Measuring the Importance and Efficiency of Research and Development (R&D) Expenditures in the Transformation of Knowledge-Based Economies (KBEs): A Case Study of the ASEAN Region

Abstract: This paper presents an evaluation of the efficient use of public research and development (R&D) expenditure in the ASEAN (Association of Southeast Asian Nations) region by using Data Envelopment Analysis (DEA). We measure the efficiency of public R&D expenditure, measured as a percentage of GDP, by considering it as an input to knowledge generation. We consider two knowledge outputs, namely real GDP growth and high-tech goods export as a percentage of total manufacturing exports. All data are collected from World Development Indicators (WDI- 2010), World Competitiveness Yearbook (WCY-2011) and ASEAN publications. The efficiency results are prepared following both constant returns to scale (CRS) and variable returns to scale (VRS) assumptions. The efficiency scores under CRS suggest that the Philippines and Indonesia were the best performers in 2010 while under VRS Singapore and Thailand were the most efficient countries in 2010. Special emphasis is placed on how to present the DEA results to government and policy makers in order to provide more policy guidance on how to achieve optimum knowledge output relative to R&D expenditure.

Keywords: KBE, Knowledge economy, public R&D expenditure, real GDP growth, high-tech exports, DEA, CRS, VRS, scale efficiency, efficiency scores, ASEAN

JEL classification: 020, 057

1.0 Introduction

The structure of a knowledge economy is central to endogenous growth models in which innovation is a main driver of sustainable long-term growth (Cullmann, Schmidt-Ehmcke, Zloczysti, 2009). The empirical literature affirms the importance of the level and dynamics of public R&D expenditures for new innovation and economic growth in KBEs (OECD, 1996). Therefore, the efficient usage of government R&D expenditure is becoming increasingly important, especially in a globalized world. Countries are exposed to high levels of competition in both domestic and foreign markets for innovative products and developing technologies. This situation forces nations to continuously update their technological capabilities and efficiency. Countries utilizing their R&D resources inefficiently will be penalized with reductions in growth. It is because of this that the mainstream economic theories emphasize R&D, innovation and human capital as the predominant determinants of growth in a knowledge-based economy (Afzal & Siddiqui, 2011).

In recent years, we have witnessed the structural transformation of several of the 10-member ASEAN economies to knowledge-based ones (Taylor, 2007). A knowledge-based economy (KBE) is one in which knowledge is at the centre of production outcomes, and the success of individuals, firms and communities depends on the efficient creation, dissemination and utilization of knowledge where outdated ideas are constantly replaced (Romer, 1986, 1990, Grossman and Elhanan, 1991). In previous studies we have used a policy-focused approach following the WBI and OECD KBE frameworks to investigate knowledge inputs and outputs in ASEAN. We investigated the resource-rich country Brunei Darussalam and found that although the per capita GDP of Brunei is higher than many OECD countries, there is no or little use of R&D expenditure on innovation or high-tech production (Afzal & Lawrey, 2012a). In another study, our findings show that the Philippines and Singapore are both scale and technically efficient in using knowledge production inputs, especially R&D expenditure (Afzal & Lawrey, 2012c, 2012b). In this paper we use Data Envelopment Analysis (DEA) to investigate the efficiency with which government funded R&D expenditure is used to produce economic growth. The paper is organized as follows: Section 2 gives a brief literature review on the importance of public R&D expenditure in KBEs and the application of DEA, Section 3 describes the research framework, Section 4 presents our results while Section 5 draws conclusions and makes policy suggestions.

2.0 Literature Review

Several methodologies and frameworks have been developed by different organizations to measure the determinants of sustainable growth in KBEs. This study utilises the OECD and WBI frameworks for analysing the importance of public R&D expenditure, innovation and economic growth in KBEs. The rationale for the project was to discover the causes underlying differing economic growth rates of ASEAN member nations during the 1990s.

Early proponents of knowledge as a driver of economic growth were Romer (1986) and Grossman and Elhanan (1991) who developed *new growth theories* to explain sustainable long-term economic growth. In new growth theory, knowledge can raise profitability which can, in turn, contribute to the greater accumulation of knowledge. The impact of knowledge is both by improving efficiency in production and by developing new and improved products and services. There is thus the possibility of sustained increases in investment and associated economic growth. Creation of new knowledge and ideas through efficient public R&D expenditure can also create external benefits in an industry or sector with new ideas used repeatedly at minimal marginal cost. Such spill-overs can reduce the constraints placed on growth by a scarcity of capital.

