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Abstract

This study applies a network data envelopment analysis model called network slacks-based measure (NSBM) to examine the R&D efficiency and socio-economic efficiency of Taiwan's dual-use (military and general public) technology development programs. We also employ the additive super-efficiency model to distinguish programs at different stages and conduct an analysis on the strengths and weaknesses of internal resource utilization. The results of this study show that the R&D efficiency is substantially higher than the socio-economic efficiency. Among the dual-use technology development programs, material and chemical engineering programs demonstrate relatively higher performance. This study provides insights into the policy of resource utilization.

Keywords: Network slacks-based measure (NSBM); Additive super-efficiency model; Performance evaluation; Dual-use technology programs; Socio-economic perspective

1. Introduction

The development of modern technologies has created gaps between technologies used for civilian life purposes and military applications. Technologies that civilians use in the daily life (e.g., global positioning system and the Internet) are initially developed and applied for the purpose of national defense. In other words, the driving force prompting developments in the emerging industries such as the information and communications technology (ICT) and semi-conductor industries is the development of technologies in military. Overall, this trend leads to the development of dual-use technologies, i.e. technologies for civilians and militaries.

According to an analysis conducted by Benoit [1], a U.S. national defense economist, at least 40 percent of successful military technologies contribute in improving people’s economic wellbeing. Specifically, military technologies are able to enhance a country’s security and the overall national economy [2-4]. By incorporating military technologies into the private industries, countries not only transfer military innovations or inventions to civilian livelihood that create incomes, but also help upgrade technologies in the private industries, which in turn actively participate in the construction of national defense.

Because of limited budgets and resources, governments of various countries would stringently review the use of defense expenditures and actively conduct performance evaluation. For example, the United States announced the Government Performance and Results Act in 1993, stipulating that public departments (including institutions involved in the research and development (R&D) of technologies) must assess their performance; in 1997, Japan approved the Practical Guide to the Evaluation of National R&D, which serves as the basic architecture of technology evaluation, and proposes that technologies should be evaluated based on their level of importance. However, adopting traditional financial reports to measure the efficiency of implementing a dual-use technology development program (DuTDP) will cause evaluators to overlook external benefits. Note that resource allocation and long-term development of the social economy are dependent on the performance of DuTDPs. If the direct benefits for R&D institutions (e.g., academic and technological outcomes and R&D revenues) and indirect benefits for the social economy (e.g., the number of technology transfer, the output value generated from investments, and the number of treasury transfers produced by R&D results) are considered in assessing performance, the actual performance of DuTDPs can be more accurately assessed.

That is, multiple indicators are required for measuring the performance of DuTDPs to prevent evaluation errors. The data envelopment analysis (DEA) approach is advantageous for performance evaluation for the following reasons: (i) it is able to simultaneously handle multiple inputs and outputs; (ii) it is not limited by the type of indicators; (iii) predetermining parameter is not necessary; (iv) weights are determined based on a mathematical approach, which provides objective perspectives and suggestions for improvement. The DEA approach has been widely applied in efficiency analyses and performance evaluations [5-10]. However, traditional DEA models neglect the link between the economic activities within an organization. Unlike the traditional DEA models, network DEA open up the ‘black box’ to provide a clearer picture of internal activities. Although some scholars have employed network production processes for measuring the operational performance of various industries [11-15], their approaches do not incorporate all interactions between processes and the overall efficiency.

To overcome this problem, we employ a network DEA model called network slacks-based measure (NSBM) introduced by Tone and Tsutsui [16]. To this end, we establish a two-stage production model to assess the R&D and socio-economic efficiencies of DuTDPs. In addition, we use the additive super-efficiency model proposed by Du et al. [17] to distinguish and rank the efficient decision making units (DMUs).

