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The Effects of Public Funding on Efficiency of Thai Public Higher Education Institutions: A Two-Stage Double-Bootstrap Data Envelopment Analysis

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Abstract

This study employs a two-stage double-bootstrap Data Envelopment Analysis (DEA) to evaluate efficiency of Thai public Higher Education Institutions (HEIs) and investigate the relationship between public funding and HEIs' efficiency. The results from the first-stage analysis disclose a rather high level of average teaching efficiency score, but low level of average research efficiency score. The results from the second-stage analysis indicate that there are two important factors having positively contribution to teaching and research efficiency: the ratio of public funding to Full Time Equivalent Students (FTEs) and the degree of HEIs' management autonomy and flexibility. Only budgetary factor negatively influencing on teaching and research efficiency is the percentage of HEIs' investment expenditure. Besides, the government's share in HEIs' revenue has negative effects on teaching efficiency, but positive effects on research efficiency. This study, therefore, suggests to Thai government that (a) public funding to HEIs based on numbers of FTEs should be increased and mechanism to allocate public funding should be related to HEIs' performance; (b) because there will be more amount of budget available for efficiency improvement, allocation of investment budget should be at the highest consideration; (c) to improve teaching efficiency, HEIs should be encouraged to increase mobilization of resources by providing an incentive which makes clear about the benefits of educational support; (d) government proportion in total HEIs' revenue should be increased to enhance research efficiency. Finally, the revolution of the public HEIs to an autonomous status should be strongly encouraged.

Keywords: Teaching and Research efficiency, Public funding for Higher Education, Data Envelopment Analysis

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ผลกระทบของงบประมาณอุดมศึกษาต่อประสิทธิภาพของสถาบันอุดมศึกษาไทย: โดยการศึกษาด้วยวิธี Two-Stage Double-Bootstrap Data Envelopment Analysis

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บทคัดย่อ

การศึกษานี้ใช้เทคนิค two-stage double-bootstrap DEA เพื่อประเมินประสิทธิภาพของสถาบันอุดมศึกษาไทย และวิเคราะห์ความสัมพันธ์ระหว่างงบประมาณแผ่นดินเพื่ออุดมศึกษาและประสิทธิภาพของสถาบันอุดมศึกษา โดยพบว่าโดยเฉลี่ยสถาบันอุดมศึกษาไทยมีคะแนนประสิทธิภาพด้านการเรียนการสอนอยู่ในระดับค่อนข้างสูง แต่มีประสิทธิภาพในด้านการวิจัยในระดับค่อนข้างต่ำ ส่วนผลที่ได้จากการวิเคราะห์ความสัมพันธ์ระหว่างงบประมาณแผ่นดินเพื่ออุดมศึกษาและประสิทธิภาพของสถาบันอุดมศึกษานั้น พบว่าสัดส่วนของงบประมาณแผ่นดินต่อจำนวน Full Time Equivalent student (FTEs) และระดับของความเป็นอิสระและความยืดหยุ่นในการบริหารจัดการของสถาบันอุดมศึกษามีผลในเชิงบวกต่อประสิทธิภาพด้านการเรียนการสอนและด้านการวิจัย ในขณะที่สัดส่วนค่าใช้จ่ายลงทุนของสถาบันอุดมศึกษามีผลในเชิงลบต่อประสิทธิภาพด้านการเรียนการสอนและด้านการวิจัย ส่วนสัดส่วนของงบประมาณแผ่นดินในรายรับทั้งหมดของสถาบันอุดมศึกษานั้น พบว่ามีผลในเชิงลบต่อประสิทธิภาพด้านการเรียนการสอน แต่กลับมีผลในเชิงบวกต่อประสิทธิภาพด้านการวิจัย จากผลการศึกษาข้างต้น การศึกษานี้จึงเสนอว่า รัฐบาลควรเพิ่มการจัดสรรงบประมาณแก่สถาบันอุดมศึกษา โดยใช้จำนวน FTEs เป็นเกณฑ์ในการพิจารณา แต่ทั้งนี้กลไกที่ใช้ในการจัดสรรงบประมาณควรต้องมีความเชื่อมโยงกับผลผลิต/ผลลัพธ์ หรือ ผลการดำเนินงานของสถาบันอุดมศึกษา นอกจากนี้ควรมีการติดตามการใช้จ่ายงบประมาณลงทุนของสถาบันอุดมศึกษาให้เป็นไปอย่างเหมาะสมและมีประสิทธิภาพ ประการต่อมารัฐบาลควรส่งเสริมให้สถาบันอุดมศึกษาเพิ่มการระดมทุนจากแหล่งต่างๆ โดยการสร้างแรงจูงใจที่ชัดเจนเกี่ยวกับสิทธิประโยชน์ของการสนับสนุนการศึกษาเพื่อเพิ่มประสิทธิภาพด้านการเรียนการสอน ส่วนเรื่องประสิทธิภาพในด้านการวิจัยนั้นรัฐบาลควรเพิ่มสัดส่วนการอุดหนุนงบประมาณแก่สถาบันอุดมศึกษาให้มากขึ้น ประการสุดท้าย รัฐบาลควรเร่งให้มีการออกนอกระบบของสถาบันอุดมศึกษา เนื่องจากความเป็นอิสระและความยืดหยุ่นในการบริหารจัดการของสถาบันอุดมจะส่งผลทำให้ประสิทธิภาพด้านการเรียนการสอนและด้านการวิจัยของสถาบันอุดมศึกษาเพิ่มขึ้น

คำสำคัญ: ประสิทธิภาพด้านการเรียนการสอนและการวิจัย, งบประมาณแผ่นดินเพื่ออุดมศึกษา การวิเคราะห์เส้นห่อหุ้ม

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1. Statement of the Problems

Recently, the role of Higher Education (HE) in promoting labor productivity, competitiveness and economic growth has been recognized. In order to survive in the world market with complex and intense competition, only primary and secondary education graduates are not sufficient to manage the modern economies (ADB, 2011). Countries increasingly require workers with skills and knowledge higher beyond primary and secondary level. Therefore, the role of HE has substantially recovered as a vital engine of economic development in the knowledge-based economy where skilled labor and technological capability are the key factor for productivity, competitiveness and economic growth.

Thailand has been trapped as a “middle income” country for a long time, the role of HE becomes, then, very necessary. Because HE plays an important role in maintaining economic growth and climbing the income ladder by providing high-level skills and research to apply current technologies as well as to assimilate, adapt, and develop new technologies which are the two drivers of productivity enhancement (World Bank, 2011). However, the role of Thai HE is questioned due to the evidence of its performance. According to the latest 2016-2017 Global Competitiveness Report of the World Economic Forum, Thailand scores on the areas of “higher education and training” is low. It ranks 62 out of 138 countries. Compared to other Asian trading partners, Thailand is lagging behind Singapore (2), Malaysia (41), Hong Kong (14), Taiwan (17), South Korea (25), and Japan (23).

It is generally recognized that HE system in Thailand has encountered several problems. According to OEC (2003), the noticeable problems of Thai HE system are: lack of unity in public policies, goals and direction; absence of a strong and effective mechanism to monitor and evaluate the performance of Higher Education Institutions (HEIs); lack of mechanism to support and assist HEIs in initiating and developing innovations; lack of flexibility and efficiency in the administration and management of HEIs; and the absence of cooperation within and outside the institutions. Besides, HE also confronts other problems such as, equity in accessing to HEIs (Kirtikara, 2001, Sangnabaworn, 2003); public funding system (Puntasen, et al., 2003; Weesakul, 2004; and Tangkitvanich et al., 2010); quality of learners and educational personnel (OEC, 2009); and the structural mismatch between offered and needed skills (Di Gropello, 2011).

Among various issues of Thai HE system, public funding system for HE should be primarily concerned as it is merely a mechanism to allocate financial resources to HEIs and student but a crucial way to improve the unsatisfactory performance of HE system. Empirical studies indicated the correlation of public funding system with HEIs’ performance, for example, McPherson and

Schapiro (1990), Lifener (2003), Amaral, et al. (2007), Strehl, et al. (2007), and Frolich, et al. (2010). The common objective of these studies is to understand how different public funding systems affect institutional strategies and behavior of academics executives which eventually result in HEIs' performance. The research results significantly reveal that the public funding systems have major influences on HEIs' performance through their strategies in responding to the public funding mechanism. However, in Thailand, public funding for HE is suffering from a number of problems, even though, the significant amount of public money has been allocated to HE sector. The following problems are the examples.

- ***Supply-side financing system***

Most of the public expenditures is channeled to HEIs. Approximately 80 percent of public expenditure goes to HEIs while the remaining is used for student loan (Thangkitvanich et al., 2010). Under this system, HEIs recruits students for the student loans, and do not give them free will to choose HEIs for their study. As a result, the student loan mechanism does not create an incentive for HEIs to create a wider variety and flexibility in the provision of education satisfying the needs and preferences of their students. Moreover, the allocation mechanism of supply-side funding is unable to induce potential students for studying in fields such as science and technology.

- ***Improper government budgets for public HEIs***

The larger part of government budget for public HEIs is spent on maintaining an operation of the institution and increasing the number of recruits. About 30 percent of the government HE budget is spent each year on the constructions of new buildings and acquisitions of new equipment. There is usually a smaller amount of budget left for quality development projects (Weesakul et al., 2004).

- ***High subsidized by the government***

Enrollment in public HEIs is highly subsidized by the government resulting in tuition fees that are set too low and do not reflect the actual cost of production. A study by the King Mongkut's University of Technology Thonburi (KMITT, 2005) found that, on average, a social science student is subsidized by 57 percent of the operating cost while a public-health student is subsidized by 77 percent. Moreover, as the poor are generally under-represented in HE system, over subsidization of HE is possibly regressive (Thangkitvanich et al., 2010).

- ***Insufficiency of government budget on education expenditure***

The rapid growth on participation in HE has exerted a lot of pressure on the current education funding system. In particular, the growth of budget on education expenditures has not kept pace with increasing number of students enrolled. As a result, public expenditure on education per student has experienced a long-term downward trend. Since education investment has an impact on education quality, there is a risk of quality degradation unless there are other financial resources that grew sufficiently quick (Thangkitvanich et al., 2010).

- ***Inefficient public funding allocation mechanisms and HEIs' budgeting system***

Although the performance-based budgeting has been put into practice since 2004, public funding to HEIs has not yet based on its performance. It is supply side-driven, i.e. changes are mainly due to new study program or research units. Basic funding for HE is still allocated via line-itemized budget according to activity plans and budget proposals that are adjusted incrementally on a year-to-year basis. Moreover, it is related to bargaining power of HEIs (Schiller and Liefner, 2008). Furthermore, HEIs employ fiscal accounting but separate public budgets from their own income which further split among faculties making it almost impossible for administrators to assess the financial status of the HE institutions or to monitor their expenditures (Weesakul et al., 2004). As a result, the present funding mechanism for HE in Thailand is still inadequate and not aim to enhance the goals of HE system.

- ***Overlapping and incoherence between the government units relating to HE funding system***

There is unconformity between government units taking responsibility for determining policies and quality control (Office of Higher Education Commission: OHEC), and the budget allocation and performance evaluation unit (Bureau of the Budget: BOB). Without cooperation with OHEC which has authority to determine policy and development plan for HE system, BOB directly allocates budget to HEIs according to necessity and acceptable budgeting, including HEIs' development plan. The non-corporation between OHEC and BOB causes the imbalance between demand and supply of education leading to the waste of educational resources. It also affects the effectiveness of OHEC to monitor and control the quality of education, especially by using public funding as a key tool. The assessment results have not been utilized as an instrument for supervising HEIs to improve their quality and to attain the standard required by OHEC.