The principal knowledge indicators, as standardized by the OECD are: i) expenditures on research and development (R&D); ii) employment of engineers and technical personnel; iii) patents; and iv) international balances of payments for technology. The WBI Knowledge for Development report states that innovation through efficient public R&D expenditure has substantial positive effects on economic growth (Chen, Dahlman, 2006), although the WBI has failed to address the benchmarking strategy for the follower countries in this aspect (Afzal & Lawrey, 2012d).

The World Bank Institute (WBI) (1999) developed a KBE framework for its member states in order to define their level of economic development and how to achieve sustainable economic growth in KBEs. It has been found that the successful transition to a knowledge economy typically relies on efficient investments in education, public R&D expenditure, developing innovation capability, modernizing the information infrastructure, and having an economic environment that is conducive to market transactions. These elements have been termed by the World Bank as the pillars of the knowledge economy and together they constitute the knowledge economy framework. Table 1 shows some studies that have applied

the DEA methodology to measure efficiency in public R&D expenditure.. Subsequently, we discuss the DEA methodology and our research framework to address the above issues.

Table 1. Studies on R&D efficiency that employ the DEA method

Studies on cross-country R&D efficiency measurement that employ the DEA method are given in Table 1. Surprisingly, by observing the literature that uses the DEA method, we found none of the existing literature comprehensively addresses the efficiency measurement of public R&D expenditure in ASEAN. This motivates us to extend the existing literature of DEA application by focusing on five ASEAN member countries namely Indonesia, Malaysia, the Philippines, Singapore and Thailand for measuring R&D efficiency on high-tech production and economic growth and their benchmarking strategy.

3.0 Research framework

Since there is an interval between R&D investment and the production of outputs, a time lag between inputs and outputs needs to be taken into consideration in conducting a deterministic DEA evaluation of R&D efforts. Based on the empirical research of Cullmann, Schmidt-Ehmcke and Zloczysti (2009) and Monica Roman's (no date) working paper, this study sets the time lag to be 2 years. The input data set for 2008 is thus matched with the output data set for 2010. This paper measures the efficiency of public R&D expenditure by considering R&D expenditure as a percentage of GDP as an input and two outputs namely the real GDP growth rate and high-tech goods exports (for instance, ICT products, electronics goods, pharmaceutical and bio-tech products) as a percentage of total manufacturing exports. Subsequently we apply the DEA method to measure R&D efficiency. We try to answer the question, "by how much can output quantities be proportionally expanded without altering

the input quantities used, and which scale size should be considered as the most productive scale size (MPSS) for inefficient countries?".

3.1 DEA methodology

According to the Charnes, Cooper and Rhodes (CCR, 1978) model, the DEA efficiency value has an upper bound of one and a lower bound of zero. Two types of DEA models, namely the input-oriented and the output-oriented models, have been widely used by researchers. Evidence indicates that research results are not sensitive to which of the models is being used (Hsu, Luo and Chao, 2005). In the application of DEA, a linear programming model needs to be formulated and solved for each decision making unit (DMU). Detailed discussion of technical issues related DEA models are given in Appendix1.

We use the output orientated model in our study; thus countries aim to maximize the knowledge outputs resulting from their R&D inputs. We estimate both the constant returns to scale model (CRS, Charnes et al., 1978) and the variable returns to scale model (VRS, Banker et al., 1984). The scale efficiency in our study can be obtained by the difference between the results of CRS and VRS efficiencies. The scale efficiency indicates the size and magnitude of the research production process.

4.0 Results and Discussion

The degree of correlation between inputs and outputs is an important issue that has great impact on the robustness of the DEA model. Thus, a correlation analysis is essential to establish whether we have used appropriate inputs and outputs in our analysis. Correlation analyses were done for each pair of variables and Table 2 presents the details. We did not find any evidence of very high correlation between any one input variable and any other (nor between output variables). Nor did we find any one input variable with very low correlation

or negative correlation with any of the output variables in Table 2. Our correlation matrix shows a positive relationship between the input and outputs variable as we expect. This is a reasonable validation of the DEA models (EI-Fattah, 2011). The following are some abbreviations used in the discussion;

CCR = Charnes, Cooper and Rhodes original model
CRS= Constant Returns to Scale
BCC= Banker, Charnes and Cooper model
VRS= Variable Returns to Scale
IRS= Increasing Returns to Scale
DRS= Decreasing Returns to Scale
TSE = Technical and Scale Efficiencies
PTE= Pure Technical Efficiencies
SE=Scale Efficiencies
MPSS= Most Productive Scale Size

Table 2. Correlation matrix of inputs and outputs

DEA analysis of the data presented in Table 3 is carried out using DEAP (Data Envelopment Analysis Programme) software, version 2.1 developed by Tim Coelli in 1996. Note that listed efficiencies should be viewed as relative to the best performing country in the particular year. Based on the rule of thumb of DEA, the number of DMU should be greater than double of the sum of inputs and outputs. Therefore we add South Korea (a member of ASEAN plus three countries) to make robust results for the DEA analysis.

