{0,1\}$ (Fried, *et* al., 2008; Cook & Seiford, 2009, p. 6). Therefore FDH is, as described by Daraio and Simar (2007), a non-convex version of DEA and is considered by some others as more economic oriented technique than DEA. The properties underlying DEA model will be discussed in detail in the following chapter *Methodology*.

In comparison to econometric techniques, nonparametric frontier approaches are preferred by many analysts due to methodological motivations. They require limited theoretical assumptions with regard to (a) the functional form of relationship between inputs and outputs and (b) the distributional form of inefficiency components, to construct the frontier that represents the unknown efficient technology (Ahn, *et al.*, 1988; Thanassoulis, 1993; Daraio & Simar, 2007). This avoids imposing considerable structure on the assessment model and hence allows greater flexibility to accommodate various needs and nature for ease of real life applications. The techniques estimate the technology by enveloping observational data with all productively dominant units that are regarded as benchmark forming the frontier (Worthington, 2001; Daraio & Simar, 2007). Thus, the observed best practices correspond to genuine input-output transformation potentials given the realistic unknown efficient technology. This is different from parametric frontier approaches that would employ parametric expressions to approximate the position and structure of the efficient boundary. They are also different from regression-based frameworks that instead locate average practices as key referral units. Non-parametric frontier approaches, therefore, give a more accurate and practical technical appreciation of performance (Daraio & Simar, 2007), particularly for HEIs.

Performance gap identified by nonparametric frontiers is solely attributed to inefficiency. As suggested by Fried, *et al.* (2008), inefficiency can be ascribed to internal operation such as operating scale, operating efficiency and operating environment. Further, they do not require price information. A kind of information which is mostly unavailable for inputs or/and outputs associated with non-profit organizations such as HEIs. Although price information makes natural means of imposing weights upon variables, such weights are not suitable in relative performance evaluation because they change over time and vary according to producers (Fried, *et al.*, 2008). Consequently, it complicates differentiation whether a change in performance is caused by price changes or quantity changes (Fried, *et al.*, 2008).

In practice, many empirical applications centre on small samples, particularly studies on developing countries. In such cases, nonparametric frontiers make better substitute for parametric frontiers. Furthermore, although consistency is essential to guarantee reliable and useful results for analysis, consistency of estimator is not improved by bigger sample size. This is in consonance with Simar and Wilson (2000) who argued that the need for large sample is an insignificant theoretical property for FDH and DEA. It is only meant to warn that statistical inferences for analysis involving small samples need to be made with acknowledgment of the possible flaw associated with the curse of dimensionality (Simar & Wilson, 2000).

2.7. Applications of DEA to HEIs

Data Envelopment Analysis (DEA) is a linear programming (LP) technique that is especially useful for appraising comparative performance between several homogeneous entities, termed as Decision Making Units, DMUs (Cooper, Seiford & Tone, 2007; Thanassoulis, 2001). Every DMU, in the current context is university, being evaluated, consumes the same set of resources to produce comparable set of outputs. This feature enables identification of feasible improvement targets for underperforming universities simply based on the outstanding performance of universities identified as efficient. To quantify performance level, DEA produces a non-parametric frontier as a reference for best practice and a university's efficiency score is estimated in terms of its distance from that EF (Thanassoulis, 2001).

Efficient frontier contouring all observed input-output mixes delineates best practice because it consists of efficient universities that demonstrate highest achievable output levels for combination of resources currently available. Here, the interesting aspect of performance concerns the university's ability to efficiently convert inputs into teaching and research related outputs. Since its first introduction by Charnes, Cooper and Rhodes in 1978 as a tool to measure the performance of non-profit organizations, DEA has been widely applied to measure the performance of private sector as well, including banks, transportation, logistics, electricity, hospitals and health, hotels and restaurants, telecommunications, and mass media (Fernando & Cabanda, 2007, p. 218). DEA has been extended theoretically and been integrated with various techniques, creating variants of its standard models. Sample discussions on its recent developments can be found in article by Cook and Seiford (2009) as well as edited books by Cooper, Seiford and Zhu (2004) and Fried, Lovell and Schmidt (2008).

Worthington's (2001) review on empirical studies employing DEA as a measurement technique in education noted that greater number of studies has been conducted to evaluate primary and secondary schools compared to tertiary education institutions. However, since the leading publications of DEA on public universities by Ahn, Charnes and Cooper (1988) and university departments by Tomkins and Green (1988), the technique has grown in popularity to evaluate HEIs worldwide. This is attributable, essentially, to its unique ability to simultaneously account for multiple inputs and multiple outputs. Moreover, DEA could conveniently accommodate HEI's typical transformation process without the need to resolve to subjectively weighted indices, a common practice in econometric techniques.

The concept of relative appraisal further adds merit to this non-statistical technique. Particularly in identifying benchmark units for quality improvement initiatives. The concept of relative efficiency considers not only the observed data or universities' achieved performance in identifying optimal production mixes, but also, helps identify alternative best possible input-output combinations, if any, without the need for changing current operating scale. In other words, not only does it give estimates of potential scope for improvements, but also, it recommends benchmark universities for inefficient universities to emulate. The latter is actually provided by recognizing all potential reference peers that could be selected by every inefficient university based on their current capabilities. The former is given by approximating production mix for composite universities who are actually the same inefficient universities but are thrusted onto the EF. Proposals such as these make DEA a very useful technique in support of universities' performance improvement programmes. However, the concept of relative efficiency generates the results of an analysis which is only applicable for a particular set of sample. Currently identified optimal solution (a) may no longer be optimal even when only one sample member is changed; or (b) may not be optimal for other samples taken from similar or identical population. Although the need for reliable data is equally necessary for other statistical techniques, it is requisite for DEA in order to render the analysis useful (Avkiran, 2001).

More importantly, universities are too complex entities to come up with consensus on definite list of variables solely defined as inputs and outputs for DEA assessment on HEIs, even when the objectives of conducting an evaluation is the same. The suitable bundle of variables is very much dependent on the data availability and operating environment, which includes local educational policies. An appraisal should also explicate the end users' interests and priorities (Sarrico, Hogan, Dyson & Athanassopoulos, 1997). Nevertheless, employing variables commonly used in previous studies will definitely be a useful guide for, enhance authority of, and boost confidence in, an analysis to be conducted. Summary of variables commonly found in the literature on DEA applications to universities worldwide is presented in Appendix 3 until Appendix 6.

University performance assessments using DEA have considered various aspects of performance that could be categorised as conducted to achieve summative objectives such as resource allocation, and formative objectives such as performance enhancement (Sarrico & Dyson, 2000; Sarrico, *et al.*, 1997). Formative purposes of evaluation seemed to be more common reason for conducting empirical analyses using DEA on HEIs. For examples, studies with the objectives to quantify efficiency levels, establish improvement targets and identify benchmark universities. In fact, some studies carry out examination on several types of efficiency measures at the same time to gain better insight into HEIs' performance.

Generally, the main focus has been to quantify HEIs' technical efficiencies (Beasley, 1990, 1995; Johnes & Johnes, 1993; Breu & Raab, 1994; Sarrico, *et al.*, 1997; Sarrico, Hogan & Dyson, 2000; Johnes, 2006b, 2006c; Joumady & Ris, 2005; McMillan & Chan, 2006; Johnes & Yu, 2008) but some studies examine the nature of prevailing operating scale or scale efficiencies of HEIs as well (Tomkins & Green, 1988; Avkiran, 2001; Abbott & Doucouliagog, 2003; Johnes, 2006a). Others studies compare cost or allocative efficiencies of HEIs (Athanassopoulos & Shale, 1997; Ng & Li, 2000; Taylor & Harris, 2004). At a more detailed level of analysis, there are researchers who are particularly keen on restricting the weight flexibility in DEA assessments (Allen, Athanassopoulos, Dyson & Thanassoulis, 1997; Madden, Savage & Kemp, 1997; Sarrico, *et al.*, 1997) and looking into productivity change via integration with Malmquist index (Flegg, Allen, Field & Thurlow, 2004; Castano & Cabanda, 2007; Fernando & Cabanda, 2007).

Technical efficiency quantifies the effectiveness of HEIs in transforming inputs into outputs such that it tells if HEIs are producing the maximum producible output levels at their current production mix. This is determined by taking into account the achievements of others within a sample. On the other hand, scale efficiency concerns whether HEIs are operating at their optimal scale or fullest potential given the current capabilities. Therefore, while technical efficiency evaluation provides short term resolution to enhance performance, scale efficiency evaluation supports longer term performance enhancement strategies.

According to Athanassopoulos and Shale (1997), in order to evaluate efficiency scores from cost perspectives, then input variables need to be all measured in monetary units. This will portray the effectiveness of fund management by the institution in addition to provide insight on the productivity of a university (Athanassopoulos & Shale, 1997). This is actually in consistent with the argument made by Tomkins and Green (1988) who put forward that better insight on HEIs' performance could be obtained by using inputs that all expressed in monetary terms as opposed to expressed in cardinal values. Further, cost efficiency is useful than technical efficiency since the latter does not guarantee that a university is operating at the optimal cost level. Having said that on the selection of technical or allocative efficiency should be strictly determined based on the nature of DMU and the performance evaluation objectives (Tomkins & Green, 1988).

Ahn, *et al.* (1988) took the lead to apply DEA to the performance of HEIs in the US. They employed ratio form DEA as the substitute to econometric-regression models to compare the performance of 161 public and private universities, particularly those institutions awarding doctoral degrees. They compared universities' technical and scale efficiencies, differentiating between those with and without medical schools. Their findings revealed additional, yet important, information on aspects of HEIs' performance which would not be known if at that time customary statistical averages, *one-at-a-time ratio* and trend analyses had been employed.

Another worth mentioning paper on US was by Breu and Raab (1994). Nevertheless, their analysis used a small sample of only 25 institutions. They made use of standard university’s performance indicators associated with students and lecturers as their DEA input and output variables. The objectives were to measure the actual performance and the perceived quality of that time *Top 25* national universities and colleges. They found that the rankings produced by the quality ranking of *U.S. News* and DEA model were not comparable.

Jill Johnes has been studying the performance of HEIs in UK and frequently writes journal articles on different aspects of measuring university’s performance, particularly using DEA. In two different publications (Johnes & Johnes, 1993; Johnes & Johnes, 1995), Johnes and Johnes discussed their studies on research activity at university Economics departments, in terms of technical efficiency of research and research funding. They studied the same sample of 36 Economics departments but using different sets of observations, data collected in 1984 and 1989. Johnes, G. (1995) later extended the analysis to examine scale and technical efficiencies of Economics department. On the other hand, Johnes, J. expanded her DEA research focus to examine UK universities’ performance, a shift of focus to broader spectrum of institutional level. This includes studies that had (a) utilised multiple regression in identifying performance indicators for UK universities in DEA framework (Johnes, 1996); (b) considered students who graduated in 1993 as the DMUs to evaluate teaching efficiency of universities (Johnes, 2006b, 2006c); as well as (c) studies that evaluated more than 100 universities as DMUs to enumerate their technical and scale efficiencies (Johnes, 2006a).

DEA is also suitably used to accommodate diverse end users' perspectives in measuring performance. This has been proven in prior studies that incorporated value judgement into DEA assessments. One of the applications of DEA on HEIs is by Athanassopoulos and Shale (1997). The authors demonstrated how DEA model could be empirically adapted to incorporate policy-making issues in the form of value judgement by translating them into variable weights. 45 universities in UK had been evaluated for this purpose. They analysed 1992/93 academic year data and computed both cost minimization and output maximization DEA scores for those institutions, making evaluation from corporate point of view.

Another study by Sarrico, *et al*. (1997) utilized DEA to customize league tables that are usually referenced for university selection, according to pre-determined applicant's categories. Based on their case study on Kenilworth School pupils, they came out with six potential student categories whose priorities had been transformed into six sets of weights attached to input and output variables. The results were six sets of university ranking developed based on students' perspective. A study on how institutional standpoint could be successfully incorporated into DEA was afterwards given by Sarrico, *et al.* (2000) when they evaluated the performance of University of Warwick. In fact, DEA was integrated with Boston Consulting Group (BCG) matrix[29] to carry out assessments in two environments representing interaction between applicants and Warwick University, and between the State and Warwick University. DEA has been

[29]*Value Based Management.net* defines BCG Matrix as a method based on product life cycle theory that can be used to determine what priorities should be given in the product portfolio of business unit (http://www.valuebasedmanagement.net/methods_bcgmatrix.html)

improved and modified to address numerous other concerns of analysts. The reader is referred to discussions made by Cooper, *et al.* (2004), and Cook and Seiford (2009).

Elsewhere, performance measurement of HEIs using DEA has been undertaken by Abbott and Doucouliagog (2003), and Avkiran (2001) who evaluated both technical and scale efficiencies of universities in Australia; Castano and Cabanda (2007), and Fernando and Cabanda (2007) who integrated DEA and Malmquist indices to study change in Philippines universities' performance using output and input oriented DEA, respectively; McMillan and Chan (2006) who compared the performance of universities in Canada based on DEA and SFA. Taylor and Harris (2004) also conducted a series of eight DEA models to measure the performance of South African universities. In the context of Japan, Hashimoto and Cohn (1997) applied DEA to evaluate the scale efficiency of Japanese private universities. In recent times, substantial attention have been given to issues of research performance (Ng & Li, 2000; Johnes & Yu, 2008), teaching performance (Johnes, 2006b), university libraries efficiency (Kao & Liu, 2000), and managerial efficiency (Liu, Lee & Tzeng, 2004) of HEIs at institutional level.

A considerable number of DEA applications are also found on the assessment of university departments of the same discipline across universities within a country. The DMUs of interest has mostly been Accounting and Economics departments. Examples are Tomkins and Green (1988) who applied DEA on Accounting departments at UK universities, and by Madden, *et al.* (1997) who applied DEA on Economics departments at Australian universities. Both used small sample of 20 and 24 departments respectively, and analysed data for two independent years. However, the objectives of making the assessments were different. The former conducted the evaluation with the objective to test the sensitivity of DEA cost efficiency scores against variable mix whereas the latter carried out the evaluation to examine the impact of national policy change on teaching and research activities. Application of DEA on much bigger sample of departments is also found in the literature. For instance, Beasley (1990) and Beasley (1995) considered 52 Chemistry and Physics Departments in UK using 1986/87 academic year data. They incorporated value judgement into their evaluation using CRS. The technical output efficiency for teaching and research activities were computed by splitting departmental inputs between teaching and research activities (Beasley, 1995) but the input were not differentiated for evaluating the university departments (Beasley, 1990).

Regarding sample size, it is worth mentioning that, to be useful, DEA does not require large samples and it is equally applicable for studies involving small samples. Example of DEA applications found to evaluate large samples include those conducted by Johnes (2006b) on 2547 graduates from UK universities; Joumady and Ris (2005) on graduates from 209 HEIs in eight European countries; Johnes (2006c) on 54,564 graduates from UK universities; and Johnes and Yu (2008) on 109 Chinese universities. In contrast, DEA has been applied to small samples by Breu and Raab (1994) to study "Top 25" US News and World Report-ranked universities and Colleges; by Sarrico, *et al*. (2000) to study 10 Academic Departments at the University of Warwick; by Taylor and Harris (2004) to study 10 from 21 public universities; and finally by Fernando and Cabanda (2007) to study 13 Colleges within a university in Philippines. In addition to the above mentioned articles, McMillan and Chan, (2006) listed articles written by Hsksever and

Muragihi (1998), Johnes and Johnes (1995), Sarafoglou and Haynes (1996), Sinuany-Stern, Mehrez and Barboy (1994), and Thursby (2000) that applied DEA to improve the performance of units within universities in terms of resource utilization without the need to change their existing operating scale.

Despite the extensive use of DEA to HEIs, analysts have been facing problem of determining the most appropriate input and output variables to include. In order to apply DEA, it is crucial that all inputs and outputs are carefully selected and accurately measured to ensure accuracy of a DEA evaluation. This is equally applicable to any other techniques, including regression, correlation analysis and ratio analysis (Breu & Raab, 1994). The difficulty in identifying the best set of variables as inputs and outputs of education process can be ascribed to (a) intangible benefits gained from education process, (b) difficulty to assign monetary values to educational outcomes, and (c) unavailability of the required information. Hence, apart from the agreed consensus on teaching, research, and community services as the basic activities of HEIs, there is no agreement on the correct mix of inputs and outputs worth selecting to assess HEIs performance (Ahn, *et al*., 1988; Avkiran, 2001).

As the general guideline, Thanassoulis (2001) articulated that inputs should reflect necessary elements to be able to provide educational outcomes while outputs should represent most valuable outcomes as expected from a university. Although some applications of DEA resort to statistical techniques, such as correlations and regression, to choose assessment variables, it is common, in practice, to select the variables on “a priori conceptual basis” (Breu & Raab, 1994, p. 36). According to Avkiran (2001, p. 64), it is acceptable to use “parsimonious” number of output variables as long as they could be of adequate “manifestations of inputs” taking into account its evaluation context. In other words, the best set of variables for an assessment is best determined based on the objectives of the evaluation and available access to the required data. As the result, justification is frequently provided for every variable chosen, and categorization given to the selected inputs and outputs employed in a DEA assessment.

In the existing DEA literature, number of academic staff and amount of expenditure are the two most frequently selected variables as inputs. Some researchers prefer to measure academician in terms of its full time equivalent number, FTE, (Athanassopoulos & Shale, 1997; Avkiran, 2001; Abbott & Doucouliagog, 2003; Flegg, *et al.*, 2004; Fernando & Cabanda, 2007) while some others prefer to measure them in actual headcount of full time members (Johnes, 2006a; Castano & Cabanda, 2007). Others were different by including non-academic staff to get total staff figure (Tomkins & Green, 1988; Taylor & Harris, 2004) or considering both academic and non-academic staff as two independent inputs in their evaluations (Avkiran, 2001; Abbott & Doucouliagog, 2003; Fernando & Cabanda, 2007). Yet, some others (Madden, *et al*., 1997; Johnes & Johnes, 1993) distinguished academician into research and teaching staff and treated them as two independent measures of academic staff.

Greater inconsistency is observed among authors when it comes to defining components for expenditure, even when they use the same phrase of *operating expenses*. Apparently, *operating expenses* has been defined to consist of, among others, general expenditure, utilities, maintenance, student services, computing services, library services, and operating costs by Athanassopoulos and Shale (1997), Ng and Li (2000), Abbott and Doucouliagog (2003), and Fernando and Cabanda (2007). Yet few do consider depreciation (Castano & Cabanda, 2007) and equipment expenses (Flegg, *et al.*, 2004) as *operating expenses* as well. Further, many evaluations on HEIs' productivity have been derived from combination of expenditure and non-expenditure variables in order to better replicate the reality of academia. Nevertheless, there are instances when assessments are made based upon variables exclusively measured in monetary units. The examples are investigations conducted by Athanassapoulos and Shale (1997), Ng and Li (2000), Taylor and Harris (2004), and Johnes (2006c). In those quoted studies, authors are particularly interested in examining cost or allocative efficiency of universities.

Other input variables frequently considered are related to students' entry qualification and could be found in articles written by Athanassapoulos and Shale (1997), Sarrico, *et al.* (1997), Johnes (2006a, 2006b, 2006c), and Joumady and Ris (2005) to name a few.

The commonly accepted measures evidently employed for teaching outcome is full time equivalent (FTE) number of student enrolments, and for research outcome is publication count. Some analysts treat every category of enrolments as one independent variable and all are included in the assessment while others use summation of all enrolment categories as a single indicator for student enrolment. See, for example, Avkiran (2001), Abbott and Doucouliagog (2003), McMillan and Chan (2006), Fernando and Cabanda (2007), and also Castano and Cabanda (2007). In particular, McMillan and Chan (2006) treated FTE enrolments for Undergraduate (science), Undergraduate (others), Masters, and Doctoral as four indicators to compute efficiency scores for Canadian universities. The argument in support of those who prefer enrolment to degrees awarded is that enrolment figures recognize duration taken for the various degree programmes being offered and hence reflects resource commitment (McMillan & Chan, 2006). In addition, statistics on enrolments also provide justification for the reported resource consumption level; especially current number of academician allocated for, and amount of operating expenditure spent by, a particular university department. For those whose preference is the number of graduates according to degree classification or count of successful leavers (see example Athanassapoulos & Shale, 1997; Madden, *et al.*, 1997; Sarrico, *et al.*, 1997; Johnes, 2006b, 2006c), it is argued that such measure indicates teaching effectiveness of, or quality of teaching provided by, the universities. Besides, other teaching outputs include number of students graduated and/or number of higher degrees conferred (Athanassapoulos & Shale, 1997; Abbott & Doucouliagog, 2003; Flegg, *et al.*, 2004; Johnes, 2006a; Fernando & Cabanda, 2007) either adjusted or not adjusted for quality measures, and also students' completion rates (Breu & Raab, 1994; Sarrico, *et al.*, 1997; Johnes, 2006b).

Tomkins and Green (1988), Beasley (1990), Johnes and Johnes (1993, 1995), Madden, *et al*. (1997), Johnes and Yu (2008) are all the examples of DEA studies that evaluate HEIs' research productivity based upon their publication counts. Additional to total number of publications, when evaluating research performance of Chinese HEIs, Johnes and Yu (2008) considered the ratio of publication count per academic staff as another research productivity indicator. In contrast, to see the impact of 1987 research policy reform on HEIs in UK, Madden, *et al*. (1997) exclusively focused their assessment on publication counts but the total were differentiated between publications made in core economic journals, in non-economic journals, in the form of authored books, and publications in the edited books including editorial content. However, publications as occasional papers, discussion papers, conference papers, and research reports were all excluded from their analysis considering the fact that these would eventually be published into any of the formerly defined variable classifications. That is to say that they have altogether four research indicators for measuring research outputs. The same practice of discriminating the different formats of publications as separate output variables is employed by Johnes and Johnes (1993, 1995) in their assessments on research activity of Economics departments at UK universities. In fact, publication count is a popular proxy measure of research outcomes because it captures the quality and quantity of research across universities; each research paper accepted for publication in a particular journal is known to have satisfied certain quality consideration.

Other research indicators, which are also frequently used, are research income, citation index, research rating and research expenditure. They have been adopted in studies among others, by Beasley (1990, 1995), Athanassapoulos and Shale (1997), Sarrico, *et al.* (1997), Ng and Li (2000), and McMillan and Chan (2006). Instead of referring to publication count, research productivity of Canadian universities had been evaluated by McMillan and Chan (2006) based on their total sponsored research expenditure and percentage of successful number of pre-selected research grants against their eligible staff members. Beasley (1990, 1995) used four research rating categories received by Economics departments in order to examine the quality and quantity of research in his assessments. Others, like Athanassopoulos and Shale (1997), and Sarrico, *et al.* (1997) quantify research performance using weighted and un-weighted research rating.

Again, the difficulty to approximate and measure research outputs is normally ascribed to issues of production and/or publication time lag, joint effort between several authors or even related to its quality aspects. It is not conclusive as to whether one should use actual or average figures to denote the outputs of research. The argument put forth by Madden, *et al*. (1997) is that, to indicate the amount at the time of publication, then one should use the actual quantity, but to even out fluctuations in publications between years, then one should opt for average quantity. For some, an average publication figure is also useful to account for time lag in production and/or publication, particularly when research income is being treated as input variable. Citation index, on the other hand, is not well accepted owing to for certain fields of knowledge, publications are frequently made in journals which are not listed as SSCI-index journals (Abbott & Doucouliagos, 2003). In this respect, the efficacy of this indicator is restricted, particularly in Malaysian cases when many publications made in Malaysian language and according to the institution's niche area such as *Islamization* niche institution focuses on Islamic-based publications. As evident in the literature, some authors tend to use several indicators in an assessment to estimate the quantity, quality and worth of research outputs.

With regards to debatable variable research income or research grant, there are instances when it is treated as outcome but there are instances when it is treated as resource for research activities. Among those who have selected this monetary indicator as input variable include Beasley (1990, 1995), Johnes and Johnes (1993, 1995), Athanassopoulos and Shale (1997) as well as Ng and Li (2000). In contrast, amongst those who have chosen it as output variable are Tomkins and Green (1988), Beasley

(1990, 1995), Ng and Li (2000), Abbott and Doucouliagog (2003), Flegg, *et al.* (2004), Taylor and Harris (2004), and Johnes (2006a). Further, among the authors as quoted above, some of them including Tomkins and Green (1988), Athanassopoulos and Shale (1997), Ng and Li (2000), Flegg, *et al.* (2004), Taylor and Harris (2004), and also Johnes (2006a), are those who have used research income measured in the actual monetary value instead of been weighted by certain criteria or approach. Therefore, treating research income as an input or an output depends on whether it is seen as the resource needed to conduct and publish researches, or as the worth of and reward for researches conducted. This is in accord with the argument of Tomkins and Green (1988) as well as Abbott and Doucouliagos (2003) who suggested that research grants makes a good research indicator because they indicate the worth of research as perceived by the public. According to Johnes and Johnes (1993), in practice research grant awarded for a particular research project is meant to cover expenses on other *facilities* as well, not limited to remunerate research assistants only. Therefore, it is a resource and should not be treated as both input and output variables to avoid double counting.

The list of variables used by all of the above-mentioned authors is summarised in a tabular format and attached as Appendix 1 until Appendix 6.

2.8. Conclusion

In order to support the national developmental reform that regards HEIs as the mechanism to transform Malaysia into a developed country, PMS and improvement action plans should be practical in nature and hence derived from operational perspective. This is because evaluation and improvement systems that are devised by taking into consideration operational reality and feasibility lead to undemanding implementation endeavours. It will also facilitate acceptance and cooperation among the affected institutions to improve their performance. Moreover, enquiry exclusively made on actual observational data at institutional level gives practical synopsis yet systematic feedback on current performance. It also provides feasible recommendations on *how to improve*, instead of ideally *what to improve*. Concerns regarding the relevance of the proposed PMS to country specific policy issues are also addressed.

DEA models have proven in the literature to effectively depict educational production function in such a way that they could (a) capture the prevailing relationship between assessment variables, (b) make account for performance deficiency innate of educational process and (c) incorporate national policy issues into performance appraisal. Therefore, not only does DEA address difficulties associated with estimating efficient technology for HEIs as highlighted by Worthington (2001), but also, it provides practical solution that requires very limited theoretical assumptions. Further, DEA enables institutions to carry out evaluation on themselves internally according to their own targets and concerns without relying on external evaluations on them. In the subsequent *Methodology* chapter, the proposal is made for an alternative implementation framework for DEA analysis, namely HRSTO, which is argued in this thesis as capable of providing better reflection of HEIs' performance. The truth is no single PMS could best recapitulate the various aspects of university's performance. HRSTO is proposed as an alternative DEA framework to complement existing PMS in Malaysia.

CHAPTER 3

METHODOLOGY

3.1. Introduction

The earlier chapter introduced Data Envelopment Analysis (DEA) in non-technical description and demonstrated the merits of applying it to the performance analysis of universities in Malaysia. This chapter extends the discussion in detail by focusing on the technical side of DEA. It starts by giving a brief synopsis of important concepts underlying efficiency measurement using DEA. Afterwards, Section 3.3.3 illustrates DEA in technological perspective (or envelopment form) which is the model being adopted for the empirical analysis of this thesis. The alternative model to the envelopment DEA is the multiplier form (Section 3.4.1), which was first introduced by Charnes, Cooper and Rhodes (1978). This is immediately followed by the DEA model introduced by Banker, Charnes and Cooper (1984) in Section 3.4.2. A review of the methodological developments of DEA is provided, followed by modifications to the basic DEA models in Section 3.4.3, specifically, approaches that incorporate weight restrictions and revise returns to scale technology. Section 3.5 presents both the conceptual and technical formulations of the proposed integration of Hybrid returns to scale (HRS) and Trade-off approaches that is introduced in this thesis as another implementation framework for DEA. The chapter concludes by highlighting the contributions of the proposed model to DEA literature.

3.2. Foundation of Efficiency Measurement Using DEA

Performance measurement of academic institutions from economic perspective regards every institution as a producer of educational benefits that transforms learning resources into intellectual outcomes. In order to undertake such analysis, it is necessary to assume some technical relationships to prevail between the components of such educational process (Worthington, 2001). The notion of economic efficiency evaluation started with the prominent studies of Koopmans (1951), Debreu (1951) and Shephard (1953). Debreu employed the coefficient of resource utilization whereas Shephard used distance functions to estimate technical efficiency. Shephard's interest was to predominantly establish the relationship between cost and production functions for the purpose of realising efficiency. In fact, his conception of distance function had been the core notion of Farrell's succeeding renowned efficiency measurement derived from empirical data (Banker, Charnes & Cooper, 1984)[30]. Farrell was also the first to put forward an assessment model that could simultaneously account for multiple inputs using simple transformation function (Coelli, Prasada Rao, O'donnell and Battese, 2005). It was a combination of these ideas that led to the measurement of performance by DEA.

DEA is a non-parametric frontier estimator commonly employed to posit the unknown efficient production technology. Such a production function is a mathematical expression of the technical relationship that is presumed to exist between inputs and outputs. It measures the efficiency of a unit in comparison to other similar units via frontier technique founded on "Farrell Measure" of efficiency. This concept draws on

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[30]Illustration on how Shephard's distance function had been adopted and adjusted to develop DEA efficiency measures can be found, for instance, on pages 1082-1084 in Banker, *et al.* (1984)

the achievement of all members of an observation set to quantify the performance of every sample member as defined by inputs consumed and outputs generated in their transformation practices (Cooper, Seiford & Zhu, 2004). The technique assumes that each decision making unit (DMU) depends on the other DMUs in the estimation of its efficiency. This is the reason why the term "relative efficiency" is applied. The technical dependency among DMUs within the technology set is represented by the Production Possibility Set (PPS). Note that since the PPS is theoretically unknown, it must be postulated using a set of properties. The DEA technique specifically evaluates a particular DMU based on the observed achievement level instead of using arithmetically derived averages which may not be producible by or meaningful to any sample member (Ahn, Charnes & Cooper, 1988).

By definition, the PPS is a set containing all feasible input-output combinations that are observed in a data. Cook and Seiford (2009, p. 5) defined the PPS "as a declaration of the totality of production activities that might plausibly have been observed on the evidence of the activities actually observed". Consider X as the vector of inputs and Y as the vector of outputs, the properties as given by Banker, *et al.* (1984, p. 1081) is reproduced here to describe the PPS:

Production possibility set is given by T and can be defined as

$$T = \{(X, Y) | Y \geq 0 \; can\; be\; produced\; from\; X \geq 0\}. \qquad (3.1)$$

Input possibility set is given by L(Y), where for each Y

$$L(Y) = \{X | (X, Y) \in T\}. \qquad (3.2)$$

Output possibility set is given by P(X), where for each X

$$P(X) = \{Y | (X, Y) \in T\}. \tag{3.3}$$

The properties underpinning the concept of the PPS adopted from Banker *et al.* (1984, p. 1081), and Banker and Thrall (1992, p. 76) with non-mathematical illustration given by Thanassoulis (2001, p. 38) are presented next.

Postulate 1: Convexity

If $(X_j, Y_j) \epsilon\, T,\ \ j = 1, 2, \dots, n\ and\ \lambda_j \geq 0$ are nonnegative scalars such that

$$\sum_{j=1}^{n} \lambda_j = 1,\ then \left(\sum_{j=1}^{n} \lambda_j X_j,\ \sum_{j=1}^{n} \lambda_j Y_j\right) \epsilon\, T.$$

By assuming convex shape of the unknown technology, interpolation between feasible input-output correspondences will result in feasible input-output correspondences.

Postulate 2: Inefficiency or Free Disposability or Monotonicity

a) If $(X, Y) \epsilon\, T,\ and\ \bar{X} \geq X,\ then\ (\bar{X}, Y) \epsilon\, T.$
b) If $(X, Y) \epsilon\, T,\ and\ \bar{Y} \leq Y,\ then\ (X, \bar{Y}) \epsilon\, T.$

It is assumed that inefficient production is possible which could either be in the form of (a) utilization of inputs higher than the minimum requirement; or (b) production of outputs lower than the maximum potential productivity.

Postulate 3: Ray Unboundness or Constant Returns to Scale (CRS) Assumption

If $(X, Y) \epsilon\, T,\ then\ (kX, kY) \epsilon\, T\ for\ any\ k > 0.$

If units X and Y are in the technology, then the scaled units of X and Y will also be in the technology.

Postulate 4: Minimum Extrapolation[31]

T is the intersection set of all $\hat{T}$ satisfying *postulate 1, 2* and *3,* and subject to the condition that each of the observed vectors $(X, Y) \epsilon \hat{T}, \; j = 1,2, \dots, n$. In other words, "the PPS is the smallest set meeting the foregoing postulations and containing all input-output correspondences observed" (Thanassoulis, 2001, p.38)

Note that depending on whether or not proportionality relationship is assumed to exist between the input and output variables, these properties can be employed to depict the PPS for technology under Constant and Variable returns to scale. CRS is when full proportionality relationship is assumed to exist between the variables and is discussed in Section 3.4.1. In contrast, Variable returns to scale (VRS) is when no proportionality relationship is assumed to exist between the variables and is discussed in Section 3.4.2. In particular, the key difference between the two technologies lies in assuming and not assuming postulation of *Ray Unboundness* during the construction of the PPS.

3.3. Data Envelopment Analysis (DEA)

DEA as a performance measurement tool is a nonparametric frontier approach to appraise the relative productivity of observed entities by estimating the true underlying technology. The technology is unknown yet assessable based upon sets of practical properties. Conceptually, DEA determines efficiency score of a unit by projecting all observations onto the boundary of the PPS. Non-dominated units have either the largest

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[31] Thanassoulis, 2001, p. 38: ***Interpolation***; Points resulting from the interpolation of two feasible input-output correspondences lie on the line joining those correspondences and in the space such lines enclose. Example, if M is the midpoint between DMU A and DMU B, its input is [(50%*A)+(50%*B)] and output is [(50%*A)+(50%*B)]

output-input ratio or the smallest input-output ratio in comparison to others in the data set. The non-dominated are extreme units that are on the boundary of the PPS, thereby constructing it, are regarded as efficient performers. The units that lie inside the PPS are dominated units or outperformed by others and are therefore regarded as inefficient. Further, the empirical orientation of DEA appraisal identifies the relatively best practice applicable for a particular sampled population only. The currently identified best practice may not be the optimal practice for others belonging to different environment or populations.