As aforementioned, good performance of HE is the basic requirement for Thailand to overcome the middle income trap and climb up to higher income ladders. Furthermore, HE performance can be improved by using the public funding system as a governance instrument for monitoring, following up and supervising HEIs to function with quality; attain the standard required through efficient administration and management; and be in consonance with the policy and direction for national development.

In order to improve HEIs' performance, the HE public funding system might be employed as a governance instrument; however the public funding system for Thai HE is facing a number of problems as revealed above. Therefore, it is fascinating to investigate whether the current public funding system for Thai HE can be employed as the governance instrument to promote the performance of HEIs. Simultaneously, it is also important to further explore whether the performance of Thai HEIs could be affected by factors other than HE public funding system. Moreover, the empirical study about the effect of public funding system for HE on HEIs' performance is non-available in Thailand, as the author knowledge. Most literatures found in the context of Thai HE system such as Kantabutra and Tang (2010), Wongchai, et al. (2012), and Sriboonchitta (2012) focus only on the measurement of HEIs' performance without involving the public funding system.

For these reasons and necessities, this study will attempt to: (1) evaluate the performance of public HEIs in term of their efficiency and (2) investigate the relationship between public funding for HEIs and their efficiency in order to address whether the performance of Thai public HEIs could be improved by using the public funding as a tool.

2. Literature Review

2.1. Definitions and Measurement of Efficiency

The modern literature on the measurement of efficiency begins with the paper by Farrell (1957). According to Farrell (1957), *overall efficiency (or total economic efficiency) consists of two components: technical efficiency and allocative efficiency.* Technical efficiency reflects the ability of a firm to avoid waste by producing as much output as technology and input usage allowed or by using as little input as required by technology and output production. Allocative efficiency refers to the ability of a firm to combine inputs and/or outputs in optimal proportions in light of prevailing prices. Thus, if a firm uses its resources completely allocatively and technically efficiently, it can be said to have achieved overall efficiency. However, in HE context, the prices of HE input and output is often unknown, the majority of literature on the measurement of HEIs' efficiency particularly centers on technical efficiency. For the sake of simplicity, this study will use the word "*efficiency*" instead of "*technical efficiency*".

In Farrell's seminal work, efficiency is measured by the method which is similar to Debreu's measure of technical efficiency- *a radial measure*. The radial measure of efficiency is defined as one minus the maximum equiproportionate reduction in all inputs that feasible with given technology and outputs, or one minus the maximum equiproportionate expansion in all outputs being at the highest possibility with given technology and inputs. In both cases, a value of unity indicates efficiency because no radial adjustment is feasible, and a value difference from unity indicates the severity of *in*efficiency.

Since, one can define the production set either in input space as input requirement set: L(y) or in output space as output correspondence set: P(x). The production frontier can then be described in two directions regarding the definition of production set. Firms are **efficient** in input space, if they are on the boundary of the input requirement set or on the input isoquant: $\partial\mathbf{L}(\mathbf{y})$. Likewise, **firms** are **efficient** according to Debreu-Farrell' measure of efficiency in output space if they are on the boundary of the output correspondence set or on the output isoquant: $\partial\mathbf{P}(\mathbf{x})$. Therefore, *the input-oriented measure of efficiency* $(\mathrm{TE}^{\mathrm{I}}(\mathrm{x,y}))$ can now be given a somewhat formal interpretation as the value of the following function: $\mathrm{TE}^{\mathrm{I}}(\mathrm{x,y}) = \min\{\theta | \theta\mathbf{x} \in \mathbf{L}(\mathbf{y})\}$. For all $\mathbf{x} \in \mathbf{L}(\mathbf{y})$, $\mathrm{TE}^{\mathrm{I}}(\mathrm{x,y}) \leq 1$ and for $\mathbf{x} \in \partial\mathbf{L}(\mathbf{y})$, $\mathrm{TE}^{\mathrm{I}}(\mathrm{x,y}) = 1$. $\mathrm{TE}^{\mathrm{I}}(\mathrm{x,y}) \leq 1$ can be implied that the radial contraction of inputs that the firm should achieve to be considered as being efficiency in the sense that $(\mathrm{TE}^{\mathrm{I}}(.)\mathbf{x},\mathbf{y})$ is on the input isoquant, $\partial\mathbf{L}(\mathbf{y})$. In addition, *the output-oriented measure of efficiency* $(\mathrm{TE}^{\mathrm{O}}(\mathrm{x,y}))$ is the value of the following function: $\mathrm{TE}^{\mathrm{O}}(\mathrm{x,y}) = \max\{\emptyset | \emptyset\mathbf{y} \in \mathbf{P}(\mathbf{x})\}$. For all $\mathbf{y} \in \mathbf{P}(\mathbf{x})$, $\mathrm{TE}^{\mathrm{O}}(\mathrm{x,y}) \geq 1$ and for $\mathbf{y} \in \partial\mathbf{P}(\mathbf{x})$, $\mathrm{TE}^{\mathrm{O}}(\mathrm{x,y}) = 1$. $\mathrm{TE}^{\mathrm{O}}(\mathrm{x,y}) \geq 1$ can be implied that the proportionate increase of outputs that the firm should achieve to be considered as being efficiency in the sense that $(\mathrm{x}, \mathrm{TE}^{\mathrm{O}}(.)\mathrm{y})$ is on the output isoquant, $\partial\mathbf{P}(\mathbf{x})$.

2.2. Methods for Measuring Efficiency

As mentioned above, the measurement of efficiency involves a comparison of actual performance with optimal performance located on the relevant production frontier. This implies that the production frontier of the fully efficient firm must be known. As this is usually not the case, the estimation of empirical production frontier by using observed data is required. Among a range of methods dedicated to estimate *a production frontier,* the most two popular methods are *Stochastic Frontier Analysis (SFA)* and *Data envelopment Analysis (DEA)*. Although both SFA and DEA are applied to identify efficient production frontier and to evaluate the efficiency, they are fundamently different in their constructions and and underlying assumptions as follows.

In the SFA, a functional from of production frontier is pre-defined. The coefficients estimated by the SFA approach are assumed to be constant across observations. Moreover, deviations (as measured by the error term) away from the determined production frontier is composed of two parts: (1) an asymmetric half-normal dirtribution component representing inefficiency, (2) a normal distribution component capturing statistical noise beyond the control of production unit, including both uncontrollable factors directly concerned with the 'actual' production function and random errors. In contrast to the SFA approach, the DEA requires no any pre-established functional form of production frontier, but the production frontier is calculated from a sample of observation. It uses linear programming methods to assign an observation-specific set of weight to outputs and inputs in such a way that the ratio of weighted output to weighted input is maximized for each observation. This ratio can then be used to construct the efficient frontier. Moreover, as a deterministic approach, the DEA requires no types of inefficiency (residual) distribution, and all deviations from the efficient frontier are due to inefficiency only which mean that there is no space for the type of bias resulting from environmental heterogeneity, external shocks, measurment error and omitted variables (Worthington, 2001).

Although DEA has its drawbacks such as unable to perform statistical inference; unable to separate statistical noise from inefficiency; valid in particular sample; sensitive to input and output specification and sample size, there are several advantages of DEA over SFA which justifies their preference by the researcher. *First*, efficiency obtained from DEA are based on the behavior of other firms; as a result, there is no need to draw assumptions about efficiency a priori. *Second*, the danger of imposing incorrect assumptions on the model is alleviated because of the non-parametric nature of DEA that requires only few assumptions on the production frontier, as well as no distributional assumptions regarding the residuals in the regression analysis. *Third*, DEA could handle with efficiency measurement of both multiple inputs and outputs. *Fourth*, DEA has an ability to identify source and amounts of inefficiency in each input and each output for each firm. *Fifth*, DEA provides a set of benchmark firms that inefficient firms should imitate in order to be more efficient. *Finally*, DEA is thought to work well with less data and limited sample sizes .

DEA, which was first introduced by Charnes et al. (1978), can be defined as a non-stochastic, non-statistical, and non-parametric method to measure relative efficiency of homogeneous units called Decision Making Units (DMUs) by comparing it with a group of DMUs that transforms the same group of measurable inputs into the same types of measurable outputs. Although, the theoretical foundations in Charnes et al. (1978)'s work based on Farrell (1957), they extended to address the problem of efficiency measurement for DMUs with multiple inputs and multiple outputs by creating a single 'virtual' output and 'virtual' input for replacement (Cooper et al., 2011). Since its introduction in 1978, DEA has remarkably developed in both empirical application and theoretical development. According to the study of S. Liu et al. (2013) that surveyed 4,936 papers listed in the ISI Web of Science (WOS) database from 1978 through August 2010, it is found around 63.6% of DEA papers embed empirical data while the remaining are purely-methodological. Among multifaceted applications, the top-five sectors addressed are: banking, health care, agriculture and farm, transportation, and education. Although, there appears to be two streams of literature of DEA application on education (HE and basic education), the recent trend of efficiency studies in the education category clearly focuses on the HE sector.

2.3. Previous Studies on HEIs' Efficiency Measurement Using DEA Technique

Although DEA technique is useful, its application in HE context is less than 4% of the DEA articles published in scientific journals over the period 1950-2007 (Wolszczak-Derlacz & Parteka, 2011). In this section, the existing empirical on HEIs' efficiency is reviewed accoording to the following methodology issues: unit of analysis, analysis options in DEA (orientation and DEA-model), iuputs/outputs specification, and explaining of efficiency determinants by two-Stage DEA.

2.3.1. Unit of Analysis

In HE context, studies on efficiency measurement have attempted to evaluate performance in various levels as follows: the HEIs themselves both in one country and more than one country, the same department or unit across different HEIs, the different departments or units within one HEIs, and the individual student level.

The studies that bases on cross-sectional data at institutions level in one country are a major part of the exisitng literatures, albeit a small sample of countries has been covered. For example, *Australia* (Avkiran, 2001; Abbott & Doucouliagos, 2003; Wortington & Lee, 2008; and Lee, 2011), *the UK* (Flegg et al., 2004; and Johnes, 2006; Johnes, 2008), China (Ng & Li, 2000; and Johnes & Yu, 2008), *Netherlands* (Cherchye & Abeele, 2005; and Groot & Gracia-Valderrama, 2006), *Germany* (Warning, 2004; Kempkes & Pohl, 2010; and Katharaki & katharaki, 2010), *the US* (Eckles, 2010; and Sav, 2012; 2013), Italy (Agasisti & Salerno, 2007), *Portugal* (Cunha & Rocha, 2012), Philippines (Castano & cabanda, 2007). Unfortunately, there exists only few studies applying DEA to investigate efficiency of HEIs in developing countries. In the case of *Thailand*, to the best of the author's knowledge, there are only two studies. The *first* is the study of Kantabutra & Tang (2010) investigating the performance of 22 Thai public universities during 2003-2006 in terms of efficiency. Two efficiency models, the teaching efficiency model and the research efficiency model are developed and the analysis is conducted at the faculty level. The *second* is the study of Wongchai & Liu & Peng (2012) which examines regional differences in efficiency of 77 national universities by using a meta-frontier model estimated by DEA to calculate the comparable efficiencies for firms operating under different technologies. Concerning the international perspective, there are few studies scrutinizing the differencre of HEIs' efficiency across counties, for example Agasisti and Johnes (2009), Agasisti and Perez-Esparrells (2010), Agasisti and Pohl (2012), Bonaccorsi et al. (2007a), Bonaccorsi et al. (2007b), Aubyn et al.(2009), Wolszczak-Derlacz and Parteka (2011), Wolszczak-Derlacz and Parteka (2014).

Apart from the cross-sectional studies regarding institutional level, there are only some studies investigating HEIs' efficiency at micro department or program level such as Cobert, et al. (2000), Cobert, et al. (2000), Cherchye & Abeele (2005), Casu and Thanassoulis (2006), Groot & Gracia-Valderrama (2006). More recently to arrive in the literature is the use of HEIs panel data in DEA. However, there appears to be few studies that have utilized panel data in exploring HEIs' efficiency and productivity changes over time via the Malmquist index, such as Flegg et al. (2004), Castano & Cabanda (2007), Johnes (2008) Wothington & Lee (2008), Agasisti & Johnes (2009), Kempkes & Pohl (2010), Agasisti & Pohl (2012), Sav (2012), and Wolszczak-Deelacz (2014).