Table 3. DEA model results

A rating of 100% (or 1) indicates that the country is located on the efficiency frontier. An efficiency rating less than 100% signals non-optimal behaviour. A second set of calculations provides a measure of the *returns to scale* of each country. Theoretically, constant returns to scale (CRS) are said to exist at a point on the frontier if an increase of all inputs by 1% leads to an increase of all outputs by 1%. Decreasing returns to scale (DRS) are said to be prevail if outputs increase by less than 1%, while increasing returns to scale (IRS) are present if they increase by more than 1%. Generally a DRS situation is associated with a mature economy where basic economic and social needs have already been covered, so that the incremental return of additional efforts is falling. In contrast to DRS, IRS would seem to be associated

with high productivity of factors of production where a nation can enjoy multiplying incremental returns on economic efforts, in our case the real GDP growth and high-tech exports as a percentage of total manufacturing exports.

We find from our DEA results (Table 3) that Indonesia and the Philippines are the most efficient countries with 100% efficiency rating in 2010 under the CRS assumption while Singapore, Thailand, Indonesia and the Philippines are the most efficient under VRS assumptions in the same year. The difference in achievement of 100% efficiency under the two assumptions is because under variable returns to scale we assume that firms can face economies or diseconomies of scale thus we remove the scale effects of inefficiency under the VRS assumption. However, Indonesia and the Philippines are found to be most productive scale size i.e. scores 1 in 2010. All other countries are showing decreasing returns to scale (DRS) which implies that these countries are not operating their R&D expenditures in an efficient way. This implies that it would be possible for these countries to reduce R&D expenditure while still obtaining the same amounts (or more) of real GDP growth and high-tech exports as a percentage of total manufacturing exports.

Inefficiency is often embedded in existing economic and social structures, like weak entrepreneurial spirit, poor functioning of capital markets, disincentives created by tax codes, lack of modern equipment in research and so on (Thore and Golany, 1997). Now the question is in such a case of inefficiency, if a DMU does not operate at its Most Productive Scale Size (MPSS) i.e. 1 in DEA, then what is its MPSS? That is, if the present scale of operation of a DMU does not lead to 100 per cent scale efficiency, then what is the scale size it should operate at, to achieve 100 per cent scale efficiency? Mathematically, the information about MPSS for an inefficient firm is contained in the weights of its peers or benchmark

countries (Ramanathan, 2003). Table 3 also gives information about peer or MPSS benchmarks for countries considered inefficient in the analysis. Peers are efficient countries with a performance score of 1 and all slacks are zero. Both Indonesia and the Philippines are found to be most productive scale size but Indonesia is not used as a benchmark for any other inefficient countries. This implies that though both the countries are efficient, Indonesia can still improve its efficiency compared to the Philippines. Hence, from our analysis we find that Malaysia and S. Korea's peer is the Philippines meaning that these two countries can try to emulate the Philippines by achieving better values of attributes that would result in the most productive scale size of 1. The Philippines had the largest share of high-tech exports in its manufacturing exports in 2010. Its percentage of high-tech products as a percentage of total manufacturing export was 65.65%.

We must point out that the variable we are concerned with is high-tech exports (US$ millions) *as a percentage of total manufacturing exports*. According to WCY-2012, Singapore, South Korea, Malaysia and Thailand had greater absolute value of high-tech exports measured in US$ millions than the Philippines. But the Philippines had the greatest share of high tech exports as a percentage of manufactured goods exports. The Philippines percentage of high-tech products in total manufacturing exports was 65.65% followed by Singapore 50.01%, Malaysia 48.11%, Indonesia 13.13% and Thailand 27.12% (WCY-2012). In the case of Singapore, Malaysia and South Korea, total manufacturing exports are diversified and consist of both high and medium tech goods, for instance bio-technology, computer equipment, electronics products, motor vehicles, ship buildings and others; whereas in the Philippines the semi-conductor industry alone comprises the largest share of both high-tech and total manufacturing exports of the country.

If we had considered the absolute value of high-tech exports as our reference variable we may have found a different picture. However, research firms such as the Meta Group ranked the Philippines number one in the world in terms of knowledge workers (http://www.slcv.edu.ph/news/news7-03.htm) recently and its Cyber Atlas of 2003 put the Philippines ahead of 47 other countries, including the United States, Australia, France, Canada, and India for the availability of quality skilled worker.