This study makes several noteworthy contributions. First, we open up the black-box process of DuTDPs through NSBM to investigate the implementation status and the outcomes of DuTDPs in various categories. We find that R&D efficiency is substantially higher than the socio-economic efficiency of DuTDPs in Taiwan. Apart from comparing the efficiency of various types of DuTDPs, we distinguish the efficient DuTDPs of various stages, all of which could provide insights into the policy of resource utilization. Second, we incorporate the externality concept to examine the overall performance of DuTDPs. Note that external benefits are essential outputs for non-profit organizations such as the Chung-Shan Institute of Science & Technology (CSIST), the primary R&D institution of the Ministry of National Defense of Taiwan that has been active in the development of dual-use technologies. Considering internal resources utilization for R&D and the external spill-over effects generated simultaneously, this study offers some important insights into not only the literature, but also the application of DEA in the real world scenario involving R&D. Specifically, we incorporate the concept of companies that emphasizes ultimate economic benefits, viz. earnings or market values into the R&D programs through ultimate economic benefits like revenue to pay national treasury. Finally, our results can motivate competent authorities to assess program performance and manage resource allocations by using

DEA. In other words, combining both internal and external perspectives, we illustrate how DEA could be used for the performance management and ranking purposes. That is, through network DEA, authorities may assess the black-box process of R&D activities through the R&D and socio-economic efficiencies of DuTDPs.

The remainder of this paper is organized as follows. Section 2 begins by discussing the current status of DuTDPs at the CSIST, and looks at the correlation between Externality and R&D, and the application of DEA in R&D programs. Section 3 describes the selection of input and output indicators as well as the preliminary requirements for DEA analysis. Section 4 discusses the research design, while Section 5 documents the research findings and discussions. The last section provides the conclusion of this study.

2. Literature Review

2.1 Overview of the CSIST in Taiwan[1]

Established in 1969, the CSIST is an R&D institution whose goal is to build autonomous national defense, to establish a military force based on technology, and to produce its own weapons [18, 19]. In 1994, the CSIST established the Dual-Use Technology Development Fund according to the policy concerning the transfer of national defense technology into civilian industries. This fund enables the CSIST to accept technology development programs commissioned by various governmental departments and civilian industries. Since 1995, the policies of the Ministry of National Defense and the Ministry of Economic Affairs have prompted the CSIST to actively

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[1] One may see http://www.csistdup.org.tw/ (in Mandarin) for further details.

participate in the technology development programs implemented by the Ministry of Economic Affairs in Taiwan [20]. Based on the research capacity of the national defense technology and industrial demands, the CSIST promotes the development of dual-use technology and converts national defense technology into applications for civilian industries. This movement has facilitated the transformation of industries in Taiwan, and thus expanding domestic and foreign markets and promoting national economic developments. In 2004, based on the government policy of expanding internal demands and reviving the industrial economy, and the goals of the Ministry of National Defense of combining civilian powers and building an autonomous defense, the CSIST executed the Suppliers for Commercial Military Products technology development program using a cooperative development model. The purpose of this project was to undergo technology transfer and guide and promote companies to invest in the development of national armaments. Particularly, DuTDPs are the first technology development program implemented by the CSIST. Note again that the CSIST is the prominent R&D institution in Taiwan and has been active in developing dual-use technologies, which have helped Taiwanese private sector to compete globally. Overall, the development of dual-use technology contributed immensely to the output and competitiveness of relevant industries in Taiwan.

2.2 Application of DEA in R&D Programs

Various performance evaluation models have been used to evaluate R&D program performances. Common performance evaluation methods include economic analysis (e.g., ratio analysis, DEA analysis, and regression analysis) and non-economic analysis (e.g., multi-criteria analysis and questionnaire survey). In Taiwan, models used to evaluate R&D program performance include the input-result-channel-effects (IRCE) model, the input-result-operations-notice effects (IRON) model, and the input-results-operation-time-phased effects (IROT) model [21]. The IRCE model can be used for analyzing the effects of research programs on industries, while the IRON model can be used for evaluating the R&D performance of large industrial technologies; and the IROT model can be used for individually examining the performance of technology programs. Summarizing these models, the four primary common elements in an R&D activity are inputs, outputs, result applications, and benefits. While these models rely on index scores and expert advices for the performance assessment, they are mostly used for assessing individual R&D program at a time [21]. See Appendix 1 for a graphical illustration of the IROT model as an example.