2.3.2. Analysis Options in DEA

As mentioned above, the scope of most empirial studies on HEIs'efficiency, with only few exceptions, is limited to the HEIs of a country, but selecting analysis options in DEA are varied. The first analysis option in DEA is the appropriate approaches for measuring efficiency, which are input-oriented and output-oriented approach. In HE sector, the HEIs may be given a fixed quantity of resources (e.g., public financial resources, students enter qualification) and asked to produce as much output as possible. This implies that input environmental of HE sector, especially public HEIs, is relatively inflexible. As a result, the majority of empirical studies on HEIs' efficiency mainly rely on an output-oriented approach. Only few studies have applied input-oriented approach, such as Colbert et al. (2000), Abbott & Doucouliagos (2003), Groot & Gracia-Valderrama (2006), Castano & Cabanda (2007), Katharaki & Katharakis (2010), Lee (2011), Cunha & Rocha (2012), and Tochkov et al. (2012).

The second analysis option in DEA is the choice between DEA-CCR and DEA-BCC model. In DEA- CCR model, the assumption of CRS holds. This model is, then, suitable only when all HEIs are operating at an optimal scale. If it is not, efficiency score will be confounded with scale efficiency. This condition is not appropriate in real-life situation especially in the context of large public-sector organizations. The CRS assumption can be relaxed and the DEA model can be easily modified to incorporate VRS, known as the DEA-BCC model. Although, from the existing, there is no definitive guideline for selecting between DEA CCR-model and DEA-BCC model, the empirical studies on HEIs' efficiency mainly apply the BCC DEA-model for analysing HEIs' efficiency. Only some studies have used the DEA-CCR model, such as Warning (2004), Groot and Gracia-Valderrama (2006), Katharaki and Katharakis (2010), Wolszczak-Derlacz and Parteka (2011), Wolszczak-Derlacz (2014).

2.3.3. Inputs/Outputs Specification

Inputs/outputs specification is an important step in DEA since the number of inputs and outputs included in any DEA affects the expected performance of efficient DMU and also the expected overall average efficiency. Owing to the complications in specifying inputs and outputs for educational units, it is a very decisive to examine the results of variation in inputs and outputs specification on efficiency scores). There exists not many empirical studies which test the sensitivity of the results to changes in inputs/ output specifications in DEA, such as Colbert et al. (2000), Abbott and Doucouliagos (2003), Johnes (2006), Johnes and Yu (2008), and Katharaki & Katharakis (2010). Most empirical studies cited above revealed that the relative efficiency score of the operating units in question, obtained by DEA, is sensitive to the specifications of inputs and outputs.

- ***Inputs Specification***

According to Johnes (2004), input variables used in investigating HEIs' efficiency at the institutional level can be divided into two categories: human-capital inputs and physical- capital inputs. The human-capital refers to staff providing students the knowledge, and students themselves. The physical-capital refers to a wide range of products used in the operation of HEIs, including land, building, plant, space, and equipment.

Human-capital inputs in HE production are often measured by staff numbers which are referred as Full Time Equivalent (FTE) staff. Normally, HEIs; staff can be divided into two types: academic staff and non-academic staff. This measure is usually employed in many empirical studies on HEIs' efficiency (see Ng & Li, 2000; Avkiran, 2001; Abbott & Doucouliagos, 2003; Flegg et al.,2004; Cherchye & Abeele, 2005; Johnes, 2006; Groot & Gracia-Valderrama, 2006; Agasisti & Serlano, 2007; Johnes, 2008; Worthington & Lee, 2008; St.Aubyn et al.,2009; Agasisti & Johnes, 2009; Kantabutra & Tang, 2010; Katharaki & Katharakis, 2010; Agasisti & Perez-Esparrells, 2010; Eckles, 2010; Kempkes & Pohl, 2010; Wolszczak-Derlacz & Parteka, 2011; Lee, 2011; Agasisti & Pohl, 2012; Sav, 2012; Sav,2013; Wongchai et al., 2012; and Wolszczak-Derlacz, 2014). While most of these studies focus only on academic staff, there are few studies that concentrate on both types of staff (see Avkiran, 2001; Abbott & Doucouliagos, 2003; Agasisti & Serlano, 2007; Worthington & Lee, 2008; Kantabutra & Tang, 2010; and Katharaki & Katharakis, 2010). In addition, an attempt to capture the quality of staff input is frequently made by including staff salaries or variables reflecting the academic qualifications, education, or experience of the staff (see Cherchye & Abeele, 2005; Joumady & Ris, 2005; Groot & Gracia-Valderrama, 2006; Johnes, 2008).

Another measure which is used to reflect labor and human capital inputs in HE production is student numbers (see Flegg et al.,2004; Cherchye & Abeele, 2005; Johnes, 2006; Groot & Gracia-Valderrama, 2006; Johnes, 2008; St.Aubyn et al.,2009; Agasisti & Johnes, 2009; Agasisti & Perez-Esparrells, 2010; Wolszczak-Derlacz & Parteka, 2011; Agasisti & Pohl, 2012; Sav, 2013; Wongchai et al., 2012; and Wolszczak-Derlacz, 2014). Although the time spent by students on homework and a number of classes taken are more refined measures of human-capital input, such data are rarely available. Alternatively, to combining data on both student and staff numbers, one composite measure, namely the student–staff ratio, is constructed and used as a measure of HEIs' input (see Collbert et al., 2000; Groot & Gracia-Valderrama, 2006; Worthington & Lee, 2008; and Cunha & Rocha, 2012). In the case of student quality, mean achievement scores of the student population on entry or proportion of the entry population achieving a given qualification is utilized to reflect student quality in aggregate-level studies of efficiency (see Collbert et al., 2000; and Johnes, 2006).

To reflect *physical-capital input* in HE production, the HEIs' financial data from common publications is used to construct input variables which is a measure of physical capital input. In numerous empirical studies, expenditures on various inputs such as library or computing facilities are used as a measure of physical capital input (see Korhonen et al.,2001; Abbott & Doucouliagos, 2003; Flegg et al.,2004; Warning, 2004; Johnes, 2006; Agasisti & Serlano, 2007; Castano & Cabanda, 2007; Johnes, 2008; Worthington & Lee, 2008; Kantabutra & Tang, 2010; Katharaki & Katharakis, 2010; Eckles, 2010; Kempkes & Pohl, 2010; Lee, 2011; Agasisti & Pohl, 2012; Cunha & Rocha, 2012; Sav, 2012; 2013). Some studies utilize income derived for specific purposes (see Ng & Li, 2000; Johnes, 2008; Agasisti & Johnes, 2009; Kantabutra & Tang, 2010; Agasisti & Perez-Esparrells, 2010; Kempkes & Pohl, 2010; Wolszczak-Derlacz & Parteka, 2011; Cunha & Rocha, 2012; Tochkov et al., 2012; and Wolszczak-Derlacz, 2014). Moreover, the value of assets and level of investment are used in many studies to incorporate measures of physical-capital input, such as Abbott & Doucouliagos (2003), Johnes (2006), Castano & Cabanda (2007), Sav (2013), and Wongchai et al. (2012). When available, the numbers of books or computers have been used as alternatives for financial data (see Joumady & Ris, 2005; Johnes, 2008; and Sav, 2012).

- ***Outputs Specification***

The HEIs' output should be primarily categorized according to the services being provided in term of teaching, research, and other ediucational services (see Avkiran, 2001; Flegg et al, 2004), Thus, aspects of HEIs' activities are generally captured by means of teaching and research output.

a. Teaching Output

The number of students graduating or achieving a particular qualification, or the number of degrees awards are common measures of student achievement used in previous studies, for example, in the study of Abbott and Doucouliagos (2003), Flegg et al. (2004), Warning (2004), Johnes (2006), Castano and Cabanda (2007), Johnes (2008), Worthington and Lee (2008), St. Aubyn et al. (2009), Agasisti and Johnes (2009), Kantabutra and Tang (2010), Agasisti and Perez-Esparrells (2010), Kempkes and Pohl (2010), Wolszczak-Derlacz and Parteka (2011), Agasisti and Pohl (2012), and Wolszczak-Derlacz (2014). However, such output measures are not adequately taken account of the quality of achievement. Consequently, there exists few studies which use mean institution examination scores and percentage success rates as an output measure in both institutional and individual level (see Johnes & Taylor, 1990; Eckles, 2010, and Smith & Naylor, 2001).

Since the number of students graduating or achieving a particular qualification cannot indicate students' productivity which might be considered as outcomes of education, and just only one of desirable outcomes of the teaching activities. Some empirical studies use graduates' employment rate (Avkiran, 2001; Kantabutra and Tang, 2010), graduates' earnings (Colbert et al., 2000; Tochkov et al., 2012), competency matching (Joumady and Ris, 2005), and employer's satisfaction (Colbert et al., 2001) as proxies of students' productivity. Additionally, HEIs also produce individuals who fail to attain a qualification. Wastage due to failure of examinations and dropping out are a by-product of the teaching process and its incidence is often concealed if numbers of enrolled or successful students or labor market successes of graduates are used to reflect teaching output. Thus retention rates (Avkiran, 2001), student progress rates (Avkiran, 2001), or drop-out rates (Agasisti & Serlano, 2007) have been included to reflect an aspect of teaching output in HEIs.

As a result of data constraints on the availability of adequate output measures, there is an endeavor to utilize input data for reflecting outputs level which may violate the aim of efficiency studies in establishing the relationship between inputs and outputs for the purpose of evaluating HEIs' efficiency. Surprisingly, there is a great number of empirical studies where teaching outputs is proxied by teaching inputs such as students numbers or enrollments (Avkiran, 2001; Abbott and Doucouliagos, 2003; Agasisti & Serlano, 2007; Castano & Cabanda, 2007, Katharaki & Katharakis, 2010, Cunha & Rocha, 2012; Wongchai et al., 2012; and Wolszczak-Derlacz, 2014) and number of credit hours (Sav, 2012; Sav,2013).

b. Research Output

Normally, the process of identifying and measuring of research outputs is more complicated than teaching outputs. Theoretically, research outputs should comprise the created new knowledge and the improved existing knowledge. However, the suitable and helpful measures of occurring knowledge in HE sector as proxies of research outputs are hard to completely obtain. Therefore, there are a number of diverge quantified measures of HEIs research outputs.

Many empirical studies use research grants, incomes, or expenditures secured by HEIs as a proxy of research output which reveals both the quality and quantity as these measures reflect the recent market value of the research performance (see Flegg et al., 2004; Johnes, 2006; Agasisti & Serlano, 2007; Johnes, 2008; Worthington & Lee, 2008; Agasisti & Johnes, 2009; Katharaki & Katharakis, 2010; Agasisti & Perez-Esparrells, 2010; Kempkes & Pohl, 2010; Lee, 2011; Agasisti & Pohl, 2012; Sav, 2012; Sav, 2013; and Wongchai et al., 2012). However, there are few empirical studies classifying a research grants, incomes, or expenditures in HE sector as an input measures, for example, Korhonen et al. (2001), Johnes and Yu (2008), Kantabutra and Tang (2010). More satisfactory measures of research output which take into account both quantity and quality include: weighted research rating derived from peer reviews (Avkiran, 2001; and Abbott & Doucouliagos, 2003. Moreover, in the absence of peer review data, total number of publications is an alternative choice of research output measures for investigating HEIs' efficiency (Ng and Li, 2000; Korhonen et al., 2001; Warning, 2004; Groot & Gracia-Valderrama, 2006; Johnes & Yu, 2008; Worthington and Lee, 2008; St. Aubyn et al., 2009; Wolszczak-Derlacz & Parteka, 2011; Lee, 2011; Wongchai et al., 2012; and Wolszczak-Derlacz, 2014). Besides, in order to account for quality as well as quantity of researches, publications in core journal (Cherchye & Abeele, 2005; Groot & Gracia-Valderrama, 2006; and Kantabutra & Tang, 2010) and citation index (St. Aubyn et al., 2009) are included as research output measures to reflect the research quality.