3.3.1. Measures of Efficiency in DEA

Productivity relates to the production of output levels using certain input levels while efficiency relates to the ability to achieve the maximum potential output or the ability to consume the minimum necessary input from technological perspective (Coelli, *et al.*, 2005; Fried, Lovell & Schmidt, 2008). Farrell (1957) noted that economic efficiency could be decomposed into technical and allocative components depending on the evaluation context. Underpinning these “Farrell measures” is the implicit assumption that all assessment units have equal access to inputs (Cooper, *et al.*, 2004). Although they are not using exactly the same amount of inputs, DEA comparatively judges performance by considering input utilization and output production levels of every other unit in an observation set. See examples Worthington (2001), Murillo-Zamorano (2004), Coelli, *et al.* (2005), Daraio and Simar (2007), and Fried, *et al.* (2008) for detailed discussions on these economic concepts.

DEA considers efficiency is always feasible because it assumes that every university to know how to achieve maximum productivity and what constitutes optimal mixes of educational inputs-outputs (Coelli, *et al.*, 2005). In measuring the efficiency of higher education institutions (HEIs), DEA will quantify their performance as producers of educational benefits relative to the performance of other HEIs, under the assumption that technical relationship exist between the assessment variables. This efficiency is estimated in terms of the proximity of the HEI to the efficient frontier (EF) that encompasses the sample of all observed HEIs (Daraio & Simar, 2007). In other words, the degree of inefficiency of a university is measured in terms of the discrepancy in the quantity of its inputs and/or outputs from that of the best performers located on the frontier (Daraio & Simar, 2007). The distance is then reported as numerical efficiency scores that give proportionate feasible changes in an activity as permitted by the prevailing technology. Therefore, theoretically justified transformation function is unnecessary and it is alleged that being on efficiency frontier is feasible but not necessarily achievable by every sample member (Banker, *et al.*, 1984).

When the aim of the performance analysis is to increase outputs given the level of inputs or to reduce inputs given the level of outputs, then technical efficiency is the performance measure. Note that economic utilization entails technical efficiency but excessive utilization is regarded as inefficiency. On the contrary, when the focus is on resource mix given their respective prices and underlying production technology, then allocative efficiency becomes the performance measure. Optimal mix entails allocative efficiency but poor mix is regarded as inefficiency. A university is said to have achieved total or full economic efficiency when it is both allocatively and technically efficient in its operations (Worthington, 2001; Coelli, *et al.*, 2005). This is when a university is able to economise its input consumption or optimise its output production while minimising its costs. However, according to Koopmans's definition (Pareto efficiency), a technically efficient unit must be able to produce an output with the least combination of input mix such that any one additional unit produced will necessitate reduction in the remaining output amount or increment in current input usage (Coelli, *et al.*, 2005; Daraio, & Simar, 2007; Fried, *et al*., 2008). This is rather a more stringent identification of an efficient unit compared to Debreu's coefficient of resource utilization and Farrell's efficiency measures (Daraio & Simar, 2007).

Debreu (1951) explained that technical efficiency could be measured by looking at *equiproportionate* improvement potentials in all outputs and inputs. The resulting efficiency measure is invariant with the units of measurement (Coelli, *et al.*, 2005; Daraio & Simar, 2007). The obtained efficiency score ranges between 0 and 1. Benchmark score of 1 is awarded to units with no further potential for radial adjustment and regarded as fully technically efficient whereas scores below 1 implies improvement potentials and hence performance deficiency (Fried, *et al.*, 2008). This concept of technical efficiency was later enhanced by Farrell as well as Charnes, A. and Cooper, W.W. in 1985 to enable measurement of efficiency on comparative basis (Daraio & Simar, 2007). Note that the Debreu-Farrell technical efficiency measure, does not account for possible remaining "slacks in inputs or surpluses in output" (Daraio & Simar, 2007, p.14). Therefore, a unit with a score of 1 is said to be weakly efficient. When slacks are accounted for, the units on the boundary are said to be fully efficient in Pareto sense, which is also in line with economic perspective (Coelli, *et al.*, 2005; Daraio & Simar, 2007).

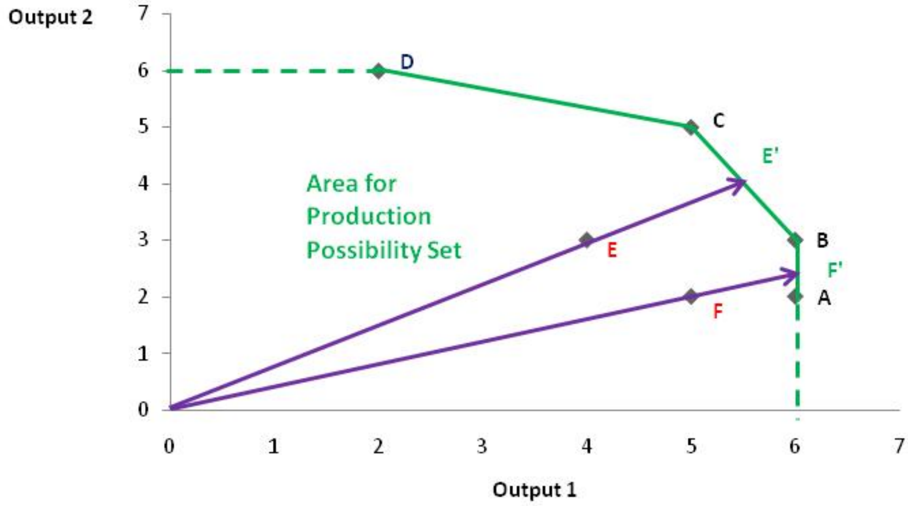
In this thesis, the efficiency of a boundary unit is measured based on Farrell's efficiency instead of Pareto efficiency. The former principally implies efficiency is obtained by jointly increasing outputs while maintaining input mix at respective levels (output-oriented) or by jointly decreasing inputs while maintaining output mix at respective levels (input-oriented). In this case, a university is considered as efficient unit when there is no possibility for further radial improvements (Fried, *et al.*, 2008). On the contrary, Pareto efficiency implies efficiency in revising current output or input mix without increasing observed input needs or deteriorating achieved output levels (Thanassoulis, 2001). Therefore, Pareto-Koopmans' efficiency further looks at the possibility of changing a production mix so as to achieve optimal potential as permitted by the prevailing technology. In this case, absence of further "coordinate wise improvements" is the criterion to be considered as an efficient unit (Fried, *et al.*, 2008**,** p. 25).

3.3.2. DEA Projection onto the Efficient Frontier

The efficiency score given by DEA for a particular unit both quantifies its current performance level and gives its radial distance from the boundary of the PPS. The units that are accorded technical efficiency scores of 1 are said to be efficient and hence constitute the boundary of the PPS. The units that are given efficiency score less than 1 are located somewhere inside the PPS and regarded as inefficient. For such units, DEA determines how far away they are from the EF and then projects their input-output bundles towards the EF. The coordinate for a point gives its input and/or output mix and for points in the PPS, their optimal coordinates are derived from those of boundary points (Thanassoulis, 2001). The radial distance of a projection signifies the highest possible increase in outputs (for output-oriented model) or decrease in inputs (for input-oriented model) to be emulated by inefficient units to improve performance and be efficient. Such recommended output augmentation or input contraction amount is calculated at current input or output levels without altering the observed production mix and the prevailing technology. Therefore, the production function estimated by means of DEA is different from the traditional economic notion of production function (Banker, *et al.,* 1984).

Figure 3.1 illustrates the DEA concept in a one input, two outputs framework and using six DMUs. The outputs are normalised to per unit of input so that the diagram shows combination of the two outputs produced at different amount of input consumed. The graph shows the diagonal projection of an inefficient DMU, say E onto the boundary of the PPS. The projection is given by the upper solid arrow pointing outward from the origin, going through the PPS and hitting the frontier at point E'. The area enclosed by the convex curve (solid and dotted lines) represents the PPS for the hypothetical sample. The convex curve itself is the EF that envelops all inefficient units including the observed DMUs in the sample as well as feasible input-output correspondences that are postulated by the above mentioned theoretical properties. All DMUs along the solid curve line of the EF are technically efficient in Farrell sense. But, only DMUs B, C and D are Pareto-efficient. This is because none of them is dominated by any other observed DMU within the PPS. This is measured in terms of the ability to produce higher output without requiring more input or could utilize lesser input without producing lower output (Thanassoulis, 2001).

Figure 3.1: DEA Projection of Inefficient DMUs onto the Efficient Frontier



Projection of Inefficient DMUs onto the Efficient Frontier via Output-oriented DEA model

The optimal amount of both outputs that should be produced by DMU E using its current input level, is determined by the interpolation between its referent peers DMU B and DMU C. Particularly, the distance by which DMU E can be moved to point E' gives the feasible increase in both outputs while maintaining existing output mix and input level. Therefore, the computation of its technical output efficiency is given by OE/OE'. Likewise, the technical output efficiency of efficient DMU B is given by OB/OB, which obviously is 1, because it is on the frontier. Inefficient DMU F could be improved via similar projection to boundary point F'. Note that, DMU A is efficient only in Farrell's sense but inefficient in Pareto's sense. Its efficiency score is 1, indicating that it is producing the highest producible outputs at the existing output and input mixes. However, its efficiency can be further increased by changing its current production mix. In other words, DMU A is allocatively inefficient or having mix-inefficiency in Pareto sense. The mathematical expression of the PPS, under CRS technology, can be given by

$$T_{CCR} = \{(X,Y) \mid X \geq \Sigma_j \lambda_j X_j,\ Y \leq \Sigma_j \lambda_j Y_j,\ Y \geq 0\}. \qquad (3.4)$$

3.3.3. DEA from Technological Perspectives

DEA offers two perspectives of measuring a unit's performance. First is the technological perspective which is given via the envelopment or primal formulation. Second is the managerial perspective which is given via the multiplier or dual formulation. According to Thanassoulis (2001), efficiency evaluation using the technological framework identifies optimal improvement factors in terms of input conservation and output augmentation amounts based on the observed DMU's distance to the EF. Conversely, an evaluation from the managerial standpoint uses virtual inputs and virtual outputs (relative levels of the imputed input-output values) to derive optimal "marginal rates of substitution between inputs or between outputs, and the marginal rates of transformation between inputs and outputs" (Thanassoulis, 2001, p. 75). Specifically, for radial measures such as CRS, envelopment form gives uniform inputs contraction (or outputs expansion) scalar in order to project the target DMU onto the EF, whereas multiplier form provides an aggregate worth of the outputs produced expressed as the proportion of the aggregated inputs consumed (Podinovski & Thanassoulis, 2007).

For an observational data, there will be n observed DMUs which is always denoted by $DMU_j = (X_j, Y_j)$ such that $j = 1, 2, ..., n$. The DMU under the assessment is denoted by $DMU_0 = (X_0, Y_0)$. Every DMU_j is using m inputs ($i = 1, 2, ..., m$) to produce s outputs ($r = 1, 2, ..., s$). All inputs and outputs are assumed to be non-negative. The vector of inputs is denoted by $X \in R_+^m$ while the vector of outputs is denoted by $Y \in R_+^s$. Individual inputs ($i = 1, 2, ..., m$) of the vector X_j are denoted by x_{ij} and individual outputs ($r = 1, 2, ..., s$) of the vector Y_j are denoted by y_{rj}.

$$
\begin{aligned}
&Max \quad \phi \\
&Subject\ to: \\
&\qquad \sum_{j=1}^{n} x_{ij}\lambda_j \le X_{i0}; \quad i = 1, 2, ..., m, \\
&\qquad \sum_{j=1}^{n} y_{rj}\lambda_j \ge \theta Y_{r0}; \quad r = 1, 2, ..., s, \\
&\qquad \qquad \lambda_j \ge 0, \qquad \theta\ sign\ free.
\end{aligned} \tag{M3.1}
$$

Model (M3.1) is an example of DEA output-maximization model being evaluated in a technological framework by assuming CRS technology. It evaluates a sample of n DMUs, each is producing combinations of s types of outputs $(y_{rj},\ r = 1, 2, \dots, s)$ by utilising m types of inputs $(x_{ij},\ i = 1, 2, \dots, m)$. In this model, every DMU_j is said to consume x_{ij} units of input i to produce y_{rj} units of output r and is assumed to have at least one input and one output which is strictly positive. The ϕ is interpreted as an output expansion factor and the reciprocal to its optimal value gives the efficiency score of DMU_0. Further, all variables (x_{ij}, y_{rj}, v_i and u_r) are assumed to be non-negative.

The efficiency scores are computed by maximizing the objective function value (ϕ) whilst being constrained by restrictions related to inputs and outputs. Firstly, the weighted sum of inputs for all the other DMUs need to be at most equivalent to current input level consumed by DMU_0 $(or\ x_{i0})$. Secondly, the weighted sum of outputs for all the other DMUs need to be at least equivalent to the product of *radial measure and current output level* produced by DMU_0 $(or\ \phi y_{r0})$. If no other DMU in the PPS is able to outperform DMU_0 by producing output greater than y_{r0} units produced by DMU_0 using the same amount of x_{i0} units consumed by DMU_0, then DMU_0 is regarded as efficient with an efficiency score of 1. If there is another DMU_j that could outperform

DMU_0 by producing greater output mix using the same input levels, then *DMU_0* is given efficiency score lesser than 1 $\left(or\ \frac{1}{\emptyset_0^*} < 1\right)$. The score is a percentage, indicating the outputs actually produced instead of the maximum producible amount at the current input levels consumed. In other words, the output augmentation amount that is feasible for inefficient DMU is given by $\left[\left(1 - \frac{1}{\emptyset_0^*}\right) * 100\right]$.

Model (M3.2) in the envelopment form, but under the input-minimisation orientation is given by.

$$\begin{aligned} & Min \quad \theta \\ & Subject\ to: \\ & \sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta X_{i0}; \quad i = 1, 2, ..., m, \\ & \sum_{j=1}^{n} y_{rj}\lambda_j \geq Y_{r0}; \quad r = 1, 2, ..., s, \\ & \lambda_j \geq 0, \qquad \theta\ sign\ free. \end{aligned} \tag{M3.2}$$

Benchmark universities that are identified as the efficient peers are awarded non-zero lambda weights (or $\lambda_j > 0$). Interestingly, λ_j values are the same for both inputs and outputs as they are allocated according to DMUs and not differentiated by the assessed variables. They denote non-priori weights attached to every university within the observed data set when the model is being solved. Whilst optimising the objective function value for a university (*DMU_0*), for instance, ϕ_0 in CRS model (M3.1), DEA will look for the best set of λ_j weights for that university which will give it an optimal augmentation factor of ϕ_0 $(this\ time, \emptyset_0^*)$ based on the observed production mix. Production mix is represented by the coordinates of points. $\emptyset_0^*$ is then used to identify if there exist an efficient composite unit corresponding to linear combination of $\left(\sum_{i=1}^{n} \lambda_j^* x_{ij}\,,\ \sum_{j=1}^{n} \lambda_j^* y_{rj}\right)$ which produces greater than $\emptyset_0^*$ amount of output from DMU_0 $(or\ \emptyset_0^* y_{ro})$ by using input levels at most as much as those consumed by DMU_0 $(or\ x_{io})$. This is called the *technical output efficiency* of DMU_0 being assessed. The technical output efficiency score of the university being assessed is given by $\left(\frac{1}{\emptyset_0^*}\right)$.

If the resulting efficiency score is 1 or 100%, it identifies that the university as efficient with λ_0 equal to 1. This implies that it is not possible for the university to further increase its current performance in comparison to the performance of the other universities within the same data set. If the resulting efficiency score is less than 1 $\left(i.e\ \frac{1}{\emptyset_0^*} < 1\ where\ \phi_0^* > 1\right)$, the university is rated as relatively inefficient and $\emptyset_0^*$ gives its outputs *equiproportional* expansion target using the current input mix. This is when there exists another unit or composite unit that outperforms the university with output level represented by $\left(\sum_{j=1}^{n} \lambda_j\, y_{rj} > \phi_0^* y_{r0}\right)$. The λ_j for its respective benchmark peers will also be positive; λ_j greater than 1 indicates scaling up (efficient peer is on a smaller scale size) while λ_j lesser than 1 indicates scaling down (efficient peer is on a bigger scale size) from the currently observed levels of those benchmark DMU_j. This inefficient university can improve its current efficiency by having the non-zero λ_j value(s) of its efficient peer(s) generated for the same data set. Again, positive λ_j value indicates the extent to which an inefficient university should *copy* the performance of that particular efficient peer university(s) to become efficient (see for example Thanassoulis, 2001; Sherman & Zhu, 2006).

It is worth mentioning that, the output efficiency score under the CRS assumption is the same as the input efficiency score. That is, $\theta = 1/\phi$ (see Charnes, Cooper & Rhodes, 1978). In fact, CRS model gives us a measurement of overall technical efficiency. This is because the efficiency of a university is assessed in terms of its ability to generate the highest attainable output levels or ability to operate at the least input consumption levels (Banker, *et al.*, 1984). In other words, the focus of CRS efficiency is on the ability to take the advantages of the prevailing production technology.

Alternative to the technological thinking paradigm is DEA assessment in value thinking paradigm or managerial viewpoint (Podinovski, 2004a). This is made possible by the DEA multiplier models. This framework will be illustrated in the subsequent discussions on CCR (i.e. Charnes, Cooper & Rhodes) models in Section 3.4.1 and BCC (i.e. Banker, Charnes & Cooper) models in Section 3.4.2. The difference in the two modelling concepts is in the use of weights in the latter. The weights in the multiplier form correspond to a relative value system for every university being assessed. Output-oriented model awards highest possible score for the university concerned, consistent with the concept that the resulting value system is simultaneously feasible for all the other universities (DMUs) such that none achieves an efficiency rating beyond a user-specified upper bound, which is ≤ 1 in CCR ratio model (M3.3; Tomkins & Green, 1988; McMillan & Chan, 2006). In simple terms, these weights signify the importance placed by a university on that particular input v_i and/or output u_r in order to attain its best reported efficiency score (Allen, Athanassopoulos, Dyson & Thanassoulis, 1997).

3.4. Developments in Data Envelopment Analysis (DEA)

Modifications to the original DEA models can be broadly categorized into two major strands. Firstly, there are interests to fine-tune the properties for projecting the underlying technology of a data set being studied i.e. studies on returns to scale (RTS). Secondly, there are interests to restrict the full flexibility of the assessed entities in choosing their optimal sets of multiplier values in order to gain favourable efficiency outlook. Discussions on recent developments can be found in studies by Cook and Seiford (2009), Thanassoulis, Portela and Despic` (2008), Thanassoulis (2001), and Cooper, Seiford and Tone (2007).

3.4.1. Basic DEA Models: The Charnes, Cooper and Rhodes (CCR)

Founded on economics and engineering concepts of efficiency measurement, Charnes, Cooper, and Rhodes (1978) developed DEA as a performance measurement model for non-profit institutions. Consistent with economics theories, production function is employed to represent the unknown efficient technology. In agreement with engineering theories, the basic productivity ratio is adopted to define efficiency score while productivity concept is adopted to discriminate between efficiencies associated with production technology and managerial competencies. The model is specifically formulated for homogenous organisations and uses assessment variables neither weighted against monetary values nor measured in a single measurement unit (Charnes, *et al.*, 1978). DEA uses actual observations to estimate the production function, determine weights, derive optimal performance levels, and identify benchmark units on comparative appraisal basis. In fact, two types of assessment models were advocated by Charnes, *et al.* (1978) to measure efficiency. The first was proposed to evaluate technical efficiency while the second was suggested to additionally gauge managerial competencies.

In a mathematical framework, Charnes, *et al*. (1978) determined efficiency score for an observed DMU_j by maximising its total weighted outputs divided by its total weighted inputs (for input-oriented DEA model) resulting in the following CCR ratio model (Charnes, *et al*., 1978, p. 430):

$$
\begin{aligned}
& Max\ h_0 \quad = \quad \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \\
& Subject\ to: \\
& \qquad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \\
& \qquad u_j, v_j \geq 0, \quad j = 1, 2, ..., n.
\end{aligned}
\qquad \text{(M3.3)}
$$

In the above fractional formulation, there are *n* DMUs being evaluated, each using *m* types of inputs or $(x_{ij},\ i = 1,2,\dots,m)$ to generate *s* types of outputs or $\left(y_{rj},\ r = 1,2,\dots,s\right)$. So DMU_j is said to consume x_{ij} units of input *i* to produce y_{rj} units of output *r*. All variables (x_{ij}, y_{rj}, v_i and u_r) are assumed to be non-negative or ≥ 0, and every DMU is assumed to have at least one input and one output which is strictly positive so that each will have finite efficiency score (Charnes, *et al.*, 1978; Banker, *et al.*, 1984; Cooper, *et al.*, 2004). The fact that this model was initially introduced in fractional form reflects its intrinsic concept of relative measurement in DEA.

To assess the efficiency of a unit, the ratio of the weights in the objective function is maximised subject to the “normalization constraint" that requires efficiency ratios for all DMUs in the data set to be at most 1 (Charnes, *et al*., 1978; Thanassoulis, 2001, p. 73; Cooper *et al.*, 2004, p. 9). An efficiency score for a DMU_j ranging between 0 and 1 and this is ascertained by the limit of ≤ 1 imposed by the first constraint and ≥ 0 value conditioned upon the weights in model (M3.3). A score of 1 indicates fully efficient and less than 1 indicates inefficient units.

Weights for inputs (v_i) and outputs (u_r) are computationally generated based solely on the observation set and they will be different for every solution[32]. Once the best set of weights for DMU_0 is found, the same set of weights is applied to assess relative performance of all the other universities in the sample. This constitutes a solution. In each solution, this process is repeated for every university (DMU_j) until a complete evaluation is made on the whole sample. Consequently, no other set of weights derived from the same data set would give a better rating or boost a university’s score such that if a university is identified as fully efficient using a particular set of weights it will also be rated as efficient using the other weight sets (Charnes, *et al*., 1978). In effect, such mechanism gives complete freedom to the universities being assessed to choose a set of weights that would boost their respective performance scores (Sarrico, *et al.*, 1997; Thanassoulis, 2001) at the expense of meaningful implementation strategies.

Note that variable λ_j (lambda) in CRS model (M3.1) is comparable to v_i and u_r in the CCR model (M3.3) to represent weights attached to input and output variables. This is

[32] The word “solution” is used to refer to a computation cycle of relative efficiency score made on one particular university (DMU_j) that will be repeated for every university in the sample

because, in formulating the linear programming (LP) for DEA models, variable λ_j is used to represent weights in the envelopment form while variables v_i and u_r are used to represent weights in its multiplier form. Technically, this is necessary as each corresponds to different piece of information that is useful for different explanations (Charnes, *et al*., 1978).

The CCR output maximization orientation can be formulated as (Charnes, *et al*., 1978, p. 431):

$$
\begin{aligned}
&Min\ f_0 \quad = \quad \frac{\sum_{i=1}^{m} v_i x_{i0}}{\sum_{r=1}^{s} u_r y_{r0}} \\
&Subject\ to: \\
&\qquad\qquad \frac{\sum_{i=1}^{m} v_i x_{ij}}{\sum_{r=1}^{s} u_r y_{rj}} \geq 1, \\
&\qquad\qquad u_j, v_j \geq 0, \quad j = 1, 2, ..., n.
\end{aligned}
\tag{M3.4}
$$

Furthermore, for the simplicity of computation and ease of empirical applications, Charnes, *et al.* (1978) formulated the fractional DEA models in the form of dual pair of LP using the Charnes-Cooper transformation[33]. In fact, the switch ability between ratio DEA and LP DEA is a significant arithmetical conversion concept that enables optimisations, interpretations and inferences to be made, based on the pre-established duality relationship (Banker, *et al.*, 1984). In practice, it is more convenient to solve CCR models in the form of LP formulation, particularly when analysing large samples

[33]That is fractional programming theory advocated by Charnes and Cooper (1962).

or having limited number of variables. In doing so, DEA models could be *efficiently* solved via any methods for solving LP problems, and take the advantage of duality theorem that permits solving either primal or dual forms to get solution as deemed convenient (Cooper, *et al.*, 2004, p. 10).

Accordingly, the linear formulation for input-minimisation DEA model is given by Cooper, *et al.* (2004, p. 10) as below:

$$\begin{aligned}
&Max\ z = \sum_{r=1}^{s} u_r y_{r0} \\
&Subject\ to: \\
&\qquad \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0; \quad j = 1, 2, ..., n, \\
&\qquad \sum_{i=1}^{m} v_i x_{i0} = 1, \\
&\qquad u_j, v_j \geq 0.
\end{aligned} \tag{M3.5}$$

On the other hand, the linear formulation for maximisation or output-oriented DEA model can be written as the following:

$$\begin{aligned}
&Min\ q = \sum_{i=1}^{m} v_i x_{i0} \\
&Subject\ to: \\
&\qquad \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} \geq 0; \quad j = 1, 2, ..., n \\
&\qquad \sum_{r=1}^{s} u_r y_{r0} = 1, \\
&\qquad u_j, v_j \geq 0.
\end{aligned} \tag{M3.6}$$

The summary of the models associated with CCR or CRS as initially introduced by Charnes, *et al.* (1978) for output maximization (Model M3.1) and its corresponding dual formulation (Model M3.6) are presented in the following Table 3.1.

Table 3.1: CCR Output Orientation Models (Constant Returns to Scale)

Envelopment Model	Multiplier Model
$$\begin{aligned} & Max \quad \phi \\ & Subject\ to: \\ & \sum_{j=1}^{n} x_{ij}\lambda_j \le X_{i0}; \quad i = 1, 2, ..., m, \\ & \sum_{j=1}^{n} y_{rj}\lambda_j \ge \theta Y_{r0}; \quad r = 1, 2, ..., s, \\ & \lambda_j \ge 0, \qquad \theta\ sign\ free. \end{aligned}$$	$$\begin{aligned} & Min\ q = \sum_{i=1}^{m} v_i x_{i0} \\ & Subject\ to: \\ & \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} \ge 0; \quad j = 1, 2, ..., n, \\ & \sum_{r=1}^{s} u_r y_{r0} = 1, \\ & u_j, v_j \ge 0. \end{aligned}$$

Source: *Cooper, Seiford & Zhu (2004, p. 12; slacks eliminated from the models)*

Similarly, the following Table 3.2 gives the primal (Model M3.2) and dual (Model M3.5) formulations for CCR input minimization model.

Table 3.2: CCR Input Orientation Models (Constant Returns to Scale)

Envelopment Model	Multiplier Model
$$\begin{aligned} & Min \quad \theta \\ & Subject\ to: \\ & \sum_{j=1}^{n} x_{ij}\lambda_j \le \theta X_{i0}; \quad i = 1, 2, ..., m, \\ & \sum_{j=1}^{n} y_{rj}\lambda_j \ge Y_{r0}; \quad r = 1, 2, ..., s, \\ & \lambda_j \ge 0, \qquad \theta\ sign\ free. \end{aligned}$$	$$\begin{aligned} & Max\ z = \sum_{r=1}^{s} u_r y_{r0} \\ & Subject\ to: \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0; \quad j = 1, 2, ..., n \\ & \sum_{i=1}^{m} v_i x_{i0} = 1, \\ & u_j, v_j \ge 0. \end{aligned}$$

Source: *Cooper, Seiford & Zhu (2004, p. 10)*

The CCR benchmarking models that have been discussed thus far assume Constant returns to scale. In other words, in measuring the efficiency of a university, its performance is compared against the observed performance of all the other universities in the same data set by assuming that each has a set of variables with full simultaneous proportional change relationship. That is, the efficiency of a university is unaffected by its operating scale (Banker, *et al.*, 1984, Thanassoulis 2001). As a result, the PPS given by the CCR model embodies the smallest set of the observed units as well as their scaled units, postulated by $T = \{(X, Y)\ and\ (kX, kY) | k > 0\}$. The concept of CRS will be revisited in Section 3.4.3.

Aside measuring technical efficiency, Charnes, *et al.* (1978) extended the CCR models to the analysis of managerial competencies. The idea can help to distinguish radial technical efficient and Pareto efficient units for those boundary units. However, managerial competencies as measured by the incorporation of slack variables into DEA models is beyond the scope of this thesis and the interested reader is referred to Charnes *et al.* (1978) as well as Cooper, *et al.* (2004) for further discussion.

3.4.2. The Banker, Charnes and Cooper (BCC) Models

In contrast to the CCR models that assume CRS technology, Banker, Charnes and Cooper (1984) initiated a DEA model that does not account for proportional relationship between variables but assumes that the efficiency of a unit is affected by its scale size. BCC models are alternatively called VRS models. Banker *et al.* (1984) introduced the convexity constraint $\left(\sum_{j=1}^{n} \lambda_j = 1\right)$ into the original CCR models. The added constraint effectively replaces postulation on the simultaneous change relationship between input-output variables. Such a modification provided two advantages. Firstly, it extended the implementability and flexibility of DEA by addressing the limitation associated with full proportional change relationship. Secondly, it helped to decompose technical efficiency scores into pure technical and scale efficiency scores, which could help in "opening the black box" of the performances of the observed DMUs.

Like the CCR, BCC employs customary axiomatic formulations to estimate efficient production technology and depict PPS. Since mix and scale inefficiencies are found in empirical data, discrimination of the types of prevailing returns to scale is made in the vicinity of one particular point along the EF. This is useful because for some units operating at different scale sizes, certain level of "average productivity at the most productive scale size (MPSS)" may not be producible (Banker, *et al.*, 1984, p. 1086). The notion of VRS is accomplished by relaxing *Ray Unboundness* postulate which state that: $If\ (X,Y)\ \epsilon\ T, then\ (kX,kY)\ \epsilon\ T$ for any k > 0 underpinning CCR model (Banker *et al.*, 1984), or could be expressed by

$$T_{BCC} = \left\{(X,Y)\middle|X \geq \Sigma_j\lambda_j X_j,\ Y \leq \Sigma_j\lambda_j Y_j,\ \lambda_j\ are\ scalars\ with\ \textstyle\sum_{j=1}^{n}\lambda_j = 1\right\}. \quad (3.5)$$

For that reason, interpolation of efficient scales of operation will solely be based on the observed DMUs while ignoring the scaled units (Thanassoulis, 2001). The advantage of this concept is, although comparator units may not be at its MPSS: a) comparator units of similar scale are generated based on frontier units which are located in vicinity to inefficient units; or b) comparator units consider individual units' respective level of operations (Thanassoulis, 2001). This also enables isolation of the PPS projected by BCC into segments of increasing, constant and decreasing returns to scale depending on operating scale sizes. Still, the BCC model employs relative efficiency theory based upon observed data with no need for strong underlying statistical assumptions (Banker, *et al.*, 1984). More information is thus derived from an empirical data set being analysed.

Similar to the CCR models, efficiency of universities under the VRS technology could be determined using either input orientation or output orientation. The linear BCC models are obtained by scaling the denominator of the fractional objective function equation in the multiplier framework equal to 1, (see for example Charnes, *et al.*, 1978; Banker, *et al.*, 1984). The formulations for BCC under input orientation and its corresponding dual formulation can be found on pages 1084 and 1085 of Banker, *et al.* (1984). The summary of the LP formulations for BCC models is given in Table 3.3.

Table 3.3: BCC Input Orientation Models (Variable Returns to Scale)

Envelopment Model	Multiplier Model
$Min \quad h_0$ $Subject\ to:$ $hx_{i0} - \sum_{j=1}^{n} x_{ij}\lambda_j \geq 0; \quad i = 1, 2, \ldots, m,$ $\sum_{j=1}^{n} y_{rj}\lambda_j \geq Y_{r0}; \quad r = 1, 2, \ldots, s,$ $\sum_{j=1}^{n} \lambda_j = 1,$ $\lambda_j \geq 0.$	$Max \quad \sum_{r=1}^{s} u_r y_{r0} - u_0$ $Subject\ to:$ $\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_0 \leq 0; \quad j = 1, 2, \ldots, n,$ $\sum_{i=1}^{m} v_i x_{i0} = 1,$ $u_j, v_j \geq 0, \quad u_0\ sign\ free.$

Source: Banker, Charnes & Cooper (1984, p. 1085)

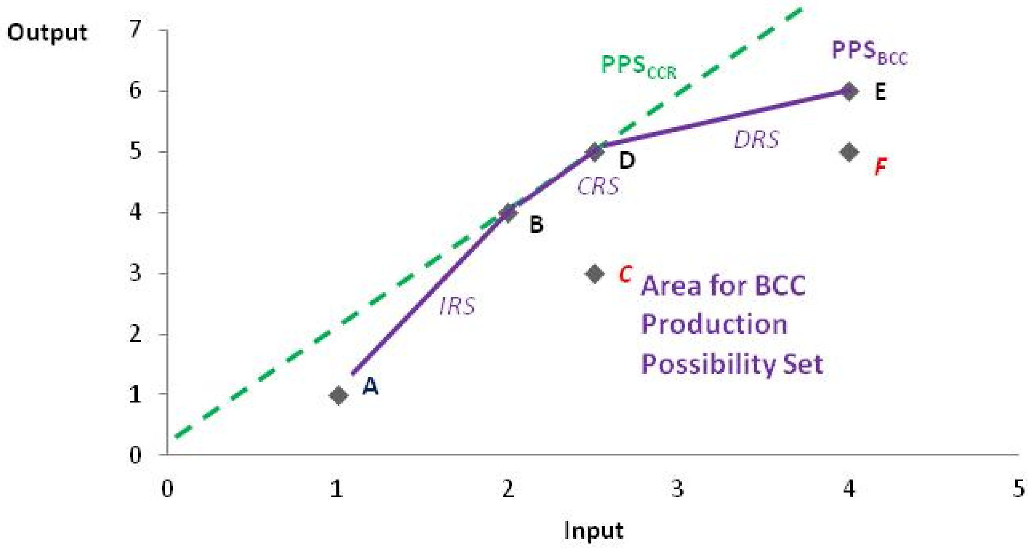
The additional convexity constraint in the envelopment framework is translated into additional variable u_0 in the multiplier framework. In principle, u_0 enables the verification of the types of prevailing scale of input-output transformations into increasing, constant or decreasing returns to scale (IRS, CRS or DRS)[34]. In other words, it gives rise to measurements of scale efficiency and returns to scale. Within the envelopment framework, BCC calculates *pure technical scores* at a given scale of operation because it reports the net of any scale effects. Since CCR reports a composite index of pure technical efficiency and scale efficiency scores, the influence of scale on a unit's performance can be calculated in terms of the discrepancy between CCR and BCC reported scores, or specifically: $\frac{CCR\ Technical\ Efficiency}{BCC\ Pure\ Technical\ Efficiency}$ (Banker, *et al*., 1984, p. 1089; Banker & Thrall, 1992, Thanassoulis, 2001, p. 140). Graphically, scale efficiency is actually the gap between projection points on the boundary of the PPS for CCR (or CRS) and BCC (or VRS) models.