In recent years, the DEA has been extensively applied in evaluating the performance of various domains, such as enterprise operations, public administrations, medicine, and education. Specifically, numerous scholars have employed the DEA approach to assess performances of project planning [8, 22], R&D organizations [23], and country [24, 25] and industry [26]. For national performances, the DEA is adopted to explore the performance of various countries in the R&D of technologies and to determine whether the country possesses international competitiveness. For an organization’s R&D performance, the adoption of the DEA approach facilitates the identification of benchmarks for learning among a group of R&D programs. For program performance, the DEA approach increases the understanding of the operational efficiency of program, thereby providing reference for management authorities to formulate policies and strategic planning.

Unlike the IRCE, IRON, and IROT models, the DEA approach is more superior as it allows performance evaluations to be conducted for many programs simultaneously.

Other advantages of using the DEA approach to measure R&D program performance include the followings. (1) It can simultaneously analyze multiple inputs and multiple outputs. (2) It does not require predetermined models. (3) It employs mathematical planning model to define weights. (4) The analysis is objective. (5) DEA provides improvement suggestions. Therefore, among all, the DEA approach could be a suitable tool for evaluating the efficiency of R&D programs. Overall, the DEA approach is suitable as an analytical tool to assess the performance of DuTDPs.

3. Data Selection and Description

3.1 Input and Output Indicators

In line with Lu and Hung [8], this study employ a multi-stage performance measurement model to estimate the efficiency of DuTDPs. Particularly, using a network DEA model, we open the black-box process of DuTDPs into two stages, namely, R&D efficiency and socio-economic efficiency.

The objective of the first stage, the R&D efficiency, is to investigate whether R&D institutions properly utilize research resources and maximize their benefits. The choice of input and output indicators in R&D performance can be traced back to the literature. For example, Sánchez and Pérez [27] conclude that time and cost are the two important input elements while patent and scientific publication are the two outputs of R&D projects. As such, in synthesizing the past studies [27-32], we employ research expenditure, manpower, and duration as the input indicators, and academic performance (e.g., dissertations and research studies), technological results (number of patents granted), and revenues generated from R&D as the output indicators.

Meanwhile, the purpose of the second stage, the socio-economic efficiency, is to explore the positive effects of R&D results, obtained based on the position and goal (i.e., transforming national defense technologies and creating industrial values) of DuTDPs, on private industries and domestic economic development from the externality perspective. Academic performance, technological results, and R&D outcomes are adopted as the input indicators, while the output indicators include technology transfer and output values generated by promoting company investments, and the income and treasury transfer achieved through R&D. Before getting too carried away, we devote some space to discuss about the externality perspective which justifies our choice of input and output indicators in the socio-economic efficiency stage.

Schmookler [33] proposes the concept of R&D spillover effects. Positive external benefits are generated when the benefit of a certain company, country, or entity, acquired from R&D activities spill over to other entities [34, 35]. The strength of protective mechanisms (e.g., patent[2] and copyright) influences the spillover effects of R&D benefits. Because the strength differs among industries and countries, the possibility of spillover varies [37]. Nadiri [38] explores the benefit of R&D investment for companies and organizations, and shows that R&D expenditures have a significantly positive correlation with product growths and total productivity, and contributed to approximately 20 to 30% of the company's return. Piric and Reeve [39] indicate that the private return of R&D activities is substantially lower than the social return. Overall, incorporating socio-economic values (e.g., benefits from technology transfer, investments in production promotion, derived investment output value, and the number of treasury transfers resulting from R&D outcomes) into external benefits allows the

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[2] Griliches Griliches [36] highlights that patent is a measure to develop the direction of spillovers.

overall execution performance of DuTDPs to be clarified from the externality perspective. The definitions of the input and output indicators for each stage are summarized in Table 1.