2.3.4 Explaining of Efficiency Determinants: Two-Stage DEA

By DEA technique, the relative efficiency of HEIs is determined by investigating relationship between inputs and outputs included into the DEA model. However, according to non-parametric nature of DEA, the uncertainty is not taken into account which means that all deviations from the production frontier results from inefficiency. Furthermore, DEA assumes that HEIs have full control over inputs, suggesting that such variables are discretionary. Obviously, this may not be the case because the deviation from production frontier may be on account of non-discretionary, or environmental factors beyond managerial control and may not directly serve as inputs into the production processes. Therefore, these non-discretionary factors should be incorporated into production models so as to correctly measure efficiency.

To take the non-discretionary factors into account, determinants of HEIs' efficiency are investigated in the second stage by employing regression analysis. Ideally, in the first stage, DEA scrutinizes the factors controlled by the decision-makers of HEIs while the impacts of variables beyond their control, non-discretionary factors are explained by regression analysis in the second stage. This procedure is, then, called *two-stage DEA technique*. A number of studies have handled the issue of non-discretionary factors, such as Warning (2004), Cherchye and Abeele (2005), Joumady and Ris (2005), Groot and Gracia-Valderrama (2006), Kempkes and Pohl (2010), Wolszczak-Derlacz & Parteka (2011), Lee (2011), Agasisti & Pohl (2012), Sav (2013), and Wolszczak-Derlacz (2014). These studies omit environmental variables in the initial DEA analysis and but later introduce them in non-DEA sequential stages (regression analysis).

Since the DEA efficiencies are less than or equal to one in value, the Tobit model comes into play for use in the majority of research, for example, Joumady and Ris (2005), Groot and Gracia-Valderrama (2006), Kempkes and Pohl (2010), Agasisti & Pohl (2012), Sav (2013). However, there is a problem in regressing DEA estimates on covariates (i.e. non-discretionary factors) that the DEA efficiency estimates are, by construction, serially correlated and yield biased estimated coefficients. To obtain unbiased estimated coefficients and valid confidence intervals, Simar and Wilson (2007) proposed an alternative estimation and statistical inference procedure, called DEA Double-Bootstrap. In the first step, bootstrapped DEA model is employed to estimate the bias-corrected efficiency scores. In the second stage, bias-corrected efficiency scores are regressed against a set of environmental variables using a truncated regression analysis. This approach allows us to solve the dependency problem whilst producing valid estimates for the parameters in the second-stage regression. There exist few studies employing the DEA double bootstrap of Simar and Wilson (2007) to estimate and explain efficiency in HE context (Lee, 2011; Wolszczak & Parteka, 2011; and Wolszczak-Derlacz, 2014).

3. Methodology

Methodology applied in this study is divided into two parts. The first part relates to the measurement of public HEIs' efficiency. In the second part, the impact of public funding on HEIs' efficiency is examined.

3.1. Measurement of Efficiency Using DEA

In HE sector, resources allocated to public HEIs are more or less fixed, and public HEIs cannot easily adjust their inputs such as academic or non-academic staff, capital without government approval. Moreover, they usually are asked to produce as much as possible outputs level. Consequently the ***output-oriented approach*** is considered to be more appropriate for constructing DEA model in HE context. Regarding output-orientation approach, efficiency is interpreted as potential increase in outputs for a given level of inputs. Another analysis optional in DEA is a choice between the assumption of Constant Return to Scale (CRS) and Variable Return to Scale (VRS). However, in the real world, the optimal scale under the CRS assumption is often precluded by a variety of circumstances such as different types of market power, constraints on finances, externalities, imperfect competition, etc (Coelli et al., 2005). As a result, the CRS assumption might yield misleading measures of efficiency in the sense that technical efficiency scores reported under that set of constraints are biased by *scale efficiencies* (Avkiran, 2001). To comply with reality, this study, then, deploys the *Output-oriented BCC Model* to obtain technical efficiency of public HEIs.

Output-Oriented DEA-BCC Model

$$\begin{aligned} \text{Maximize} \quad & \emptyset_t + \varepsilon \textstyle\sum_{r=1}^{m} s_r + \varepsilon \sum_{r=1}^{n} s_i \\ \text{Subject to} \quad & \emptyset_t y_{rt} - \textstyle\sum_{j=1}^{N} \lambda_j y_{rj} \leq 0; \; r = 1, \dots, m \\ & x_{it} - \textstyle\sum_{j=1}^{N} \lambda_j x_{ij} \geq 0; \; i = 1, \dots, n \\ & \textstyle\sum_{j=1}^{N} \lambda_j = 1 \\ & \lambda_j, s_r, s_i \geq 0; \; \forall j = 1, \dots, N \end{aligned} \qquad (1)$$

Where x_{ij} and y_{rj} denote the amount of input i (i=1,…,n) and amount of output r (r =1,…,m) used by HEIs j (j=1,…, t,…,N), the solution of the linear programming problem (3) is a set of efficiency scores, where the efficiency of HEIs t is θ_t. while, the solution of the linear programming problem (4) is a set of efficiency scores, where the efficiency of HEIs t is $1/\emptyset_t$.

3.1.1 <u>Inputs-Outputs Specification</u>

Since, the core missions of a HEI are teaching and research, particular attention in this study has been paid on teaching and research missions. Moreover, separate assessment of teaching and research efficiencies is expected to provide more insight in the Thai HE system. In order to capture HEIs' efficiency in these different aspects, two efficiency models are created: (a) teaching efficiency and (b) research efficiency. Therefore, the specification of inputs-outputs employed in DEA model will be explained regarding the efficiency model type, as follows.

(1) Teaching Efficiency Model

a. Teaching Inputs

To produce and disseminate knowledge through teaching activity, HEIs employ human-capital and physical-capital inputs to educate the enrolled students for the purpose of producing graduates with a certain level of quality. One of teaching inputs included into HE production process as a measure of human-capital is the number of Full Time Equivalent students (FTEs) (see Flegg et al.,2004; Cherchye & Abeele, 2005; Johnes, 2006; Groot & Gracia-Valderrama, 2006; Johnes, 2008; St.Aubyn et al.,2009; Agasisti & Johnes, 2009; Agasisti & Perez-Esparrells, 2010; Wolszczak-Derlacz & Partera, 2011; Agasisti & Pohl, 2012; Sav, 2013; Wongchai et al., 2012; and Wolszczak-Derlacz, 2014). Therefore, in this study, the *number of FTEs (FTEST)* is utilized as a measure of human-capital input. In the past, in order to take quality of student enrolled in HEIs into account, some previous studies used entrance examination scores to reflect the quality of students. Unfortunately, since there is unavailability of the data reflecting the quality of student enrolled in Thai HEIs, this study focuses only on quantitative dimension of this input.

Another common measure used to represent human-capital input is the number of academic staffs (for example, see Avkiran, 2001; Abbott & Doucouliagos; Johnes, 2006; johns, 2008; Johnes & Yu, 2008; Worthington & lee, 2008; St. Aubyn *et al*., 2009; Agasisti & Johnes, 2009; Kantabutra & Tang, 2010; Katharaki & Katharakis, 2010; Wolszczak *et al*., 2011; Lee, 2011; Cunha & Rocha, 2012; and Sav,2012). This category of input includes all personnel whose primary assignment is instruction or research. Although, generally, the number of FTEs academic staff should be considered as additional measures of teaching input in HE production process, due to the unavailable of FTEs data in Thai HE system, the total number of academic staff is utilized instead of the number of FTEs academic staff. Moreover, to reflect both quantitative and qualitative aspects of academic staff in one variable, the *number of academic staff holding assistance professor or higher (ACSTWAP)* is employed in this study. However, the roles of non-academic staff are also important in administering students and academic staffs, and in facilitating the research and teaching process in general. Thus, the *number of non-academic staff (NACST)* is also taken as many further measures of teaching input in production process.

In previous studies, to reflect physical-capital input in HE production, expenditures on various inputs such as library or computing facilities (see Johnes, 2006; Agasisti & Serlano, 2007; Castano & Cabanda, 2007; Johnes, 2008; Worthington & Lee, 2008; Kantabutra & Tang, 2010; Katharaki & Katharakis, 2010; Eckles, 2010; Kempkes & Pohl, 2010; Lee, 2011; Agasisti & Pohl, 2012; Cunha & Rocha, 2012; Sav, 2012; 2013), income derived for specific purposes (see Ng & Li, 2000; Johnes, 2008; Agasisti & Johnes, 2009; Kantabutra & Tang, 2010; Agasisti & Perez-Esparrells, 2010; Kempkes & Pohl, 2010; Wolszczak-Derlacz & Partera, 2011; Cunha & Rocha, 2012; Tochkov et al., 2012; and Wolszczak-Derlacz, 2014), value of assets and level of investment (see Abbott & Doucouliagos, 2003; Johnes, 2006; Castano & Cabanda ,2007; Sav, 2013; Tochkov et al., 2012; and Wongchai et al., 2012) and numbers of books or computers (see Joumady & Ris, 2005; Johnes, 2008; Sav, 2012) are used as a measure of physical-capital input. Since, the financial data of HEIs as mentioned above are hardly acquired in Thai HE system, this study simply employs the *numbers of computer and registered Wi-Fi (COMP)* as a proxy of physical-capital inputs.

b. Teaching Outputs

There is considerable disagreement among researchers as to what is the best way to quantify the output of teaching activities. However, the common measures of teaching outputs used in previous studies are concentrated on the number of graduates in undergraduate and graduate levels (see Abbott and Doucouliagos, 2003; Flegg et al., 2004; Warning, 2004; Johnes, 2006; Worthington & Lee, 2008; Agasisti and Johnes, 2009; Kantabutra and Tang, 2010; Wolszczak-Derlacz & Partera, 2011; Agasisti & Pohl, 2012; and Wolszczak-Derlacz, 2014). Thus, in this study, the number of Master and Doctoral degree graduates (MDG) and the number of graduates in areas of study, namely medicine, dentistry, Pharmaceutical science, and engineering (G4F) are employed to represent the quantity of teaching output.

However, the number of students graduating or achieving a particular qualification cannot indicate all the skills which might be considered as outcomes of education increasing in students' productivity in labor market is another aspect to reflect an additional teaching output. Some empirical studies use graduates' employment rate (See Avkiran, 2001; Kantabutra and Tang, 2010; Tochkov et al., 2012), graduates' earnings (Colbert et al., 2000; Tochkov et al., 2012), competency matching (Joumady and Ris, 2005), and employer's satisfaction (Colbert et al., 2001) as proxies of rising in students' productivity. In order to capture the skills which might be considered as outcomes of education, the *percentage of employed Bachelor degree graduates within 1 year (PEREBG)* and the *employer satisfaction score to all levels graduates (SATSC)* are included to represent quality aspect of teaching output.

(2) Research Efficiency Model

a. Research Inputs

Similar to teaching efficiency model, HEIs employ human-capital input and physical-capital inputs to produce research outputs. Research inputs utilized in the research efficiency model are discussed below.