In terms of the effect on PPS, the convexity constraint caused PPS to contract in size that results in the PPS constructed founded on BCC is smaller than that of CCR. Therefore, it can be concluded that VRS efficiencies will always be bigger if not equal to the efficiency scores given by CRS scale assumption. The difference between the PPS constructed by using the CCR and BCC models is illustrated in Figure 3.2 using a hypothetical set of data.

---

[34]Thanassoulis, 2001, p. 137: The value of variable $\boldsymbol{u_0}$ reflects the impact of scale size on the productivity of a DMU. If $\boldsymbol{u_0} = 0$ at an optimal solution to output-oriented multiplier VRS model, the model collapses to output-oriented envelopment VRS model. In such a case DMU_j lies on or is projected at a point on the Pareto-efficient boundary where locally CRS hold. If the optimal value of $\boldsymbol{u_0}$ is not 0 it may be positive or negative, its sign depending on the type of returns to scale holding locally where DMU_j lies on or is projected at a point on the Pareto-efficient boundary

Figure 3.2: Production Possibility Set for CCR and BCC Models



Production Possibility Set for CCR and BCC models with Decomposition of PPS for BCC into Increasing (IRS), Constant (CRS) and Decreasing (DRS) returns to scale

For a single-input single-output or multi-inputs multi-outputs case, respectively, for Pareto-efficient units, the PPS is at different regions. They are:

(a) ***IRS*** when an increase in output is greater than the increase in input or when a percentage of expansion (contraction) in inputs is smaller than the percentage of expansion (contraction) in outputs

(b) ***CRS*** when the increase in output and input is the same or when the percentage of expansion (contraction) in inputs and outputs is the same

(c) ***DRS*** when an increase in output is smaller than the increase in input or when a percentage of expansion (contraction) in inputs is bigger than the percentage of expansion (contraction) in outputs (Thanassoulis, 2001, p. 125).

Then again, Thanassoulis (2001, p. 124) gives the formal definition for decomposing a PPS into its segments as:

> A production correspondence is said to exhibit *increasing returns to scale* (IRS) if a radial increase in input levels (i.e. keeping input mix constant) leads under Pareto-efficiency to a more than proportionate radial increase in output levels; If the radial increase in output levels is less than proportionate we have *decreasing returns to scale* (DRS) and otherwise we have *constant returns to scale* (CRS).
>
> [Thanassoulis, E. (2001, p. 124)]

The following Table 3.4 provides the formulations for BCC under output orientation and its corresponding dual formulation.

Table 3.4: BCC Output Orientation Models (Variable Returns to Scale)

Envelopment Model	Multiplier Model
$Max \quad Z_0$ $Subject\ to:$ $\sum_{j=1}^{n} x_{ij}\lambda_j \le x_{i0}; \quad i=1,2,...,m,$ $Z_0 y_{r0} - \sum_{j=1}^{n} y_{rj}\lambda_j \le 0; \quad r=1,2,...,s,$ $\sum_{j=1}^{n} \lambda_j = 1,$ $\lambda_j \ge 0.$	$Min \quad \sum_{i=1}^{m} v_i x_{ij} - u_0$ $Subject\ to:$ $\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_0 \le 0; \quad j=1,2,...,n,$ $\sum_{r=1}^{s} u_r y_{rj} = 1,$ $u_j, v_j \ge 0, \quad u_0\ sign\ free.$

Source: Thanassoulis (2001, p. 138; edited)

In conclusion, the only difference between CCR and BCC models is the inclusion of the normalizing constraint $\left(\sum_{j=1}^{n} \lambda_j = 1\right)$ in the envelopment form, which corresponds to the presence of variable $\boldsymbol{u_0}$ in the multiplier form. Otherwise, their performance measurement concepts to estimate production function, determine weights, derive optimal performance level and identify benchmark units are all the same. Even so, this constraint contributes a great deal of information to performance analysis of a unit in comparison to the CRS technology. In addition to being able to distinguish the nature of prevailing scale segments along the EF, the VRS model enables the discovery of the MPSS for a particular university. Subsequently, the knowledge of prevailing scale operation could facilitate improvement of inefficiencies associated with not operating at the most productive scale of operation (Banker, 1984; Thanassoulis, 2001).

Last but not least, the choice of model orientation via VRS technology does impact the projection point on its PPS. As the result, unlike CRS, the scores of a unit evaluated via input orientation cannot be used to obtain equivalent scores for output orientation. Nevertheless, universities identified as efficient when employing input-oriented will also be regarded as efficient when employing output-oriented VRS or BCC model.

3.4.3. Extensions to Basic DEA Models

As aforementioned, the original DEA models under CRS and VRS technologies have been revised in order to fine-tune the properties for estimating the efficient frontier and to impose weight restrictions on the multiplier values. For detailed discussions on the theoretical developments of DEA see the collective works of Cook and Seiford (2009), Thanassoulis, *et al.* (2008), Thanassoulis (2001) and Cooper, *et al.* (2004). Cooper, *et al.* (2004) summarises the theoretical extensions this way:

> At present, DEA actually encompasses a variety of alternate (but related) approaches to evaluating performance. Extensions to the original CCR work have resulted in a deeper analysis of both the “multiplier side” from the dual model and the “envelopment side” from the primal model of the mathematical duality structure. Properties such as isotonicity, nonconcavity, economies of scale, piecewise linearity Cobb-Douglas loglinear forms, discretionary and nondiscretionary inputs, categorical variables, and ordinal relationships can also be

> treated through DEA. Actually, the concept of a frontier is more general than the concept of a "production function" which has been regarded as fundamental in economics in that the frontier concept with the frontier boundaries consisting of "supports" which are "tangential" to the more efficient members of the set of such frontiers.
>
> [Cooper, W.W., Seiford, L.M. and Zhu, J. (2004, p. 8)]

Cook and Seiford (2009) examined the methodological developments of DEA over 30 years since the first CCR model (1978). Their review dwelled on four dimensions of theoretical modifications to the original CCR and BCC models:

(a) Efficiency measurement models

(b) Multipliers restriction approaches

(c) Adjustments to variables status and

(d) Modelling data variation.

The first dimension pertains to studies on RTS or those that revise the properties for estimating the EF. Cook and Seiford (2009) remarked that efficiency measurement models than have been developed from the basic DEA models could be ascribed to single level and multi levels models. Single level DEA models include (i) non-radial projection models such as the additive or Pareto-Koopmans model (Charnes, Cooper, Golany, Seiford & Stutz, 1985b), Slacks-based measures (SBM; Tone, 2001), Russell measure model (Fare & Lovell, 1978; Fare, Lovell & Zieschang, 1983) and Range Adjusted measure (RAM; Cooper, Park & Pastor, 1999); (ii) models based on alternative views such as the Free Disposal Hull (FDH; Deprins, Simar & Tulkens, 1984) and Cross Efficiency models (Sexton, Silkman & Hogan, 1986); (iii) least distance projection models such as using Euclidean norm (Frei & Harker, 1999) and minimum city block distance (Charnes, Haag, Jaska & Semple, 1992); and (iv) models involving data alterations either with properties of units invariance or translation invariance (Lovell & Pastor, 1995).

On the other hand, multi levels DEA models consist of (i) multistage or serial models - including Network DEA (Fare & Grosskopf, 1996) and supply chains (Seiford & Zhu, 1999; Chen & Zhu, 2004); (ii) multi-component or parallel models (Cook, Hababou & Tuenter, 2000); and (iii) hierarchical or nested models (Cook, Chai, Doyle & Green, 1998; Cook & Green, 2005). Besides, there are models for testing types of RTS (Cooper, Thompson & Thrall, 1996; Podinovski, 2004a). In addition to the above mentioned models are MPSS (Banker, 1984) and multiplicative (Charnes, Cooper, Seiford & Stutz, 1982) models. Despite the variety of technicalities employed and properties assumed, each model is associated with postulating the unknown production frontier that envelopes observed data and affects the discriminatory power of DEA assessments.

The additive models can be regarded as having a mixed orientation of CRS and VRS models that generate a quadrant within which any projections onto the frontier are feasible but the construct, instead, aims at maximising the distance to the EF (Cook & Seiford, 2009). It "simultaneously maximizes outputs and minimizes inputs, in the sense of a vector optimization" (Banker, Cooper, Seiford, Thrall & Zhu, 2004, p. 355). It is therefore a non-radial efficiency measure. The basic additive model in (M3.7) optimises the sum of slacks using the same constraint space as the VRS model (Cook & Seiford, 2009, p. 5).

$$P_0 = \max \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+$$

$$\begin{aligned}
&\textit{Subject to}: \\
&\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{i0}, \quad i = 1,...,m \\
&\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{r0}, \quad r = 1,...,s \\
&\sum_{j=1}^{n} \lambda_j = 1, \\
&\lambda_j, s_i^-, s_r^+ \geq 0, \quad \forall j, i, r.
\end{aligned} \tag{M3.7}$$

However, Russell (1988) criticised the optimisation of the slack variables in model (M3.7) as being impractical due to non-commensurate measurement units of input and output variables. Charnes, *et al*. (1985) also added that it did not allow for proper measurement of inefficiency consistently with the underlying concepts of CCR and BCC models. A number of adjustments and extensions have been proposed to the basic additive model, particularly modifications to the definition of its objective function equation. Consequently, several types of additive models have been created including conception of new models, namely Slacks-based Measures (SBM) which is basically “dimension free” and “unit invariant”, has been made. See for examples Tone (2001, 2003).

The second dimension of DEA methodological developments examined by Cook and Seiford (2009) is the multiplier restrictions. Since Charnes, Cooper, Huang and Sun (1990) discovered many DEA empirical applications had *naturally* resulted in disagreeable weighting schemes, Cook and Seiford (2009) next focused their DEA review on the previous studies focusing on overcoming problems pertaining to restricting multiplier weights generated by DEA, directly and indirectly. To resolve the issue related to weights, authors have theorised Absolute Multiplier restrictions (Roll, Cook & Golany, 1991), Cone Ratio restrictions (Charnes, *et al.*, 1990), Assurance Region restrictions (Thompson, Singleton, Thrall & Smith, 1986; Thompson, Langemeir, Lee, Lee & Thrall, 1990), Facet models (Bessent, Bessent, Elam & Clark, 1988) as well as Unobserved DMUs (Thanassoulis & Allen, 1998). In fact, the first three models restrict DEA weights flexibility by introducing additional constraints and hence cause a decrease in the efficiency score of a unit (Cook & Seiford, 2009). Assurance Region restrictions developed by Thompson, *et al.* (1986, 1990) is a special case of Cone Ratio, and has captured major attention of scholars to expand its concept of imposing weight restriction via constraining range of values for DEA multipliers (Cook & Seiford, 2009).

Non-discretionary variables (Banker & Morey, 1986a), non-controllable variables, categorical variables/DMUs (Banker & Morey, 1986b), ordinal variables/data (Cook & Seiford, 2009), modelling undesirable factors, and classification of inputs-outputs are among the conceptual issues related to adjustments of variables employed in DEA assessments that have been examined by numerous authors worldwide (Cook & Seiford, 2009). With regards to modelling variation and uncertainty in observational data, as opposed to assumption of fixed and known data values, studies found in DEA literature could be attributed to Sensitivity analysis; including Super-efficiency model to rank DEA efficient units (Anderson & Petersen, 1993), Data uncertainty and probability-based models (Thore, 1987), Time series data via Window analysis (Charnes, Clarke, Cooper & Golany, 1985a), Time series data via the Malmquist Index (Fare, Grosskopf and Lovell, 1994), and also statistical inference on stochastic data (Banker &

Maindiratta, 1992; Banker 1993). The above listed issues related to DEA modelling and applications are not exhaustive. They are rather issues commonly addressed in current DEA literature.

Despite the many extensions of the original DEA models, the next focus of the discussion is on those proposals that deal with RTS and incorporation of value judgments. Regarding value judgments, attention is given to the group of scholars that aim at imposing weight restrictions instead of modifying observational data in DEA formulations (Thanassoulis, Portela & Allen, 2004). In fact, the subsequent focus provides background for the technical framework for the methodological tools employed to conduct empirical analysis for current research.

Hybrid returns to scale (HRS) is the chosen model for capturing the relationship among the assessment variables. Trade-off is the adopted approach as a means to incorporate preferences via weight restrictions. The key contribution of this thesis is the proposal of integration of HRS and Trade-off as a means to provide better insight into a unit's performance which subsequently refines definition of benchmark performance. The proposed model incorporates additional relevant and necessary information about the transformation activities by the universities under investigation. A by-product of the proposed method is that it helps to improve the discriminatory power of DEA analysis, particularly in the presence of the small population of Malaysian public universities.

3.4.3.1. Returns to Scale and Hybrid Returns to Scale

RTS is about studying what will be the consequences of changes in inputs (or outputs) on the changes in outputs (or inputs). Presuming CRS postulates an increase in inputs will lead to the increase in outputs while a decrease in inputs will lead to the decrease in outputs, proportionally. Presuming VRS postulates an increase or a decrease in inputs may cause the outputs to increase or decrease or stagnate. Given the uncertain consequences of an input change, such information is treated as irrelevant by VRS.

Further, examinations of RTS provide justification for technically efficient units to improve their efficiency by changing current operating scale size (Podinovski, 2004c). For instance, a technically efficient unit that demonstrates IRS is scale inefficient and thus should take the advantage of the prevailing local scale by increasing its production to the point it reaches its MPSS where CRS prevails. In contrast, a technically efficient unit that demonstrates DRS is also scale inefficient therefore should take the advantage of the prevailing local scale by decreasing its production to the point it reaches its MPSS (Thanassoulis, 2001; Podinovski, 2004c). This is because, at a boundary point exhibiting IRS, a small percentage increase in input levels will lead to an even larger percentage increase in output levels whilst the unit assumed to remain Pareto-efficient (Thanassoulis, 2001). The opposite is true for DRS. For that reason, RTS is implicitly confined to the technical aspects of efficiency which render information on price and cost are not necessary in RTS analysis (Banker, *et al*., 2004). Also, analysis of RTS is affected by the choice of input or output orientation because RTS pertains to a particular projection point on the frontier (Banker, *et al*., 2004).

Knowledge of the prevailing types of RTS is useful for efficient universities, for activity planning and resource allocation purposes since it dictates optimal strategies to take advantage of the current scale operation. For inefficient universities, RTS is a valuable concept for identifying the “direction of marginal rescaling” to pursue in order to become a fully productive unit (Podinovski**,** 2002, p. 1). The many DEA extended models to treat RTS could be attributed as originating from two basic concepts, either as advocated by Fare, Grosskopf and Lovell (FGL; 1985, 1994) or lead by Banker (1984). However, greater attention is found in the DEA literature accounts for RTS as advanced by Banker (1984). Further, models associated with treating RTS can be categorized as qualitative and quantitative models. Qualitative models determine RTS by ascribing a projection point as belonging to increasing, constant or decreasing returns to scale based on certain model-specific conditions (Banker, *et al*. 2004). Conversely, quantitative models calculate numerical values in the form of scale elasticity of the prevailing RTS to determine its type (Banker, *et al*. 2004).

In practice, the application of DEA is often initiated by first deciding on how to describe the disposition of relationship between the assessment variables. There is not one best model yet the assumption made on the change relationship between inputs and outputs helps determine the *right* type of DEA model to employ for a particular analysis. Generic DEA models have two production technologies that deal with the relationship among inputs and outputs. CRS assumes total proportional relationship between all variables while VRS ignores existence of proportional relationship between any variables. The former assumes that every scalar change in an input or output will result in uniform scalar changes in the values of the remaining inputs and outputs. As the results, the PPS is expanded to consist of both the observed and the resulting scaled units (Podinovski, 2004a). This is rather a stringent relationship. The latter draws on the *convexity* and *free disposability* axioms by Banker *et al*. (1984) to model the relationship between variables and are less desirable as some valuable information will be forgone which sometimes may be useful for certain reasons.

In reality, it is very rare to find a group of input-output variables that change in respond to any changes in each of them. To improve the flexibility and practicality of DEA, the first modification to CRS was proposed by Banker *et al*. (1984) by introducing a convexity constraint into CRS, called VRS model. This additional constraint replaces the assumption made on the proportionality relationship between variables that is now treated as insignificant information for evaluating a unit's efficiency. For the current research, a novel model of Hybrid returns to scale is adopted. HRS that is initiated by Podinovski (2004a) advocates *selective proportionality* relationship between variables and can be regarded as the mediator between CRS and VRS models. For the same data set, input and output variables are sub-categorized into Proportional and Non-proportional variables. Proportional Inputs (I^P) and Proportional Outputs (O^P) consist of the variables with proportional change relationship; that is, they have direct or expressive influence on each other. Non-proportional Inputs (I^{NP}) and Non-proportional Outputs (O^{NP}) consist of the variables without proportional relationship. Absence of influence or presence of influence is known, yet, the proportional relationship is explicitly indefinable or impassive.

By adopting selective proportionality assumption, the properties underpinning the PPS defined for CRS and VRS by Banker *et al.* (1984), and Banker and Thrall (1992) need to be revised. The definition for selective proportionality and the properties underpinning HRS technology as given by Podinovski (2004a, p. 267-268) is reproduced below:

Input set is given by *I* consists of proportional and non-proportional inputs

$$I = I^P \cup I^{NP}. \quad (3.6)$$

Output set is given by *O* consists of proportional and non-proportional outputs

$$O = O^P \cup O^{NP}. \quad (3.7)$$

Selective proportionality in the Expansion scenario ($\boldsymbol{\alpha > 1}$)

The inputs from the set I^P and outputs from the set O^P are simultaneously multiplied by α while the remaining inputs and outputs left unchanged. The resulting $DMU\ (X^\alpha, Y^\alpha)$ is defined as follows

$$X_i^\alpha = \begin{cases} \alpha X_i \ if \ i \in I^P \\ X_i \ if \ i \in I^{NP} \end{cases} \quad (3.8)$$

$$Y_r^\alpha = \begin{cases} \alpha Y_r \ if \ r \in I^P \\ Y_r \ if \ r \in I^{NP} \end{cases}$$

For any expansion factor $\alpha > 1$, the $DMU\ (X^\alpha, Y^\alpha)$ defined for (3.8) should be deemed feasible

Selective proportionality in the Contraction scenario ($\boldsymbol{0 \leq \alpha < 1}$)

The inputs from the set I^P and outputs from the set O^P are simultaneously multiplied by α while the remaining outputs from the set O^{NP} will also have to be reduced, the exact extent is not known but the lowest producible unit is 0. The resulting $DMU\ (X^\alpha, Y^\alpha)$ is defined as follows

$$X_i^\alpha = \begin{cases} \alpha X_i \ if \ i \in I^P \\ X_i \ if \ i \in I^{NP} \end{cases} \quad (3.9)$$

$$Y_r^{\alpha} = \begin{cases} \alpha Y_r \; if \; r \in I^P \\ 0 \; \; if \; r \in I^{NP} \end{cases}$$

For any contraction factor $(0 \leq \alpha < 1)$, the DMU (X^{α}, Y^{α}) defined for (3.9) should be deemed feasible

Accordingly, the axiomatic foundations for the HRS technology are:

Axiom 1: Feasibility of Observed Data

The unit $\left(X_j, Y_j\right) \epsilon \, T_{HRS} \; for \; any \; j \; \epsilon \; J$.

Axiom 2: Convexity

The set T_{HRS} is convex.

Axiom 3: Free Disposability

If $(X, Y) \, \epsilon \, T_{HRS}, \; Y \geq Y' \geq 0 \; and \; X \leq X' \; implies \; (X', Y') \, \epsilon \, T_{HRS}$.

Axiom 4: Selective proportionality

Let $(X, Y) \, \epsilon \, T_{HRS}$, for any

a) $\alpha > 1$: define unit (X^{α}, Y^{α}) as in (3.8)

b) $0 \leq \alpha < 1$: define unit (X^{α}, Y^{α}) as in (3.9)

⇨ Then $(X^{\alpha}, Y^{\alpha}) \, \epsilon \, T_{HRS}$.

Axiom 5: Closedness

The set T_{HRS} is closed or contains all its limit points.

Axiom 6: Minimum Extrapolation

The T_{HRS} is the minimal set that satisfies Axiom 1 until Axiom 5 or T_{HRS} is the intersection of all sets that satisfies all Axioms 1 until 6.

In mathematical representation, the HRS model in envelopment form for input contraction and output augmentation scenarios as proposed by Podinovski (2004a, p. 270) are presented in Table 3.5 next.

Table 3.5: Output and Input Orientation Models (Hybrid Returns to Scale)

Output Orientation	Input Minimization
$Max \quad \theta$	$Min \quad \theta$
$Subject\ to:$	$Subject\ to:$
$\sum_{j=1}^{n} \bar{x}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{x}_{ij}\mu_j - \sum_{j=1}^{n} \hat{x}_{ij}\nu_j \leq x_{i0},$	$\sum_{j=1}^{n} \bar{x}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{x}_{ij}\mu_j - \sum_{j=1}^{n} \hat{x}_{ij}\nu_j \leq \theta x_{i0},$
$\sum_{j=1}^{n} \bar{y}_{rj}\lambda_j + \sum_{j=1}^{n} \hat{y}_{rj}\mu_j - \sum_{j=1}^{n} \bar{y}_{rj}\nu_j \geq \theta y_{r0},$	$\sum_{j=1}^{n} \bar{y}_{rj}\lambda_j + \sum_{j=1}^{n} \hat{y}_{rj}\mu_j - \sum_{j=1}^{n} \bar{y}_{rj}\nu_j \geq y_{r0},$
$\sum_{j=1}^{n} \lambda_j = 1,$	$\sum_{j=1}^{n} \lambda_j = 1,$
$\lambda_j \geq \nu_j, \quad for\ all\ j \in J,$	$\lambda_j \geq \nu_j, \quad for\ all\ j \in J,$
$\lambda, \mu, \nu, \pi \geq 0, \quad i = 1, 2, \ldots m, \quad r = 1, 2, \ldots, s,$	$\lambda, \mu, \nu, \pi \geq 0, \quad i = 1, 2, \ldots m, \quad r = 1, 2, \ldots, s,$
$\theta\ sign\ free.$	$\theta\ sign\ free.$

Source: Edited from Podinovski (2004a, p. 270; edited)

Evaluating performance under HRS technology is indeed very similar to applying CRS and VRS assessments under both input and output orientations. Even the resulting radial projections generated by HRS may not be Pareto-efficient and may require second stage optimisation using slack variables, as in the case of the latter. The only difference is that HRS recognizes two types of variable relationships (proportional and non-proportional) that coexist within a sample in its evaluation. These constitute additional terms that modify the definition of composite units in both input and output constraints.

Specifically, $\sum_{j=1}^{n} \bar{x}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{x}_{ij}\mu_j - \sum_{j=1}^{n} \hat{x}_{ij}v_j$ replaces $\sum_{j=1}^{n} x_{ij}\lambda_j$ for inputs while $\sum_{j=1}^{n} \bar{y}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{y}_{ij}\mu_j - \sum_{j=1}^{n} \bar{y}_{ij}v_j$ replaces $\sum_{j=1}^{n} y_{ij}\lambda_j$ for outputs in VRS formulation. Both of the modifying terms define selective proportionality relationship according to the foregoing *Axiom 4* and are illustrated in greater detail in discussion on the proposed DEA framework in section 3.5.2. Therefore, in the HRS formulation, instead of having only matrices of X and Y to represent inputs and outputs, there are separate variables to represent matrices of *all observed inputs*$(\bar{X})$ and *all observed outputs*$(\bar{Y})$ as well as matrices of *proportional inputs*$(\hat{X})$ and *proportional outputs*$(\hat{Y})$. Individual inputs ($i = 1,2,...,m$) of the matrix $\bar{X}$ are denoted by $\bar{x}_{ij}$ and individual outputs ($r = 1,2,...,s$) of the matrix $\bar{Y}$ are denoted by $\bar{y}_{rj}$. Similarly, individual inputs ($i = 1,2,...,m$) of the matrix $\hat{X}$ are denoted by $\hat{x}_{ij}$ and individual outputs ($r = 1,2,...,s$) of the matrix $\hat{Y}$ are denoted by $\hat{y}_{rj}$. Variables attached to those inputs and outputs represent the associated weights for each which are assumed to be nonnegative or ≥ 0. Additional to constraints within VRS formulation is that λ_j must be bigger if not equal to v_j that is $\lambda_j \geq v_j$. Otherwise, HRS uses common notations as in the other DEA models, or VRS in particular.

In fact, HRS models are very flexible in terms of modelling relationship between assessment variables. They could easily be modified to conduct DEA assessments when the relationship between input and output variables has full proportionality (by defining input set $I = I^{P}$) or has no proportionality (by defining input set I^{P} to be empty set). While the former is consistent with employing the CRS technology, the latter is consistent with employing the VRS technology, wherein both are treated as special cases in the HRS technology (Podinovski 2004a, p. 268). More importantly, this ensures that any additional variables (proportional or non-proportional) are then easily and conveniently added without dilemma on the validity of the framework on RTS that was initially opted at the formulation stage (Podinovski, 2004a).

In addition to the methodological advantage of making a more accurate account of the underlying technology for PPS, employing HRS technology is seen as a natural alternative technique to impose weight restrictions for an improved DEA discrimination. Discrimination of a DEA evaluation is increased despite having small samples. This is because HRS explicitly imposes a restriction on the behaviour of the variables that there should be some synchronised proportional changes between subsets of them. Consequently, HRS gives a more stringent evaluation than VRS and a comparable evaluation to CRS models. Moreover, as put forward by Podinovski (2004a), by integrating the *true* behaviour of input-output variables, the resulting PPS is able to reflect the actual underlying technology for a particular data set more accurately. Therefore, the efficiency assessment in effect is neither too overoptimistic nor too pessimistic.

For the present study, HRS technology is adopted in light of its ability to give a more realistic and accurate depiction of reality. This is possible since both types of prevailing relationship are being recognised, either proportional or non-proportional, between input-output variables. Hence, there is no need for compromise between the advantages of using CRS or VRS for a given data set to have an implementable, yet accurate and reasonable model of reality.

3.4.3.2. Weight Restrictions and Trade-Off Approach

Freedom of choosing weight profile among DMUs by DEA models is seen as advantageous as it permits every unit to reflect its individual strength and weaknesses or even priorities in operation. But according to Podinovski and Thanassoulis (2007), such a mechanism sometimes generates unrealistic optimal weight profile because optimal weights reflect shadow prices or marginal rates of substitution (MRS). To buttress this point, any input or output can be assigned a zero value thereby creating imbalance pairs of transformation activities, indicating for instance, that, an input is not required to produce the outputs or an input can choose to produce nothing, which, in practice, will be unacceptable to management.

Analogous to imposing weight restrictions into DEA analysis is increasing the discriminatory power of DEA assessment. By definition, lack of discrimination is when DEA awards many DMUs with “maximum or near maximum efficiency scores” (Podinovski & Thanassoulis, 2007, p. 118). This could be correct if there exist consistency of performance among them but incorrect if it is caused either by false identification of Pareto-Efficient units or overestimation of their performance as compared to the actually observed performance (Podinovski & Thanassoulis, 2007). Therefore, another motivation for scholars to impose weight restrictions is to curtail the possibility of such efficiency overestimation by improving the discriminatory power of DEA assessments.

There are few studies that explain the lack of discrimination in DEA analysis related to the presence of possible curse of dimensionality, an example of which was suggested by Podinovski and Thanassoulis (2007, p. 118). The first relates to the presence of few

DMUs in comparison to the number of necessary variables to adequately characterise DMUs' activities. That is, DEA is less discriminating when too many variables are used to evaluate small samples of DMUs. The second point relates to the presence of outliers. That is, DEA is less discriminating in the presence of outliers despite having "adequate" or many DMUs in comparison to the number of necessary variables to characterize DMUs' activities. Further, there are two possible conditions for the second explanation; when using radial measures of efficiency and employing VRS technology. For the former, radial measures of efficiency weigh performance of every DMU, even those few with significantly different mix, against each other with similar production mix, thus the extreme performance (could be good or poor) is not reflected in the resulting scores (Podinovski & Thanassoulis, 2007). For the latter, VRS technology makes evaluation based on the local scale of operation that every DMU, even those few with significantly different scale size, is compared against each other in close proximity or with identical production scale, thus the extreme scale size (could be good or poor) is not reflected in the resulting scores (Podinovski & Thanassoulis, 2007).

In the literature, DEA modifications that impose weight restrictions or improve the discriminatory power of DEA analysis range from simple techniques to the more advanced statistical approaches. The simple techniques include approaches that (a) increase the number of DMUs in small sample by pooling longitudinal data into single cross-section data, and (b) decrease the number of variables via either aggregation or elimination of less important, identical or overlapping variables (Podinovski & Thanassoulis, 2007, p. 119). The advanced models to increase the discrimination in DEA analysis are ascribed by Podinovski and Thanassoulis (2007) into approaches that

(a) derive additional measures based on standard technology, and (b) integrate supplementary information about production process being modelled. Production trade-offs, unobserved DMUs (UDMUs) and HRS are among the many models that could add more information to characterise the transformation activities of DMUs as a means of imposing weight restrictions and enhancing the discrimination of DEA assessments.

The present study imposes weight restrictions in order to explicitly define the relationship between the assessment variables, to increase the accuracy of DEA evaluation and to incorporate the preferences of educational regulator, namely Ministry of Higher Education (MOHE) as well as the concerns of the University managements. To achieve this, a newly introduced Trade-off approach by Podinovski (2004b) is employed. The trade-off approach can be considered as a special case of incorporating preferences in the form of weight restrictions that could generate DEA efficiency scores that are agreeable to management.

Podinovski (2004b) extended Banker's (1984) axioms of production technology by developing Trade-off approach as a means of imposing weight restrictions. The motivation was to improve the discrimination of DEA analysis whilst maintaining the concept of technical efficiency and feasibility within DEA. The approach explicitly refines the weights chosen by DMUs, and simultaneously generates technologically realistic radial efficiency measures and producible radial improvement targets (Podinovski, 2004b). Note that Trade-off approach is perfectly flexible for measuring performance under both CRS and VRS assumptions using either input or output orientation (Podinovski, 2004b).

For easy reference, listed are the axiomatic properties for employing the Trade-off approach within CRS technology (Podinovski, 2004b, p. 1314):

Axiom 1: Feasibility of Observed Data

The unit $(X_j, Y_j) \epsilon\, T\ for\ any\ j\ \epsilon\, J$.

Axiom 2: Convexity

The set T is convex.

Axiom 3: Free Disposability

If $(X, Y)\ \epsilon\ T,\ Y \geq Y' \geq 0\ and\ X \leq X'\ implies\ (X', Y')\ \epsilon\ T$.

Axiom 4: Feasibility of Trade-offs

Let $(X, Y)\ \epsilon\ T$, then for any trade-off t in the form of $(P_t,\ Q_t)$ and any $\pi_t \geq 0$, the unit $(X + \pi_t P_t,\ Y + \pi_t Q_t)\ \epsilon\ T$, provided that $(X + \pi_t P_t \geq 0)$ and $(Y + \pi_t Q_t \geq 0)$.

Axiom 5: Proportionality

$(X, Y)\ \epsilon\ T$ and $\alpha \geq 0$ implies $(\alpha X, \alpha Y)\ \epsilon\ T$.

Axiom 6: Closedness

The set T is closed.

The above revision in the properties for constructing the PPS for CRS technology incorporates trade-offs restrictions, and can be mathematically seen in the following algebraic expression of CRS (Table 3.6).

Table 3.6: DEA with Trade-off (Constant Returns to Scale)

Output-oriented Envelopment	Output-oriented Multiplier
$Max \quad \theta$ $Subject\ to:$ $\sum_{j=1}^{n} x_{ij}\lambda_j + \sum_{t=1}^{K} \pi_t P_t \le x_{i0}, \quad i = 1,2,\ldots,m,$ $\sum_{j=1}^{n} y_{rj}\lambda_j + \sum_{t=1}^{K} \pi_t Q_t \ge \theta y_{r0}, \quad r = 1,2,\ldots,s$ $\lambda, \pi \ge 0, \qquad \theta\ sign\ free.$	$Min \quad \sum_{i=1}^{m} v_i x_{i0}$ $Subject\ To:$ $\sum_{r=1}^{s} u_r y_{r0} = 1,$ $\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1,2,\ldots,n,$ $\sum_{r=1}^{s} u_r Q_t - \sum_{i=1}^{m} v_i P_t \le 0, \quad t = 1,2,\ldots,K,$ $u, v \ge 0.$

Input-oriented Envelopment	Input-oriented Multiplier
$Min \quad \theta$ $Subject\ to:$ $\sum_{j=1}^{n} x_{ij}\lambda_j + \sum_{t=1}^{K} \pi_t P_t \le \theta x_{i0}, \quad i = 1,2,\ldots,m,$ $\sum_{j=1}^{n} y_{rj}\lambda_j + \sum_{t=1}^{K} \pi_t Q_t \ge y_{r0}, \quad r = 1,2,\ldots,s,$ $\lambda, \pi \ge 0, \qquad \theta\ sign\ free.$	$Max \quad \sum_{r=1}^{s} u_r y_{r0}$ $Subject\ to:$ $\sum_{i=1}^{m} v_i x_{i0} = 1,$ $\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1,2,\ldots,n,$ $\sum_{r=1}^{s} u_r Q_t - \sum_{i=1}^{m} v_i P_t \le 0, \quad t = 1,2,\ldots,K,$ $u, v \ge 0.$

Source: *Podinovski (2004b, p. 1315; edited)*

The objective function equation of the envelopment form gives technologically realistic radial input contraction or output expansion factor. Both $\sum_{j=1}^{n} x_{ij}\lambda_j$ and $\sum_{j=1}^{n} y_{rj}\lambda_j$ on the left side correspond to all of the composite units being evaluated and present within the CRS formulation. They are now being modified by production trade-offs, $(\sum_{t=1}^{K} \pi_t P_t)$ and $(\sum_{t=1}^{K} \pi_t Q_t)$ for inputs and outputs, respectively. It is assumed that there are K judgements denoting trade-offs altogether and each is given a weight of π_t, while P_t and Q_t are user-specified constant vectors. In the multiplier form, the trade-offs are integrated as additional constraints to the customary CRS formulation. They are written in the form of $u^T Q_t - v^t P_t \leq 0$.