[Insert Table 1 about here]

3.2 Preliminary Requirements of DEA

The sample of this study consists of DuTDPs executed by the CSIST. In this study, we have fulfilled the following requirements to ensure the validity of the two-stage DEA model used:

(i) Homogeneity of DMUs. In the seminal DEA study, Farrell [40] proposes that evaluation results would be significant only when DMUs are homogenous. Recently, this requirement has been relaxed, whereby Cook et al. [41] and Du et al. [42] suggest a series of DEA models for dealing with non-homogenous DMUs. Different from settings where non-homogenous sub-units operate in parallel network structures, we emphasize that DMUs used in this study are programs of DuTDPs which have the same objective, or in other words, they are homogenous in their own nature. DuTDPs primarily focus on implementing programs of the Ministry of Economic Affairs in Taiwan and their development is one of the main factors that prompt domestic economic development and enhance technologies of private industries. Non-homogeneity is thus not an issue in this study. Considering that DMUs of a DEA model must possess identical attributes, similar objectives and same market conditions [43], this study therefore only selects the DuTDPs from the CSIST as the DMUs.

(ii) Minimum number of DMUs. The input and output indicators of this study are selected from the results management database of the CSIST dual-use technology.

According to relevant legislations, the CSIST compiles yearly data on the overall execution performance of the DuTDPs and submits the data regularly to the Ministry of Economic affairs in Taiwan. Furthermore, our sample period is between July 2004 and July 2011 because the Military Product Commercialization technology development program was introduced in 2004;[3] and a total of 39 DuTDPs are obtained, after excluding programs that are with insufficient and missing data and incomplete programs; all of which ensure the comprehensiveness of the data and the representativeness of the program. According to Golany and Roll [43], the number of DMUs should be at least twice the number of input and output indicators. In this study, the 39 DMUs exceeds and thus satisfies the requirement for the two stages [i.e., 39＞2×(3+3+3)]. That is, the construct validity of the two-stage DEA model used in this study is stable and reliable.

(iii) Isotonic indicators. Golany and Roll [43] indicate that correlation analysis must be performed to verify whether an isotonic relationship (i.e., an increase in a portion of input increases a portion of output) exists between the input and output indicators. Based on the Spearman's rho correlation test in Table 2, significantly positive relationships exist between the input and output indicators of this study, indicating that the assumption of isotonicity for the DEA indicator selection is satisfied.

[Insert Table 2 about here]

(iv) The importance and relevance of indicators. The final step involves a determination of the relationships between input and output indicators and the direction of the relationships to verify the importance and relevance of the indicators [45]. Lewin

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[3] Note that this study is not about multi-period data. However, consistent with prior studies [8, 44], we consider different DuTDPs, which were completed over the sample period, as DMUs.

et al. [46] note that log-log regression model yields more robust results than linear model because it allows decreasing or increasing returns to scale. Moreover, the estimated coefficients by log-log model can be interpreted as elasticities, meaning that the percentage change in an output is for each 1% change in an input [46]. The relevant statistical significance of the model parameters and the results of R^2 are presented in Table 3. The input indicators in the first stage, left side of the table, explain 89.9% of the variation in the output of academic performance; 51.1% of technological results; and 94% of revenues. The results of Table 3, first stage, suggest that research expenditure can be viewed as a strong positive factors, implying that the increase in this input factor leads to increases in all output factors. For other input factors, the relationships are weaker, in particular research duration. However, research duration has been verified as one of the important indicators in R&D project management [22, 27, 47-49]. Therefore, the research duration should not be excluded from the R&D efficiency stage in order to yield a meaningful estimation. For the second stage, as shown in the right side of the table, the input indicators explain 74.9%, 33.2% and 99.3% variations in the outputs of technology transfer, derivative value and revenue to pay national treasury, respectively. In this stage, by and large the increases in input factors leads to increases in output factors. These results validate our model using the abovementioned inputs and outputs as being a good representation of DuTDP performance evaluation.

[Insert Table 3 about here]

4. Methodology

4.1 Two-Stage Production Processes for DuTDPs

Based on the multiple input and output evaluation concept of the DEA approach, we employ a network DEA model, NSBM [16], to develop a two-stage production process for DuTDPs. Moreover, to select a relatively efficient DMU as a benchmark reference, the DEA model developed in this study measures program performance from the perspective of relative efficiency, rather than the overall perspective.