In order to reflect academic staff time for research activities, the *ratio of FTEs to academic staff (FTESPACST)* is utilize as a measure of human-capital input. Additionally, the *number of academic staffs holding assistance professor or higher (ACSTWAP)* is considered as a measure of academic staffs' quality based upon the assumption that the promoted academic staff (in term of higher academic position and/or higher education level) is more productive in performing a research. These are similar to measures used in previous empirical studies (Breu & Raab, 1994 and Johnes & Yu, 2008). The premise underlying academic staffs' quality is based on Johnes and Yu (2008) that the promoted academic staff (assistance, associate and full professors) are more productive than their colleagues. Moreover, research can be produced in association with postgraduate students. The ideal measures to reflecting this aspect would be based on number of master and doctoral students. Therefore, the *number of graduate student (GST)* is included into DEA model as the measures of research input.

Since, financial data of HEIs is hardly acquired in Thai HEIs, this study simply employs the *number of computer and registered Wi-Fi (COMP)* as a proxy of physical-capital input. Additionally, the roles of non-academic staff are also important in supporting academic staffs for research activities that the *number of non-academic staff (NACST)* is also taken as another input of HE production of research work.

b. Research Outputs

As discussed in a large number of studies, measuring the research output of HEIs confronts many difficulties. The main reason of these difficulties is that the research produced in HEIs is an intangible asset which it is hard to evaluate its values. Moreover, research output has many characteristics causing the complexity to measure it, such as, productivity, quality, eminence, impact and progress. In addition, different measures capture different aspects of the activity (Johnes and Yu, 2008).

Most empirical studies use number of publications (see Chorchye & Abeele, 2005; Groot et al. (2006); Johnes & Yu, 2008; Worthington & Lee, 2008; St. Aubyn et al.,2009; Kantabutra & Tang, 2010; Wolszczak et al., 2011; and Lee, 2011) as quantitative measures to capture the total volume of research activity. In this study, the number of publications including all articles published in: (1) the proceedings of a national/an international academic conference, or in a nationally-renowned academic journal that is listed in the TCI database; (2) a nationally-renowned academic journal that is listed in ONESQA pronouncements; (3) an internationally-renowned academic journal that is listed in the SJR database (SCImago Journal Rank: www.scimagojr.com) that ranks academic journals, and during the most recent year, the journal was listed in the 3rd or 4th quartiles for the article's subject category; or publication in an internationally-renowned academic journal that is listed in ONESQA pronouncements; (4) article published in an internationally-renowned academic journal that is listed in the SJR database (SCImago Journal Rank: www.scimagojr.com) that ranks academic journals, and during the most recent year, the journal has been listed in the 1st or 2nd quartiles for the article's subject category, or publication in an internationally-renowned academic journal that appears in the ISI global.

In order to assign the weight to 4 categories of publications regarding the quality aspect, as mentioned above, this paper applies the procedure proposed by OENSQA for evaluating the research performance of Thai HEIs using the following aggregate index of publications:

Publications index = 1*articles published in category (4) + 0.75*articles published in category (3) + 0.5*articles published in category (2) + 0.25*articles published in category (1)

Moreover, as graduate student is an input in research production process, graduates' thesis and dissertation should be included as a part of research output. Therefore, publication index used as a measure of research output in this study is composed of the *academic staff's publication index (ACSTPID)* and the *graduate student's publication index (GSTPID).*

Although using a category normalized weight of journal publications allows controlling for the quality of research, the research output of HEIs is not limited to journal publications such as conference papers, book reviews, and patents. Despite a possibility of bias the result on simply choosing only journal publications, this study is obliged to, due to the constraint on availability of data regarding other type of research output, this study concentrates on journal publications.

Additionally, to reflect research productivity across the HEI, the *ratio of publication numbers to academic staff numbers (PNPACST)* is also included. This depends on the argument that the best performing HEIs should have most of its staff actively engaged in research to score highly on both ACSTPID and PNPACST. A HEI which has only a small number of active researchers might score relatively high on ACSTPID (and hence perform well in producing volume of research), but would inevitably have a small score on PNPACST (its productivity would be low). These, aforementioned, three research output measures, are similar to measures used by Korhonen et al. (2001) and Johnes and Yu (2008). Furthermore, the percentage of academic staff's research article published in category 4 (PERACSTR4) and the percentage of graduate student's research article published in category 4 (PERGSTR4) should be embraced into the research efficiency model to reflect quality of its output.

Another indicator of research output is its funds. Although, research funding fails to account for the quality and field differences, the advantage of this indicator is that it directly relates to the annual costs. It is more difficult to relate publications and other similar indicators to annual costs, since the research conducted in a particular year is usually published in the form of journal paper with some time lag (Daghbashyan, 2011). Many researchers using research funding as a measure of its output also argue that the ability of HEIs to generate such funds is closely correlated with its research output (see Cohn, et al, 1989).

However, there is some disagreement on whether research funds should be used as an input or an output. Many empirical studies agrees on using the its funds and the amount of money received for financing the research as a good proxy for its value and therefore as an output (see Robst, 2001; Abbot & Doucouliagos, 2003; Flegg et al., 2004; and Bonaccorsi et al., 2006; Johnes, 2006; Agasisti & Serlano, 2007; Johnes, 2008; Worthington & Lee, 2008; Agasisti & Johnes, 2009; Katharaki and Katharakis, 2010; Agasisti and Perez-Esparrells, 2010; Kempkes & Pohl, 2010; Lee, 2011; Agasisti & Pohl, 2012; Sav, 2012; 2013; and Wongchai et al., 2012). However, not all such funds are spent for the purpose of research but also on other facilities which should be identified as research inputs, thus the funds do not completely reflect the research output but income for other related activities (Johnes and Johnes, 1993). Based on this argument, there are few empirical studies classifying a research grants, incomes, or expenditures in HE sector as an input measures, for example, Korhonen et al. (2001), Johnes and Yu (2008), Kantabutra and Tang (2010), and Tochkov et al. (2012). In agreement with the main part of the empirical studies, this study uses the research funds from external sources (EXRF), mainly from government agencies, as a research output.

3.2. Investigation on the effects of public funding on HEIs' efficiency Using Double Bootstrap procedure for two-stage DEA

The nonparametric nature of DEA approach brings about a key drawback of using DEA approach in evaluating HEIs' efficiency. That is ignorance of an error term and considering all deviations from the frontier as inefficiency. The technical efficiency scores obtained from the DEA are, then, insufficient to detect reasons of differences in HEIs' efficiency.

Moreover, not only inputs and outputs which are generally thought to be endogenous and under the control of HEIs' management that indicate the efficiency score but also other uncertainty factors involved in HE production process. Of course, this is not the case since deviations from the frontier may be caused by environment factors beyond any managerial control. The environment factors are categorized into two groups: *nondiscretionary inputs/outputs*, and *the external context* (Agasisti, 2011). Logically, the two groups of factors are completely separated: the former represents input/output that must be included into the production process (but they are not under the control of HEIs); the latter is external factors that actually influence in production process.

The most common approach to incorporate these environmental factors into analysis of efficiency is the *two-stage DEA*. In the first-stage, the linear programming problem is solved to obtain the efficiency score, and afterwards, in the second-stage, the computed efficiency scores from the first stage are regressed on the environment factors that would not be part of the production directly but are believed to affect HEIs' efficiency in producing outputs from inputs that are included in the first-stage. Unfortunately, the division between management and environmental factors is not always distinct. Generally, the actual inputs and outputs belong in the DEA while factors explaining the efficiency where inputs produce outputs belong in the regression.

However, the two-stage approach has been criticized by Simar and Wilson (2007) in four ways: *Firstly*, the DEA-efficiency scores obtained by solving the linear programming problem are serially correlated (in finite samples), since they depend on the same best practice frontier. This means that the error term of the second-stage regression is serially correlated as well. Therefore, using these DEA-efficiency scores in a second stage regression might violate the basic assumptions required by a regression model. *Secondly*, since the environmental factors are correlated with the inputs and outputs (otherwise there would be no need for a second-stage regression), the environmental variables must also be correlated with the error term of the second-stage regression. Indeed, both correlations disappear asymptotically, but only at a slow rate. *Thirdly*, the DEA efficiency scores obtained by solving the linear programming problem are biased towards one in small samples. *Finally*, due to the deterministic nature of DEA estimation (omission of random error), DEA-efficiency score is criticized for the inability to perform statistical testing regarding the estimated efficiency score. To improve the statistical inference of estimated parameter in the second stage regression, Simar and Wilson (2007) suggests the double bootstrap procedure (called Algorithm #2) where, in the *first-stage*, a set of bias-corrected DEA-efficiency scores and confidence intervals is generated by the *first bootstrap procedure*. Subsequently, the standard errors of the estimated coefficients in the *second-stage* regression of the bias-corrected DEA-efficiency on the environmental variables are constructed by the *second bootstrap procedure*. After that, the confidence intervals for the regression estimated coefficients are created. Moreover, they suggest that the second-stage regression should be conducted by a truncated maximum likelihood instead of a censored regression since the efficiency scores are truncated (at one) by construction and not because of censoring. Therefore, the truncated regression model of the bias-corrected DEA-efficiency on environmental variables can be written as:

Teaching Model $$\hat{\hat{\phi}}^{T}_{jt} = E_j\beta^{T} + \varepsilon_j \quad (2)$$

Research Model $$\hat{\hat{\phi}}^{R}_{jt} = E_j\beta^{R} + \varepsilon_j \quad (3)$$

Where $\hat{\hat{\phi}}^{T}_{j} = \hat{\phi}^{T}_{j} - \mathrm{bias}(\hat{\phi}^{T}_{j})$ and $\hat{\hat{\phi}}^{R}_{j} = \hat{\phi}^{R}_{j} - \mathrm{bias}(\hat{\phi}^{R}_{j})$ are the biased-corrected estimator of teaching and research efficiency score of HEI j, respectively.

3.2.1 Variables Specification

According to the previous studies such as Robst (2001), Kuo and Ho (2007), St.Aubyn et al. (2009), Wolszczak-Derlacz and Parteka (2011); Daghbashyan (2011); Sav (2013); and Tochkov et al. (2012), public funding for HEIs is considered as an nondiscretionary factor which is beyond the control of HEIs' management and is expected to have some influence on efficiency in which HEIs uses inputs to produce outputs. Therefore, in order to examine the relationship between public funding for HEIs and HEIs' efficiency, public funding variables are included in to the second stage regression analysis.

In case of Thailand, the significant amount of HEIs' revenues is financed by the government and the rest comes from their own income, including tuition and fees, benefits from intellectual properties (such as research & academic services and investment), donations, and others. The government allocation of funds is mainly based on the number of students. Thus, though the HEsector is mainly publicly financed, the share of government support in the total revenues varies across HEIs. To investigate whether public funding for HEIs impacts on HEIs' efficiency, the *ratio of public funding to FTEs student numbers (PFPFTES)*, the *percentage of public funding in all amount of HEIs' revenues (PERPF)* is incorporated into the vector of environmental factor (E). In addition, since public funding and HEIs' own income is appropriated according to the five categories of expenditure type: personnel expenses, operating expenses, subsidies expenses, investment expenses, and other expenses, the *percentage of HEIs' investment expenditure in all amount of HEIs' expenditure (PERINEX)* is then integrated into the truncated regression model (2) and (3) to deeply scrutinize the effect of public funding for HE on HEIs' efficiency.