On the contrary, existing approaches have been based on value judgements and monetary considerations to impose weight restrictions into the multiplier DEA models which, unfortunately, do not consider the efficiency scores to be technologically improvement factors (Podinovski, 2004b, 2007). Value judgements impose weight restrictions by incorporating managerial perceived importance of inputs and outputs in the form of weights. Monetary considerations award weights according to the costs of inputs and prices of outputs as a way to impose weight restrictions (Podinovski, 2004b). Consequently, although the value judgement approach helps to improve discrimination of DEA analysis, but the resulting efficiency measures and improvement targets can no longer be interpreted as realistic improvement factor and though desirable, sometimes, are not producible.

The point worth emphasising is that technology thinking is necessary in the construction of weight restrictions as recommended by the Trade-off approach. In fact, the actual difference between this approach and the other approaches is not in the mathematical expressions but the underlying thinking paradigm. This has to be based on “technology thinking” instead of “value thinking” as phrased by Podinovski (2004b, p. 1316). In other words, in specifying the compromising values, the former requires specification of production trade-offs grounded solely on technology judgments rather than managerial perception of importance (Podinovski, 2007). Therefore, when specifying weights, delineation of synchronised change relationships must always contain technological information to ensure that they are producible in the real production process. As an example, the statement "*a Masters student requires at least twice as much lecturer's time as an Undergraduate student*" is a production trade-off but "*Masters student is at least twice as important as Undergraduate student*" is a managerial judgement.

The Trade-off approach further guarantees consistency with production realities by requiring direct translation of production trade-offs specified in technology thinking paradigm (envelopment framework) into their equivalent weight restrictions in value thinking paradigm (multiplier framework). Such direct translation makes it possible to preserve the technological gist of the resulting efficiency measures and improvement targets, despite making assessment via multiplier formulation or from value thinking point of view. In fact, weight restrictions constructed by the Trade-off approach is guaranteed to give technologically realistic efficiency measures. This is founded on *the fundamental theorem of weight restrictions* (Podinovski, 2004b, p. 1318-1319).

In comparison to value judgements, Trade-off approach also has a technical merit of the flexibility to choose either making assessment via envelopment or multiplier formulations as preferred while guaranteeing the same efficiency scores. This is indeed advantageous and useful given that it is not so when employing customary value judgements techniques (Podinovski, 2004a). Trade-off approach entails realistic expected changes. Note that the Trade-off values are different from the MRS. This is because the former does not correspond to an absolute proportional change between inputs and outputs along the EF as it is for the latter. Trade-off values are rather a range of undemanding expected changes which are applicable to all units within the currently observed technology or the PPS (Podinovski, 2004b).

Moreover, the Trade-off approach explicitly moderates or refines the contextual factor that affects the transformation of inputs into outputs at individual DMU level according to decision makers' preferences. Production trade-offs are derived from an observed practice or expected performance levels. They need to be realistic and acceptable by the affected units under the assessment only. Hence, they are undemanding, yet, technologically possible. Trade-offs are commonly enumerated in pairs denoting range of possible changes, as opposed to exact change, analogous to the increase and decrease in variable amount scenarios between pairs of input or/and output variables. Therefore, they effectively replicate the uncertainty in the actual substitution rates.

Trade-offs is defined for every unit change in a particular variable on the remaining variables; say having an increase in one STAFF lead to technologically feasible increase of 5 Undergraduate student enrolments. In order to get the overall effect of a change in the variable, the full impact is determined by compounding the pre-determined trading figure with the change amount i.e. 3 STAFF increase should lead to technologically feasible increase of 15 Undergraduate enrolments. The resulting composite units are also producible since they are "created" by the postulation process that satisfies the fundamental properties of the CRS or VRS technology, as selected (Podinovski, 2004a). In fact, this mechanism will also result in a meaningful expansion of the PPS as it modifies the PPS based on some producible and achievable improvement targets. The revised PPS generates technologically realistic radial efficiency measures and producible radial improvement targets (Podinovski, 2004b).

Effectively, Trade-off approach can also be extended to any *non-homogenous* weight restrictions such as weight bounds. The approach is a valuable alternative technique for those who prefer the concept of absolute weight restrictions while concerned with sustaining the technological gist of efficiency (Podinovski, 2004b). This is accomplished by applying the suggested translation formulae (Podinovski, 2004b, p. 1317-1318) to transform the required restrictions in the form of absolute weight bounds into weight restrictions equations to conform to the Trade-off approach. The resulting ratio is technologically sensible and it is not the same as the fixed ratio of the required changes as specified by absolute numerical values (Podinovski, 2004b).

Interestingly, duality theory guarantees that imposing weight restrictions in the form of weight bounds by means of Trade-off will not lead to infeasibility in the multiplier model, which is a common setback of the other methods (Podinovski, 2004b). According to the duality theorem, infeasibility in the multiplier model implies unboundness in the envelopment form (Podinovski, 2004b). Therefore, an unbounded solution of the envelopment model indicates a mistake in the assessment of trade-offs that should trigger a re-evaluation of the trade-offs to rectify the problem (Podinovski, 2004b). This is another valuable feature of the Trade-off approach as a mechanism to impose weight restrictions in the form of value judgements.

Table 3.7: DEA with Trade-offs (Variable Returns to Scale)

Output-oriented Envelopment	Output-oriented Multiplier
$\begin{aligned} & Max \quad \theta \\ & Subject\ to: \\ & \sum_{j=1}^{n} x_{ij}\lambda_j + \sum_{t=1}^{K} \pi_t P_t \le x_{i0}, \quad i = 1, 2, \ldots, m, \\ & \sum_{j=1}^{n} y_{rj}\lambda_j + \sum_{t=1}^{K} \pi_t Q_t \ge \theta y_{r0}, \quad r = 1, 2, \ldots, s \\ & \sum_{j=1}^{n} y_j = 1, \\ & \lambda, \pi \ge 0, \qquad \theta\ sign\ free. \end{aligned}$	$\begin{aligned} & Min \quad \sum_{i=1}^{m} v_i x_{i0} - u_0 \\ & Subject\ To: \\ & \sum_{r=1}^{s} u_r y_{r0} = 1, \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_0 \le 0, \quad j = 1, 2, \ldots, n, \\ & \sum_{r=1}^{s} u_r Q_t - \sum_{i=1}^{m} v_i P_t \le 0, \quad t = 1, 2, \ldots, K, \\ & u, v \ge 0, \quad u_0\ sign\ free. \end{aligned}$

Input-oriented Envelopment	Input-oriented Multiplier
$\begin{aligned} & Min \quad \theta \\ & Subject\ to: \\ & \sum_{j=1}^{n} x_{ij}\lambda_j + \sum_{t=1}^{K} \pi_t P_t \le \theta x_{i0}, \quad i = 1, 2, \ldots, m, \\ & \sum_{j=1}^{n} y_{rj}\lambda_j + \sum_{t=1}^{K} \pi_t Q_t \ge y_{r0}, \quad r = 1, 2, \ldots, s, \\ & \sum_{j=1}^{n} y_j = 1, \\ & \lambda, \pi \ge 0, \qquad \theta\ sign\ free. \end{aligned}$	$\begin{aligned} & Max \quad \sum_{r=1}^{s} u_r y_{r0} - u_0 \\ & Subject\ to: \\ & \sum_{i=1}^{m} v_i x_{i0} = 1, \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_0 \le 0, \quad j = 1, 2, \ldots, n, \\ & \sum_{r=1}^{s} u_r Q_t - \sum_{i=1}^{m} v_i P_t \le 0, \quad t = 1, 2, \ldots, K, \\ & u, v \ge 0, \quad u_0\ sign\ free. \end{aligned}$

Source: *Based on Podinovski (2004b)*

Table 3.7 gives the necessary modification to the VRS model as far as the imposition of weight restrictions by means of the Trade-off approach is concerned. In the multiplier form, the production trade-offs are written in the form of additional *homogenous weight restrictions* equation, that is $\sum_{r=1}^{s} u_r Q_t - \sum_{i=1}^{m} v_i P_t$. The same third constraint is written and the same set of trade-offs are applicable to any DEA models, without any adjustment to the equation or re-assessment of the trade-offs to accommodate variations in the form of input-oriented or output-oriented formulation whilst adopting either CRS or VRS technology assumption. This is very appealing because it tackles the dispute related to introducing weight restrictions into VRS and it is an advantage over *non-homogeneous weight restrictions* models (Podinovski, 2004b, p. 1315-1317). To be exact, the transformation of CRS into the VRS is made simply by eliminating the fifth axiom of *proportionality* defining the PPS for the CRS with trade-offs (Podinovski, 2004b). Mathematically, the VRS has additional normalising constraint, $\sum_{j=1}^{n} \lambda_j = 1$ in the envelopment form and the presence of variable u_0 in the multiplier form. Removing the said additional component will give CRS with trade-offs.

3.5. Proposed Integration of Hybrid Returns to Scale and Trade-off Models

3.5.1. Conceptual Framework of HRSTO

The proposed integration of HRS technology and Trade-off restriction as an alternative framework for DEA application is argued in this study to be capable of providing a better insight of a unit's performance and hence capable of refining the definition of benchmark practice. The HRS technology is assumed to accurately capture the inherent relationship between assessment variables. At the same time, the Trade-off approach is employed to impose the technologically realistic compromises between assessment variables. The resulting integrated technique, namely, HRS model with trade-off or HRSTO, assimilates additional relevant information about transformation process into traditional DEA models. An indirect benefit of the framework is its ability to address the well-known curse of dimensionality of DEA technique particularly when applied on small datasets.

The conception in this study is that the accurateness of DEA evaluation can be enhanced by a correct replica of transformation process via a non-technically extensive modification to the generic DEA formulation. It is worth emphasising that the technological gist of DEA assessment has not been nullified by the proposed HRSTO model. In fact, this study is not advocating for a singularly unique theory. Rather, this is a novel implementation framework, which is consistent with the many suggested approaches in the DEA literature associated with refining the postulation of the EF and imposing weight restrictions on the multiplier values.

There are two generic concepts of technology that describe the relationship between variables. CRS assumes full proportionality relationship between variables whereas VRS assumes no proportionality relationship between variables. In other words, CRS posits increase in inputs will lead to increase in outputs while decrease in inputs will lead to decrease in outputs, proportionally. In contrast, VRS posits increase or decrease in inputs may cause outputs to increase or decrease or stagnate. An intermediary technology recently introduced by Podinovski (2004a) is the HRS that assumes selective proportionality relationship between variables. Selective proportionality relationship implies that within any dataset, there is a subgroup of input-output bundles with proportional relationship or with expressive influence on each other, as in CRS, while the remaining variables without proportional relationship or impassive influence on each other, as in VRS, (Podinovski, 2004a). In principle, the third postulation of relationship is the best resemblance of the connection among assessment variables in practice, such as those characterising the academe. This is because, although a group of input-output variables are interdependent, they often do not actually change in response to any changes in each one of them. Only some of them do actually change by the same scalar change of the other variables due to certain and implicit relationship between them. In other words, it is selective or partial proportional change relationship that commonly prevails between any groups of mutually dependent variables, not limited to those variables characterising aspects of a performance only. The technical detail about the HRS technology can be found in the preceding Section 3.4.3.1.

In terms of the flexibility, HRS formulation could be applied to any datasets containing all proportionally related or some proportionally related or even non-proportionally related variables. It is sufficient to modify the elements of proportional inputs and/or proportional outputs matrices in the HRS formulation (Podinovski, 2004a). Note that, it is the concept of explicitly controlling and defining behaviour between variables that increases its restriction in DEA. Besides, this concept works as a trade-off that imposes limit on the possible change behaviour between variables. Hence, indirectly and naturally, HRS enhances the discriminatory power of DEA on small samples. This argument will be proven in the subsequent chapter when discussing the findings of the application of HRSTO model.

Incorporation of weight restrictions will modify the size and shape of the PPS and therefore the EF that consists of exemplary efficient units on their respective operating scales. Trade-off approach is preferable as it expands the PPS founded on realistic technological compromises. It explicitly moderates the contextual factor that affects the transformation process based on “user’s intervention”. In effect, the generated improvement targets for inefficient units are always producible and sensible, not at the expense of altering their current input and output mix in order to attain 100% efficiency (Podinovski, 2004b). These are all very practical in real life applications such as the evaluation of universities wherein the institutions have limited control over their publicly subsidised resources that they need to make the best use of what currently available.

From a methodological viewpoint, instead of allowing the algorithm to automatically calculate and assign values to the multipliers, the Trade-off approach enables users to pick and deliberately impose acceptable range of multiplier values for pairs of relevant variables grounded solely on the technology thinking paradigm (Podinovski, 2004b, 2007). Besides capturing the end users' priorities (through variable and weight selections), the approach facilitates implementation by producing practical and producible improvement targets (Podinovski, 2004b). This is in contrast with the effects of imposing weight restrictions such as using value judgement or monetary consideration that no longer embody the technological gist and feasibility of performance improvement (Podinovski, 2004b, 2007). The Trade-off approach can be meaningfully applied in either the envelopment or the multiplier form. This is an advantage, given that the type of framework used will influence the interpretation of the resulting efficiency measures. The envelopment form that defines efficiency in terms of resource consumption and output production is employed in this thesis to construct the proposed HRSTO model (Podinovski, 2004b, 2007).

An integration of the HRS and the Trade-off models for DEA analysis could provide a better insight into the performance of a unit. This is a key contribution of the present study. "Better insight of a performance" is when DEA correctly captures the prevailing relationship between variables that implicitly influence performance and when the approach gives relevant evaluations in accordance with the end users' priorities and environment. The underpinning notion is that DEA would discover better insight of a performance when it explicitly inflicts acceptable pattern of variable change relationship and when it defines a range of producible selective changes between the assessment variables. Specifically, HRS is adopted as the underlying technology so that either/both proportional and non-proportional relationships that prevail among variables within a data set could be effectively acknowledged. In doing so, it does not require compromise to be made in between the advantages of considering (CRS) and ignoring (VRS) information about some synchronized proportional change relationship in performance assessment.

The roles of Trade-off in the formulation of HRSTO are to:

(a) Explicitly link the minimum required changes in outputs whenever there are minimum changes in the relevant inputs, and

(b) Give conservative range for acceptable changes between pairs of relevant variables ("safe lower bound" that should be acceptable to all).

The proposed integration is used to refine the weights chosen by, and used to generate technologically realistic and producible radial efficiency measures for, the universities under evaluation. Consequently, the discriminatory power of DEA related to the dimensionality curse caused by small sample size is addressed via a non-technically extensive procedure.

3.5.2. Technical Framework of HRSTO

The HRS model with trade-off is presented in model (M3.8). In the proposed framework, there are a group of *j* DMUs being evaluated in an observation set of *n* and denoted by $J = \{1, 2 \ldots n\}$. The nonnegative matrices of $\sum_{j=1}^{n} \bar{x}_{ij}$ and $\sum_{j=1}^{n} \bar{y}_{ij}$ represent all of the observed inputs and all of the observed outputs while the nonnegative matrices of $\sum_{j=1}^{n} \hat{x}_{ij}$ and $\sum_{j=1}^{n} \hat{y}_{ij}$ correspond, respectively, to the proportional inputs and the proportional outputs. So DMU_j is said to consume x_{ij} units of input i to produce y_{rj} units of output r. In similar vein, DMU_0 refers to the DMU being assessed based on its consumption of x_{i0} units of input i in producing y_{r0} units of output r. There are K judgements denoting trade-offs altogether and each is given a weight of π_t, while P_t and Q_t are user-specified constant vectors.

$$
\begin{aligned}
&Max \quad \theta \\
&Subject\ to: \\
&\qquad \sum_{j=1}^{n} \bar{x}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{x}_{ij}\mu_j - \sum_{j=1}^{n} \hat{x}_{ij}v_j + \sum_{t=1}^{K} \pi_t P_t \le x_{i0}, \\
&\qquad \sum_{j=1}^{n} \bar{y}_{rj}\lambda_j + \sum_{j=1}^{n} \hat{y}_{rj}\mu_j - \sum_{j=1}^{n} \bar{y}_{rj}v_j + \sum_{t=1}^{K} \pi_t Q_t \ge \theta y_{r0}, \\
&\qquad\qquad\qquad \sum_{j=1}^{n} \lambda_j = 1, \\
&\qquad\qquad \lambda_j \ge v_j, \quad for\ all\ j \in J, \\
&\qquad \lambda, \mu, v, \pi \ge 0, \quad i = 1, 2, \ldots m, \quad r = 1, 2, \ldots, s, \\
&\qquad\qquad\qquad \theta\ sign\ free.
\end{aligned}
\tag{M3.8}
$$

For this model, the notations are similar to those described in any DEA models. Note that $\sum_{j=1}^{n} \bar{x}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{x}_{ij}\mu_j - \sum_{j=1}^{n} \hat{x}_{ij}v_j$ replaces $\sum_{j=1}^{n} x_{ij}\lambda_j$ for inputs while $\sum_{j=1}^{n} \bar{y}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{y}_{ij}\mu_j - \sum_{j=1}^{n} \bar{y}_{ij}v_j$ replaces $\sum_{j=1}^{n} y_{ij}\lambda_j$ for outputs in VRS formulation. Both are the modifying terms that define selective proportionality relationship between variables using HRS. Matrices for the proportional input $(\sum_{j=1}^{n} \hat{x}_{ij})$ and proportional output $(\sum_{j=1}^{n} \hat{y}_{ij})$ variables are derived from the matrices for all the observed inputs $(\sum_{j=1}^{n} \bar{x}_{ij})$ and observed outputs $(\sum_{j=1}^{n} \bar{y}_{ij})$ by replacing the actual values in every row associated with the corresponding non-proportional variables to zero. This requires at least one variable to be defined as element belonging to the set I^P (proportional input) and the set O^P (proportional output) each. Further, both $(\sum_{t=1}^{K} \pi_t P_t)$ for inputs and $(\sum_{t=1}^{K} \pi_t Q_t)$ for outputs are added to incorporate the expected performance on units of the assessment in the form of weight restrictions via Trade-off approach. DEA formulation under VRS scale assumption is obtained by omitting all of those additional components. In effect, the proposed assessment framework of HRSTO is an integration of VRS, HRS and Trade-off approaches.

Additional condition to convexity assumption of $\sum_{j=1}^{n} \lambda_j = 1$ is for λ_j to be bigger if not equal to v_j that is $\lambda_j \geq v_j$. All variables are assumed to be non-negative or $\lambda, \mu, \upsilon, \pi \geq 0$ and every DMU_j is assumed to have at least one input and one output which is strictly positive. Similar to any other DEA models, the computation of efficiency scores is done by optimising the objective function value of θ subject to the requirements as imposed by the listed constraints. DMU_0 is regarded as productive efficient if there is no other DMU or composite unit that could outperform it by producing extra unit of an output while maintaining the same level of the other outputs or maintaining the same input mix.

Further on the above mathematical expression, the HRS technology presumes the existence of selective proportionality relationship for two concurrent but independent scenarios namely, expansion and contraction. In an expansion scenario, the proportional inputs $(\sum_{j=1}^{n} \hat{x}_{ij})$ and proportional outputs $(\sum_{j=1}^{n} \hat{y}_{ij})$ are accordingly weighted or expanded by an improvement factor denoted by $+\mu$ whose value is always positive or $\mu_j > 1$. However, in a contraction scenario, the proportional inputs $(\sum_{j=1}^{n} \hat{x}_{ij})$ and all the observed outputs $(\sum_{j=1}^{n} \bar{y}_{ij})$ are accordingly weighted or contracted by a contraction factor denoted by $-\upsilon$ whose values ranging between $0 \leq \upsilon_j < 1$. Note that, for an expansion scenario, only the proportional outputs are expanded while for a contraction scenario, it is all the observed outputs that are being contracted. This is actually a technicality necessity to anticipate the unknown impact on the non-proportional outputs and to ensure feasibility of the contracted units of the proportional variables. Note that, a decrease in input will cause the decrease in all outputs and the worst unknown impact on non-proportional outputs need to be zero. In fact, the extreme anticipated consequence on outputs was assumed for both scenarios for a change in the proportional input availability. An increase in the inputs will directly cause increment in the proportional outputs thus matrix $\sum_{j=1}^{n} \hat{y}_{ij}$ applies in expansion scenario while the pits of a decrease in the inputs is on all outputs to drop to zero thus matrix $\sum_{j=1}^{n} \bar{y}_{ij}$ applies in a contraction scenario; direct decrease of proportional and indirect decrease of non-proportional outputs. Further discussion on this particular aspect of HRS is provided by Podinovski (2007) on page 267.

The next chapter describes the implementation of the proposed framework on measuring the performance of public universities in Malaysia. The objective of the performance appraisal is to gauge their competence in the utilisation of academic resources in the provision of education and publication of research at institutional level.

3.6. Conclusion

In practice, it is very difficult to determine a unit's *true potential* and even the best practice exists, the performance frequently changes over time. This motivates some analysts to employ frontier approaches based on an observational data, including DEA, as a means to estimate the true but unknown efficient reference technology. DEA makes estimation of an efficient production function based on the available information from the observed production activities in the sample observation (Banker, *et al.*, 1984). The basic theory is to identify the best-practice units within a sample to be the benchmark and to relatively compare the remaining units against them (Fried, *et al.*, 2008). Such a method of quantifying efficiency is preferred as an optimal level is defined based upon the observed achievement within a sample. This will better represent an industry hence guarantee feasible and realistic improvement targets. Also in the reality, the best theoretical level is hardly achievable that using the best observed level as the optimal achievement target as suggested via frontier approaches is more reasonable and doable (Daraio & Simar, 2007).

The suggested HRSTO aims at enhancing the accuracy of DEA assessment by correctly captures the transformation activities undertaken by DMUs via non-technically extensive concept. It is introduced in the envelopment form, in consistent with the operational perspective of quality enhancement implementation initiatives. In addition to able to give a better reflection of a unit's performance, indirectly it is able to deal with the curse of dimensionality angst associated with DEA application on small data sets.

Firstly, a "better insight of performance" is reflected when the underlying technology assumed to postulate EF could capture either type of possible relationship between variables; proportional or non-proportional. Therefore, a better account of the unknown efficient technology is being made. This is necessary as the inherent relationship between the assessment variables does implicitly influence a DMU's performance. Employing DEA under HRS technology could explicitly inflict an acceptable pattern of change behaviour between them. Secondly, a "better insight of performance" is revealed when DEA evaluation is made relevant to the end users' priorities and environment. In the reported case study for instance, Research University is a nationally pursued award by, and sets the benchmark performance for, all HEIs in Malaysia. Their performance, thus, should be considered in defining expected performance targets on HEIs. Integrating Trade-off restriction into HRS further explicitly moderates the contextual factor of the activities being examined and refines the weights chosen by the DMUs. Consequently, the resulting assessment is meaningful to the end users, in our case MOHE and public universities, while at the same time consistent with the technological reality and feasibility.

In practice, the common problem is getting the most desired variables which are always constrained by the access to the required data. However, by developing a framework that could better account a unit's activity, DEA is still able to give a correct measure of efficiency despite restrictions related to variable availability. In this regard, the proposed HRSTO model contributes to the DEA literature by improving conceptualisation of transformation activities in measuring university performance. HRSTO gives a measurement of performance which is neither too optimistic nor too pessimistic. HRSTO incorporates additional relevant information to better reflect a performance while sustaining the technology gist of a DEA evaluation. In short, the motivation of the model presented is to have an implementable yet an accurate and a reasonable model of reality.

CHAPTER 4

ANALYSIS AND DISCUSSION

4.1. Introduction

The technical background of Data Envelopment Analysis (DEA) methodology precedes this chapter. Description of the conceptual and technical framework of the proposed DEA application framework, namely Hybrid returns to scale model with trade-off (HRSTO), is also given in the foregoing chapter *Methodology*. This chapter continues the discussion on the proposed DEA model for providing a better insight of an organisation performance. Its generic construction is briefly introduced again before presenting its specific arithmetic formulation for the reported case study. The examination of the performance of higher education institutions (HEIs), or particularly Malaysian public universities from 2006 to 2008, is then recapitulated and discussed to illustrate the suggested evaluation framework. Section 4.4.2 makes comparison of the results obtained via the proposed HRSTO and the standard DEA models. This is followed by a brief insight into the sensitivity of HRSTO to different specification of weight restrictions. Section 4.5 compares the HRSTO results with that of *Malaysia Research Assessment System* (MyRA) and *Rating System for Malaysia Higher Education* (SETARA), the existing performance measurement system (PMS) applicable on Malaysian public universities. This chapter concludes on the merits of the proposed performance measurement framework to DEA literature.

4.2. Measuring University Performance

The present study employs DEA to develop a performance measurement model that would give a "better insight" of a unit's relative performance. It is believed that "better insight" of a performance can be obtained by accurately capturing the inherent relationship between assessment variables and impose technologically realistic compromises between variables into an empirical analysis. This is necessary as the presumed technical relationship between variables underpins DEA projection of efficient boundary contouring an observational data. Further, an accurate account of the end users' priorities in the form of technological compromises renders an analysis more acceptable, feasible and useful.

In the context of the current case study, the interest is to measure the efficiency of public universities that transform teaching and research inputs into intellectual outputs. The end users are the Ministry of Higher Education (MOHE) and the public universities being examined. Universities generally have homogenous characteristics in the sense that they use similar resources to generate similar outcomes in the educational process. However, from an operational perspective, universities vary at the operational level and they are complex service organisations. Measurement is complicated because their performance level is also implicitly affected by the quality of academicians and students they attract and pool. Moreover, it is complicated to price certain educational variables and to quantify the quality and outcome of the intangible benefits that universities produce.

At present, a great deal of DEA studies has been conducted on measuring HEIs performance worldwide. Nevertheless, there exist disagreements on the definite set of variables to use to evaluate HEIs. There appears to be no uniformity in the units of measurement of a particular variable and input-output combinations required to determine the performance of such tertiary educational system. To buttress this point, the number of academic staff is sometimes proxied by full-time equivalent (FTE) figures and sometimes accounted by the actual total staff figures. Further, there are instances where research income is treated as a research input and in other instances as a research output.

Given the unique features of the academia, it is important to focus more on modelling the framework that appropriately captures their true performance as opposed to technical issues such as variable selection that can be regarded as secondary to DEA model conceptualisation. This is particularly true when the choice of variable depends upon the availability and accessibility of the required information. In fact, the variable choice also varies according to the objectives of an appraisal exercise. Once the framework has correctly captured the reality of the transformation process of an academic institution, the end users can then implement the outcomes. This includes customising what aspects of HEIs to evaluate, what variables to select, how to classify a variable as input or output, which measurement unit to employ, or what range of observational data to consider. Not limited to the academe, this framework is equally applicable to any other institutions facing the same scenario.

4.3. Hybrid Returns to Scale Model with Trade-offs (HRSTO)

4.3.1. Formulation of HRSTO in General

Model (M4.1) presents the general formulation for Hybrid returns to scale model with trade-off (HRSTO) that can be used to evaluate *n* DMUs (decision making units) in a sample denoted by $J = \{1, 2, \ldots, n\}$. The matrices $(\sum_{j=1}^{n} \bar{x}_{ij})$ and $(\sum_{j=1}^{n} \bar{y}_{ij})$ are nonnegative and represent all the observed inputs and all the observed outputs. Matrices $(\sum_{j=1}^{n} \hat{x}_{ij})$ and $(\sum_{j=1}^{n} \hat{y}_{ij})$ are also nonnegative, and correspond to the proportional inputs and proportional outputs. Every DMU_j is assumed to produce y_{rj} units of output *r* utilising x_{ij} units of input *i*. There are *K* judgements representing trade-offs with each being weighted by the variable π_t and represented by user-specified constant vectors P_t and Q_t.

$$
\begin{aligned}
& Max \quad \theta \\
& Subject\ to: \\
& \qquad \sum_{j=1}^{n} \bar{x}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{x}_{ij}\mu_j - \sum_{j=1}^{n} \hat{x}_{ij}\nu_j + \sum_{t=1}^{K} \pi_t P_t \le x_{i0}, \\
& \qquad \sum_{j=1}^{n} \bar{y}_{rj}\lambda_j + \sum_{j=1}^{n} \hat{y}_{rj}\mu_j - \sum_{j=1}^{n} \bar{y}_{rj}\nu_j + \sum_{t=1}^{K} \pi_t Q_t \ge \theta y_{r0}, \\
& \qquad \sum_{j=1}^{n} \lambda_j = 1, \\
& \qquad \lambda_j \ge \nu_j, \quad for\ all\ j \in J, \\
& \qquad \lambda, \mu, \nu, \pi \ge 0, \quad i = 1, 2, \ldots m, \quad r = 1, 2, \ldots, s, \\
& \qquad \theta\ sign\ free.
\end{aligned}
\tag{M4.1}
$$

Additional components to the familiar notations as commonly used to describe any DEA models that are present in model (M4.1) merit extra illustration. Let us consider the DEA formulation under Variable returns to scale (VRS) scale assumption. It is being modified by Hybrid returns to scale (HRS) scale assumption to inflict notion of selective proportionality relationship between variables using $\sum_{j=1}^{n} \bar{x}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{x}_{ij}\mu_j - \sum_{j=1}^{n} \hat{x}_{ij}v_j$ for inputs and $\sum_{j=1}^{n} \bar{y}_{ij}\lambda_j + \sum_{j=1}^{n} \hat{y}_{ij}\mu_j - \sum_{j=1}^{n} \bar{y}_{ij}v_j$ for outputs. Further, $(\sum_{t=1}^{K} \pi_t P_t)$ for inputs and $(\sum_{t=1}^{K} \pi_t Q_t)$ for outputs are added to incorporate expected performance on the assessment units in the form of weight restrictions via Trade-off approach. To all intents and purposes, the resulting formulation is an integration of VRS, HRS and Trade-off approaches. Section 3.5 in *Methodology* chapter gives a detail description and justification of the proposed HRSTO model.

4.3.2. Formulation of HRSTO for Malaysian Public Universities

Efficiency is measured in terms of using academic resources to provide education and to produce research. University performance is evaluated at an institutional level and interpreted for individual universities. The efficiency analysis generated by the proposed DEA framework is also compared to the analysis via VRS and CRS (Constant returns to scale) models. The comparison indicators include efficiency scores, efficient peers and efficient targets. The objectives of HRSTO assessment are to quantify a university's current performance, identify benchmark universities, determine reference peers and set improvement targets. The results are then graphically presented in order to understand the universities' performance from alternative perspective that is probably, more comprehensible by the end users, namely, MOHE and the universities. This includes examination on the distribution of the universities as well as the gap between efficient frontier and inefficient universities.

The mathematical formulation for evaluating Malaysian public universities using the proposed HRSTO is presented in model (M4.2). Let $J = \{1, 2 ..., n\}$ be the set of public universities in Malaysia. Here, there are two educational inputs (STAFF and GRANT) used to produce four educational outputs (UG, MS, PhD and PUB) related to teaching and research activities[35]. The efficiency of the public universities is evaluated using the output-oriented envelopment model. Subsequent sections will explain the model in detail.

$$
\begin{aligned}
&Max \quad \theta \\
&Subject\ to: \\
&\sum_{j=1}^{n} STAFF_j \lambda_j + \sum_{j=1}^{n} STAFF_j \mu_j - \sum_{j=1}^{n} STAFF_j v_j + \sum_{t=1}^{K} \pi_t P_t \le x_{i0}, \quad STAFF \\
&\sum_{j=1}^{n} GRANT_j \lambda_j \le x_{i0}, \quad GRANT \\
&\sum_{j=1}^{n} UG_j \lambda_j + \sum_{j=1}^{n} UG_j \mu_j - \sum_{j=1}^{n} UG_j v_j + \sum_{t=1}^{K} \pi_t Q_t \ge \theta y_{r0}, \quad UG \\
&\sum_{j=1}^{n} MS_j \lambda_j + \sum_{j=1}^{n} MS_j \mu_j - \sum_{j=1}^{n} MS_j v_j + \sum_{t=1}^{K} \pi_t Q_t \ge \theta y_{r0}, \quad MS \\
&\sum_{j=1}^{n} PhD_j \lambda_j + \sum_{j=1}^{n} PhD_j \mu_j - \sum_{j=1}^{n} PhD_j v_j + \sum_{t=1}^{K} \pi_t Q_t \ge \theta y_{r0}, \quad PhD \\
&\sum_{j=1}^{n} PUB_j \lambda_j - \sum_{j=1}^{n} PUB_j v_j \ge \theta y_{r0}, \quad PUB \\
&\sum_{j=1}^{n} \lambda_j = 1, \\
&\lambda_j \ge v_j; \quad for\ all\ j \in J, \\
&\lambda, \mu, v, \pi \ge 0, \quad \theta\ sign\ free.
\end{aligned}
\qquad \text{(M4.2)}
$$

Arithmetically, instead of allowing the algorithm to automatically calculate the values for the multipliers, which is the fundamental procedure in general DEA models, those multiplier values are deliberately restrained to be positive and allowed to vary within

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[35]STAFF is number of academic staff; GRANT is monetary amount of research grant; UG is number of Undergraduate students enrolment; MS is number of Masters students enrolment; PhD is number of PhD students enrolment; PUB is publication count

certain range of acceptable values. This is necessary to ensure that the weights attached to the variables are consistent with the national policies stipulating that *Research Universities* (RUs) set the yardstick of expected performance for all public universities. Thus, instead of asking the stakeholders to specify their *a priori* judgements, trade-offs are derived from the existing RUs. Therefore HRSTO appreciates the stakeholder's priorities through variables and weights selection, whilst the technical meaning and feasibility of the model components, including multiplier values and target performance levels, are preserved. In doing so, from a managerial perspective, it makes it possible for MOHE or the university's top management to incorporate their performance targets on universities into their appraisal. Particularly, targets related to changes in their policies on academic staff and research grant are properly set. From an operational perspective, the adopted analysis ensures that the expected changes in performance - reflected in the imposed trade-off values - are always realistic, doable and achievable.