In general, DEA models can be categorized as follows [50]: separate DEA model [SDEA; e.g., 51, 52], separate two-stage DEA model [STDEA; e.g., 11, 53], network DEA model [NDEA; e.g., 16, 54, 55, 56], and integrated two-stage DEA model [ITDEA; e.g., 14, 57, 58]. To evaluate two-stage efficiency with intermediate measures in a single implementation, a researcher can apply NDEA or ITDEA.[4] However, due to the complexity of the modeling, the scale economy and slack values for each DMU are hard to compute using the NDEA model proposed by Yu and Lin [55], Yu [54] and Kao [56], which is only applicable to the case of constant returns to scale. In addition, the traditional DEA models, the abovementioned NDEA models [54-56] and the ITDEA models [14, 57, 58] utilize the radial measure to evaluate the relative efficiency of DMUs in multi-stage production process. As a solution, Tone and Tsutsui [16] introduced a non-radial NDEA model, called NSBM, which considers the possibility of non-proportional changes of inputs and outputs.

Therefore, this study adopts the network model of Tone and Tsutsui [16], NSBM, by establishing a two-stage DEA model with intermediate measures in a single

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[4] In a two-stage efficiency evaluation, the performance improvement of one stage affects the efficiency status of the other through intermediate measures. Therefore, the SDEA and STDEA that lack interrelated performance among different stages are not suitable in this study.

implementation. To further illustrate, Figure 1 depicts the two-stage[5] production processes for DuTDPs, using input and output indicators that are selected based on the characteristics of DuTDPs, in line with theories proposed by Swink et al. [22], Wu et al. [26], Wang and Huang [25], Lu and Hung [7], and Lu and Hung [8].

[Insert Figure 1 about here]

4.2 Network SBM Model

The traditional network DEA models utilize the radial measure to evaluate the relative efficiency for each organization in multi-stage production process. The radial models may lack objectivity in terms of reflecting the real input/output conditions for each organization and stand on the assumption that inputs or outputs undergo proportional changes. As in the multi-stage production process used in this study, it is hard to assign input/output-oriented models without being subjective. In other words, non-radial measures, instead of radial measures, which deal directly with the input excesses and the output shortfalls and do not change proportionally, should be a main concern when seeking to achieve more realistic results.

To overcome the shortcomings discussed above, this study utilizes a slacks-based network data envelopment analysis [16], called Network SBM with internal linking activities in a single implementation, to evaluate the R&D and socio-economic efficiencies of the Taiwan's dual-use technology programs. Assume this study deals with n programs ($j=1,\ldots,n$) consisting of K stages ($k=1,\ldots,K$). m_k and h_k are

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[5] We caution readers that we develop a two-stage network structure (see [59] for further details). See also Du et al. [60] and Sahoo et al. [61].

the numbers of inputs and outputs to stage k, respectively. The non-oriented Network SBM model under free link activities program problem is as follows.

$$\begin{aligned}
&\rho_o = MIN\sum_{k=1}^{K}\left[1-\frac{1}{m_k}\left(\sum_{i=1}^{m_k}\frac{s_i^{k^-}}{x_{io}^{k}}\right)\right]\Big/\sum_{k=1}^{K}\left[1+\frac{1}{r_k}\left(\sum_{r=1}^{h_k}\frac{s_r^{k^+}}{y_{ro}^{k}}\right)\right]\\
&S.T.\\
&\quad x_{io}^{k}=\sum_{j=1}^{n}x_{ij}^{k}\lambda_j^{k}+s_i^{k^-},\quad i=1,\dots,m_k,\\
&\quad y_{ro}^{k}=\sum_{j=1}^{n}y_{rj}^{k}\lambda_j^{k}-s_r^{k^+},\quad r=1,\dots,h_k,\\
&\qquad \sum_{j=1}^{n}z_{dj}^{(f,g)}\lambda_j^{t}=\sum_{j=1}^{n}z_{dj}^{(f,g)}\lambda_j^{f},\ d=1,\dots,D,\\
&\qquad \sum_{j=1}^{n}\lambda_j^{k}=1,\\
&\qquad \lambda_j^{k}\geq 0,\ s_i^{k^-}\geq 0,\ s_r^{k^+}\geq 0,\ \forall k,\forall\ (f,g).
\end{aligned}\tag{1}$$