Besides public funding variables, there are many other environmental factors which should be included to explain the variation in efficiency across HEIs. For this purpose, five variables are chosen. The options of these variables, together with predictions concerning their impact on HEIs' efficiency scores, are discussed briefly below. Similar to the studies of Kempkes & Pohl (2010) and Wolszczak-Derlacz (2011), HEIs' location is chosen to be an important factor in determining HEIs' efficiency. The idea is that HEIs which is located in the region with high income can take advantages from positive spillover effects, resulting from the cooperation with research intensive companies in the region as well as the existence of laboratories, research institutions and big libraries, which might lead to increasing in HEIs' efficiency. Therefore, the *value of real Gross Regional Product per capita (GRP)* in which HEIs located is utilized as a proxy for the characteristics of HEIs' location. Moreover to take into account the specification of faculty composition, the *dummy variable for HEIs with medical faculty (MED)* is included into the second stage regression analysis. Furthermore, it is commonly recognized that HEIs with a longer tradition have a better reputation, but it could also be the case that new HEIs have more flexible and modern structures, assuring a more efficient performance. As a result, the *age of HEIs since its foundation (AGEF)* is employed as a proxy of the level of traditional. Additionally, to investigate relationship between the quality and efficiency aspects of HEIs, the *internal quality score from Self-Assessment Report (IQA_ASSC)* is included into the second stage regression analysis. Finally, three *dummy variables for the institution type* (three variables: RM.U, PB.U, and AUTO.U for 4 types) are included to control the difference in strength and aspiration of HEIs. Therefore, the model to be estimated in the second stage regression analysis takes on the following form:

Teaching Model: $$BTEFFSC_{jt} = \beta_0 + \beta_1 PFPFTES_{jt} + \beta_2 PERPF_{jt} + \beta_3 PERINEX_{jt} + \beta_4 GRP_{jt} + \beta_5 MED_j + \beta_6 AGEF_{jt} + \beta_7 IQA\_ASSC_{jt} + \beta_8 RM.U_j + \beta_9 PB.U_j + \beta_{10} AUTO.U_j + \varepsilon_{jt} \quad (4)$$

Research Model: $$BREFFSC_{jt} = \beta_0 + \beta_1 PFPFTES_{jt} + \beta_2 PERPF_{jt} + \beta_3 PERINEX_{jt} + \beta_4 GRP_{jt} + \beta_5 MED_j + \beta_6 AGEF_{jt} + \beta_7 IQA\_ASSC_{jt} + \beta_8 RM.U_j + \beta_9 PB.U_j + \beta_{10} AUTO.U_j + \varepsilon_{jt} \quad (5)$$

Practically, to obtain the DEA efficiency scores, this paper utilizes rDEA 1.2-4 software (2016) which is freely available online, and the truncated regression models are later performed in STATA12.

4. Empirical Results

4.1. Data and Sample

This study gathers data of public HEIs in Thai HE system during the years 2010-2012. The main source of HE data is the OHEC which provides information about inputs and outputs of HE production. For the purpose of maintaining HEIs' homogeneity, some types of HEIs are excluded from the analysis such as Open University (Ramkhamhaeng University, Sukhothai Thammathirat Open University), Monk University (Mahamakut Buddhist University, Mahachu-lalongkornrajavidyalaya University), and HEIs which mainly devotes to educate and train only for graduate studies level (National Institute of Development Administration). The final sample comprises of 55 public HEIs of which complete data are available for the years 2010-2012.

The descriptive statistics of input and output variables employed in teaching efficiency model are presented in Table 1 in which there is consideration variation in the teaching input and output variables across HEIs' type. In order to provide some preliminary ideas about the differences of HEIs across HEIs' type, table 6 is constructed to briefly reveal the relative position of HEIs. Regarding teaching inputs and outputs used over the year 2010-2012, it is clearly seen that, on average, public university and autonomous university have a relatively high level of all inputs (number of FTEs: FTEST, number of academic staff with assistance professor or higher: ACSTWAP, number of non-academic staff: NACST, and number of computer and registered Wi-Fi: COMP) and some outputs (number of Master and Doctoral degree graduates: MDG, number of graduates in four fields (medicine, dentistry, pharmaceutical science, and engineering): G4F). In contrast, Rajabhat University and Rajamangala University of Technology have a relatively low level of all inputs. However, they have a relatively high level of 2 outputs: percentage of employed Bachelor degree graduates within 1 year (PEREBG) and employer satisfaction score to all levels graduates (SATSC).

The descriptive statistics of input and output variables employed in research efficiency model are presented in Table 3. From table 2, it is found that there are four research inputs that are relatively low in Rajabhat University: number of academic staffs holding assistance professor or higher (ACSTWAP), number of graduate students (GST), number of non-academic staff (ACSTPNACST), number of computer and registered Wi-Fi (COMP). On the contrary, those inputs are high in public university and autonomous university while the remaining research inputs: Ratio of FTEs to academic staff (FTESPACST) is relatively low in public university and autonomous university. Regarding research outputs, public university and autonomous university have a relatively high level of all research outputs (academic staff's publication index (ACSTPID), graduate student's publication index (GSTPID), ratio of academic staff's publication numbers to academic staff numbers (PNPACST), percentage of academic staff's research article published in category 4 (PERACSTR4), percentage of graduate student's research article published in category 4 (PERGSTR4), research funds from external sources (EXRF)) while Rajabhat University and autonomous university have low level of all research outputs.

Table 1: Teaching Input and Output Variables by HEIs' Type (2010-2012)

Type	Statistic	Input				Output			
		FTEST	ACSTWAP	NACST	COMP	MDG	G4F	PEREBG	SATSC
Rajaphat University (n=29)	Mean	12,556.08	81.99	369.68	7,066.32	165.06	1.00	80.99	4.26
	S.D.	6,673.81	44.79	248.59	7,269.29	171.13	0.00	10.30	0.40
Rajamangala University of Technology (n=6)	Mean	17,556.11	198.06	672.81	7,804.22	86.33	576.44	86.02	4.23
	S.D.	10,366.82	79.51	255.12	5,767.04	106.99	451.39	5.35	0.20
Public University (n=10)	Mean	30,274.52	571.54	3,842.55	27,342.24	1,311.20	1,027.87	84.20	4.08
	S.D.	13,852.04	377.10	2,808.46	36,745.55	1,024.15	676.21	5.94	0.20
Autonomous University (n=10)	Mean	21,903.47	642.23	4,433.08	17,259.87	1,359.53	1,124.93	83.73	4.14
	S.D.	9,719.28	615.57	7,074.89	15,713.69	1,210.79	670.51	5.30	0.14

Table 2: Research Input and Output Variables by HEIs' Type (2010-2012)

Type	Statistic	Input				
		FTESPACST	ACASTWAP	GST	NACAST	PC
Rajaphat University (n=29)	Mean	35.78	81.99	641.86	369.68	7,066.32
	S.D.	16.74	44.79	631.64	248.59	7,269.29
Rajamangala University of Technology (n=6)	Mean	22.86	198.06	408.78	672.81	7,804.22
	S.D.	4.84	79.51	453.35	255.12	5,767.04
Public University (n=10)	Mean	22.68	571.54	5,136.10	3,842.55	27,342.24
	S.D.	6.55	377.1	3,657.37	2,808.46	36,745.55
Autonomous University (n=10)	Mean	22.83	642.23	5,591.10	4,433.08	17,259.87
	S.D.	12.44	615.57	3,923.17	7,074.89	15,713.69

Type	Statistic	Output					
		ACASTPID	GSTPID	PNPACST	PERACSTR4	PERGSTR4	EXRF
Rajaphat University (n=29)	Mean	26.43	38.41	0.2	10.46	2.37	12.72
	S.D.	19.8	45.21	0.12	10.47	9.04	11.93
Rajamangala University of Technology (n=6)	Mean	58.57	23.86	0.19	15.15	3.72	14.25
	S.D.	49.56	36.61	0.1	10.77	10.79	10.26
Public University (n=10)	Mean	464.13	424.3	0.46	32.52	7.94	459.38
	S.D.	449.99	380.48	0.21	12.3	7.22	1,030.16
Autonomous University (n=10)	Mean	661.68	351.94	0.67	42.01	19.05	398.75
	S.D.	783.08	363.78	0.25	23.06	22.42	444.05

4.2. Teaching Efficiency of Thai Public Higher Education Institutions

The DAE and double-bootstrap DEA methods for investigating teaching efficiency models provide two teaching efficiency scores as shown in Table 3: (1) original teaching efficiency scores and (2) bias-corrected teaching efficiency scores, respectively.

Table 3: Original and Bias-Corrected Teaching Efficiency scores

Type	Year	Original Teaching Efficiency Score	Bias-Corrected Teaching Efficiency Score	Bias	Lower Bound	Upper Bound
Rajaphat University (n =29)	2010	0.9339	0.8967	0.0371	0.8687	0.9321
	2011	0.9325	0.8990	0.0336	0.8725	0.9333
	2012	0.9253	0.8926	0.0327	0.8680	0.9229
Rajamangala University of Technology (n =6)	2010	0.9469	0.9051	0.0418	0.8722	0.9451
	2011	0.9361	0.9032	0.0329	0.8763	0.9270
	2012	0.9412	0.9183	0.0230	0.9016	0.9359
Public University (n =10)	2010	0.9243	0.8918	0.0326	0.8676	0.9199
	2011	0.9528	0.9158	0.0371	0.8863	0.9510
	2012	0.9438	0.9179	0.0259	0.8970	0.9407
Autonomous University (n =10)	2010	0.9757	0.9322	0.0435	0.8954	0.9930
	2011	0.9737	0.9409	0.0329	0.9124	0.9889
	2012	0.9741	0.9409	0.0332	0.9137	0.9873

Note: Due to space limitation, the author cannot report the original and bias-corrected teaching efficiency scores for all observations in this paper, but they are available upon requested.

The original teaching efficiency scores are used in the first stage of analysis in order to examine the efficiency of HEIs over the year 2010-2012, while the bias-corrected teaching efficiency scores are employed in the second stage of analysis to investigate the effects of public funding for HE on HEIs' efficiency.

With regard to the original teaching efficiency score, the findings suggest that the majority of Thai public HEIs are *teaching inefficient*. Over the periods of study on 44 out of 165 are teaching efficient HEIs, accounted for 26.67 percent of all HEIs (see Table 4). Each year, the percentage of teaching efficient HEIs varies from 30.91, 25.45, and 23.64 in 2010, 2011, and 2012, respectively. When comparing number of teaching efficient HEIs across HEIs' types over three years, the results as reveal that autonomous university have a relatively large share of teaching efficient HEIs. On average, the percentage of the teaching efficient HEIs in this type is about 53.33 percent over three years, followed by public university with the percentage of 30.00. In contrast, the share is the lowest with Rajabhat University as it is about 27.78 percent.

Regarding the descriptive statistics of teaching efficiency scores as shown in Table 5, the results show that, on average over three years, teaching efficiency score of Thai public HEIs is 0.9415, its range varies from 0.7580 to 1.0000 with 0.0557 standard deviation. This means that teaching inefficient HEIs could increase the producing of their outputs (given level of inputs) by 6.21percent to be teaching efficient HEIs. Moreover, the average of teaching efficiency score in each year is slightly stable during three years. Concerning HEIs type, autonomous university has the highest level of average teaching efficiency score over three years (0.9745), followed by Rajamangala University (0.9414). The HEIs' type of the lowest average teaching efficiency score is Rajabhat University as over three years the score is 0.9306. Therefore, to reach the efficiency level, Rajabhat University require to increase their outputs level, given inputs level, by 7.45percent.