Despite having a small population of only 20 public universities in Malaysia, the issue about the likely weak discriminatory power of DEA assessment is not a concern in the current case study due to the framework being adopted. It will later be demonstrated (in Section 4.4) that using the proposed framework, DEA appraisal is still well discriminating. This is made possible because of the proposed integration of HRS and Trade-off approaches contain supplementary information that refines the efficient frontier (EF) and restricts the multiplier values. This added information in effect naturally increases restrictions of DEA assessments. Based on this concept, it is argued that the resulting performance measure is a better reflection of the performance of the units under investigation.

4.3.2.1. Model Orientation

To choose model orientation is to determine the focus of evaluation which should be on what to achieve or evaluation objectives. It is also affected by the degree of control that units being assessed have over changes in inputs compared to changes in outputs. The focus of evaluation for this study is to maximise educational outputs in consistent with the national policy to develop human capital. In other words, HRSTO aims to maximize student enrolments and research publications. It is deemed inappropriate to consider reducing STAFF in optimising university efficiency as for a developing country, i.e. Malaysia, reducing staff is associated with reducing employment of the citizen. It contradicts with the national policy to boost country's development via human capital development. Thus, input orientation is not an ideal orientation for this study. Further, from decision-making viewpoint, a university has limited discretion and control over its resource availability. The reason is a university need to compete for its resources; to pool outstanding academicians and secure research grants. However, a university is in full command of its teaching and research activities at institutional level. Consequently, a university's achievement becomes the point of assessment.

Student enrolments looks like incoming students (input) but treated in this study as equivalent to student graduates (output). This does not mean to say no student drop-out but according to the feedback during data collection, drop-out rate in Malaysia is insignificant. This is to say that both variables could not be used at the same time to avoid double counting. Therefore, from a university management point of view, incoming students is treated as equivalent to outgoing students. To buttress this point, the evaluation focus is to maximise enrolments to be able to maximise graduates as a university's contribution towards the country's development. Consequently, the more access (enrolment) to higher education opportunities is provided by the universities, then the more educated human capital will be in the workforce, which will then guarantee the more sustainable country's development. Moreover, information on enrolments does provide a justification for resource requirement and commitment at specific faculty level (Avkiran, 2001; Abbot & Doucouliagos, 2003; McMillan & Chan, 2006).

4.3.2.2. Variable Selection

Variables are selected in consonance with the aims of the efficiency measurement on HEIs. Such a definition is made after considering Malaysian government's vision to transform Malaysia into a fully developed country through the development of human capital. In actual fact, tertiary education system is considered as one of the nationwide mechanisms to achieve the said national agenda. Currently, there are 20 public universities spread in every state throughout Malaysia. The oldest 4 of them were designated as RUs in 2006. Presently, there are 5 RUs in Malaysia (Nordin, 2011). An RU is awarded a national recognition of excellence in teaching and research. It is regarded as a prestigious status to be aimed for by every university.

To ensure the relevance of the resulting performance measures to the target end users, the analysis uses variables that are being compiled and monitored by the MOHE on annual basis. Regarding teaching activity, UNESCO 1999 and World Bank 2000 advocated that ratios of student-staff provide a reasonable proxy of quality and efficiency of teaching at institutional levels (Wilkinson & Yussof, 2005). In the literature, the statistics on enrolment is preferred to degrees awarded by some because enrolment figures take into account the duration of degree programmes which reflect the resources committed to produce the graduates (Avkiran, 2001; Abbot & Doucouliagos, 2003; McMillan & Chan, 2006). Moreover, to measure teaching activity, FTE enrolments are frequently used (Avkiran, 2001; Abbot & Doucouliagos, 2003; McMillan & Chan, 2006). On the other hand, Avkiran (2001, p.71) argued that research grant is appropriately treated as an input considering it corresponds to the resource for carrying out research whereas research outcomes should include among others research rating, number of publications, or "money indexed to number of publications". Unless the evaluation focus is on financial perspective instead of the productivity of research activity, it should be treated as an output.

In the present study, there are 6 variables used to measure the performance of HEIs[36]. These are categorised into 2 inputs and 4 outputs as in model (M4.2). The definitions of the assessment variables have been adopted from MOHE in order to ensure consistency:

a) **STAFF**; Number of academic staff

- ✓ Total number of full time (FT) academic staff (permanent/contract) employed during the current academic year including professors, associate professors, senior lecturers and lecturers
- ✓ The figures are inclusive of those on sabbatical leave, study leave and leave for training because they are being replaced by part-time academic staff

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[36]Appendix 7: Variables Employed in HRSTO with Supporting DEA papers

- ✓ The figures represent the number of academic staff who are actually available and active to conduct teaching and research activities
- ✓ Examples of the articles that employ FT academic staff as input variables are Tomkins & Green (1988), Johnes (2006b) and Castano & Cabanda (2007)

b) **GRANT**; Monetary Amount of Research Grant

- ✓ Total amount of research money available to support research related activities during the current academic year
- ✓ According to *Times Higher Education World University Ranking* (*THE*, 2010[37]), it is the best "proxy for high-quality knowledge transfer" because the amount indicates the worth of the research conducted and signifies a university's capability in attracting commercial sources of funding
- ✓ Beasley, 1990, p. 174: "Even though the success or ability of an institution to attract research grant is important, it is considered more important to evaluate the effectiveness in the utilisation of the funding to produce research outputs"
- ✓ Examples of the studies that regard research grant as an input variable are Beasley (1990, 1995), Johnes & Johnes (1993, 1995), Ng & Li (2000) and Athanassopoulos & Shale (1997)

[37]http://www.timeshighereducation.co.uk/world-university-rankings/2011-2012/analysis.html

c) **UG**; Number of Undergraduate Enrolment

- ✓ Total number of FT Undergraduate students enrolled for the current academic year
- ✓ The figures include both home and international students
- ✓ Undergraduate degree programmes in Malaysia are exclusively offered by the public universities on full time basis; except for those degree programmes offered via alternative modes of education such as distance learning or open learning concept which is excluded in the present study
- ✓ Examples of the articles that consider student enrolments as an output are Avkiran (2001), McMillan & Chan (2006), Castano & Cabanda (2007) and Fernando & Cabanda (2007)

d) **MS**; Number of Masters Enrolment

- ✓ Number of FTE Masters students enrolment for the current academic year
- ✓ Conversion of part-time to FTE number is made by using a multiplier of 1/3, consistent with the approach adopted by *THE* in 2009
- ✓ The figures include both home and international students
- ✓ Examples of the articles that consider masters enrolments as an output are Avkiran (2001), McMillan & Chan (2006) and Fernando & Cabanda (2007)

e) **PhD**; Number of PhD Enrolment

- ✓ Number of FTE PhD student enrolment for the current academic year
- ✓ Conversion of part-time to FTE number is made by using a multiplier of 1/3, consistent with the approach adopted by *THE* in 2009
- ✓ *THE* (2010) regards the universities having a high density of PhD students to be "more knowledge-intensive" and indicative of "teaching at the highest level" such that they are able to attract graduates to further their studies. Moreover, an active Postgraduate community is the most valued attribute of a "research-led teaching environment"
- ✓ Examples of the articles that consider Postgraduate enrolments as an output are Avkiran (2001), McMillan & Chan (2006) and Fernando & Cabanda (2007)

f) **PUB**; Publication Count

- ✓ Total number of publications in citation-indexed journals that have been published within the current academic year
- ✓ The quality aspect of publications is accounted for by the fact that they are all published in the recognised refereed journals
- ✓ Examples of the articles that consider research publications as an output are Madden, Savage & Kemp (1997), Taylor & Harris (2004) and Johnes & Yu (2008)

A summary of the variables commonly used in the evaluation of HEIs worldwide is provided in Appendix 1 until Appendix 6 of this thesis.

4.3.2.3. Selective Proportionality Relationship

Indeed, the definition of selective proportionality and trade-off relationships are not arbitrary but reflect the current practice as observed at the universities whose performance is under evaluation. It is a fact that students are proportionally related to the academic staff. That is to say, for every number change in the count of lecturers (STAFF) available, the effect on the enrolments, be it for Undergraduate (UG) or Masters (MS) or even doctoral (PhD) programmes, could be expressively or directly seen and physically measured. Because of this, it is argued that there is a proportional relationship among STAFF, UG, MS and PhD.

On the other hand, the impact of a change in STAFF on research activities (PUB) may or may not be proportional. In contrast, research publications (PUB) are directly influenced by available or unavailable grants but not the monetary amount of research grants (GRANT). Therefore, although the availability of GRANT influences the number/count of PUB, its impact could not be expressively or directly defined. In other words, there is a relationship between GRANT and PUB such that an increase in GRANT may increase, reduce or stagnate the volume of PUB. Because of this, it is argued that there is a non-proportional relationship between GRANT and PUB.

Whilst full proportionality between STAFF and different types of student enrolments could be reasonably assumed via CRS, no proportionality between STAFF, GRANT and PUB could be reasonably assumed via VRS. If VRS were to be adopted, then the information that STAFF and students were mutually proportional is being ignored. These are in agreement with the feedback that was obtained through structured interviews at selected universities during the fieldwork. Accordingly, the proposed model shows that lecturers (STAFF) influence student enrolments (UG, MS and PhD) and hence the variables are termed as proportional variables whereas monetary amount of grants (GRANT) may or may not influence publication counts (PUB) and hence the variables are termed as non-proportional variables. To be specific, selective proportionality relationship among the assessment variables is identified based on the following presumptions:

a) Changes in the number of *academic staff* (STAFF) have expressive or direct influence on the quality as well as the number of student enrolments (UG, MS and PhD) but are impassively or indirectly proportional to the number of publications (PUB). Therefore change relationship among the proportional teaching variables STAFF, UG, MS and PhD is postulated by *Ray Unboundness* property stating that

$$If\ (X, Y) \epsilon\ T, then\ (kX, kY) \epsilon\ T\ for\ any\ k > 0.$$

b) Changes in the monetary amount of *research grant* (GRANT) does influence the number of publications (PUB) although not expressively or directly proportional and somehow does impassively or indirectly affect teaching activity as reflected in the number of student enrolments (UG, MS and PhD). Therefore change relationship in between non-proportional research variables GRANT and PUB is not postulated using *Ray Unboundness* property.

In particular, the input indicator STAFF is categorised as the proportional input while output indicators UG, MS and PhD as the proportional outputs. On the other hand, the research variables, GRANT and PUB are treated as non-proportional input and non-proportional output, respectively.

There are two definitions of *Selective Proportionality* variable relationship for HRS with and without trade-off restrictions that have been tested in this study. The first definition stipulates that all outputs to be treated as having full proportionality relationship with STAFF. That is:

I^P {STAFF} O^P = {UG, MS, PhD, PUB}

I^{NP} {GRANT} O^{NP} = {0}

The second definition stipulates that all teaching variables to be treated as having full proportionality relationship while all research variables are regarded as having no proportionality relationship. That is:

I^P {STAFF} O^P = {UG, MS, PhD}

I^{NP} {GRANT} O^{NP} = {PUB}

The second definition is opted in the proposed framework. With reference to model (M4.2) or model (M4.3), this definition is imposed by using expansion factor *mju* (or μ) on proportional variables (i.e. $STAFF\mu$, $UG\mu$, $MS\mu$ and $PhD\mu$) to represent possibility of expansion scenario and concurrently using contraction factor *nju* (or ν) on the same proportional variables (i.e. $STAFF\nu$, $UG\nu$, $MS\nu$ and $PhD\nu$) to represent possibility of contraction scenario. For non-proportional variables, whilst output PUB is also being contracted by the same contraction factor *nju* (or ν). i.e. $PUB\nu$, input GRANT takes identical format as in VRS formulation.

4.3.2.4. Trade-off Restrictions

It is worth noting that the proposed model is indeed a data driven approach. In Malaysia, an RU is regarded to be an exemplary institution and hence defines the benchmark practice for all the other local universities. As a result, to construct the trade-off relationships, the figures are derived based on reported RUs' statistics. For every expected compromise to be imposed via the model, the minimum and maximum observed performance levels are first identified and then represented in mathematical expressions in the form of trade-off relationships. A more detailed discussion on the process of deriving trade-off relationships for this study is given next.

Trade-off relationships that are derived based solely on the performance of RUs could be regarded as conservative targets and are achievable by all public universities. Note that only about 50% of the universities being examined are well-established universities. The rest either are newly established universities (after 2000) or recently (in 2006) upgraded to university status. Yet the targets are feasible and realistic since they are based on the observed achievements and all RUs are operating in the same environment, disregarding subject-focus. The universities are also regulated by the same policies. This is useful for devising performance improvement strategies. It is also consistent with the national policy stipulating that RUs are outstanding institutions and regards them as role models in teaching and research activities for all the other public universities in Malaysia.

Trade-off values are selected from the highest and the lowest reported performance levels of RUs. In general, the highest observed levels constitute the upper bounds while the lowest observed levels constitute the lower bounds for pairs of trade-off relationships. For the present study, to be conservative, the highest observed levels define the consequence of decrease in input STAFF while the lowest observed levels define the consequence of increase in input STAFF. In constructing the trade-off equations, different combinations of simple and complex trade-off relationships have been tested to examine the effect of different structure and intensity of ranges of compromise between variables on the resulting efficiency scores of the universities. It is also important to only judge based on the production realities of trade-off figures selected. This is to ensure that the resulting efficiency measures reflect the technological meaning of radial improvement factor (Podinovski, 2007). The exact observed values are deliberately selected instead of the average or weighted values to derive the trading figures. This will ensure acceptability among the affected universities and feasibility of the implementation. By doing so, a reasonable form of assessment framework is constructed. In search of the best set of equations, it is necessary to minimise the number of equations while simultaneously ensuring that they do integrate critical performance targets into the assessment. Further, integration of trade-offs into the formulation is best made in stages until all critical performance targets are incorporated into the appraisal.

In fact, two sets of trade-off relationships have been tested in this study. The first focuses mainly on explicitly defining expected compromises between teaching output variables only. The second explicitly defines the range of expected changes in proportional outputs for a unit change in the proportional input. For the proposed HRSTO model, the second basis of defining trade-offs is deemed more appropriate. Note that trade-offs could be enumerated either in whole numbers or decimal numbers because they are multipliers for every one unit change in a variable. Altogether, 8 trade-off relationships have been adopted. They are defined as follows:

a) *Compromise between Undergraduate and Postgraduate degrees*: To enforce that teaching Postgraduate students will require greater amount of STAFF commitment as compared to teaching Undergraduate students. This relationship is represented by simple trade-off statements because it defines changes among two variables only

- ✓ For every 1 MS student decrease in enrolment, then it is technologically possible to raise 1 UG student enrolment
- ⇨ Represented by expressions $+\pi_1$ in 3rd constraint for UG and $-\pi_1$ in 4th constraint for MS
- ✓ For every 5 decrease in UG student enrolments, then it is technologically possible to raise 1 MS student enrolment
- ⇨ Represented by expressions $-5\pi_2$ in 3rd constraint for UG and $+\pi_2$ in 4th constraint for MS
- ✓ Multipliers π_1 and π_2 only appear in constraints associated with UG and MS students indicating that the inflicted range of acceptable changes of “1-5 UG students for every unit change in MS student” is applicable to the two outputs only and should not affect the other variables

b) *Acceptable ratios of* STAFF *and students*: To impose acceptable ranges of ratio between staff and students enrolling for different types of programmes. The consideration is to optimise teaching capacity of staff but at the same time not to jeopardise learning effectiveness and research productivity of the lecturers. Also, as long as a change in a particular type of enrolment is within the pre-determined range, then claim for an additional STAFF is considered as unjustifiable. Note that changes in STAFF will cause concurrent changes in all types of student enrolments thus to be represented by complex trade-off statements:

- ✓ For every 1 STAFF increase in availability, then it is technologically possible to raise 7 UG student enrolments, 1 MS student enrolment and 0.5 PhD student enrolment simultaneously
- ⇨ Represented by expressions $+\pi_3$ in 1st constraint for STAFF, $+7\pi_3$ in 3rd constraint for UG, $+\pi_3$ in 4th constraint for MS and $+0.5\pi_3$ in 5th constraint for PhD
- ✓ For every 1 STAFF decrease in availability, then it is technologically possible to reduce 14 UG student enrolments, 4 MS student enrolments and 1 PhD student enrolment simultaneously
- ⇨ Represented by expressions $-\pi_4$ in 1st constraint for STAFF, $-14\pi_4$ in 3rd constraint for UG, $-4\pi_4$ in 4th constraint for MS and $-\pi_4$ in 5th constraint for PhD
- ✓ The same multipliers π_3 and π_4 are used to inflict range of acceptable change in values for all teaching outputs namely UG, MS and PhD to indicate the multiple effects of every unit change in input STAFF. In particular, for every

unit change in STAFF, concurrently the effect on student enrolments will be within the range of (i) 7-14 units for UG students; (ii) 1-4 units for MS students; and (iii) 0.5-1 unit for PhD students

Model (M4.2) with the trade-offs actually employed in HRSTO that measures the performance of Malaysian public universities is reproduced below as model (M4.3):

$$
\begin{aligned}
& Max \quad \theta \\
& Subject\ to: \\
& \sum_{j=1}^{n} STAFF_j \lambda_j + \sum_{j=1}^{n} STAFF_j \mu_j - \sum_{j=1}^{n} STAFF_j v_j + \pi_3 - \pi_4 \le x_{i0}, \quad STAFF \\
& \sum_{j=1}^{n} GRANT_j \lambda_j \le x_{i0}, \quad GRANT \\
& \sum_{j=1}^{n} UG_j \lambda_j + \sum_{j=1}^{n} UG_j \mu_j - \sum_{j=1}^{n} UG_j v_j + \pi_1 - 5\pi_2 + 7\pi_3 - 14\pi_4 \ge \theta y_{r0}, \quad UG \\
& \sum_{j=1}^{n} MS_j \lambda_j + \sum_{j=1}^{n} MS_j \mu_j - \sum_{j=1}^{n} MS_j v_j - \pi_1 + \pi_2 + \pi_3 - 4\pi_4 \ge \theta y_{r0}, \quad MS \\
& \sum_{j=1}^{n} PhD_j \lambda_j + \sum_{j=1}^{n} PhD_j \mu_j - \sum_{j=1}^{n} PhD_j v_j + 0.5\pi_3 - \pi_4 \ge \theta y_{r0}, \quad PhD \\
& \sum_{j=1}^{n} PUB_j \lambda_j - \sum_{j=1}^{n} PUB_j v_j \ge \theta y_{r0}, \quad PUB \\
& \sum_{j=1}^{n} \lambda_j = 1, \\
& \lambda_j \ge v_j; \quad for\ all\ j \in J, \\
& \lambda, \mu, v, \pi \ge 0, \quad \theta\ sign\ free.
\end{aligned}
\tag{M4.3}
$$

4.3.2.5. Data Collection

The reported case study focuses on the performance in research and teaching activities of Malaysian universities. For cross-reference and validation purposes, two sources of information have been used to gather the required data. That is, MOHE (data user) and individual universities (data providers).

Respondents

During the fieldwork in Malaysia, MOHE and 28 universities were approached. The universities included 20 public universities, 4 private universities and 4 overseas branch campuses. Unfortunately, only complete data requested from MOHE and public universities managed to be collected. Hence, the sample size was reduced to twenty respondents.

Data

The information collected included

a) 8 variables related to (i) students according to degree levels (*new student intake*, *current year enrolment*, *annual graduates*), (ii) lecturers according to employment status (based on *qualification* and *position*), (iii) research activities (*research outcomes*; *amount* and *number of research grants* available on accumulated and annual basis), and (iv) library (*annual library spending*).

b) Information for deriving trade-off values such as official key performance indicators, teaching workload, and performance appraisal reports.

c) Short structured interviews to understand the current practice related to students, lecturers and research at selected universities.

However, only 6 variables are used in this study. The data collected for these variables is summarised in tabular format in Appendix 8.

Problems encountered

The major problem faced during the fieldwork was the inability to obtain access to complete information on private universities. This is because, not only limited information on them were available from MOHE's database and all home private universities provided partial information, but also, none of the overseas branch campuses agreed to furnish the requested numerical data. The research focus was accordingly redefined to meet the available information. In order to ensure the validity of the data, it was decided that information collected from MOHE's official database to be the primary source. Even so, only information on public universities is completely available.

4.4. Implementation of HRSTO

Prior to running the analysis, some adjustments were made and some structures were outlined. They are as follows:

a) Number of *Diploma* and *Degree* enrolments are combined as Undergraduate enrolment (UG) based on the fact that, on annual basis, resource commitment to teach both programmes is the same
b) Conversion of *Part-time* to FTE figures for enrolments is made by using a multiplier of 1/3. This is consistent with the approach adopted by *THE* in 2009

c) Current practice of employing *Part-time Academic Staff* in Malaysia mainly meant to cover *Full-Time Academic Staff* who are on official leaves (such as study-leave and sabbatical-leave). Hence it is deemed as a justifiable reason for using FT figures for STAFF. Also, since it is treated as an input, the figure should rightly represent the count of staff that actually available for teaching and research activities

d) Initial analysis on the collected data using DEA models under VRS and CRS were first conducted by using *Warwick DEA* before running the same models using programming languages *LINDO 6.1* and *LINGO 11.0 Optimization Modelling* software as the method to test the accuracy of the programming written

e) It is worth noting that in 2006, the last two universities (UMK and UPNM) were not yet established[38]. This reduced the number of DMUs for 2006 from 20 to 18

f) Imbalanced number of DMUs was considered between the years in order to ensure the homogeneity of DMUs and the validity of the analysis. This was decided based on the fact that some DMUs were recently upgraded to university status in 2006 and some DMUs had initial focus of teaching Undergraduate degrees only (Table 1.1). In particular,

    (i) For 2006, only 17 public universities are considered since in 2006 UMK and UPNM were not yet established while UDM (newly established in 2005) was only offering Undergraduate programmes

    (ii) For 2007, 18 public universities are considered since UMK and UPNM were only offering Undergraduate programmes in 2007

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[38]UMK is Universiti Malaysia Kelantan, UPNM is Universiti Pertahanan Malaysia and UDM is Universiti Darul Iman Malaysia

(iii) For 2008, 18 public universities are considered since in 2008 UPNM was only offering Undergraduate programmes. Further, UMK, although it started offering Postgraduate programmes in 2008, it did not have any research outcomes (*PUB*)[39].

Therefore, UMK (newly established institution in 2006) and UPNM (upgraded to university status in 2006) are being eliminated from the whole analysis.

g) The aims of defining trade-off relationships between the proportional variables, particularly in between STAFF and *enrolments* at various degree levels (UG, MS and PhD) are:

(i) To require a university to satisfy expected range of lecturer-student ratio between different degree levels

(ii) To acknowledge the fact that Postgraduate students consume relatively more resources compared to Undergraduate students (Beasley, J.E, 1990). Therefore, the ratio of average class size for Undergraduate and taught Postgraduate programmes is used in the reported analysis

(iii) To require a university to satisfy expected range of teaching workload

4.4.1. Empirical Analysis on HEIs via HRSTO Model

The performance of public universities in Malaysia, particularly in teaching and research activities, are evaluated using the output-oriented DEA model. The model

[39]In fact both UMK and UPNM universities had not been included in the Government's official evaluation reports via SETARA in 2007 and 2009 for the same reasons given (http://www.mqa.gov.my/SETARA09/pdf/result_en.pdf)

looks for a composite university that consumes as many units of inputs as observed at every university while producing as many units of outputs as producible. The DEA model is formulated using the proposed HRSTO framework in the form of model (M4.3) for each university using *LINDO 6.0 Programming Language*. 54 programs identical to model (M4.3) are written and evaluated using *LINDO* in every set of trade-offs being tested to derive at the final set of trade-offs (Trade-off set 10). Samples of the formulations are included in Appendix 9 until Appendix 11.

Tables 4.1, 4.2 and 4.3 present the results of HRSTO evaluation on Malaysian public universities for 2006 until 2008. In fact, those institutions are arranged in chronological order such that their sequence does roughly symbolise their succession of establishment[40]. Particularly, UTHM, UTeM, UMP and UniMAP are new institutions that have been established in/after the year 2000[41]. Efficient ones are distinguished from inefficient universities by listing them in the shaded rows. During 2006 to 2008, only UM, USM, UKM and UPM were awarded the status of *Research University*[42]. The first columns list the names of the universities and the institution that is excluded in the analysis for 2006 is noted by the word "N/A" in its corresponding row. The second columns give output-oriented efficiency scores of the universities under evaluation. The third columns headed by *Times Cited* show the frequency of a university has been cited as a significant reference peer by the other universities who are inefficient. The greater

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[40]Year of establishment for every public university in Malaysia is given as Table 1.1 in chapter Introduction at the beginning of the thesis

[41] UTHM is Universiti Teknologi Tun Hussein Onn Malaysia, UTeM is Universiti Teknikal Malaysia Melaka, UMP is Universiti Malaysia Pahang and UniMAP is Universiti Malaysia Perlis

[42]UM is Universiti Malaya, USM is Universiti Sains Malaysia, UKM is Universiti Kebangsaan Malaysia and UPM is Universiti Putra Malaysia

count of citation signifies the stronger merit of a university as a benchmark institution for others to emulate and better model of best practice to analyse. *Significant Role Models* enumerated in the forth columns provide information on specific benchmark institutions that should be emulated by every inefficient universities in devising their performance enhancement strategies[43]. For this measure, only those universities with more than 10% influence as a recommended reference peer by DEA are listed. In order to determine target improvement in the current performance to achieve full efficiency using existing input mix, the fifth columns of the tables give technically feasible output augmentation amounts. This is derived by DEA based on the comparative evaluations made in between a university's achieved performance and the sample's observed best achievements.

The results of HRSTO assessment on the universities in 2006 are presented as Table 4.1. Within this year, there are 5 technically efficient universities among which 3 *Research Universities* (UM, USM and UPM) are rated as efficient. 2 currently non-benchmark universities in Malaysia (UNIMAS and UPSI) are rated as efficient and there is a new university UMT (94%) that outperforms *Research University* UKM (83%) by 11%[44]. In comparison to the average efficiency score of 72%, there are 5 and 7 universities performing above and below the average, respectively. Exclusion of the fully efficient institutions gives the average output inefficiency score of 61%. This alerts

[43] Efficient benchmark universities are those institutions with the best overall performance. In contrast, inefficient benchmark universities are those institutions that have reasonably good practice to be emulated in consideration of its operating scale is of comparable size to the inefficient university being examined. Efficient universities certainly make better models of best practice yet HRS model also takes into account inefficient universities in devising optimal solutions for inefficient ones. In fact this is the unique feature of HRS as compared to the standard DEA models that only generate efficient units as the reference peers.
[44] UNIMAS is Universiti Malaysia Sarawak, UPSI is Universiti Pendidikan Sultan Idris and UMT is Universiti Malaysia Terengganu

considerable need for improvement in the universities' efficiency. Further, based on the number of times a university is used as a significant reference peer, UPSI (11 times) is the strongest benchmark institution than the other 3 efficient universities UNIMAS (7 times), USM (4 times) and UM (3 times). They are chosen as the role models not only by the above-average institutions such as UKM, UTM, UUM, UIAM and UMT but also by the below-average institutions including UMS, UiTM, UTHM, UMP and UniMAP[45]. For this year, in account of the efficiency scores and frequency of becoming a significant reference peer, the best 2 universities (in descending order) are UPSI and UNIMAS. In contrast, the bottom 3 universities (in ascending order) are USIM, UTeM and UniMAP[46]. The performance of UTeM and USIM can be regarded as at critical level since at their respective product mix each is in need for 75% and 70% boost in their respective productivity. However, when considering the fact that they were both recently upgraded to university status in 2006, the low productivity may be temporarily acceptable. In particular, for the weakest 2, it was recommended by HRSTO for USIM to emulate UNIMAS and UPSI while UTeM to emulate UPSI. For the remaining 5 below-average universities, UPSI and UNIMAS make very good models of best practice.

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[45] UTM is University Teknologi Malaysia, UUM is Universiti Utara Malaysia, UIAM is Universiti Islam Antarabangsa Malaysia, UMS is Universiti Malaysia Sabah and UiTM is Universiti Teknologi Mara

[46]USIM is Unversiti Sains Islam Malaysia

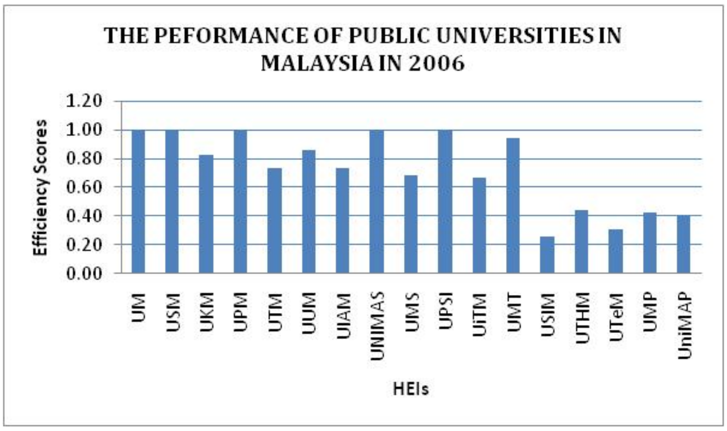
Table 4.1: 2006Performance of Public Universities in Malaysia Using HRSTO

	HEIs	2006 HRSTO	Times Cited	Reference Set Universities (Significant Role Models)	Output % Increase
1	UM	1.00	3	N/A	
2	USM	1.00	4	N/A	
3	UKM	0.83	0	USM, UPM, UNIMAS	**17.41**
4	UPM	1.00	2	N/A	
5	UTM	0.73	0	UM, USM, UPM, UPSI	**26.66**
6	UUM	0.86	1	USM, UPSI	**14.05**
7	UIAM	0.73	0	USM, UNIMAS, UPSI	**27.01**
8	UNIMAS	1.00	7	N/A	
9	UMS	0.68	0	UPSI	**31.66**
10	UPSI	1.00	11	N/A	
11	UiTM	0.67	0	UM, UUM, UNIMAS, UPSI	
12	UDM	N/A	N/A	N/A	N/A
13	UMT	0.94	0	UM, UNIMAS, UPSI	**5.99**
14	USIM	0.26	0	UNIMAS, UPSI	**74.22**
15	UTHM	0.45	0	UPSI	**55.44**
16	UTeM	0.31	0	UPSI	**69.49**
17	UMP	0.42	0	UNIMAS, UPSI	**57.56**
18	UniMAP	0.41	0	UNIMAS, UPSI	**59.42**
	Average efficiency score				72%
	Count of efficient universities				5

Performance of Public Universities in Malaysia in 2006 using the proposed DEA assessment framework, Hybrid returns to scale with trade-off (HRSTO)

Figure 4.1 gives a graphical summary of the universities performance in 2006. The best 5 could be identified as those universities that are plotted along the horizontal line when the efficiency score is 1 whilst the weakest are those 5 plotted at the lower part of the graph when the scores ranging in between 20-45%. At least 60% (8 out of 13) of the inefficient universities are middling about the average efficiency of 72%. The moderately low standard deviation for the sample of 26% or among the inefficient units of 23 % is demonstrated by the low variability in their efficiency score distribution. Further, more than 70% universities which are either efficient or above average are all relatively older institutions. The significant gap as observed between relatively new universities and the EF suggests a certain degree of influence of age on a university's performance.

Figure 4.1: 2006Performance of Public Universities in Malaysia Using HRSTO



Overview performance of public universities in Malaysia in 2006 using the proposed DEA assessment framework, Hybrid returns to scale with trade-off (HRSTO)

Assessment of 2007 (Table 4.2) indicates mixed changes in the efficiency; positive for overall universities but negative for *Research Universities*. Of the 7 universities rated as efficient by HRSTO, only UM, UPM and UNIMAS could maintain their technical output efficiency score of 1. Both inefficient *Research Universities* USM and UKM are being dominated by 3 non-benchmark universities namely UTM, UPSI and UDM. It is a concern that *Research University* UKM is performing slightly below the average and has been outperformed by inefficient institutions by as high as 21%. For the entire sample, the mean score is 79% while for inefficient units the mean score is 66%. Thus, overall efficiency has increased by 7%, but overall inefficiency warrants significant need for improvement in the universities' productivity. Although USM, UTM, UPSI and UDM were not rated as efficient, they were outstanding above-average universities with efficiency scores middling at 96%. In between are UKM and UiTM with corresponding efficiency scores of 76% and 70%. Yet the significantly low productivity identified among the below-average which are also the worst 5 universities (UTeM, USIM, UMP, UTHM and UniMAP) necessitates substantial improvement. For them the top 3 universities UMS (7 times), UNIMAS (6 times) and UUM (5 times) make ideal significant reference peers. For this year, the optimal target in output expansion for the universities in general ranging from as low as 3% to as high as 69%.