where x_{ij}^{k} is the amount of input i to the unit j at stage k; y_{rj}^{k} is the amount of output *r* to the unit j at stage k; $z_{dj}^{(f,g)}$ is the amount of linking intermediate product d from stage f to stage g to the unit j; D is the numbers of linking intermediate product ; $\sum_{j=1}^{n}\lambda_j^{k}=1$ suggests that the constructed best practice frontier exhibits variable returns to scale (VRS)[6] technology [62] at stage k. This program problem can be solved by transforming into a linear program using Charnes and Cooper transformation [63].

If $\rho_o^{*}=1$ in Eq. (1), the observed unit is called overall efficient. The stage k efficiency score of the observed unit can be defined by:

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[6] Here we choose VRS technology to offset the possible influence of different scales of inputs and outputs on our efficiency results. We also conducted statistical test between the efficiency scores under CRS and VRS technologies for the two stages. The results further support the use of VRS technology where the significant difference exists between the two groups of scores in socio-economic efficiency stage.

$$\rho_{ok}=\frac{1-\frac{1}{m_k}\left(\sum_{i=1}^{m_k}\frac{s_i^{k^{-*}}}{x_{io}^k}\right)}{1+\frac{1}{r_k}\left(\sum_{r=1}^{h_k}\frac{s_r^{k^{+*}}}{y_{ro}^k}\right)},\ \left(k=1,...,K\right), \tag{2}$$

where $s_i^{k^{-*}}$ and $s_r^{k^{+*}}$ are the optimal input slacks and output slacks in Eq. (1). If ρ_{ok}^* =1, then the target unit is technically efficient at stage k . If ρ_{ok}^* is smaller than one, then the target unit is technically inefficient.

4.3 Additive Super-efficiency Model

Suppose the observed unit is additive efficient at the stage k ; by removing the observed unit from the reference set, we obtain the super efficiency of the observed unit at the stage k under model (1). If we do that, the resulting model may not have a feasible solution. For an additive efficient observed unit at the stage k , this study has the following additive super-efficiency model [17, 64]:

$$\begin{aligned}
&\delta_o^{k*}=Min\ \frac{1}{m_k+r_k}\left(\sum_{i=1}^{m_k}\frac{t_{io}^{k-}}{x_{io}^k}+\sum_{r=1}^{h_k}\frac{t_{ro}^{k+}}{y_{ro}^k}\right)\\
&s.t.\\
&x_{io}^k+t_{io}^{k-}=\sum_{\substack{j=1\\ j\neq o}}^{n}x_{ij}^k\lambda_j^k,\quad i=1,...,m_k,\\
&y_{ro}^k-t_{ro}^{k+}=\sum_{\substack{j=1\\ j\neq o}}^{n}y_{rj}^k\lambda_j^k,\quad r=1,...,h_k,\\
&\sum_{\substack{j=1\\ j\neq o}}^{n}\lambda_j^k=1,\\
&\lambda_j^k,t_{io}^{k-},t_{ro}^{k+}\geq 0,\quad k=1,2,...,K,
\end{aligned} \tag{3}$$

According to Du et al. [17], there are actually two types of additive super-efficiency models: one is unit-invariant super-efficiency, and the other is not. Here this paper chooses the unit-invariant model because it is more suitable for the following the dual-use technology program efficiency application. The dual-use technology programs from the same sample may have quite different input and output scales. In that case, unit-invariant super-efficiency model is better choice to offset the influence on results caused by different scales.