Table 4: Number and Percentage of Teaching Efficient HEIs by Year and HEIs' Type

Type	2010		2011		2012		2010-2012 (n =165)	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Rajaphat University (n=29)	6.00	20.69	4.00	13.79	4.00	13.79	14.00	16.09
Rajamangala University of Technology (n=6)	2.00	33.33	2.00	33.33	1.00	16.67	5.00	27.78
Public University (n=10)	2.00	20.00	4.00	40.00	3.00	30.00	9.00	30.00
Autonomous University (n=10)	7.00	70.00	4.00	40.00	5.00	50.00	16.00	53.33
Total (n= 55)	17.00	30.91	14.00	25.45	13.00	23.64	44.00	26.67

Table 5: Descriptive Statistics of Teaching Efficiency Scores by Year and HEIs' Type

Type	Statistic	2010	2011	2012	2010-2012 (n =165)
Rajaphat University (n=29)	Mean	0.9339	0.9325	0.9253	0.9306
	S.D.	0.0644	0.0603	0.0536	0.0591
Rajamangala University of Technology (n=6)	Mean	0.9469	0.9361	0.9412	0.9414
	S.D.	0.0506	0.0547	0.0569	0.051
Public University (n=10)	Mean	0.9243	0.9528	0.9438	0.9403
	S.D.	0.0597	0.0454	0.0545	0.053
Autonomous University (n=10)	Mean	0.9757	0.9737	0.9741	0.9745
	S.D.	0.0437	0.034	0.0381	0.0375
Total	Mean	0.9412	0.9441	0.9393	0.9415
	S.D.	0.06	0.0544	0.0535	0.0557

4.3. Research Efficiency of Thai Public Higher Education Institutions

Similar to examining of teaching efficiency, the original research efficiency scores, as shown in Table 6, are used in the first stage of analysis in order to examine such HEIs efficiency during 2010-2012 while the bias-corrected research efficiency scores, as shown in Table 6, are employed in the second stage to investigate the effects of public funding on HEIs' research efficiency.

Table 6: Original and Bias-corrected Research Efficiency scores

Type	Year	Original Research Efficiency Score	Bias-Corrected Research Efficiency Score	Bias	Lower Bound	Upper Bound
Rajaphat University (n =29)	2010	0.6588	0.5231	0.1356	0.4452	0.6298
	2011	0.7015	0.5523	0.1492	0.4662	0.6781
	2012	0.7496	0.5733	0.1764	0.4781	0.7033
Rajamangala University of Technology (n =6)	2010	0.9016	0.6643	0.2373	0.5424	0.8105
	2011	0.6157	0.4726	0.1431	0.3935	0.5912
	2012	0.6585	0.5201	0.1385	0.4439	0.6064
Public University (n =10)	2010	0.6936	0.5950	0.0986	0.5302	0.6859
	2011	0.7458	0.6517	0.0941	0.5858	0.7526
	2012	0.8062	0.6980	0.1081	0.6241	0.7959
Autonomous University (n =10)	2010	0.8793	0.7386	0.1407	0.6434	0.9128
	2011	0.8605	0.7289	0.1316	0.6418	0.9052
	2012	0.9109	0.7768	0.1341	0.6854	0.9215

Note: Due to space limitation, the author cannot report the original and bias-corrected research efficiency scores for all observations in this paper, but they are available upon requested.

With regard to the original research efficiency, the findings disclose that the majority of Thai public HEIs is *research inefficiency*. Since only 60 out of 165 HEIs are research efficient, accounted for 36.36% of all HEIs (see Table 7). Each year, the percentage of research efficient HEIs varies from 34.55, 34.55 and 40.00 in 2010, 2011, and 2012, respectively. When comparing number of research efficient HEIs across their types over three years, the results as shown in Table 16 reveal that autonomous university has a relatively large share. On average, the percentage of research efficient HEIs in this type is about 60 over three years, followed by Rajamangala University of Technology (44.44%). In contrast, the share is at the lowest in public university (20.22%).

Regarding the descriptive statistics of research efficiency scores, Table 8 shows that, on average of three years, the score of Thai public HEIs is 0.7467, its range varies from 0.0861 to 1.000 with 0.2561 standard deviation. This implies that research inefficient HEIs could increase the producing of outputs (given level of inputs) by 33.92%to be research efficient HEIs. Moreover, the average score of each year is slightly stable in three years. Concerning HEIs type, autonomous university has the highest level of average research efficiency score (0.8835), followed by public university (0.7485). In contrast, Rajabhat University has the lowest score (0.7003). This implies that it would be possible for Rajabhat University to become research efficient HEIs by increasing their outputs level, given inputs level around 42.82%.

Table 7: Number and Percentage of Research Efficient HEIs by Year and HEIs' Type

Type	2010		2011		2012		2010-2012 (n =165)	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Rajaphat University (n =29)	6.00	20.69	10.00	34.48	12.00	41.38	28.00	32.18
Rajamangala University of Technology (n =6)	5.00	83.33	2.00	33.33	1.00	16.67	8.00	44.44
Public University (n =10)	2.00	20.00	1.00	10.00	3.00	30.00	6.00	20.00
Autonomous University (n =10)	6.00	60.00	6.00	60.00	6.00	60.00	18.00	60.00
Total (n= 55)	19.00	34.55	19.00	34.55	22.00	40.00	60.00	36.36

Table 8: Descriptive Statistics of Research Efficiency Scores by Year and HEIs' Type

Type	Statistic	2010	2011	2012	2010-2012 (n =165)
Rajaphat University (n =29)	Mean	0.6588	0.7015	0.7496	0.7033
	S.D.	0.2896	0.2725	0.2732	0.2778
Rajamangala University of Technology (n =6)	Mean	0.9016	0.6157	0.6585	0.7253
	S.D.	0.241	0.3148	0.2018	0.2739
Public University (n =10)	Mean	0.6936	0.7458	0.8062	0.7485
	S.D.	0.2276	0.1634	0.1814	0.1917
Autonomous University (n =10)	Mean	0.8793	0.8605	0.9109	0.8835
	S.D.	0.2079	0.2199	0.1509	0.1896
Total	Mean	0.7317	0.7291	0.7793	0.7467
	S.D.	0.274	0.2555	0.2391	0.2561

4.4. Effects of Public Funding on HEIs' efficiency

In order to provide evidences on the effects of public funding for HE and other environment factors on HEIs' efficiency, the teaching model (4) and research model (5) are estimated by using the bootstrap truncated regression method based on Simar and Wilson (2007). By this method, the unbiased regression's coefficient and valid confidence interval are obtained. Because the value of bias-corrected teaching and research efficiency scores as dependent variable in regression equation (4) and (5) are in [0,1], this implies that a positive sign of estimated regression' s coefficients indicates that, ceteris paribus, an increase in independent variable corresponds to higher efficiency, while a negative sign of estimated regression' s coefficients indicates lower efficiency. The descriptive statistics of independent variables used in the second stage analysis on teaching and research model are presented in Table 9.

The results of estimation are presented in Table 10, 11. From the two tables, it is clear that, overall, both teaching and research model perform well. Most estimated coefficients are statistically significant at 0.01 statistically significant levels. Moreover, 7 out of 10 independent variables carry the same sign in both teaching and research models but slightly differences in the magnitude of coefficients. Those variables are: ratio of public funding to FTEs student (PFPFTES); percentage of HEIs' investment expenditure in HEIs' expenditure (PERINEX); value of Gross Regional Product per Capita (GRP); internal quality score from Self-Assessment Report (IQA_ASSC); Age of HEIs (AGEF); dummy variable for public university (PBU); and dummy variable for autonomous university (AUTOU).

The results in Table 10 and 11 reveal that all variables in the group of public funding variables have statistically significant effect on teaching and research efficiency of Thai public HEIs. The ratio of public funding to FTEs student (PFPFTES), in log value, has a positively and statistically significant impact on both teaching and research efficiency. This outcome suggests that 100 percent increase in PFPFTES would result in a 0.0807 and 0.2743 increase in teaching and research efficiency, respectively. The positive contribution of PFPFTES to efficiency implies that the more funding per head from government would enhance the ability to efficiently transform teaching/research inputs into teaching/research outputs. However, based on the estimated coefficients of PFPFTES, the impact of PFPFTES on research efficiency is larger than teaching efficiency. Conversely, the percentage of public funding in HEIs' revenue (PERPF) has a different impact on teaching and research efficiency. In term of teaching efficiency, PERPF negatively and statistically significant affects teaching efficiency, but positively on research efficiency. The negative sign of its coefficient in teaching model shows that lower teaching efficiency is with larger proportion of public funding whereas higher teaching efficiency is with smaller proportion. In contrast, the positive sign of its coefficient in research model shows that HEIs with a higher proportion of public funding have higher research efficiency score or another word more efficient. A hundred percent increase in this variable would result in a 0.0810 fall and a 0.5180 up in the teaching and research efficiency, respectively.

The next statistically significant of public funding variable is the percentage of HEIs' investment expenditure in its expenditure (PERINEX). The negative sign of estimated coefficient of PERINEX in both teaching and research model means HEIs with higher share of revenue from government source are less teaching and research efficient. The estimated coefficient of PERINEX is -0.1867 in teaching model and -0.0929 in research model which indicates that 100 percent rise in the share of revenue from government source is associated with the decrease in teaching and research efficiency of 0.1867 and 0.0929, respectively.

Regarding the group of variables expressing the specific characteristic of HEIs, there are four variables exhibiting the same positive influence on both teaching and research efficiency. They are: internal quality score from Self-Assessment Report (IQA_ASSC), HEIs' age (AGEF), dummy variable for public university (PBU), and dummy variable for autonomous university (AUTOU). In the case of IQA_ASSC, the results suggest that the quality aspect of HEIs reflected in internal quality assurance scores have a positively and statistically significant effect on teaching and research efficiency of Thai public HEIs. However, based on the estimated coefficients of IQA_ASSC, the impact of IQA_ASSC on research efficiency is larger than teaching efficiency about six-fold. Concerning the estimated coefficient of AGEF, it is reasonable to state that younger HEIs are less efficient than the old ones. According to the estimated coefficients of AUTOU, it is obviously seen that autonomous university reveals the highest teaching and research efficiency, comparing to other HEIs types. This might imply that the difference in HEIs' teaching and research efficiency across HEIs might be due to the degree of autonomy and flexibility of their management that less restrictive management could lead to higher level of teaching and research efficiency. Although the estimated coefficient of PBU exposes the positive relationship to teaching and research efficiency, it statistically significant impacts only on research efficiency. On the contrary there is only one variable, exhibiting the same negatively and statistically significant effect on both teaching and research efficiency: value of real gross regional product per capita (GRP). Regarding its estimated coefficient of GRP in research model, it is evidence that HEIs located in the area with high economic prosperity cannot gain benefit from the environment to augment their research efficiency, such as opportunities to cooperate with research intensive companies, to reach modern laboratories, research institutions and big libraries, and to have more appeal when offering research/academic positions due to location. However, in the case of teaching efficiency, the results reveal that the estimated coefficient related to the real GDP per capita of the region where the HEIs is located is not statistically significant which can be implies that development level of the region is not among statistically significant determinants of HEIs' teaching efficiency.

Moreover, there are two variables exhibiting the disparity of an impact on teaching and research efficiency: dummy variable for having medical faculty (MED) and dummy for Rajamangala University of Technology (RMU). As for the estimated coefficient of MED, the results show that the existence of one medical faculty has a positively and statistically significant impact on research efficiency but not on teaching efficiency. This implies that HEIs with a medical faculty are more research efficient. In case of RMU, the results of estimation in teaching model indicate that Rajamangala University of Technology has a higher teaching efficiency than Rajabhat University and public university.