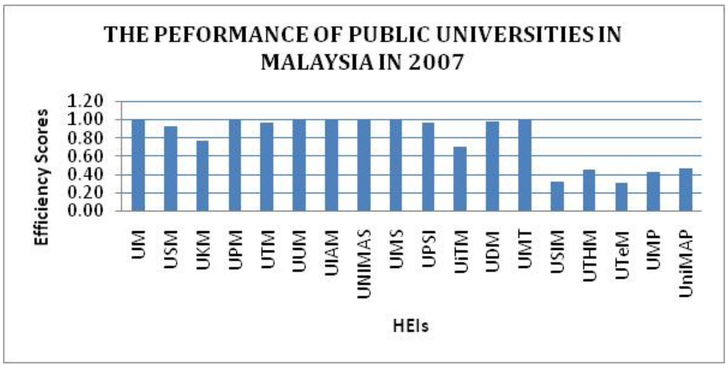
Table 4.2: 2007Performance of Public Universities in Malaysia Using HRSTO

	HEIs	2007 HRSTO	Times Cited	Reference Set Universities (Significant Role Models)	Output % Increase
1	UM	1.00	2	N/A	
2	USM	0.92	0	UKM, UPM, UUM	**8.20**
3	UKM	0.76	1	UPM, UUM	**23.63**
4	UPM	1.00	2	N/A	
5	UTM	0.96	0	UM, UMS	**3.72**
6	UUM	1.00	5	N/A	
7	UIAM	1.00	0	N/A	
8	UNIMAS	1.00	6	N/A	
9	UMS	1.00	7	N/A	
10	UPSI	0.97	0	UNIMAS, UMS	**3.46**
11	UiTM	0.70	1	UM, UNIMAS, UMS	**29.62**
12	UDM	0.97	0	UNIMAS, UMS	**2.73**
13	UMT	1.00	2	N/A	
14	USIM	0.32	0	UUM, UNIMAS, UMS	**68.14**
15	UTHM	0.45	1	UUM, UNIMAS, UMT	**55.08**
16	UTeM	0.31	0	UUM, UMS, UMT	**69.07**
17	UMP	0.42	0	UMS, UiTM, UTHM	**58.41**
18	UniMAP	0.47	0	UNIMAS	**53.25**
	Average efficiency score				79%
	Count of efficient universities				7

Overview performance of public universities in Malaysia in 2007 using the proposed DEA assessment framework, Hybrid returns to scale with trade-off (HRSTO)

In addition to Table 4.2, Figure 4.2 also summarises the performance of the public universities in 2007. At the top of the graph, 7 universities are plotted along the horizontal line expanding from the point when the score is unity so they are all fully efficient. At the bottom of the graph, 5 universities are plotted within the range of 30-50% so relatively they are all 5 weakest universities. In between, almost 55% of the inefficient universities are concentrating about the average efficiency score of 79%. Although the average efficiency score for 2007 is better than 2006 (72%), its average inefficiency score is worse, that is 66% compared to 61% for 2006. Its only 1% higher standard deviation than for 2006 gives identical pattern of overall university performance for both years. Again, for this year, relatively older institutions are either fully or above-average efficient.

Figure 4.2: 2007Performance of Public Universities in Malaysia Using HRSTO



Overview performance of public universities in Malaysia in 2007 using the proposed DEA assessment framework, Hybrid returns to scale with trade-off (HRSTO)

In 2008, the universities, on average, are 72% technically efficient and 57% technically inefficient (Table 4.3). Only UM and UPM are the *Research Universities* among the 6 universities that are identified as efficient. The other efficient universities are UTM, UUM, UNIMAS and UMT. Although the inefficient *Research Universities* USM and UKM are the above-average institutions, their efficiency is no more than 10% higher than mean efficiency of 72%. And again, UM, UPM and UNIMAS are the only universities that could always maintain their output efficiency score of 100% from 2006 through 2008. There are 6 universities having efficiency rating below 50% of which the lowest is USIM at 30% efficiency level. For USIM, again UUM and UNIMAS are the significant benchmark peers to emulate. Even so, the mean inefficiency score for 2008 is the lowest, only 57% compared to 61% and 66% for 2006 and 2007, respectively. The best 2 universities in 2008 are UUM and UNIMAS whilst the bottom 5 universities are

USIM, UTHM, UTeM, UMP and UDM. Most inefficient universities in this year need to strive for about 65% expansions in their output productivity and for them UUM (12 times) in addition to UNIMAS (8 times) are the stronger significant reference peers.

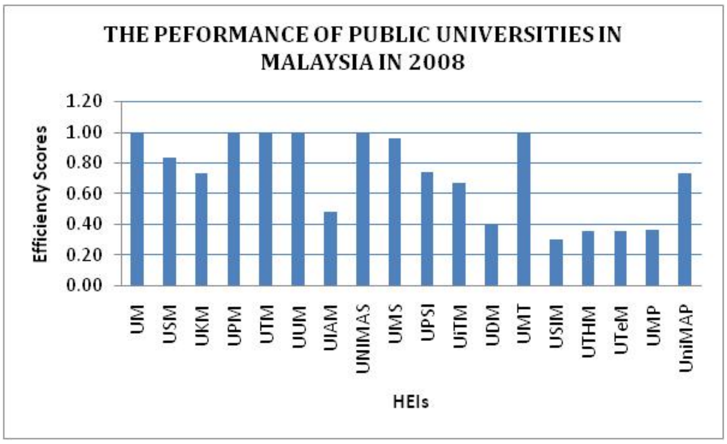
Table 4.3: 2008Performance of Public Universities in Malaysia Using HRSTO

	HEIs	2008 HRSTO	Times Cited	Reference Set Universities (Significant Role Models)	Output % Increase
1	UM	1.00	2	N/A	
2	USM	0.83	0	UPM, UUM	**17.20**
3	UKM	0.73	0	UPM, UUM	**26.84**
4	UPM	1.00	2	N/A	
5	UTM	1.00	0	N/A	
6	UUM	1.00	12	N/A	
7	UIAM	0.47	1	UM, UUM	**52.51**
8	UNIMAS	1.00	8	N/A	
9	UMS	0.96	0	UUM, UIAM, UniMAP	**4.24**
10	UPSI	0.73	0	UUM, UNIMAS	**26.54**
11	UiTM	0.67	0	UM, UUM, UNIMAS, UMT	**33.30**
12	UDM	0.39	0	UUM, UNIMAS	**60.90**
13	UMT	1.00	3	N/A	
14	USIM	0.30	0	UUM, UNIMAS	**70.40**
15	UTHM	0.35	0	UUM, UNIMAS, UMT	**64.81**
16	UTeM	0.35	0	UUM, UNIMAS	**64.81**
17	UMP	0.36	0	UUM, UNIMAS, UMT	**64.14**
18	UniMAP	0.73	1	UUM, UNIMAS	**27.01**
	Average efficiency score				72%
	Count of efficient universities				6

Overview performance of public universities in Malaysia in 2008 using the proposed DEA assessment framework, Hybrid returns to scale with trade-off (HRSTO)

From Figure 4.3, a greater variability in performance for 2008 is evident. It has a slightly higher standard deviation of 28%, but the highest as compared to 2006 (26%) and 2007 (27%). This justifies a wider dispersion of scores distribution among the universities in Figure 4.3. Dividing the graph at the mean efficiency score of 72% places 61% of the institutions above-average performance with 7 of them are rated as fully efficient and are plotted on the 100% efficient boundary. The observed pattern of performance is random hence can no longer be associated with a university's age. This may suggest the initial implication of the nationwide higher education policy reform in 2006.

Figure 4.3: 2008Performance of Public Universities in Malaysia Using HRSTO



Overview performance of public universities in Malaysia in 2008 using the proposed DEA assessment framework, Hybrid returns to scale with trade-off (HRSTO)

In brief, the proposed HRSTO has identified that *Research Universities* are not consistently outstanding institutions and the variability in performance between the existing universities is consistent at 27% standard deviation within the study period. In fact, there are only 2 *Research Universities*, UM and UPM, that are consistently rated as fully efficient. It seems reasonable to argue that having a certain years of experience (length of establishment) is a necessary “know-how” to develop the competency in teaching and research related activities among both academic and administrative staff. This also signifies that the proposed DEA framework offers a complementary perspective to the existing PMS, namely MyRA, thus will be constructive for HEIs’ quality enhancement, management and development agenda.

4.4.2. Empirical Analysis on HEIs via Different DEA Technologies

The proposed HRSTO model is claimed in this study to have a greater discrimination power and be more rigorous in its definition of efficient performance. The argument is made because fewer universities are rated as efficient, smaller efficiency scores are awarded to every inefficient university and lower annual ratings are given in terms of the average efficiency scores compared to the standard DEA models. For each of the following tables presented, the first columns for every year demonstrate a more stringent assessment of university performance made by HRSTO in comparison to the other DEA models. Although the achievement is less indicative when compared according to the years, the overview change in annual performance does reflect a sign of performance improvement or deterioration. Note that the trade-offs adopted in this study are derived from *Research Universities'* performance as observed in between 2006 and 2008. This is necessary since in Malaysia, *Research Universities* are benchmark institutions authoritatively recognised by the Government and the public. Since VRS is a more sensible model in practice, more analysis and most narrative comparisons are made between HRSTO and VRS models.

Table 4.4: Efficiency Scores of Public Universities in Malaysia between 2006 and 2008 Using HRSTO, CRS and VRS

HEIs	2006			2007			2008		
	HRSTO	CRS	VRS	HRSTO	CRS	VRS	HRSTO	CRS	VRS
UM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
USM	1.00	1.00	1.00	0.92	0.93	0.93	0.83	0.84	0.86
UKM	0.83	0.91	1.00	0.76	0.77	0.84	0.73	0.74	0.84
UPM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UTM	0.73	0.77	0.94	0.96	0.98	1.00	1.00	1.00	1.00
UUM	0.86	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UIAM	0.73	1.00	1.00	1.00	1.00	1.00	0.47	0.48	0.55
UNIMAS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UMS	0.68	0.70	0.71	1.00	1.00	1.00	0.96	1.00	1.00
UPSI	1.00	1.00	1.00	0.97	1.00	1.00	0.73	0.81	1.00
UiTM	0.67	0.88	1.00	0.70	0.76	0.76	0.67	0.80	1.00
UDM	N/A	N/A	N/A	0.97	1.00	1.00	0.39	0.47	1.00
UMT	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
USIM	0.26	0.27	1.00	0.32	0.35	0.39	0.30	0.40	0.76
UTHM	0.45	0.70	0.73	0.45	0.47	0.51	0.35	0.38	0.39
UTeM	0.31	0.32	0.34	0.31	0.31	0.33	0.35	0.37	0.40
UMP	0.42	0.46	1.00	0.42	0.45	0.51	0.36	0.44	0.62
UniMAP	0.41	0.42	1.00	0.47	0.49	0.57	0.73	0.64	1.00
Efficient	5	8	13	7	9	10	6	7	11
Average	**0.72**	**0.79**	**0.92**	**0.79**	**0.81**	**0.82**	**0.72**	**0.74**	**0.86**

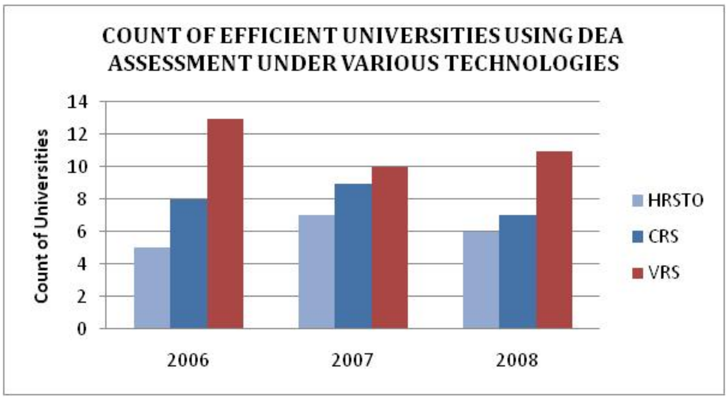
Summary of efficiency scores of public universities in Malaysia between 2006 and 2008 generated by Hybrid returns to scale with trade-offs (HRSTO), Constant returns to scale (CRS) and Variable returns to scale (VRS)

Table 4.4 compares results of the performance evaluation made using the proposed HRSTO against the standard DEA models, CRS and VRS. It shows in general, HRSTO framework increases the discriminatory power of DEA assessment as reflected by the lesser number of universities identified as efficient and smaller efficiency scores (individual or average) being awarded. It is evident that every university identified as efficient by HRSTO has also been regarded as efficient using the standard DEA models. In fact, every university which is given a greater than 90% HRS efficiency score is given both CRS and VRS efficiency scores of 100%, i.e. it is considered as fully efficient university; apart for once but trivial in 2007 when UTM is given CRS efficiency score of 98% and VRS efficiency score of 100%[47]. Hence, the distinction quality of efficient units recognized by HRSTO is well supported by CRS and VRS.

There is not even one university being given HRSTO score which is bigger than VRS score for any given years being examined. However, compared to CRS, UniMAP in 2008 is the only university receives bigger HRSTO score than CRS score while others are given HRSTO scores smaller than CRS scores during the three years. The three models are in agreement that *Research Universities* UM and UPM as well as a non-benchmark university UNIMAS are consistently fully efficient from 2006 through 2008. For USM, UUM and UMT, although they are not, in consensus, regarded as efficient by the three models, they are constantly considered as very good institutions and receive scores greater than 80% if not 100%. For many inefficient universities, evaluations made by HRSTO are mostly consistent with CRS but mostly inconsistent with VRS. There are instances when HRSTO gives significantly conflicting evaluation than VRS such as on UiTM, USIM, UTHM, UMP and UniMAP for 2006 as well as on UiTM, UDM and USIM for 2008.

[47] Exemption is made for USM in 2007 when all of the three DEA models unanimously agree that it is 92% or 93% efficient.

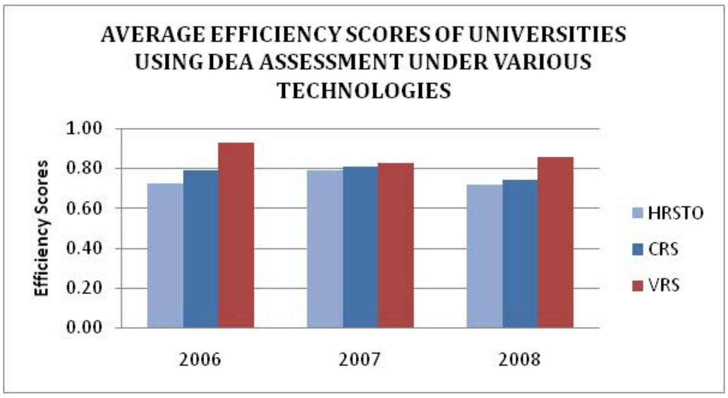
Figure 4.4: Count of Efficient Public Universities in Malaysia between 2006 and 2008 Using HRSTO, CRS and VRS



Count of efficient public universities in Malaysia between 2006 and 2008 as identified via Hybrid returns to scale with trade-offs (HRSTO), Constant returns to scale (CRS) and Variable returns to scale (VRS)

In terms of count of efficient universities, only 5, 7 and 6 universities are regarded as benchmark institutions by HRSTO in 2006, 2007 and 2008, respectively. In contrast, VRS identifies 13, 10 and 11 benchmark universities for 2006, 2007 and 2008, respectively. CRS on the other hand is a moderately discriminating model compared to the former two models since it considers 8, 9 and 11 universities to be the benchmark institutions between 2006 and 2008 for others to emulate.

Figure 4.5: Average Efficiency Scores of Public Universities in Malaysia between 2006 and 2008 Using HRSTO, CRS and VRS

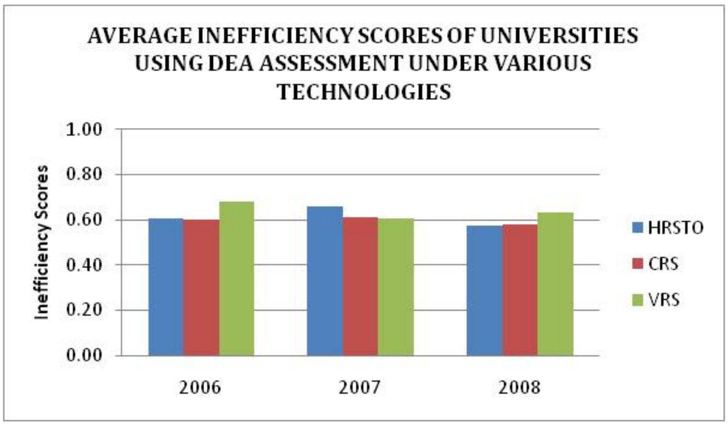


Average efficiency scores of public universities in Malaysia between 2006 and 2008 as identified via Hybrid returns to scale with trade-offs (HRSTO), Constant returns to scale (CRS) and Variable returns to scale (VRS)

According to annual performance, the average efficiency score for 2006 given by VRS appears to be too optimistic such that it does not signify the existence of extremely below-average institution UTeM. UTeM's extremely low performance (34%) is not reflected in the VRS mean score of 92% efficiency thus giving the impression that every university is performing very well in 2006. Note that, for the remaining inefficient institutions in 2006, they are given scores of 71%, 73% and 94%, thus only 1 university is realistically represented by the given average score. The same over optimistic review is given by VRS when it gives 86% average efficiency for 2008 despite the presence of significantly below-average institutions namely UTHM that earns only 39% and UTeM that earns only 40% VRS efficiency scores. The three models agree when they quantify 2007 performance of the universities within the range 79-82%. Therefore, for the current sample, HRSTO gives a relatively more realistic performance assessment, particularly when it gives more reasonable average scores compared to the individual scores of the universities.

In addition, observation on the average inefficiency scores allocated by the models reveals consistent assessment among each other. This indicates a more rigid achievement of efficient units being demanded by HRSTO but it is consistent with the other models in evaluating performance of inefficient units. To reinforce this point, HRSTO refines definition of benchmark practice. It, thus, provides empirical evidence that HRSTO is more discriminative and it increases the discriminatory power of DEA assessment.

Figure 4.6: Average Inefficiency Scores of Public Universities in Malaysia between 2006 and 2008 Using HRSTO, CRS and VRS



Average inefficiency scores of public universities in Malaysia between 2006 and 2008 as identified via Hybrid returns to scale with trade-offs (HRSTO), Constant returns to scale (CRS) and Variable returns to scale (VRS)

As noted earlier, due to full proportional relationship within groups of variables is hardly found, CRS technology is less realistic to be adopted in practice, particularly in evaluating the performance of public universities in Malaysia. The next analysis will thus focus on comparing the results of evaluation using HRSTO and VRS with trade-offs (VRSTO). In theory, the efficiency scores of those universities determined using DEA should be decreased when weight restriction is imposed into the formulation by means of the Trade-off approach. This presumption is well supported by the results of the assessment conducted via VRSTO as presented in Table 4.5 next. The table shows, again, consistency in identification of efficient universities made by HRSTO and VRSTO models for 2006 until 2008.

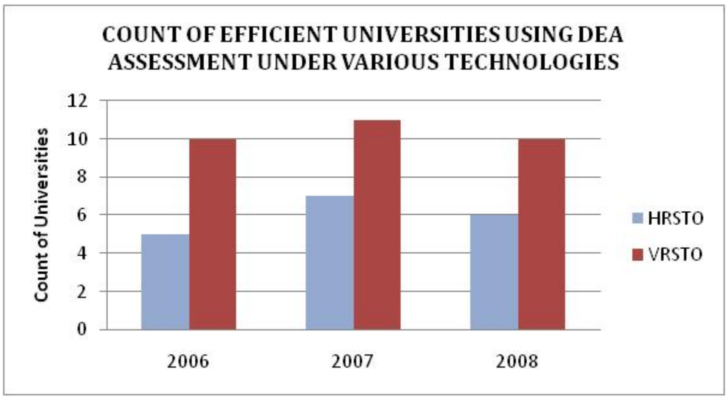
Table 4.5: Efficiency Scores of Public Universities in Malaysia between 2006 and 2008 Using HRSTO and VRS with Trade-offs (VRSTO)

HEIs	2006		2007		2008	
	HRSTO	VRSTO	HRSTO	VRSTO	HRSTO	VRSTO
UM	1.00	1.00	1.00	1.00	1.00	1.00
USM	1.00	1.00	0.92	0.92	0.83	0.85
UKM	0.83	0.90	0.76	0.81	0.73	0.80
UPM	1.00	1.00	1.00	1.00	1.00	1.00
UTM	0.73	0.94	0.96	1.00	1.00	1.00
UUM	0.86	1.00	1.00	1.00	1.00	1.00
UIAM	0.73	0.92	1.00	1.00	0.47	0.53
UNIMAS	1.00	1.00	1.00	1.00	1.00	1.00
UMS	0.68	0.71	1.00	1.00	0.96	1.00
UPSI	1.00	1.00	0.97	1.00	0.73	0.87
UiTM	0.67	1.00	0.70	1.00	0.67	1.00
UDM	N/A	N/A	0.97	1.00	0.39	1.00
UMT	0.94	1.00	1.00	1.00	1.00	1.00
USIM	0.26	0.72	0.32	0.38	0.30	0.67
UTHM	0.45	0.48	0.45	0.46	0.35	0.35
UTeM	0.31	0.34	0.31	0.33	0.35	0.37
UMP	0.42	1.00	0.42	0.50	0.36	0.39
UniMAP	0.41	1.00	0.47	0.57	0.73	1.00
Efficient	5	10	7	11	6	10
Average	0.72	0.88	0.79	0.83	0.72	0.82

Summary of efficiency scores of public universities in Malaysia between 2006 and 2008 generated by Hybrid returns to scale with trade-offs (HRSTO) and Variable returns to scale with trade-offs (VRSTO)

According to Table 4.5, the discrepancy between efficiency scores allocated by the two models has been reduced due to the imposed trade-offs. Further, comparison of every individual and the average efficiency scores assigned to all universities confirms smaller scores given by HRSTO than VRSTO. That is to say, although imposition of trade-offs has improved the discrimination of DEA assessment in general, HRSTO has a greater discriminatory power than VRSTO. Note that the only difference between the models is in the presumed technical relationship between the assessment variables. Therefore, the underlying technology, or the types of returns to scale, which is assumed to trigger transformation activities of institutions does have certain level of significance in a performance evaluation being made.

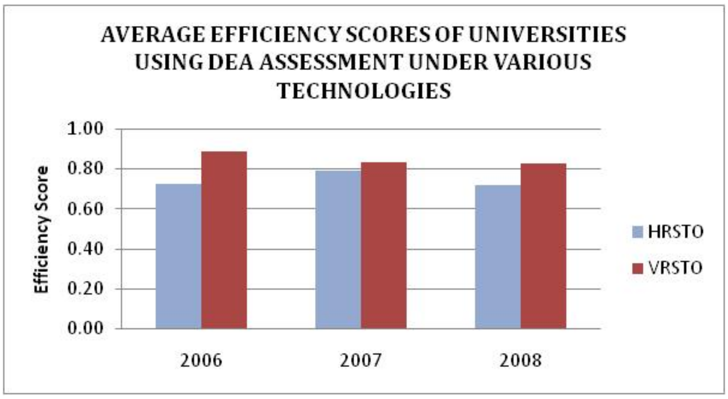
Figure 4.7: Count of Efficient Public Universities in Malaysia between 2006 and 2008 Using HRSTO and VRSTO



Count of efficient public universities in Malaysia between 2006 and 2008 as identified using Hybrid returns to scale with trade-offs (HRSTO) and Variable returns to scale with trade-offs (VRSTO)

In accordance with Table 4.5, Figures 4.7 and 4.8 reproduce the efficiency measures that support the proposed HRSTO model. Therefore, it can be concluded that the discrimination of DEA evaluation has been improved via the proposed HRSTO framework.

Figure 4.8: Average Efficiency Scores of Public Universities in Malaysia between 2006 and 2008 Using HRSTO and VRSTO



Average efficiency scores of public universities in Malaysia between 2006 and 2008 as identified using Hybrid returns to scale with trade-offs (HRSTO) and Variable returns to scale with trade-offs (VRSTO)

Next, to further examine the improvement in the discrimination made by the proposed model, the study compares the performance of universities evaluated via HRS with and without the same set of trade-off equations. The results of the comparison are shown in the following Table 4.6.

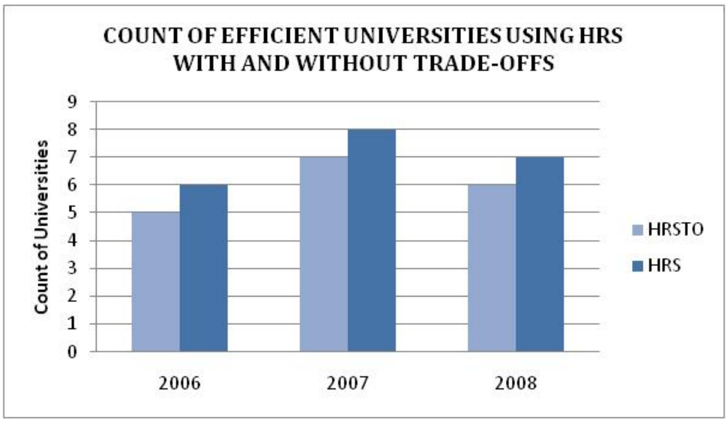
Table 4.6: Performance of Public Universities in Malaysia between 2006 and 2008 Using HRSTO and HRS

HEIs	2006		2007		2008	
	HRSTO	HRS	HRSTO	HRS	HRSTO	HRS
UM	1.00	1.00	1.00	1.00	1.00	1.00
USM	1.00	1.00	0.92	0.93	0.83	0.84
UKM	0.83	0.83	0.76	0.77	0.73	0.74
UPM	1.00	1.00	1.00	1.00	1.00	1.00
UTM	0.73	0.75	0.96	0.97	1.00	1.00
UUM	0.86	0.87	1.00	1.00	1.00	1.00
UIAM	0.73	0.73	1.00	1.00	0.47	0.48
UNIMAS	1.00	1.00	1.00	1.00	1.00	1.00
UMS	0.68	0.69	1.00	1.00	0.96	1.00
UPSI	1.00	1.00	0.97	0.98	0.73	0.77
UiTM	0.67	0.67	0.70	0.75	0.67	0.76
UDM	N/A	N/A	0.97	1.00	0.39	0.46
UMT	0.94	1.00	1.00	1.00	1.00	1.00
USIM	0.26	0.26	0.32	0.34	0.30	0.35
UTHM	0.45	0.56	0.45	0.45	0.35	0.37
UTeM	0.31	0.31	0.31	0.31	0.35	0.37
UMP	0.42	0.43	0.42	0.45	0.36	0.43
UniMAP	0.41	0.41	0.47	0.49	0.73	0.77
Efficient	5	6	7	8	6	7
Average	0.72	0.74	0.79	0.80	0.72	0.74

Performance of public universities in Malaysia between 2006 and 2008 based on DEA evaluation via Hybrid returns to scale with trade-off (HRSTO) and Hybrid returns to scale without trade-off (HRS)

The proposed HRSTO is slightly more discriminating than the HRS without trade-off (HRS). This is identified by taking into account the customary efficiency measures generated by the DEA models including individual efficiency scores, average efficiency scores and count of efficient universities given by the two models and presented as Table 4.6. Both give exactly the same score of efficiency for 11 universities in 2006, 9 universities in 2007 and 6 universities in 2008. But when they give inconsistent scores, mostly, HRSTO gives 1-3% smaller individual scores than HRS for the three years. In fact, not even one university is awarded a bigger efficiency score when trade-offs are imposed into HRS formulation, indicating a further increased in the discriminatory power of DEA assessments. Therefore, by restricting the weights permissible in the HRS model, not only DEA identifies fewer universities as efficient but awards smaller scores for each. The subsequent Figures 4.9 and 4.10 sum up the important findings presented in the foregoing Table 4.6.

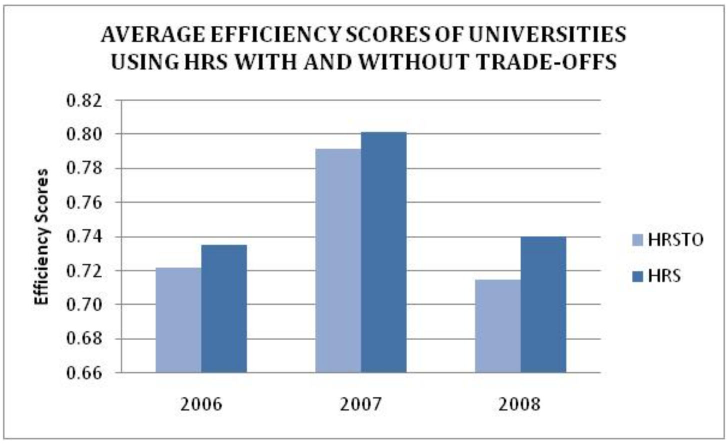
Figure 4.9: Count of Efficient Public Universities in Malaysia between 2006 and 2008 Using HRSTO and HRS



Count of efficient public universities in Malaysia between 2006 and 2008 as identified based on DEA evaluation via Hybrid returns to scale with trade-off (HRSTO) and Hybrid returns to scale without trade-off (HRS)

Figure 4.9 indicates that the count of efficient university identified by HRS with and without trade-offs is only different by 1 university every year. Figure 4.10 shows that the discrepancy between the mean efficiency scores for 2006 until 2008 given by HRSTO and HRS is only 1-2%. Therefore, an empirical evidence is now given to support the fact that the trade-offs being employed is practically undemanding in consonance with its basic theoretical concept (please refer to Section 3.4.3.2 on Trade-off approach in chapter *Methodology* for a more detail discussion on this concept). Also it supports HRS notion of *selective proportionality* which by itself enhances the discriminatory power of DEA assessments (please refer to Section 3.4.3.1 on HRS model in chapter *Methodology* for a more detail discussion on this concept).

Figure 4.10: Average Efficiency Scores of Public Universities in Malaysia between 2006 and 2008 Using HRSTO and HRS



Average efficiency scores of public universities in Malaysia between 2006 and 2008 as identified based on DEA evaluation via Hybrid returns to scale with trade-off (HRSTO) and Hybrid returns to scale without trade-off (HRS)

Information provided thus far justifies that escalating restriction in HRS formulation via Trade-off approach gives the most stringent DEA assessment framework. As always, models are being compared and contrasted by focusing on the count of universities rated as efficient, the efficiency scores of individual universities and the average scores on annual basis. Moreover, there is always very strong consistency in the classification of efficient universities made by HRSTO with the other DEA models. The optimism is further reinforced by the results indicating that for every university awarded a score greater than 90% by HRSTO in between 2006 and 2008; it is also identified to be fully efficient by both VRS and CRS; except for once but insignificant for 2007 when UTM is given CRS efficiency score of 98% and VRS efficiency score of 100%.

4.4.3. Sensitivity of Efficiency Scores with Respect to Weight Restriction Specifications

In theory, the broader the weight bounds are selected, the weaker the discriminatory power of a DEA assessment. For the proposed HRSTO model, weight bounds have been specified in terms of production trade-offs that have been derived based on the observed performance of existing *Research Universities* in Malaysia. This is because those institutions are regarded by the Malaysian Government and the public as models of the best practice. The lowest observed values are selected to define lower bounds while the highest observed values are selected to be the upper bounds.

For the purpose of examining the influence of different intensity of weight restrictions on the discriminatory power of HRSTO, sensitivity analysis is conducted by comparing HRSTO evaluation against HRS and HRSTO7. HRS is a DEA model using HRS technology without trade-offs and is chosen to represent unbounded or the broadest weight spectrum among the 3 models. The intermediary model, called HRSTO7, has a broader weight bounds than HRSTO which are specified based on the performance of all public universities in Malaysia. In particular, for every unit change in STAFF, concurrently the effect on student enrolments will be within the range of (i) 5-25 units for UG students; (ii) 0.05-4 units for MS students; and (iii) 0.01-1 unit for PhD students. On the other hand, relatively the narrowest weight bounds are imposed by HRSTO. According to HRSTO, for every unit change in STAFF, concurrently the effect on student enrolments will be within the range of (i) 7-14 units for UG students; (ii) 1-4 units for MS students; and (iii) 0.5-1 unit for PhD students.

Table 4.7: Sensitivity of HRSTO to Different Sets of Weight Restrictions

HEIs	2006			2007			2008		
	HRS	HRSTO7	HRSTO	HRS	HRSTO7	HRSTO	HRS	HRSTO7	HRSTO
UM	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USM	1.000	1.000	1.000	0.927	0.918	0.918	0.837	0.832	0.828
UKM	0.826	0.826	0.826	0.769	0.764	0.764	0.743	0.736	0.732
UPM	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
UTM	0.751	0.733	0.733	0.967	0.967	0.963	1.000	1.000	1.000
UUM	0.867	0.860	0.860	1.000	1.000	1.000	1.000	1.000	1.000
UIAM	0.730	0.730	0.730	1.000	1.000	1.000	0.476	0.475	0.475
UNIMAS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
UMS	0.686	0.683	0.683	1.000	1.000	1.000	1.000	1.000	0.958
UPSI	1.000	1.000	1.000	0.984	0.979	0.965	0.773	0.773	0.735
UiTM	0.667	0.667	0.667	0.750	0.735	0.704	0.762	0.745	0.667
UDM	N/A	N/A	N/A	1.000	1.000	0.973	0.458	0.444	0.391
UMT	1.000	1.000	0.940	1.000	1.000	1.000	1.000	1.000	1.000
USIM	0.263	0.258	0.258	0.338	0.329	0.319	0.351	0.339	0.296
UTHM	0.561	0.446	0.446	0.450	0.449	0.449	0.366	0.366	0.352
UTeM	0.307	0.305	0.305	0.309	0.309	0.309	0.366	0.352	0.352
UMP	0.431	0.424	0.424	0.451	0.439	0.416	0.428	0.414	0.359
UniMAP	0.410	0.406	0.406	0.490	0.486	0.467	0.765	0.756	0.730
Efficient	**6**	**6**	**5**	**8**	**8**	**7**	**7**	**7**	**6**
Average	**0.735**	**0.726**	**0.722**	**0.802**	**0.799**	**0.791**	**0.740**	**0.735**	**0.715**

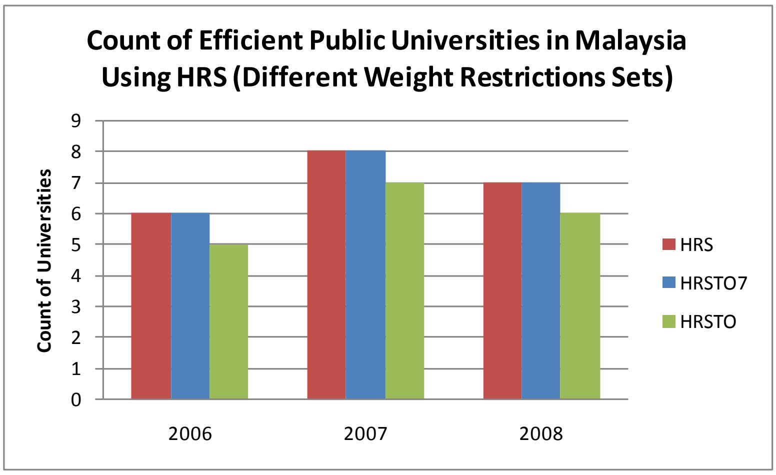
The effects of different specifications of weight restrictions on the discriminatory power of the proposed Hybrid returns to scale with trade-off (HRSTO) model

Table 4.7 sums up the measures indicative of the effects of different spectrum of weight bounds imposed in the formulation of HRSTO on DEA evaluation of all Malaysian public universities. It is evident that despite about tripled width discrepancy of the weight ranges that are imposed by HRSTO7 and HRSTO in defining the effects of change in STAFF on student enrolments; its discriminatory power, particularly on this data set, remains reasonably strong[48]. This can be attributed to the conceptualisation of HRSTO model in terms of its definition of *selective proportionality* and specification of

[48] For every unit change in number of STAFF, concurrently the effect on student enrolments will be within the range of (i) 5-25 units according to HRSTO7 while 7-14 units according to HRSTO for UG students; (ii) 0.05-4 units according to HRSTO7 while 1-4 units according to HRSTO for MS students; and (iii) 0.01-1 unit according to HRSTO7 while 0.5-1 unit according to HRSTO for PhD students

trade-off relationships. For every year from 2006 until 2008, as the width of the weight bounds considerably decreased for HRS, HRSTO7 then HRSTO, the count of efficient universities is only reduced by 1 university and the average efficiency scores is only reduced by less than 1%. With regard to individual score of efficiency, consistent scores are given by HRSTO7 and HRSTO for 2006, average of 1% smaller scores are given by HRSTO than by HRSTO7 for 2007, and average of 2% smaller scores are given by HRSTO than by HRSTO7 for 2008. Within the period, in no occasion did HRSTO give a score higher than HRS or HRSTO7 while every university identified as efficient by HRSTO is also regarded as efficient by both HRS and HRSTO7 models. In fact, a university only need to attain at least 95% HRSTO efficiency score to be regarded as 100% efficient by either HRS or HRSTO7. This implies that the proposed HRSTO model results in an increased rigidity of DEA assessment thus consistent with the well known effect of narrower weight bounds on any evaluation.