Let $\left\{\delta_o^{k*};\lambda_j^{k*},\ j=1,2,...,n,\ j\neq o;t_{io}^{k-*},i=1,...,m_k;t_{ro}^{k+*},r=1,...,h_k;k=1,2,...,K\right\}$ be an optimal solution to model (3), then we can define:

$$\pi_o^{k*}=\frac{\frac{1}{m_k}\sum_{i=1}^{m_k}\left(x_{io}^k+t_{io}^{k-*}\right)\Big/x_{io}^k}{\frac{1}{h_k}\sum_{r=1}^{h_k}\left(y_{ro}^k-t_{ro}^{k+*}\right)\Big/y_{ro}^k}\geq 1 \tag{4}$$

as the additive super-efficiency score for the observed unit. As shown in Du et al. [17], this additive super-efficiency model (3) enables us to measure super-efficiency performance under VRS.

5. Empirical Result Analysis

5.1 Analysis of the R&D and Socio-Economic Efficiencies

Table 4 shows the overall and network efficiency values and the rankings of 39 DuTDPs. The higher efficiency score implies that a program is more efficient relative to its peers. The average overall efficiency, R&D efficiency, and socio-economic efficiency are 0.4778, 0.9127, and 0.4167, respectively. There are 29 and 36 inefficient programs in R&D stage and socio-economic stage, respectively. In fact, the majority of programs present relatively low socio-economic efficiencies which negatively contribute to the overall efficiencies.

[Insert Table 4 about here]

On the one hand, the results show that DuTDPs are more adept at R&D because of their long-term focus on technological R&D and system integration. On the other hand, the socio-economic efficiency should be reinforced and expanded to achieve the dual-effect (i.e., military and civilian) of improving national economy and reinforcing autonomous national defense. In the following paragraphs in this section, we provide some suggestion for strategies.

First, functions of management teams should be strengthened to enhance marketing and effectively integrate industrial needs. These functions include planning strategies for dual-use technology, integrating relevant resources, promoting technologies (e.g., domestic and international exhibitions, science park visits, and exchange and collaborations), producing print media propaganda and digital media reports, and expanding industries.

Second, the operation and management of intellectual property (IP) should be improved. Examples include planning various programs to enhance values of R&D results, establishing portfolio analysis for R&D to create R&D values, and identifying patent infringement. These approaches could help equilibrate the importance of R&D output and quality, thereby generating high value-added economic values.

Finally, topics or areas of focus for DuTDPs should be carefully considered. The national defense technology, purely used for military applications, is developed based on the notion of protecting national security and ensuring the safety of citizens' lives and properties. Therefore, resources can be invested into this area at all costs to achieve specific military or political purposes. In contrast, civilian technology is developed for profits. Therefore, selecting areas that are suitable for industry requirements is another crucial factor that requires consideration. However, Taiwan is a country with scarce resources and an unstable economy (referred to as a shallow-plate economy) that depends on import and export trades. R&D resource outputs in Taiwan are also limited and unstable. Thus, topics concerning global developments and public welfare (e.g., green energy) should be highlighted by DuTDPs to improve the international competitiveness of industries, thereby contributing to the social economy of Taiwan.

5.2 Ranking the Efficient Programs

The results of R&D and socio-economic efficiencies (Table 4) show that, among 39 programs, 10 and three are additive efficient, respectively. Therefore, this study employs additive super-efficiency model to distinguish the additive efficient DMUs of two stages obtained from NSBM analysis. Subsequently, additive efficient programs, those with scores of unity in NSBM, are further ranked.

Table 5 presents the efficient DMU ranking results for R&D efficiency stage. It reports the additive super-efficiency scores, the rankings and the corresponding optimal slacks for all 10 additive efficient programs. The results show that among 10 additive efficient DuTDPs, six programs have superior number of patents (with non-zero t_2^{1+*}). This indicates that if these DuDTPs were to reduce their number of patents, they still remain additive efficient units. For example, KTAS and DKTNEG would maintain the same level of efficiencies even with reducing their patents by 9.771 and 8.225 units, respectively. In terms of academic performance, measured by the number of published papers and research reports, only FIBCTD and PESPISI produced excess publications. Likewise, four programs gained extra revenue from technology transfer and patents. In addition, five of 10 programs could increase their research expenditure meaning they have the capacity to expand the R&D investment without diminishing the performance.