Table 9: Descriptive Statistics of Variables in Second Stage Analysis by HEIs type

Type	Statistics	PFPFTES	PERPF	PERINEX	GRP	IQA_ASSC	AGEF
Rajaphat University (n =29)	Mean	2.18	0.59	0.21	27.26	3.96	4.20
	S.D.	0.18	0.12	0.1	1.86	0.45	0.43
Rajamangala University of Technology (n =6)	Mean	2.21	0.77	0.23	27.75	3.96	4.28
	S.D.	0.15	0.05	0.08	0.95	0.34	0.36
Public University (n =10)	Mean	2.15	0.44	0.14	27.99	4.01	4.12
	S.D.	0.13	0.1	0.07	0.88	0.6	0.42
Autonomous University (n =10)	Mean	2.23	0.5	0.1	28.03	3.86	3.99
	S.D.	0.15	0.16	0.1	0.88	0.81	0.52
Total	Mean	2.19	0.56	0.18	27.59	3.95	4.16
	S.D.	0.16	0.15	0.11	1.52	0.55	0.44

Table 10: Second Stage Analysis Results of Teaching Model, Bootstrap -Truncated Regression estimates

Dependent Variable: BTEFFSC	Estimated Coefficient		SE	Z value	Pr > |Z|	95% Confidence Intervals	
						Lower Bound	Upper Bound
(Intercept)	0.6142	***	0.0300	20.4451	0.0000	0.5544	0.6721
· Public Funding Variables							
PFPFTES	0.0807	***	0.0076	10.5824	0.0000	0.0651	0.0950
PERPF	-0.0810	***	0.0115	-7.0770	0.0000	-0.1033	-0.0584
PERINEX	-0.1867	***	0.0117	-15.9932	0.0000	-0.2096	-0.1638
· HEIs' specific characteristic variables							
GRP	-0.0001		0.0008	-0.1821	0.4278	-0.0014	0.0016
IQA_ASSC	0.0095	***	0.0022	4.2780	0.0000	0.0065	0.0152
AGEF	0.0087	***	0.0031	2.8010	0.0025	0.0025	0.0147
MEDS	-0.0053		0.0046	-1.1480	0.1255	-0.0138	0.0044
RMU	0.0398	***	0.0042	9.4228	0.0000	0.0315	0.0481
PBU	0.0038		0.0045	0.8391	0.2007	-0.0056	0.0122
AUTOU	0.0528	***	0.0047	11.1408	0.0000	0.0430	0.0616

Notes: * Value of zero does not fall within 90% confidence interval, ** Value of zero does not fall within 95% of confidence interval, *** Value of zero does not fall within 99% confidence interval. Confidence intervals obtained from 1500 bootstrapping interactions. Constants are not reported.

Table 11: Second Stage Analysis Results of Research Model, Bootstrap -Truncated Regression estimates

Dependent Variable: BTEFFSC	Estimated Coefficient		SE	Z value	Pr > |Z|	95% Confidence Intervals	
						Lower Bound	Upper Bound
(Intercept)	-0.0239		0.1339	-0.1785	0.4905	-0.3106	0.2145
· Public Funding Variables							
PFPFTES	0.2743	***	0.0292	9.4048	0.0000	0.2158	0.3302
PERPF	0.5180	***	0.0439	11.7917	0.0000	0.4309	0.6031
PERINEX	-0.0929	**	0.0480	-1.9353	0.0265	-0.1878	0.0003
· HEIs' specific characteristic variables							
GRP	-0.0448	***	0.0038	-11.8092	0.0000	-0.0508	-0.0359
IQA_ASSC	0.0584	***	0.0088	6.6047	0.0000	0.0415	0.0761
AGEF	0.0418	***	0.0127	3.2980	0.0005	0.0167	0.0664
MEDS	0.2152	***	0.0175	12.2955	0.0000	0.1830	0.2516
RMU	-0.0741	***	0.0152	-4.8746	0.0000	-0.1041	-0.0445
PBU	0.1502	***	0.0175	8.5986	0.0000	0.1149	0.1834
AUTOU	0.3161	***	0.0177	17.8765	0.0000	0.2800	0.3493

Notes: * Value of zero does not fall within 90% confidence interval, ** Value of zero does not fall within 95% of confidence interval, *** Value of zero does not fall within 99% confidence interval. Confidence intervals obtained from 1500 bootstrapping interactions. Constants are not reported.

5. Conclusions and Recommendations

The main objective of this study is to evaluate teaching and research efficiency of Thai public HEIs as well as the significance of public funding and potential factors in improving HEIs' efficiency. To achieve the objective, two-stage analysis is employed.

In the *first-stage analysis*, the author evaluated relative teaching and research efficiency of 55 Thai public universities over the period between 2010 and 2012 using DEA. However, in public HE sector, resources allocated to HEIs are more or less fixed, and they cannot easily adjust their inputs such as academic or non-academic staff, capital without government approval. Consequently, the output-oriented approach is considered to be more appropriate for constructing DEA model in public HE context. Moreover, to comply with the real world that the optimal scale under the CRS assumption is often precluded by a variety of circumstances such as different types of market power, financial constraints, externalities, imperfect competition, this study, then, deploys the DEA model with VRS assumption called Output-oriented DEA-BCC Model to obtain teaching and research efficiency of Thai public HEIs.

The results of the first-stage analysis reveal the majority of Thai public HEIs are teaching and research inefficiency as only 26.67 and 36.36 percent of public HEIs are teaching and research efficient, respectively. Surprisingly, there are only 7.27 percent of Thai public HEIs that are both teaching and research efficient within the three years of study. Regarding teaching efficiency, the findings disclose a rather high level of average score at 0.9415 which implies that, on average, teaching inefficient HEIs could expand the producing of teaching output (given technology and input level) by 6.21 percent in order to reach the teaching efficient. Additionally, such efficiency of public HEIs varies across HEIs' type. Autonomous university has the highest level of average teaching efficiency score (0.9745), followed by Rajamangala University (0.9414). HEIs' type that has the lowest average teaching efficiency score is Rajabhat University (0.9306). As for research efficiency, the findings expose a rather low level of average score at 0.7467. To be research efficient HEIs, research inefficient HEIs should enlarge their producing of research output (given technology and input level) by 33.91 percent. Furthermore, the research efficiency of Thai public HEIs diverges across HEIs' type. The findings additionally reveal that, autonomous university has the highest level of average research efficiency score (0.8835), followed by public university (0.7485), while Rajabhat University has the lowest level (0.7003).

In the second-stage analysis, the double bootstrap truncated regression, based on Simar and Wilson (2007), is employed to investigate the importance of public funding and potential factors in improving HEIs efficiency. In the first bootstrap procedure, a set of bias-corrected DEA-efficiency scores and confidence intervals is calculated. Subsequently, in the second bootstrap procedure, the bias-corrected efficiency scores from the first procedure are regressed on public funding variables and environmental variables to obtain unbiased estimated coefficient of these variables and their standard errors.

Concerning public funding variables, the results from the second-stage analysis indicate that ratio of public funding to FTEs positively contributed to the teaching and research efficiency. This implies that to enhance teaching and research efficiency of Thai public HEIs, the pace of public funding for HE must be in line with the growth in numbers of students since the funding reduction to FTEs causes negative influences on both teaching and research efficiency. In contrast, percentage of HEIs' investment expenditure has a negative impact on teaching and research efficiency. This means that, the higher HEIs' expenditure on investment, the lesser teaching and research efficient HEIs because, it is possible that there is smaller budget left for efficiency improvement. Besides, the source of funding is an important efficiency determinant since increasing in percentage of public funding in total HEIs' revenue is related to the downfall of teaching efficiency but increase in research efficiency.

In case of HEI's characteristic variables, one interesting result indicates higher teaching and research efficiency of HEIs with larger internal quality assurance score. However, based on the estimated coefficients of IQA_ASSC, the impact of IQA_ASSC on research efficiency is about six-fold larger than teaching efficiency. Moreover, it is reasonable to state that younger HEIs are less efficient than the old ones. In addition, the difference in teaching and research efficiency across HEIs might be due to the degree of autonomy and flexibility of their management, in direction that less restrictive management could lead to higher level of teaching and research efficiency. Besides, evidences show that HEIs located in the area with high economic prosperity are unable to benefit from the environment to improve their research efficiency. On the contrary, the regional development level is insignificant determinants for HEIs' teaching efficiency.

The empirical results of this study lead to some policy recommendations. *First,* since there are about three-quarters and two-third of public HEIs which are inefficient in teaching and research, respectively, a way to improve teaching and research efficiency is that government should increase public funding to HEIs on the basis of the number of FTEs. The reason is that the growth of government budget on HE expenditures has not kept pace with the growth in numbers of students enrolled, as a result, the efficiency of HE could be impacted by insufficiently growing of public funding. However, only increasing in public funding allocated to HEIs without enhancing incentive for improving their performance would simply lead to wasteful use of resources. Therefore, allocation of public funding to HEIs should relate to their performance. Although the performance-based budgeting system was firstly introduced into Thai HE since 2000 and has been put into practice since 2004, the present public funding allocation mechanism has continued to be determined through negotiation without reliance on performance or output/outcome measures. Moreover, this system provides no incentives for HEIs to manage their resources efficiently. Therefore, government should employ an innovative allocation mechanism that link funding directly to some measures of teaching and research output/outcome rather than inputs.

The following four types of allocation mechanisms for teaching are the example of performance-based that the government might utilize to connect public funding with teaching outputs/outcomes. *(1) Performance set-asides* where a portion of public funding is set aside to pay on the basis of various performance measures. The performance measures are typically decided through negotiations between a government agency or buffer body and the institutions. *(2) Performance contracts* where performance contracts typically are regulatory agreements more than legally binding documents and can take a number of forms. Performance-based evaluation criteria are negotiated between government agencies or buffer bodies and institutions. A portion of overall funding may be based on whether institutions meet the requirements in the contracts. *(3) Payments for results,* where government might apply two ways for funding. First, a set of performance measures is used to calculate institutional eligibility for all or part of their formula funding of recurrent expenses. Second, government or private entities agree to pay institutions for each student enrolled or degree recipient in certain fields of study or with specific skills. *(4) Competitive funds,* where the competitive funds are usually funded on a project-by-project basis, typically for the purposes which are difficult to achieve through funding formulas or categorical funds, for example to improve quality and relevance, to promote innovation, and foster better management. Furthermore, government might utilize the following allocation mechanism to connect public funding with HEIs' research outputs/outcomes or performance. *(1) Block grant funding for research:* institutions receive a block grant allocation specifically for research activities but not differentiated or specified by project. The size and purpose of the block grant may be based on: specific research proposals, institution demonstrated capacity, research centers of excellence in certain fields or endeavors. The block grant levels are largely determined by evaluation of specific project proposals by peer review or institutions' capacity to conduct research innovatively. *(2) Project Funding:* institutions receive allocated funds for research according to proposed projects, usually based on peer reviews of proposals.

Second, since HEIs' expenditure on investment has a negative contribution to both teaching and research efficiencies, government should be more careful about the investment budget allocating to HEIs, such as capital acquisition and construction costs. Consequently, there exists more amount of budget available for transfer to the general subsidy for the for the efficiency improvement projects. *Third,* since public HEIs funded predominantly from the public funds exhibit lower teaching efficiency and higher research efficiency. Therefore, for improving teaching efficiency, government should encourage HEIs to increase mobilization of resources from various sources, such as generating business income from institutional assets, seeking donation and sponsorship from private sectors and philanthropists, and mobilizing additional resources from students and their families. However, the government should provide an incentive to encourage resource mobilization for education to be clear about benefits of supporting education, for example, revising the tax deduction code or the tax exemption code to be more attractive to the private sectors. On the other hand, to enhance research efficiency; the government might consider increasing its proportion in total HEIs' revenue and also assuring that the mechanism for allocating public funding to research activities should be related to research outcome or performance. *Forth,* the revolution of the public HEIs to an autonomous status should be strongly encouraged since the results in this study indicate that autonomous universities are more efficient in producing teaching and research outputs compared to other types of HEIs which is because an autonomous university operates under flexible rules and procedures.

This study has contributed to the existing literature in Thai HE by estimating the teaching and research efficiency determinants through using the new method never been utilized in Thai HE context: two-Stage Double-Bootstrap Data envelopment Analysis proposed by Simar and Wilson (2007) while efficiency scores derived for the period 2010-12 are recent findings on teaching and research efficiency of Thai public HEIs.

However, this study should be viewed as the first step for a more detailed analysis of the topic where more work can be done on improving the study by introducing qualitative data especially with regard to the teaching. Besides, the Malmquist approach can be applied with panel data to investigate the improvement on teaching and research efficiency of public HEIs, as well as total factor productivity and technical change. Although, it would also be very fascinating to compare the patterns of teaching and research efficiency in public and private HEIs, the unavailability of data (especially concerning funding) for private HEIs remains the major impediment.

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