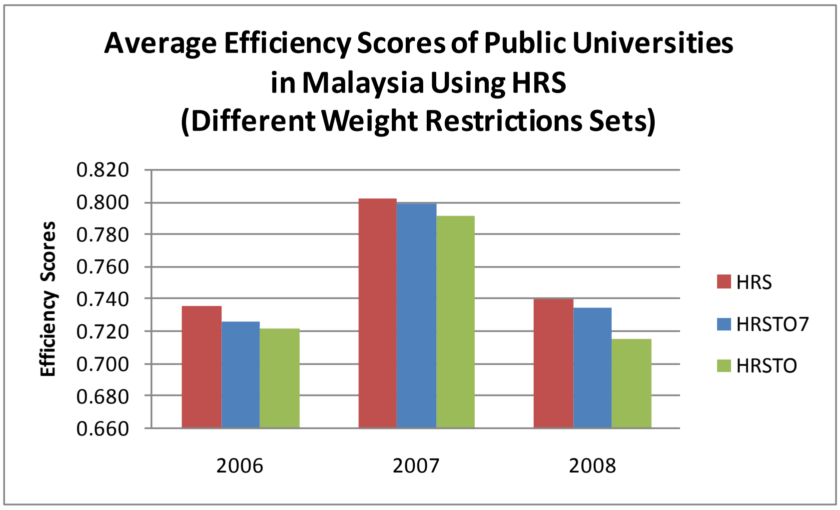
Figure 4.11: Count of Efficient Public Universities in Malaysia between 2006 and 2008 Using Different Weight Restrictions for HRSTO



The effects of different specifications of weight restrictions of the proposed Hybrid returns to scale with trade-off (HRSTO) model on the count of efficient public universities in Malaysia (2006 and 2008)

Both of figures 4.11 and 4.12 emphasise using graphical presentation on the insignificant loss of the discriminatory power of HRSTO when the width of its weight bounds is broaden. Therefore it could be concluded that the proposed HRSTO model is rather robust to a varied width of weight restrictions that it could satisfactorily maintain the strength of its discriminatory power. This also provides empirical support that HRSTO model should be a practical and reliable PMS for university appraisals that need to accommodate various local policies and standard practice.

Figure 4.12: Average Efficiency Scores of Public Universities in Malaysia between 2006 and 2008 Using Different Weight Restrictions for HRSTO



The effects of different specifications of weight restrictions of the proposed Hybrid returns to scale with trade-off (HRSTO) model on the average efficiency scores of public universities in Malaysia

4.5. Comparison of Evaluation Perspectives of MyRA, SETARA and HRSTO

At present, *Malaysia Research Assessment System* (MyRA) and *Rating System for Malaysia Higher Education* (SETARA) are the two PMS being administered by MOHE to evaluate, monitor and enhance the performance of HEIs in Malaysia. MyRA is a rating instrument to appraise public and private HEIs' performance in research related aspects or particularly in research and developments and commercialisation activities

(R&D&C). Therefore, HRSTO complements MyRA by providing an evaluation of research performance from a different perspective. In other words, whilst HRSTO evaluates research efficiency from an operational viewpoint, MyRA evaluates research efficiency from an administrative viewpoint. Nevertheless, HRSTO quantifies a university's efficiency in joint activities of research and teaching, and gives 100% relative efficiency score for its excellence in managing resources for both activities. MyRA determines a university's efficiency by focusing on research activity only and acknowledges its research excellence by presenting *Research University* award. It is, thus, essential to emphasise that, given the limited similarity in the point of evaluation focus, the comparability of assessments made via HRSTO and MyRA is restricted to the consistency in acknowledgment of performance excellence as accredited via having RU status in setting benchmark practice for HEIs in Malaysia.

On the other hand, SETARA evaluates the effectiveness of Undergraduate teaching and learning activities from an operational perspective, but limited to the assessment on the criteria belonging to literal components of a transformation activity namely inputs, process and outputs only. Hence, HRSTO complements SETARA that examines teaching related criteria characterising such transformation activity by further looking into the effectiveness of the process in terms of university capability to produce maximum teaching outputs from the teaching inputs currently consumed. Both models report a university's performance in the form of numerical scores. However, HRSTO focuses on the efficiency in teaching both Undergraduate and Postgraduate programmes, whilst SETARA only focuses on the teaching of Undergraduate programmes. Therefore, the scores are not meaningfully equivalent due to the difference in their evaluation focuses[49]. In short, HRSTO is a single model that bridges MyRA and SETARA by providing a performance evaluation of Malaysian HEIs in a relatively more comprehensive view considering HRSTO jointly evaluates the two primary activities of universities. Note that, MyRA and SETARA were first implemented in 2007 using 2006 data. This is in consistent with the study period being examined and reported in this thesis that uses data for 2006 until 2008.

Table 4.8: 2006 Performance of Public Universities in Malaysia Using SETARA 2007 Evaluation

HEIs	SETARA 2007	
	2006	
UM	0.87	Excellent
USM	0.58	Good
UKM	0.63	Good
UPM	0.68	Excellent
UTM	0.52	Good
UUM	0.39	Good
UIAM	0.63	Good
UNIMAS	0.46	Good
UMS	0.47	Good
UPSI	0.43	Good
UiTM	0.63	Good
UDM	0.08	Satisfactory
UMT	0.40	Good
USIM	0.35	Good
UTHM	0.44	Good
UTeM	0.32	Satisfactory
Efficient		**2**
Average	**0.49**	

According to HRSTO, UM, UPM and UNIMAS remain excellent since 2006 through 2008 thus make the excellent benchmark practice for others. However, MyRA acknowledges instead UM, USM, UKM and UPM as the benchmark public universities for the same years. Although not directly comparable, SETARA identified only UM and

[49]Only scores for SETARA 2007 that reports universities' performance in 2006 is available during data the collection period which was conducted in 2009

UPM as excellent universities. This indicates that UM and UPM are truly very good benchmark institutions as they are both selected by the 3 methods as excellent even from different viewpoints of performance evaluation. Further, HRSTO identifies that UM is the best as it outperforms UPM in terms of its frequency of being considered as a significant reference peer. In fact, UM is at least once enumerated to determine output expansion targets for more universities including UTM, UIAM, UiTM and UMT between 2006 and 2008[50]. In contrast, the strength of UPM as a benchmark university is lesser that it is at least once enumerated as reference peer only for USM, UKM and UTM.

Inconsistent evaluation on the reputation of USM and UKM as benchmark universities is given between MyRA and HRSTO. Even though HRSTO does recognize USM as a very good institution, it does not regard it as continuously efficient university except for once in 2006. Its efficiency score is 92% in 2007 but only 83% in 2008. For USM, UPM is consistently suggested as its best role model. Nonetheless, UKM is only regarded as an above-average university. It gains efficiency rate of 83% in 2006, 76% in 2007 and 73% in 2008. The best role model for UKM is consistently identified to be UPM while the second best model is UUM. In addition, UNIMAS is another excellent university from HRSTO perspective. It becomes benchmark for at least once to universities such as UKM, UIAM, UPSI, UiTM, UDM, UMT, USIM, UTHM, UMP, and UniMAP.

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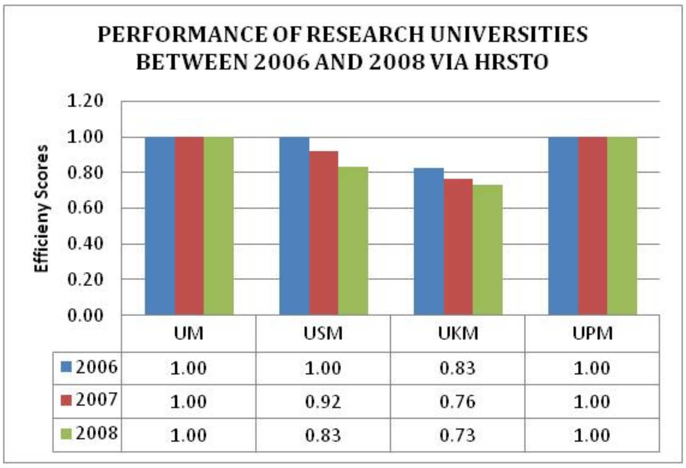
[50]Disregarding the minimum of 10% significant of influence as a reference peer identified by DEA; UM is the significantly more frequently cited university as a reference peer and is the role model for more universities compared to the currently reported universities as the “significant role models”. This is because, there are many instances when UM was suggested as a reference peer but the influence is mostly about 1% only which is deemed not significant enough to be cited as a role model

In addition, HRSTO, VRS and CRS agree that UM, UPM and UNIMAS are continuously efficient universities throughout the years. Even though USM, UUM and UMT are not mutually regarded as efficient, they are persistently rated as very good and given scores greater than 80%, if not 100%. Further, identical pattern of *Research Universities'* performance has been identified by the three DEA models under the different technological assumptions. Both UM and UPM are, in agreement, continuously rated as efficient universities from 2006 through 2008. USM is regarded by them as fully efficient in 2006 but about 93% efficient in 2007 and only about 84% efficient in 2007. UKM is identified as worse than USM that it is given varied scores but middling at corresponding models' sample mean efficiency scores for the same years under examination. As an example, Figure 4.5 gives a graphical summary of the existing 4 *Research Universities'* performance from the perspective of HRSTO.

Figure 4.13: Average Efficiency Scores of Research Universities between 2006 and 2008 Using HRSTO



Average efficiency scores of research universities in Malaysia between 2006 and 2008 as identified based on DEA evaluation via the proposed Hybrid returns to scale with trade-off (HRSTO)

To summarise, the efficiency measures that have been analysed hitherto concluded an alarming observation that, only 50% of the *Research Universities* are truly efficient from DEA perspective and those inefficient (USM and UKM) are reported by each DEA model as experiencing regress in performance between 2006 and 2008.

4.6. Conclusion

The empirical support has now been given on the merits of employing the proposed HRSTO as DEA framework on evaluating the performance of public universities in Malaysia. Despite the small observation set of only 18 institutions, the proposed model has been proven to be well discriminating. 6 variables have been considered and differentiated between those with and without proportional relationship among themselves. The number constitutes a-third of the current sample size. Also, 4 pairs of trade-off relationships are imposed to moderate range of acceptable compromise between proportional teaching variables. Subsequently, it is evident that HRSTO consistently results in lesser count of universities regarded as efficient and smaller efficiency scores given to the individual universities. This has improved the discriminatory power of DEA assessment on small sample.

It is argued that HRSTO is now proven to be capable of giving a better reflection of a university's performance on the hypothesis better insight of a performance is revealed when DEA correctly replicates transformation process and gives relevant performance evaluation. This is accomplished by incorporating more information associated with transformation activities of the units being assessed. The basic notion is to refine postulation of the unknown efficient boundary and impose weight restriction on the multiplier values. The additional information has been meaningfully supplemented into DEA formulation via *selective proportionality* concept of HRS and undemanding range of compromise of Trade-off. This improves the accuracy while preserving the technological gist of the resulting DEA measures. Most importantly, the proposed modification to basic DEA models is made via non-technically extensive procedure making it very user friendly.

The discriminatory power of DEA within HRSTO framework is increased by its more stringent definition of an efficient performance. The definition of efficiency is more rigid because it also takes into account the required synchronised change between selected variables and imposed range of acceptable compromise between selected variables. This is proven by the consistency in recognition of efficient units made by HRSTO with the different DEA models. It indicates the distinction quality of efficient units as recognized by HRSTO is well supported by CRS, VRS (with and without trade-offs) as well as by HRS without trade-offs. Despite significant discrepancy in efficiency scores, reasonably consistent average inefficiency scores allocated by the models among each other. Therefore rigorousness of HRSTO evaluation is more demanding on efficient units but less demanding on inefficient units which is plausible in search for high quality practice.

In comparison to VRS, it is believed that HRS technology is better able to approximate the unknown efficient educational technology. In practice, within a group of variables characterising academe, some of them do change according to changes in some of them. Hence, information on proportionality relationship, which is ignored by VRS, is deemed to be relevant in a performance evaluation. Further, HRS formulation is very flexible to be adopted for any dataset because it can accommodate the prevailing relationship between variables, be it fully proportionally related (CRS) or partially proportionally related (HRS) or even non-proportionally related (VRS) to each other. For that reason, HRSTO offers several advantages. For methodological interest, it increases the discriminatory power of DEA on small sample. For theoretical interest, it enables extra information be incorporated into an appraisal while preserving the technological gist of DEA assessment such that the resulting measures are always producible and sensible. For empirical interest, it enriches choice of frameworks for evaluating academic institutions via DEA technique. For practical interest, it makes performance measurement relevant and meaningful to the end users' priority and concerns. Finally, the proposed DEA framework offers complementary perspective to, and complements the focus of, existing PMS in Malaysia. Hence, HRSTO is constructive in supports of quality management agendas for HEIs.

CHAPTER 5

CONCLUSION

5.1. Introduction

It was the author's curiosity to contribute to Data Envelopment Analysis (DEA) literature as well as to Malaysian tertiary academe in pursuing the doctoral degree via this documented thesis. The motivating goals were to propose a DEA framework that could unveil a better insight of a unit's performance and to offer an evaluation system that is complementary to the existing performance measurement systems (PMS) of Malaysian public universities. A complementary PMS which is more integrated and comprehensive that enhances evaluation, understanding and appreciation of the performance and prospective of public universities in Malaysia from different point of view. It was not suggested as a substitute but is recommended to be applied along with all the currently being used evaluation models.

5.2. Research Background

A correct conceptualisation of universities' transformation activities was argued in this study as giving a better insight of an institution performance. Generally, it was achieved by way of refining the postulation of the unknown efficient educational technology. Particularly, this was accomplished in two synchronized stages; by positing the implicit technical relationship between variables and imposing the weight restrictions on the multiplier values. It was also the research motivation to have a rigorous framework without being constrained by limited availability of observational data thus able to tackle the limitation of DEA related to dimensionality caused by small sample sizes. In doing so, contributions have been made to both, DEA and non-DEA methodologies.

From DEA methodological perspective, the proposed Hybrid returns to scale model with Trade-off (HRSTO) could be considered as a novel DEA framework. It was first proposed and tested on real-life data in this thesis. Further, it could sustain the technological gist of the resulting DEA measures when most of the earlier suggested modifications in DEA literature associated with the weight restrictions invalidate technical essence of the measures. This concern was addressed in the written review on the currently proposed extensions to basic DEA models in Section 3.4.3 of *Methodology* chapter. The model's elementary conception was that the accuracy of DEA evaluation (or discriminatory power) could be improved by increasing the restrictions in the formulation of the standard DEA models. Restriction was increased by integrating more technologically grounded information that helped refining the postulation of efficiency boundary contouring an observational data. This is necessary as the efficiency measures given by DEA assessments draw on the hypothesised efficient frontier (EF) which in reality unknown. It is worth to emphasise that the concerns of the end users were technologically acknowledged and were then translated into realistic and doable performance targets by HRSTO.

For the current case study, the necessary information to refine the postulation of EF for the public universities were deemed to be explicit DEA expression of synchronised change among proportional teaching variables and undemanding range of compromises between the teaching variables. The latter was empirically derived based on the achievements of existing benchmark universities in Malaysia. In fact, review of DEA applications on higher education institutions (HEIs) worldwide indicated that often analysts need to choose between Constant and Variable returns to scale (CRS and VRS) technologies. Thus, some end up forgoing valuable information on a disposition of relationship between variables that implicitly influence performance as well. Indeed, HRSTO valued information describing relationship that prevails between inputs and outputs selected for any DEA appraisal. By using HRSTO, it was no longer necessary to compromise between the advantages of using either CRS or VRS technology. Instead HRSTO could as well, if necessary, accommodate variable relationship as defined based upon CRS or VRS. This is because, HRSTO is a flexible framework that it could be used to model the prevailing relationship be it fully proportional (CRS), partially proportional (HRS) or non-proportional (VRS) related inputs-outputs bundles. Also, it was demonstrated that it is feasible to incorporate preferences (in terms of country-specific policies and standard practice) into a performance measurement while being practically and technologically feasible by employing the proposed HRSTO model. In support of the implementation reasons, practical and straight forward improvement strategies were being advocated. Hence, HRSTO facilitates implementation and encourages acceptance among the affected institutions.

Usually, to ensure certain level of statistical precision in DEA analysis, when the more number of variables is necessary to be considered in an evaluation, then the more number of observations is needed (Dariao & Simar, 2007, p. 2). Nonetheless, studies involving empirical applications of DEA are often constrained by limited availability of the required data and access to the intended respondents. This limits the sample size for the majority of DEA investigations. Further, there are instances where number of variables necessary to evaluate a performance is too many compared to the number of units of assessment obtainable. In this regard, HRSTO addressed this concern by providing a DEA evaluation which was proven in this thesis to be well discriminating despite it was applied on a small population of only 18 institutions using 6 variables.

On the other hand, to non-DEA methodologies, the application of HRSTO to study the performance of HEIs, or particularly Malaysian public universities in between 2006 and 2008, is a contribution. The empirical contribution was made by providing analysis of Malaysian university performance from an alternative perspective. It was believed that an efficiency measurement should be based on operational objectives and performance targets rather than focusing solely on the public expectations. HRSTO did also study inefficiency in university performance related to its productivity from an operational perspective. Analysis of performance inefficiency will reveal new aspects of performance that are worthy of weight and focus in measuring excellent performance of a university. Subsequently, it will become a useful empirical input for revising educational policies in order to enhance performance (Fried, Lovell & Schmidt, 2008).

According to Fried, *et al.* (2008), the only common basis to compare public organisations' performance is on technical efficiency. This is because they are non-profit-oriented institutions and being constrained by beyond control country-specific regulations, targets and policies that are imposed on them. Consequently, in addition to providing both qualitative and quantitative justifications for their performance, an "empirical measurement" becomes the "control mechanism" for the administration teams in supervising their performance (Fried, *et al.*, 2008, p. 15).

Today, the Malaysian Ministry of Higher Education (MOHE) applies *Malaysia Research Assessment System* (MyRA) and *Rating System for Malaysia Higher Education* (SETARA) as the official instruments to evaluate, monitor and enhance the performance of HEIs in Malaysia. The proposed HRSTO was in consonance with MyRA as both focused on the universities' performance in terms of research efficiency. However, HRSTO concurrently looked into the universities' performance in terms of teaching efficiency as well. Moreover, the performance evaluation carried out by HRSTO was from an operational perspective while MyRA was from a managerial perspective. The former recognised an excellence performance by giving 100% relative efficiency score but the latter did so by awarding *Research University* (RU) status. Given such limited similarity in the focus of evaluation, the results generated by HRSTO and MyRA were compared but restricted to the consistency in recognition of excellence performance as attributed by RU status award in terms of defining benchmark practice for others.

HRSTO was in consistent with SETARA as they both reviewed teaching efficiency and considered it as a transformation activity. Nevertheless, SETARA measures efficiency of teaching in terms of reaching certain critical levels; every criterion which is attributed to input, process or output being evaluated independent of each other and each has pre-determined threshold points to be achieved by HEIs to be considered as efficient. However, HRSTO looks deeper into the effectiveness of a university in transforming teaching inputs into teaching outputs that is HRSTO evaluates teaching variables as dependent of each other. Further, HRSTO concerned with the efficiency in teaching Undergraduate and Postgraduate programmes while SETARA only concerned with teaching Undergraduate programmes. Although both quantify performance using efficiency scores, the results are not comparable due to their different focus in evaluation. Therefore, HRSTO provides a complementary vision of university performance by providing an operational viewpoint of performance measurement model and making a more comprehensive review of university performance that also works as an integrated model of the existing instruments MyRA and SETARA. Indeed, it is necessary to treat research efficiency and teaching efficiency of a university as a part and parcel of an academic excellence rather than treating them as two independent perspectives of university performance. The justification is the fact that the two activities are simultaneously carried out by using the same bundles of resources.

5.3. Research Key Findings

5.3.1. Improved DEA Discriminatory Power via HRSTO

Application on Malaysian public universities provided the empirical supports that the proposed HRSTO model has increased the discriminatory power of DEA assessment. Evaluation conducted for 2006 considered 17 universities while for 2007 and 2008 considered 18 universities using 2 input and 4 output variables. Review indicated that HRSTO has more demanding requirements for an excellent performance yet is consistent with the other DEA models pertaining to expectation on university's general performance (as measured by average inefficiency scores).

Analyses were conducted by comparing HRSTO results against the results given by VRS and CRS models, with and without trade-offs. There are three points that worth emphasis. Firstly, every university that was identified as efficient by HRSTO was also rated as efficient by both VRS and CRS for every year without exception. Secondly, all universities that were identified to be greater than 90% efficient between 2006 and 2008 by HRSTO were regarded as fully efficient by both VRS and CRS; with the exception of UTM in 2007 which was given almost fully efficient score of 98% by CRS. Thirdly, the average inefficiency scores were fairly consistent between the three models. In fact efficiency scores given by HRSTO were very close to those given by CRS model. In brief, although both VRS and CRS models were in accordance with an outstanding performance from HRSTO's perspective, the latter was the most discriminating.

In no occasion did HRSTO give a score bigger than VRS model. The same was true when HRSTO scores were compared against CRS scores, except for once (UniMAP in 2008). According to HRSTO only 5, 7 and 6 universities were efficient in 2006, 2007 and 2008, respectively. However, VRS considered 13, 10 and 11 as fully efficient for the same years. Comparison of the annual performances demonstrated that HRSTO gave, relatively, a more reasonable overview of performance than VRS such that the reported average scores were less optimistic that they did somewhat "echo" the existence of significantly below-average performance of the few. This is because HRSTO average scores given were sensibly acceptable in comparison to universities' individual score distributions. In contrast, for 2006 for example, VRS average efficiency score was 92% indicating outstanding performance of all institutions. It was not fairly representative of the 4 inefficient universities, particularly the worst 3 namely UTeM (34%), UMS (71%) and UTHM (73%). This concludes that HRSTO is more discriminating and rigorous in its recognition of efficiency yet it is well supported by VRS and CRS models.

Evidence was also obtained in favour of the importance of the technology assumed to underlie a university's transformation activities. The customary efficiency measures generated by DEA via (a) VRS with and without trade-offs; (b) CRS without trade-offs; as well as (c) HRS with and without trade-offs were reported. It was revealed that relatively HRSTO has the greatest discriminatory power thus would be useful for formulating strategies and policies for excellent practice. Further, the small discrepancies between efficiency scores, average efficiency scores and count of efficient universities given by HRS with and without trade-offs confirmed that the suggested range of trading figures for HRSTO was technically undemanding. Both HRSTO and HRS models gave identical scores of efficiency for 11 universities in 2006, 9 universities in 2007 and 6 universities in 2008. But when their scores are different, HRSTO gave only 1-3% lesser scores than HRS while the difference in mean efficiency scores for 2006 until 2008 given by HRSTO and HRS was only 1-2%.

5.3.2. Research Universities Performance via HRSTO

HRSTO consistently concluded UM, UPM and UNIMAS as the benchmark public universities in Malaysia [51]. On the other hand, existing PMS administered by the Government, MyRA, identified instead UM, USM, UKM and UPM as the benchmark public universities and thus awarded the status of *Research University* to each [52]. Therefore, the proposed HRSTO was in agreement with MyRA only with regards to the performance of *Research Universities* UM and UPM. According to HRSTO, UM is

[51] UM is Universiti Malaya; UPM is Universiti Putra Malaysia; and UNIMAS is Universiti Malaysia Sarawak
[52] USM is Universiti Sains Malaysia; and UKM is Universiti Kebangsaan Malaysia

better than UPM in terms of the number of universities that had considered it as a reference peer.

The proposed HRSTO did not consider *Research Universities* namely USM and UKM as benchmark universities. HRSTO did identify USM as a very good institution but did not consider it as continuously efficient university other than once in 2006. Therefore, in consideration of different perspectives (HRSTO and MyRA), UM and UPM were the truly benchmark public universities in Malaysia. It is pertinent to note that even though USM and UKM were not consensually considered as efficient, they were still constantly identified as the above-average universities by HRSTO.

5.3.3. Overall Public Universities Performance via HRSTO

In 2006, 5 universities were identified as efficient by HRSTO namely UM, USM, UPM, UNIMAS and UPSI[53]. Among them, UPSI and UNIMAS were the strongest benchmark considering their efficiency score of unity and they were the 2 most frequently chosen universities as the reference peers for underperforming universities. Universities on the average were 72% efficient or 61% inefficient. There were 5 above-average and 7 below-average universities reported for the same year. The bottoms 3 were USIM, UTeM and UniMAP[54].

In 2007, there were 7 efficient universities; UM, UPM and UNIMAS maintained their efficiency into 2007 whilst UUM, UIAM, UMS and UMT managed to boost their

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[53]UPSI is Universiti Pendidikan Sultan Idris
[54]USIM is Universiti Sains Islam Malaysia; UTeM is Universiti Teknikal Malaysia Melaka; and UniMAP is Universiti Malaysia Perlis

performance and became efficient in 2007[55]. The overall performance in 2007 was the best in terms of the mean efficiency sore of 79% but the worst in terms of the mean inefficiency score of 66%. Further, all of the below-average (also the bottom 5) universities had productivity of less than 50%. They were UTeM, USIM, UMP, UTHM and UniMAP[56]. For them, ideal reference peers were the top 5 universities UMS, UNIMAS, UUM, UM and UPM. However, the strongest benchmark institutions among the top 5 were UMS, UNIMAS and UUM.

In 2008, UM, UPM, UTM, UUM, UNIMAS and UMT were the only 6 universities identified by HRSTO as fully efficient[57]. Of these, UUM and UNIMAS were the strongest and most frequently chosen as reference peers by underperforming universities. On the average, universities in this year were 72% efficient and 57% inefficient. For 2008, the overall university performance measured from efficiency perspective is not the best between the three years, but performance from inefficiency perspective was the best. The top 5 universities were UUM, UNIMAS UMT, UM and UPM. The bottom 5 universities were USIM, UTHM, UTeM, UMP and UDM[58].

In brief, employing the proposed HRSTO model to evaluate Malaysian university performance via DEA framework was proven meritorious. Not only HRSTO gave a different perspective of measuring their performance, it also gave tactical solutions that would be useful in devising implementation strategies to enhance quality and

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[55]UUM is Universiti Utara Malaysia; UIAM is Universiti Islam Antarabangsa Malaysia; UMS is Universiti Malaysia Sabah; and UMT is Universiti Malaysia Terengganu
[56]UMP is Universiti Malaysia Pahang; and UTHM is Universiti Teknikal Tun Hussein Onn Malaysia
[57]UTM is Universiti Teknologi Malaysia
[58]UDM is Universiti Darul Iman Malaysia

performance of the existing universities. The solutions include among others the feasible improvement targets to aim for, equivalent benchmark practice to replicate and specific areas of improvement to focus on. Most importantly, in quantifying the universities' current performance level and devising improvement implementation strategies, HRSTO did take into account local policies, capabilities and environment. This was accounted for by the fact that the national policies, and achieved performance of the existing public universities in the country, were observed and acknowledged in HRSTO model's conceptualisation.

5.4. Research: Ways Forward

Indeed, HRSTO is not a universal DEA framework. It is not applicable on just anything due to the need for a bundle of inputs and outputs to have *selective proportionality* relationship. In general, HRSTO is applicable for conducting relative performance appraisal on a group of units having (a) similar concept of *selective proportionality* relationship; or (b) small number of observations. Firstly, this methodology is useful when *selective proportionality* is observed. This relationship usually exists in cases where certain rates or ratios are expected between inputs and outputs such as employees need to process certain amount of outputs within a particular period. In this case, the apparent examples are in education industry such as at schools where the teachers are assigned to teach certain number of pupils; in banking industries where bank officers are to process certain number of accounts; in tourism industries such as at hotels where cleaning staff are required to service certain number of rooms; at hospitals where the doctors or nurses are supposed to treat certain number of patients; at post offices where counter staff are to serve certain number of customers; at call centres where operators are assigned to accept certain number of incoming calls. Secondly, the advantages of HRSTO methodology is particularly clear when the number of observations is small due to the imposed weight restrictions; imposition of *selective proportionality* relationship and trade-offs relationship. Although HRSTO is not specifically designed for small samples and will equally work on large samples, it would be useful on a small observational data set due to its stronger discriminatory power.

Many aspects of this initially proposed HRSTO model could be improved and be regarded as areas for future research. Among possible enhancements include, the multiplier framework for HRSTO model. At the moment, its important groundwork of the original Hybrid returns to scale (HRS) model introduced by Podinovski (2004a) has only been constructed in technological perspective or in the envelopment form. Therefore, extensive testing and further formulation with HRSTO model in value judgement or multiplier framework are required to ensure its validity and effectiveness. Undemanding developments to HRSTO consist of replicating evaluation on public universities in Malaysia but accounting for broader aspects of performance such as to add quality indicators and to consider inputs other than the primary inputs (academic staff and research grant) into HRSTO appraisal. The quality of graduates produced in terms of academic achievements and employability could also be included as another aspect of performance to be measured using HRSTO in the future. Further, it is the author’s plan to further test on the robustness of this model pertaining to the curse of dimensionality on small samples by manipulating number of assessment units and inputs-outputs variables in the assessments in the near future.