On average, the government provided 65.7% of the R&D expenditure in the Philippines in the period 1996-2010 in an attempt to speed up the production of high-tech goods from FDI. In short we can say the Philippines government agencies, universities and educated English speaking workers contributed to the efficient use of R&D expenditures to produce high value-added goods compared to neighbouring Indonesia, Malaysia and Thailand during last decade or so (Nelson, 1993).

Apart from emulation of the peer, under the CRS assumption, Malaysia, Singapore, Thailand and S. Korea can expand 87%, 93%, 56% and 98% of their output respectively without altering the input quantities used, while under the VRS assumption, Malaysia (20%) and S. Korea (43%) can improve their real GDP and high-tech goods production without altering the current amount of R&D expenditure as a percentage of GDP. This implies that governments of the respective countries should use R&D expenditure in an efficient way that yields optimal outputs. In order to get the optimal results from public R&D expenditure, governments of follower countries should emphasize, inter alia, the fundamentals of strong market economies. These include the spirit of entrepreneurship; sophisticated financial systems that can provide venture capital; strong intellectual property rights; a well-functioning patent system; and a good ICT network among the R&D agencies.

5.0 Conclusion and Policy suggestions

The results of our analysis have interesting policy implications for promoting knowledge-based economic growth in the ASEAN region. This paper demonstrates the importance of the efficient use of public R&D expenditure using a theoretical approach from the OECD and WBI knowledge economy frameworks and applying the DEA linear mathematical model. Our study calculates two efficiency scores of DEA for robust results. According to the DEA CRS assumption, Indonesia and the Philippines are the most efficient countries with a 100% efficiency rating in 2010 while Singapore, Thailand, Indonesia and the Philippines are the most efficient under the DEA VRS assumptions in the same year. The Philippines is considered to be the benchmark or most productive scale size for consideration by Malaysia and South Korea. However, apart from emulation of the peer, Malaysia, Singapore, Thailand and South Korea can expand 87%, 93%, 56% and 98% of their output respectively without altering the input quantities used under the CRS assumption. Under the VRS assumption, Malaysia (20%) and South Korea (43%) can improve their outputs i.e. real GDP and high-tech goods exports without altering the current amount of R&D expenditure as a percentage of GDP.

To strengthen the efficiency of public R&D expenditure in creating knowledge-based high-tech driven new industries, the follower countries can learn from the economic framework of the most efficient nations and consider policies such as the promotion of active collaboration between private-public R&D activities, development of new industry clusters, the establishment of techno-parks and a technological cooperation network both domestically and internationally. Finally strengthening the financial support system together with government R&D expenditure will encourage sustainable knowledge-based growth in the ASEAN region.

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Table 1. Studies on R&D efficiency that employ the DEA method

Authors	*Data sets*	*Inputs and outputs used in DEA model*	*Key results*
Cullmann, Schmidt-Ehmcke and Zloczysti (2009)	OECD data base, PATSTAT	DEA on 30 OECD countries. Inputs: R&D expenditure and researchers. Outputs: Number of Patents	Germany, Sweden and United States are the most efficient countries; Mexico and China have low efficiency. High regulation in product markets lowers research efficiency in the economy.
Schmidt-Ehmcke and Zloczysti (2009)	OECD data base	DEA on 17 European countries. Inputs: R&D expenditure, high and medium skill labour. Outputs: number of patents	Small economies (for instance Belgium, the Netherlands, Ireland) have high efficiency, while the United Kingdom, France and Spain lag behind
Roman (No Date)	2003 and 2005, EUROSTAT, National Institute for Statistics of Romania and Bulgaria	Inputs: R&D expenditure, total researchers. Output: patents, scientific & technical articles, high-tech exports as % of total	Both the countries show DRS in knowledge production. Bulgaria is slightly better than Romania
EI-Fattah (2011)	World Development Indicators (WDI-1996 to 2008) data base	Inputs: R&D expenditure. Outputs: high-tech exports and real GDP growth	The government of Egypt should expand more R&D expenditure to reach the optimum level. It is still underutilized.
Hui and Chee (2007)	2001WDI database	Inputs: R&D expenditure, labour productivity, average schooling. Output: mobile phone users, internet users, PC penetration, hi-tech export etc	India, Indonesia, Thailand and China are inefficient countries due to outflow of human resources and Finland, Malaysia, Singapore and South Korea are relatively efficient