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APPENDICES

Appendix 1: Input and Output Variables in Evaluation of University Departments Using DEA (Part 1)

PAPER	**Madden, G., Savage, S. & Kemp, S. (1997)** Measuring Public Sector E: A Study of Economics Depts at Australian Univs. *Education Economics,* 153-167
MODEL	Input oriented DEA; to see the impact of 1987 HE policy reforms on T&R @economics depts (new univ n funding arrangements)
DMU	24 Australian Univ Econs depts using data for 1987 and 1991 (total 29 universities but 5 provided incomplete data)
INPUTS	1) No of teaching staff 2) No of research staff
OUTPUTS	1) Teaching output: No of graduating UG students 2) Teaching output: No of graduating PG students 3) Research Output 1: Publication count in selected 93 core economies journals 4) Research Output 2: Publication count in other, non-economic, journals 5) Research Output 3: Publications in the form of authored books 6) Research Output 4: Publications in the edited books including editorial content
PAPER	**Johnes, J. n Johnes, G. (1995)** Research Funding n Performance in UK Univ Depts of Econs: A Frontier Analysis. Economics o*f Education Review* , 14, 301-314
MODEL	DEA technical efficiency of the economics departments as producers of research * focusing on the role of external funding of research as an input into the research process
DMU	36 UK University Economics Depts in 1989
INPUTS	1) Teaching/research and research-only staff 2) Per-capita research grants 3) UG student load
OUTPUTS	1) Papers n letters in academic journals 2) Articles in professional n popular journals 3) Authored n edited books 4) Published works 5) Edited works
PAPER	**Beasley, J. E. (1995)** Determining Teaching n Research Efficiencies. The Journal of Operational Research Society, 46(4), 441-452
MODEL	Modified Output maximixation DEA model
DMU	Chemistry and Physics Departments at 52 UK universities using 1986/87 academic year data
INPUTS	1) General expenditure (majority is on salaries) 2) Equipment expenditure 3) Research income; corrected for depts' size (research income per academic or $ of general expenditure)
OUTPUTS	1) No of UG students 2) No of taught PG students 3) No of research PG students 4) Research income; In terms of actual monetary amount as proxy for quantity for research output (which not yet available) 5) If a department is rated STAR (outstanding) at research 6) If a department is rated A+ (above average) at research 7) If a department is rated A (average) at research 8) If a department is rated A- (below average) at research

Appendix 2: Input and Output Variables in Evaluation of University Departments Using DEA (Part 2)

PAPER	**Johnes, G. n Johnes, J. (1993)** Measuring the Research Performance of UK Economics Dept: An Appli. Of DEA. *Oxford Economics Papers* , 45, 332-347
MODEL	Comparison of Efficiency indices across alternative specifications
DMU	36 UK University Economics Depts in 1984-1988
INPUTS	1) Teaching/research and research-only staff 2) Per-capita research grants 3) UG student load
OUTPUTS	1) Papers n letters in academic journals 2) Articles in professional n popular journals 3) Authored n edited books 4) Published works 5) Edited works
PAPER	**Beasley, J. E. (1990)** Comparing University Departments. *International Journal of Management Science* , 18(2), pp. 171-183
MODEL	Output oriented DEA model using CRS
DMU	Chemistry and Physics Departments at 52 UK universities using 1986/87 academic year data
INPUTS	1) General expenditure (majority is on salaries) 2) Equipment expenditure 3) Research income; corrected for depts' size (research income per academic or $ of general expenditure)
OUTPUTS	1) No of UG students 2) No of taught PG students 3) No of research PG students 4) Research income; In terms of actual monetary amount as proxy for quantity for research output (which not yet available) 5) If a department with UGC research rating STAR 6) If a department with UGC research rating A+ 7) If a department with UGC research rating A 8) If a department with UGC research rating A-
PAPER	**Tomkins, C. and Green, R. (1988)** An Experiment in the Use of Data Envelopment Analysis for Evaluating Efficiency of UK University Departments of Accounting. International Journal of Management Science, 18(2), pp. 171-183
MODEL	6 DEA models to test the consistency of DEA efficiency scores when using different sets of variables
DMU	20 Accounting departments using 1984 and 1985 data
INPUTS	DEA 1: No of Full time staff DEA 2: No of Full time staff DEA 3: No of Full time staff; Non-staff expenditure DEA 4: Academic Salaries; Non-staff expenditure DEA 5: Academic Salaries; Non-staff expenditure DEA 5: Total expenditure
OUTPUTS	DEA 1 (4xOutputs): No of Undergraduate; No of Research Postgraduate; No of Taught Postgraduate; Total income DEA 2 (5xOutputs): No of Undergraduate; No of Research Postgraduate; No of Taught Postgraduate; Total income; Publication count DEA 3 (5xOutputs): No of Undergraduate; No of Research Postgraduate; No of Taught Postgraduate; Total income; Publication count DEA 4 (5xOutputs): No of Undergraduate; No of Research Postgraduate; No of Taught Postgraduate; Total income; Publication count DEA 5 (7xOutputs): No of Undergraduate; No of Research Postgraduate; No of Taught Postgraduate; Publication count Research council income; Other research income; Other income DEA 6 (7xOutputs): No of Undergraduate; No of Research Postgraduate; No of Taught Postgraduate; Publication count Research council income; Other research income; Other income

Appendix 3: Input and Output Variables in Evaluation of Universities Using DEA (Part 1)

PAPER	Johnes, J. and YU, L. (2008) Measuring the Research Performance of Chinese HEIs using DEA, *China Economic Review* , 19, 679–696
MODEL	4 DEA models for different sets of variables used in the assessment + Descriptive Stats used to present findings
DMU	109 Chinese regular universities
INPUTS	Input variables reflect staff, students, capital and resources: 1) STAFFT = Staff Time = FT Staff to student ratio 2) STAFFQ = Quality of staff input reflected by % of faculty => AP position 3) PG = no of doctoral students because research can be produced in associations with PGs => input to research *= measure the proporotion of all students who are PG* 4) FUNDS = research funding measured using research expenditure 5) BOOKS = capital input = library books derived from unweighted ave based on total n per student no 6) BLDG = capital input = the area of the buildings
OUTPUTS	Output variables measure the impact and productivity of research: 1) RES = total number of research publications to capture the total volume of research activity 2) RESPP = research publications per member of academic staff also included to reflect research productivity across the HEI 3) REPUT = the prestige of HEIs *= measures HEI's academic reputation perceived by survey respondents incl academy fellows,scholars,education experts,presidents*
PAPER	**Castano, M. C. N. and Cabanda, E. C. (2007)** Performance Evaluation of the Efficiency of Philippines Private Higher Education Institutions: Application of Frontier Approaches *International Transactions in Operational Research* , 14, 431-444
MODEL	DEA-Malmquist Indices + SFA: DEA Output-oriented
DMU	30 Universities within a country
INPUTS	1) No of full time faculty members 2) Property, plant, equipment = Tangible assets used for more than 1yr in the process 3) Operating expenses = COF/Depreciation
OUTPUTS	1) Student enrolment per year = resource users of educational instituitions 2) No of Graduates per year = total graduates/yr of each school 3) Total revenue = inflows of assets, including income from tuition and fees
PAPER	**Johnes, J. (2006a)** DEA n Its Application to the Measurement of **Efficiency in HE**, ***Economics of Education Review*** , 25, 273-288
MODEL	DEA => measures Technical n Scale E - existing relevant entensions to basic DEA discussed
DMU	More than 100 HEIs in England using data for the year 2000/01
INPUTS	1) UGQUAL = Total no of FTE UG students studying for a 1st degree multiplied by the ave. A level pts for 1st yr FT UG students 2) PG = Total no of FTE postgraduate students 3) STAFF = Total no of FT academic staff for teaching or teaching and research or research only purposes 4) CAPITAL = Total depreciation and interest payable in £ 5) LIBCOMP = Total expd. on central libraries n info services & central computer n computer networks excl. lecturer costs n depr in £ 6) ADMIN = Expd. on central admin n central services excl. academic staff costs and depr in £
OUTPUTS	1) GRADQUAL = Total no of 1st degrees awarded weighted by degree classification *GRADQUAL= ¼ (no of firsts*30)+(no of upper 2nd*25)+(no of lower 2nd*20)+(no of 3rd*15)+(no of unclassifieds*10)* 2) POSTGRAD = Total no of higher degrees awarded (includes doctorate n other higher degrees) 3) RESEARCH = Value of the recurrent grant for research awarded by the HEFCE in £

Appendix 4: Input and Output Variables in Evaluation of Universities Using DEA (Part 2)

PAPER	**Fernando, B. I. S. and Cabanda, E. C. (2007)** Measuring Efficiency and Productive Performance of Colleges at the University of Santo Tomas: A Nonparametric Approach International Transactions in Operational Research, 14, 217-229
MODEL	DEA-Malmquist Indices; Input-oriented VRS, Multi-stage DEA model to evaluate with financial resources and efficeincy objectives
DMU	13 Colleges within a university; efficiency & productivity change
INPUTS	1) Total FTE Academic Staff 2) Total FTE Non-Academic Staff 3) Operating Expenses # directly attributable to the colleges; utilities, maintenance, operating costs # excluding salary & wages
OUTPUTS	1) Total FTE Students enrolled 2) Total Graduate degrees conferred 3) Total revenue/income per college # Educational outputs of these sample colleges are similar and homogenous in all aspects = Faculty members paid based on their ranks (not their degree qualifications) = All students charged tuition fees based on the same rate per unit => these colleges generate the same income/semester n only differ depending on no of enrollees # Total revenue/income used instead of research because in UST not all sample colleges incorporated research in their prog # For the purpose of measuring productivity the revenue/income may be considered as 1 most commonly used variable to masure if orgn is maximizing its resource to the fullest
PAPER	**Johnes, J. (2006b)** Measuring Teaching E in HE: An application of DEA to economics graduates from UK Universities 1993, *EJOR* , 174, 443-456
MODEL	DEA efficiency decomposed into 2 components: attributable to the university and attributable to the student himself The main study purposes: To compare the results of aggregate and individual level DEAs, and To assess the usefulness to managers of the information derived from an individual level DEA
DMU	2547 Economics graduates from UK Universities in 1993 - to avoid potential problems arising from a cross-subject comparison
INPUTS	1) Individual Data a) ASCORE: Score based on best 3 A levels or equivalent (i.e. 2 AS levels = 1 A level) *For A levels: A = 10; B = 8; C = 6; D = 4; E = 2* *For AS levels: A = 5; B = 4; C = 3; D = 2; E = 1. Note that duplicate subjects are not counted* b) GENDER: 1 = female, 0 = male c) SCHOOL: 1 = did not attend an independent secondary school; 0 attended an independent secondary school 2) Department Data a) AVASCORE = Mean value of ASCORE b) %FEM = Percentage of graduates who are female c) %NOTIND = Percentage of graduates who did not attend an independent school
OUTPUTS	1) Individual Data a) DEGMARK: Pass/other = 38, 3rd = 45, lower 2nd = 55, upper 2nd = 65, 1st = 75 b) DEGVALUE: Pass/other = 2.00, 3rd = 2.20, lower 2nd = 2.30, upper 2nd = 2.45, 1st = 2.85 (weights from Mallier & Rodgers, 1995) 2) Department Data a) AVVALUE = Mean value of DEGVALUE b) AVMARK = Mean value of DEGMARK c) %121 = Percentage of graduates with 1st or upper second

Appendix 5: Input and Output Variables in Evaluation of Universities Using DEA (Part 3)

PAPER	**Johnes, J. (2006c)** Measuring Efficiency:Comparison of Multilevel Modelling and DEA in the Context of HE, *Buletin of Economics Research* ,58(2),75-104
MODEL	DEA n Multilevel Modelling (MLM)
DMU	A data set of 54,564 graduates from UK universities in 1993
INPUTS	1) A level score 2) Age in 1993 3) Categorical explanatory variables: # F/M, Married/Single, UK/Otherwise, PT/FT, Home/Not, Halls of Residence/Not, Attended Independent School prior Univ/Not, Attended Comprehensive School prior Univ/Not,
OUTPUTS	1) UG degree Classifications # No Degree; Pass; 3rd Class Honours; Lower 2nd Class Honours; Upper 2nd Class Honours; 1st Class Honours
PAPER	**McMillan, M.I. and Chan, W.H. (2006)** University E: Comparison n Consolidation of Results from Stochastic n Non-stochastic Methods, Education Economics, 14 (1), 1-30
MODEL	DEA n SFA used to calculate E scores of Canadian universities
DMU	45 publicly funded Canadian Universities for academic year 1992-93
INPUTS	TOTAL EXP = Total operating expenditure and sponsored research expenditure
OUTPUTS	1) UG SCI = FTE UG enrolment in sciences 2) UG OTHER = FTE UG enrolment in other programmes 3) MASTER'S = FTE enrolment in master's level programmes 4) DOCTORAL = FTE enrolment in doctoral level programmes 5) RESEARCH$ = Total sponsored research expenditure 6) AVSALARY = Average salary and benefit for faculty 7) %SSHRC = Number of active SSHRC & CC grants as % of eligible faculty 8) %MRCNSE = Number of active MRC & NSERC grants as % of eligible faculty 9) DV = Dummy variable for no PhD programme
PAPER	**Othman Joumady and Catherine Ris (2005)** Performance in European HE: A Non-parametric Production Frontier Approach, *Education Economics* , 13 (2), pg 189-205
MODEL	DEA - Technical E
DMU	Large sample of young graduates interviewed 3 yrs after graduation from 209 HEIs among 8 European countries
INPUTS	1) Students' Entry characteristics: *Entry qualification, Entry Grade* 2) Study Provision 1: *Teaching Characteristics, Libraries Equipment n Stocking, Supply of Teaching Material, Technical Equipments* *Course Content of Major, Practical Emphasis of Teaching n Learning* 3) Intensity of Job Search: *No of Job Seeking Modes Used by Graduates, Duration of Job Search* 4) Study Provision 2: *Provision of Work Placements, Importance of Work Experience in HEI*
OUTPUTS	1) Level of Vocational competencies acquired 2) Level of Generic competencies acquired 3) Vertical Vocational competencies match 4) Vertical Generic competencies match 5) Horizontal competencies match

Appendix 6: Input and Output Variables in Evaluation of Universities Using DEA (Part 4)

PAPER	**Taylor, B. and Harris, G. (2004)** Relative Efficiency Among South African Universities: A Data Envelopment Analysis. Higher Education, 47, 73-89
MODEL	DEA; 7 separate efficiency models + 1 consolidated model
DMU	10 from 21 public universities
INPUTS	1) Total expected/adjusted expenditure 2) Capital employed 3) No of students 4) No of staff
OUTPUTS	1) Academic qualifications completed = degrees, diplomas, certificates 2) Research outputs = books, articles, conference proceedings, patents/licenses, research income
PAPER	**Flegg, A.T., Allen, D.O., Field, K. & Thurlow, T.W. (2004)** Measuring the Techl E of British Univs: A Multi-period DEA, *Education Economics,* 12(3), 231-249
MODEL	DEA used to measure techl E + Malmquist appr to distinguish between changes in TE n intertemporal shifts in the E frontier
DMU	45 British Universities in the period of 1980/81-1992/93
INPUTS	1) No of academic n academic-related staff - PT staff given weight of 0.5 2) No of FTE UG students = FTE student load 3) No of FTE PG students = research + taught programmes *# 2 Business Schools excluded from the analysis becausedon't have UG* 4) Aggregate departmental expd *= total deptl recurrent expd (other than that on academic n academic-related staff) + deptl equipt expd*
OUTPUTS	1) Income from research n consultancy *# likely to reflect the perceived quality n quantity of research o/p* *# should provide more up-to-date picture of research o/p than publications n citations due to considerable time lag* 2) No of UG degrees awarded, adjusted for Quality *# taking quality into a/c by multiplying No of degree awarded * Proportion of students gaining 'good' (1st) degree* 3) No of PG degrees awarded = Masters degrees + Doctorates
PAPER	**Abbott, M. and Doucouliagog, C. (2003)** The Efficiency of **Australian Universities**: A DEA, ***Economics of Education Review*** , 22, 89-97
MODEL	DEA to estimate **technical n scale E** of Australian university system in 1995 # To test *sensitivity E scores to i/p used ==> combinations of i/p n o/p used*
DMU	36 Australian government universities (all) incorporated into the Unified National System => from same set of general regulation
INPUTS	1) Total no of FTE academic staff 2) No of FTE non-academic staff (gen n admin staff, bldgs n grounds, student services, delivery support staff) *# they administer students, teaching n research staff; generally facilitate T&R process* 3) Expenditure on all other inputs other than labour *# expd on energy, non-salary academic n admin services, bldgss n grounds, libraries, student services* 4) The value of non-current assets *# a rough proxy for the university's capital stock*
OUTPUTS	1) Measures of Teaching outputs: a) EFTS = No of FTE Students b) No of PG n UG degrees enrolled c) No of PG degrees conferred d) No of UG degrees conferred 2) Measures of Research outputs: a) Research Quantum Allocation that each univ receives

Appendix 7: Variables Employed in HRSTO with Supporting DEA Papers

VARIABLE		DEFINITION/SAMPLE IN DEA LITERATURE
INPUTS		***The 'source' of teaching and research activities that influence the quality of outcomes***
ACADEMIC STAFF	**(STAFF)**	**Number of FT lecturers employed (all positions and qualifications) during a year**
		Castano, M. C. N. and Cabanda, E. C. (2007); No of full time faculty members
		Johnes, J. (2006a); Total No FT Academic Staff for Teaching/Research; Research only
		Tomkins, C. and Green, R. (1988): No of FT staff
RESEARCH GRANT	**(GRANT)**	**Total amount of Research Grants in RM awarded throughout the year**
		Athanassopoulos & Shale (1997); Research Income as principal support of Teaching & Research
		Ying Chu Ng & Sung Ko Li (2000); Research Income
		Johnes, J. n Johnes, G. (1995): Per-capita research grants
		Beasley, J. E. (1995, 1990): Research income corrected for departments' size (research income per academic)
		Johnes, G. n Johnes, J. (1993): Per-capita research grants
OUTPUTS		***The outcomes of teaching and research activities that consume resources***
FTE ENROLLMENTS		
a) U/GRADUATE	**(UG)**	**FT number of Student Enrolments for Diploma & Degree programs for the year**
b) MASTERS	**(MS)**	**FTE number of Student Enrolments for Masters programs for the year**
c) PhD	**(PhD)**	**FTE number of Student Enrolments for PhD programs for the year**
		Castano, M. C. N. and Cabanda, E. C. (2007); Students enrolment/year
		Fernando, B. I. S. and Cabanda, E. C. (2007); Total FTE Students enrolled
		Mc Millan, M.I. and Chan, W.H. (2006); FTE Enrolments for UG in Sciences, UG in Others, Master's, Doctoral
		Avkiran, N.K. (2001): UG Enrolments and PG Enrolments
d) PUBLICATIONS	**(PUB)**	**Number of referred papers published during a year**
		Johnes, J. and Yu, L. (2008): Total no. of research publications
		Taylor, B. and Harris, G. (2004): books, articles, conference proceedings, patents/licenses
		Madden, G., Savage, S. & Kemp, S. (1997): Publication count in a) selected 93 core economies journals;
		b) other, non-economic, journals; c) the form of authored books; d) edited books including editorial content

Appendix 8: Data for Variables Used in Measuring the Performance of Public Universities in Malaysia

HEIs	2006 DATA						2007 DATA						2008 DATA					
	STAFF	GRANT	UG	MS	PhD	PUB	STAFF	GRANT	UG	MS	PhD	PUB	STAFF	GRANT	UG	MS	PhD	PUB
UM	1875	242.736	13615	4198	1152	1289	2035	682.297	17458	6301	1750	1069	2077	572.803	17176	7466	2212	1626
USM	1589	397.849	22346	2518	1189	126	1668	1490.73	21507	2599	1407	132	1780	644.938	20653	3195	1709	69
UKM	1922	362.094	19301	2128	1180	174	2136	2160.56	20257	3117	1633	205	2247	1068.54	20046	3633	2058	230
UPM	1849	1020.7	23599	3159	1340	766	1920	1237.81	22088	4187	1994	1032	1938	623.423	20882	5146	2496	678
UTM	1741	172.903	22512	1769	544	221	1842	406.628	28145	3331	910	524	1905	54.3224	26420	3746	1093	792
UUM	1145	12.0017	20160	814	411	7	1177	16.9466	24662	1634	630	4	1200	12.9457	28008	1980	855	2
UIAM	1581	25.1106	15286	1159	420	106	1706	15.4833	16043	1489	545	178	1731	144.214	15661	1817	667	171
UNIMAS	570	4.13905	4155	547	47	35	634	4.12043	6099	463	55	38	672	3.74296	6207	508	60	17
UMS	629	31.066	10518	317	80	0	625	104.517	14803	498	109	8	634	31.4856	15592	644	132	0
UPSI	507	10.1646	13634	265	32	6	564	18.8683	12918	368	43	12	656	11.2262	12257	506	67	15
UiTM	4966	95.613	65019	895	263	344	6001	238.72	102614	1562	361	188	6354	105.327	115795	2134	491	222
UDM	N/A	N/A	N/A	N/A	N/A	N/A	272	5.12356	4823	23	3	15	363	12.2759	3856	40	9	16
UMT	318	30.8511	5097	198	54	136	384	57.4261	5304	276	74	182	412	46.619	5506	358	89	320
USIM	292	7.46475	1877	15	12	4	395	13.2045	3162	17	16	0	490	5.041	4199	27	19	2
UTHM	678	33.9976	5422	620	22	27	797	50.1364	6631	579	33	39	869	23.4188	7205	326	47	41
UTeM	520	17.7389	3932	91	29	0	564	78.5659	3965	175	38	1	620	27.9921	5443	261	56	5
UMP	301	4.9793	3245	35	21	0	366	131.373	3679	32	21	13	452	18.6047	4442	29	20	22
UniMAP	296	8.32862	2906	57	23	6	354	88.7574	3667	108	29	23	461	4.17662	4410	160	43	12
UMK	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	94	2.71317	623	6	3	0

Appendix 9: Sample of LINDO Programming for 2008 Using HRSTO

DMU1=UM: HRS2 2008 T/O SET 10 on 18 HEIs

Max Z

Subject to

2077L1+ 1780L2+ 2247L3+ 1938L4+ 1905L5+ 1200L6+ 1731L7+ 672L8+ 634L9+ 656L10+ 6354L11+ 363L12+ 412L13+ 490L14+ 869L15+ 620L16+ 452L17+ 461L18+ 2077M1+ 1780M2+ 2247M3+ 1938M4+ 1905M5+ 1200M6+ 1731M7+ 672M8+ 634M9+ 656M10+ 6354M11+ 363M12+ 412M13+ 490M14+ 869M15+ 620M16+ 452M17+ 461M18- 2077N1- 1780N2- 2247N3- 1938N4- 1905N5- 1200N6- 1731N7- 672N8- 634N9- 656N10- 6354N11- 363N12- 412N13- 490N14- 869N15- 620N16- 452N17- 461N18+ P3- P4 <= 2077

572.8032676L1+ 644.93801L2+ 1068.536385L3+ 623.42345L4+ 54.32244L5+ 12.94565L6+ 144.2137L7+ 3.74296L8+ 31.48557L9+ 11.22619L10+ 105.32673L11+ 12.27591L12+ 46.619L13+ 5.041L14+ 23.41881L15+ 27.9921246L16+ 18.6047L17+ 4.17662L18 <= 572.8032676

17176L1+ 20653L2+ 20046L3+ 20882L4+ 26420L5+ 28008L6+ 15661L7+ 6207L8+ 15592L9+ 12257L10+ 115795L11+ 3856L12+ 5506L13+ 4199L14+ 7205L15+ 5443L16+ 4442L17+ 4410L18+ 17176M1+ 20653M2+ 20046M3+ 20882M4+ 26420M5+ 28008M6+

15661M7+ 6207M8+ 15592M9+ 12257M10+ 115795M11+ 3856M12+ 5506M13+ 4199M14+ 7205M15+ 5443M16+ 4442M17+ 4410M18- 17176N1- 20653N2- 20046N3- 20882N4- 26420N5- 28008N6- 15661N7- 6207N8- 15592N9- 12257N10- 115795N11- 3856N12- 5506N13- 4199N14- 7205N15- 5443N16- 4442N17- 4410N18+ P1- 5P2+ 7P3- 14P4- 17176Z >= 0

7466L1+ 3195L2+ 3633L3+ 5146L4+ 3746L5+ 1980L6+ 1817L7+ 508L8+ 644L9+ 506L10+ 2134L11+ 40L12+ 358L13+ 27L14+ 326L15+ 261L16+ 29L17+ 160L18+ 7466M1+ 3195M2+ 3633M3+ 5146M4+ 3746M5+ 1980M6+ 1817M7+ 508M8+ 644M9+ 506M10+ 2134M11+ 40M12+ 358M13+ 27M14+ 326M15+ 261M16+ 29M17+ 160M18- 7466N1- 3195N2- 3633N3- 5146N4- 3746N5- 1980N6- 1817N7- 508N8- 644N9- 506N10- 2134N11- 40N12- 358N13- 27N14- 326N15- 261N16- 29N17- 160N18- P1+ P2+ P3- 4P4- 7466Z >= 0

2212L1+ 1709L2+ 2058L3+ 2496L4+ 1093L5+ 855L6+ 667L7+ 60L8+ 132L9+ 67L10+ 491L11+ 9L12+ 89L13+ 19L14+ 47L15+ 56L16+ 20L17+ 43L18+ 2212M1+ 1709M2+ 2058M3+ 2496M4+ 1093M5+ 855M6+ 667M7+ 60M8+ 132M9+ 67M10+ 491M11+ 9M12+ 89M13+ 19M14+ 47M15+ 56M16+ 20M17+ 43M18- 2212N1- 1709N2- 2058N3- 2496N4- 1093N5- 855N6- 667N7- 60N8- 132N9- 67N10- 491N11- 9N12- 89N13- 19N14- 47N15- 56N16- 20N17- 43N18+ 0.5P3- P4- 2212Z >= 0

1626L1+ 69L2+ 230L3+ 678L4+ 792L5+ 2L6+ 171L7+ 17L8+ 0L9+ 15L10+ 222L11+ 16L12+ 320L13+ 2L14+ 41L15+ 5L16+ 22L17+ 12L18-1626N1- 69N2- 230N3- 678N4-

792N5- 2N6- 171N7- 17N8- 0N9- 15N10- 222N11- 16N12- 320N13- 2N14- 41N15- 5N16- 22N17- 12N18- 1626Z >= 0

L1 + L2 + L3 + L4 + L5 + L6 + L7 + L8 + L9 + L10 + L11 + L12 + L13 + L14 + L15 + L16 + L17 + L18 = 1

L1-N1>=0 L2-N2>=0 L3-N3>=0 L4-N4>=0 L5-N5>=0 L6-N6>=0 L7-N7>=0 L8-N8>=0 L9-N9>=0 L10-N10>=0 L11-N11>=0 L12-N12>=0 L13-N13>=0 L14-N14>=0 L15-N15>=0 L16-N16>=0 L17-N17>=0 L18-N18>=0

END

Appendix 10: Sample of LINDO Programming for 2007 Using HRSTO

DMU2=USM: HRS2 2007 T/O SET 10 ON 18HEIs

Max Z

Subject to

2035L1+ 1668L2+ 2136L3+ 1920L4+ 1842L5+ 1177L6+ 1706L7+ 634L8+ 625L9+ 564L10+ 6001L11+ 272L12+ 384L13+ 395L14+ 797L15+ 564L16+ 366L17+ 354L18+ 2035M1+ 1668M2+ 2136M3+ 1920M4+ 1842M5+ 1177M6+ 1706M7+ 634M8+ 625M9+ 564M10+ 6001M11+ 272M12+ 384M13+ 395M14+ 797M15+ 564M16+ 366M17+ 354M18- 2035N1- 1668N2- 2136N3- 1920N4- 1842N5- 1177N6- 1706N7- 634N8- 625N9- 564N10- 6001N11- 272N12- 384N13- 395N14- 797N15- 564N16- 366N17- 354N18+ P3- P4 <= 1668

682.296751L1+ 1490.72802L2+ 2160.561512L3+ 1237.81203L4+ 406.62753L5+ 16.94657L6+ 15.48329L7+ 4.12043L8+ 104.51713L9+ 18.86833L10+ 238.72046L11+ 5.12356L12+ 57.4260737L13+ 13.20446L14+ 50.13638L15+ 78.565948L16+ 131.37268L17+ 88.75736L18 <= 1490.72802

17458L1+ 21507L2+ 20257L3+ 22088L4+ 28145L5+ 24662L6+ 16043L7+ 6099L8+ 14803L9+ 12918L10+ 102614L11+ 4823L12+ 5304L13+ 3162L14+ 6631L15+ 3965L16+ 3679L17+ 3667L18+ 17458M1+ 21507M2+ 20257M3+ 22088M4+ 28145M5+ 24662M6+ 16043M7+ 6099M8+ 14803M9+ 12918M10+ 102614M11+ 4823M12+ 5304M13+

3162M14+ 6631M15+ 3965M16+ 3679M17+ 3667M18- 17458N1- 21507N2- 20257N3- 22088N4- 28145N5- 24662N6- 16043N7- 6099N8- 14803N9- 12918N10- 102614N11- 4823N12- 5304N13- 3162N14- 6631N15- 3965N16- 3679N17- 3667N18+ P1- 5P2+ 7P3- 14P4- 21507Z >= 0

6301L1+ 2599L2+ 3117L3+ 4187L4+ 3331L5+ 1634L6+ 1489L7+ 463L8+ 498L9+ 368L10+ 1562L11+ 23L12+ 276L13+ 17L14+ 579L15+ 175L16+ 32L17+ 108L18+ 6301M1+ 2599M2+ 3117M3+ 4187M4+ 3331M5+ 1634M6+ 1489M7+ 463M8+ 498M9+ 368M10+ 1562M11+ 23M12+ 276M13+ 17M14+ 579M15+ 175M16+ 32M17+ 108M18- 6301N1- 2599N2- 3117N3- 4187N4- 3331N5- 1634N6- 1489N7- 463N8- 498N9- 368N10- 1562N11- 23N12- 276N13- 17N14- 579N15- 175N16- 32N17- 108N18- P1+ P2+ P3- 4P4- 2599Z >= 0

1750L1+ 1407L2+ 1633L3+ 1994L4+ 910L5+ 630L6+ 545L7+ 55L8+ 109L9+ 43L10+ 361L11+ 3L12+ 74L13+ 16L14+ 33L15+ 38L16+ 21L17+ 29L18+ 1750M1+ 1407M2+ 1633M3+ 1994M4+ 910M5+ 630M6+ 545M7+ 55M8+ 109M9+ 43M10+ 361M11+ 3M12+ 74M13+ 16M14+ 33M15+ 38M16+ 21M17+ 29M18- 1750N1- 1407N2- 1633N3- 1994N4- 910N5- 630N6- 545N7- 55N8- 109N9- 43N10- 361N11- 3N12- 74N13- 16N14- 33N15- 38N16- 21N17- 29N18+ 0.5P3- P4- 1407Z >= 0

1069L1+ 132L2+ 205L3+ 1032L4+ 524L5+ 4L6+ 178L7+ 38L8+ 8L9+ 12L10+ 188L11+ 15L12+ 182L13+ 0L14+ 39L15+ 1L16+ 13L17+ 23L18-1069N1- 132N2- 205N3-

1032N4- 524N5- 4N6- 178N7- 38N8- 8N9- 12N10- 188N11- 15N12- 182N13- 0N14- 39N15- 1N16- 13N17- 23N18- 132Z >= 0

L1 + L2 + L3 + L4 + L5 + L6 + L7 + L8 + L9 + L10 + L11 + L12 + L13 + L14 + L15 + L16 + L17 + L18 = 1

L1-N1>=0 L2-N2>=0 L3-N3>=0 L4-N4>=0 L5-N5>=0 L6-N6>=0 L7-N7>=0 L8-N8>=0 L9-N9>=0 L10-N10>=0 L11-N11>=0 L12-N12>=0 L13-N13>=0 L14-N14>=0 L15-N15>=0 L16-N16>=0 L17-N17>=0 L18-N18>=0

END

Appendix 11: Sample of LINDO Programming for 2006 Using HRSTO

DMU3=UKM: HRS2 2006 T/O SET 10 on 17 HEIs

Max Z

Subject to

1875L1+ 1589L2+ 1922L3+ 1849L4+ 1741L5+ 1145L6+ 1581L7+ 570L8+ 629L9+ 507L10+ 4966L11+ 318L13+ 292L14+ 678L15+ 520L16+ 301L17+ 296L18+ 1875M1+ 1589M2+ 1922M3+ 1849M4+ 1741M5+ 1145M6+ 1581M7+ 570M8+ 629M9+ 507M10+ 4966M11+ 318M13+ 292M14+ 678M15+ 520M16+ 301M17+ 296M18- 1875N1- 1589N2- 1922N3- 1849N4- 1741N5- 1145N6- 1581N7- 570N8- 629N9- 507N10- 4966N11- 318N13- 292N14- 678N15- 520N16- 301N17- 296N18+ P3- P4 <= 1922

242.7359038L1+ 397.84946L2+ 362.09448L3+ 1020.69897L4+ 172.90327L5+ 12.00171L6+ 25.1106L7+ 4.13905L8+ 31.066L9+ 10.16457L10+ 95.61296L11+ 30.85108L13+ 7.464745L14+ 33.99755L15+ 17.73892L16+ 4.9793L17+ 8.32862L18 <= 362.09448

13615L1+ 22346L2+ 19301L3+ 23599L4+ 22512L5+ 20160L6+ 15286L7+ 4155L8+ 10518L9+ 13634L10+ 65019L11+ 5097L13+ 1877L14+ 5422L15+ 3932L16+ 3245L17+ 2906L18+ 13615M1+ 22346M2+ 19301M3+ 23599M4+ 22512M5+ 20160M6+ 15286M7+ 4155M8+ 10518M9+ 13634M10+ 65019M11+ 5097M13+ 1877M14+ 5422M15+ 3932M16+ 3245M17+ 2906M18- 13615N1- 22346N2- 19301N3- 23599N4-

22512N5- 20160N6- 15286N7- 4155N8- 10518N9- 13634N10- 65019N11- 5097N13- 1877N14- 5422N15- 3932N16- 3245N17- 2906N18+ P1- 5P2+ 7P3- 14P4- 19301Z >= 0

4198L1+ 2518L2+ 2128L3+ 3159L4+ 1769L5+ 814L6+ 1159L7+ 547L8+ 317L9+ 265L10+ 895L11+ 198L13+ 15L14+ 620L15+ 91L16+ 35L17+ 57L18+ 4198M1+ 2518M2+ 2128M3+ 3159M4+ 1769M5+ 814M6+ 1159M7+ 547M8+ 317M9+ 265M10+ 895M11+ 198M13+ 15M14+ 620M15+ 91M16+ 35M17+ 57M18- 4198N1- 2518N2- 2128N3- 3159N4- 1769N5- 814N6- 1159N7- 547N8- 317N9- 265N10- 895N11- 198N13- 15N14- 620N15- 91N16- 35N17- 57N18- P1+ P2+ P3- 4P4- 2128Z >= 0

1152L1+ 1189L2+ 1180L3+ 1340L4+ 544L5+ 411L6+ 420L7+ 47L8+ 80L9+ 32L10+ 263L11+ 54L13+ 12L14+ 22L15+ 29L16+ 21L17+ 23L18+ 1152M1+ 1189M2+ 1180M3+ 1340M4+ 544M5+ 411M6+ 420M7+ 47M8+ 80M9+ 32M10+ 263M11+ 54M13+ 12M14+ 22M15+ 29M16+ 21M17+ 23M18- 1152N1- 1189N2- 1180N3- 1340N4- 544N5- 411N6- 420N7- 47N8- 80N9- 32N10- 263N11- 54N13- 12N14- 22N15- 29N16- 21N17- 23N18+ 0.5P3- P4- 1180Z >= 0

1289L1+ 126L2+ 174L3+ 766L4+ 221L5+ 7L6+ 106L7+ 35L8+ 0L9+ 6L10+ 344L11+ 136L13+ 4L14+ 27L15+ 0L16+ 0L17+ 6L18- 1289N1- 126N2- 174N3- 766N4- 221N5- 7N6- 106N7- 35N8- 0N9- 6N10- 344N11- 136N13- 4N14- 27N15- 0N16- 0N17- 6N18- 174Z >= 0

L1 + L2 + L3 + L4 + L5 + L6 + L7 + L8 + L9 + L10 + L11 + L13 + L14 + L15 + L16 + L17 + L18 = 1

L1-N1>=0 L2-N2>=0 L3-N3>=0 L4- N4>=0 L5-N5>=0 L6- N6>=0 L7-N7>=0 L8-N8>=0 L9-N9>=0 L10-N10>=0 L11-N11>=0 L13-N13>=0 L14-N14>=0 L15-N15>=0 L16-N16>=0 L17-N17>=0 L18-N18>=0

END