Table 2. Correlation matrix of inputs and outputs

	GDP growth rate	High-tech exports as a % of total exports	R&D expenditure as a % GDP
GDP growth rate	1	0.3843	0.4074
High-tech exports as a % of total exports	0.3843	1	0.0711
R&D expenditure as a % GDP	0.4074	0.0711	1

Source: authors' calculations

Table 3. DEA model results

DMU	TSE (CRS)	% of output that can be proportionally expanded without altering the input quantities used	PTE (VRS)	% of output that can be proportionally expanded without altering the input quantities used	Scale efficiency (TSE/PTE)	Returns to scale	MPSS/Peers/ Benchmarks
Indonesia	1.000		1.000		1.000		
Malaysia	0.133	87%	0.798	20%	0.167	DRS	Philippines
Philippines	1.000		1.000		1.000		
Singapore	0.067	93%	1.000		0.067	DRS	
Thailand	0.438	56%	1.000		0.438	DRS	
South Korea	0.024	98%	0.567	43%	0.042	DRS	Philippines

Source: authors' calculations

Appendix1:

1.1 Theoretical construction of DEA System: As we have seen, DEA is based on Technical Efficiency (TE) or the performance efficiency concept which can be shown as:

$$\text{Technical efficiency (TE)} = \frac{\sum WO}{\sum WI}$$

WO= weighted output, WI= weighted input

Mathematically we can express the above relation by the following formula:

$$E_k = \frac{\sum_{j=1}^{M} U_j O_{jk}}{\sum_{i=1}^{N} V_i I_{ik}}$$

E_k = TE for the DMU_k (between 0 and 1)

K = Number of DMU_k in the sample

N=Number of inputs used (i= 1, L, *N*)

M= Number of outputs (j= 1, L, *M)*

O_{jk} = The observed level of output j from DMU_k

I_{ik} = The observed level of input i from DMU_k

V_i = The weight of input i

U_j = The weight of output j

To measure TE_k for DMU_k by using linear programming the following problem must be solved which is

Max TE_k

Subject to $E_k \leq 1$, k= 1,2, L, K

The above problem cannot be solved as stated because of difficulties associated with nonlinear (fractional) mathematical programming. Charnes, Cooper and Rhodes (1978) have developed a mathematical transformation called the CCR (the initials of their names) model which converts the above nonlinear programming to a linear one under constant-returns-to-scale (CRS) (Afzal and Lawrey, 2012b, 2012c), by the following formula:

$$\text{Max} \sum_{j=1}^{M} U_j O_{jk}$$

$$S.t.$$

$$\sum_{i=1}^{N} V_i I_{ik} = 1$$

$$\sum_{j=1}^{M} U_j O_{jk} \leq \sum_{i=1}^{N} V_i I_{ik}$$

$$U_j \, , \, V_i \geq \varepsilon > 0$$

$$\varepsilon > 0$$

The optimization procedure in DEA ensures that the particular DMU, in our study *the countries*, being evaluated is given the highest score possible by maximizing its relative efficiency ratio, at the same time maintaining equity for all other DMUs. DEA establishes relative efficiency scores led by the benchmark of unity (100%) as the highest score possible for one or more DMUs. For all DMUs (countries) there are mainly two efficiency scores namely overall *technical and scale efficiencies* (TSE) and *scale efficiencies (SE) (*Afzal and Lawrey, 2012c*)*. TSE refers to the extent to which countries achieve the overall productivity attainable in the most efficient manner (Banker, Charnes and Cooper, 1984) and it can be further decomposed *into pure technical efficiencies (PTE)* and *scale efficiencies (SE)*. PTE refers to how efficiently countries use their inputs. Scale efficiency, on the other hand, represents how productive is the scale size. It is the ratio of TSE from the constant-return-to-scale (CRS) to PTE obtained from the variable–returns-to-scale (VRS).

The scale efficiencies of a DMU reveal whether it is performing with increasing (IRS), decreasing (DRS) or constant-returns-to-scale (CRS). The scale efficiency of a DMU operating in its most productive size is thus 1 (Afzal and Lawrey, 2012c). Banker, Charnes and Cooper (1984) developed the concept of variable returns to scale (VRS) by examining the sum of weights which are determined in the CCR (Charnes, Cooper and Rhodes) model. They add the modification in the original CCR model by arguing that, if the sum of weights

of inputs and outputs in the CCR model add up to more than 1, the scale size of a DMU is DRS. To achieve CRS or optimum productive size a DMU should downsize or reduce the excess use of inputs. However, if the sum of weights adds up to less than 1, a DMU is said to have IRS. To achieve the most productive size i.e. 1, a DMU should expand or increase its productive resources. This modification to get the returns to scale in DEA is called the BCC model named after Banker, Charnes and Cooper.