However, there are only two programs, FIBCTD and PESPISI, with the ability to increase the manpower and only one program, DHWCT, could extend the research duration.

[Insert Table 5 about here]

Table 6 presents the super-efficiency ranking for the few efficient DuTDPs in socio-economic efficiency stage. The results suggest that DHWCT and ARDSMM could substantially decrease their investment, the measurement for derivative value, in the relevant industry without changing the efficiency status while KTLEV needs to continue with the current investment in order to remain additive efficient. The other two outputs, technology transfer and revenue to pay national treasury, could be reduced by no means if the three efficient programs aim to remain efficient. In addition, DHWCT and ARDSMM could not increase any of their inputs while KTLEV is able to increase academic performance and revenue. These results are advantageous to efficient DuTDPs which highlight the capacities to increase the inputs or decrease the outputs and allow the programs to remain efficient relative to other peers.

[Insert Table 6 about here]

5.3 Efficiency Analysis on Various Applications

This study provides references for military policy makers to make decisions and enables the CSIST to prepare funds that assist in its transformation into a non-departmental public party. We comprehensively examine the performance of the CSIST in applying key technologies in the DuTDPs, and categorize the programs into four specific categories: mechanics and transportation (a total of 23 programs), communication and optoelectronics (6 programs), materials and chemical engineering (8 programs), and biotechnology and pharmaceutics (2 programs). Particularly, the mechanics and transportation category encompasses the aviation and transportation industries; the communication and optoelectronics category covers the wireless communication industries; the materials and chemical engineering category includes nanotechnology and the metal material industries; and the biotechnology and pharmaceutics category includes the medical equipment industries.

[Insert Table 7 about here]

The efficiency values for these categories are summarized in Table 7. The results show that the average overall efficiency of the materials and chemical engineering category is 0.6126 (the highest), while those of the communication and optoelectronics, mechanics and transportation, and biotechnology and pharmaceutics categories are 0.5689, 0.4402, and 0.0976, respectively. The rankings for the socio-economic efficiencies of the various categories are identical to that of overall efficiencies whereby the material and chemical engineering category excels in socio-economic efficiency as well. The reason is that the material and chemical engineering category includes industries that specialize in chemical engineering, electronic materials, nanotechnology, and metal materials. These industries are generally common civilian industries with outstanding investment performance. Moreover, companies tend to invest in these industries, and the socio-economic benefits of this category are relatively high.

Furthermore, the CSIST is highly competent in developing aircrafts and missiles and gains considerable experience in the mechanics and transportation and communication and optoelectronics categories. The two categories are the core value of the CSIST, which is a national defense technology R&D institution and national laboratory in Taiwan.

Finally, the biotechnology and pharmaceutics category in the CSIST is a relatively new area of interest. Interestingly, as compared to other categories, the R&D efficiency of this category is considerably better than its socio-economic efficiency, indicating the necessity for further improvements. While the R&D efficiency of biotechnology and pharmaceutics category is the highest (0.9418), its socio-economic efficiency is the least (0.0560) among other categories. In fact, the government has invested substantially in nurturing this infant category, yet it has not benefited the private industries and domestic economic development. However, since industries require biotechnological and pharmaceutical technologies, governments should continuously invest in related R&D resources to cultivate this industry and plan to transform the positive effects of R&D results into social welfare.

5.4 Discussions

The results of this study convey a number of important messages to the managers of the CSIST. First, the active reinforcements of benefits and strict management of IPs have to be promoted. In fact, there is a vital need for the improvement of socio-economic benefits through systematic integration and well marketed technology incentives. Second, the CSIST authorities must give a careful contemplation of organizational positioning and selection of DuTDPs. Such thoughtful positioning will amplify the niche strengths of the CSIST in specific categories. While the materials and chemical category is the core competency of the CSIST, the socio-economic deficiency of biotechnology and pharmaceutics category should receive an attentive consideration. Third, the current organizational transformation of the CSIST has to be supported and promoted in future. Granting the CSIST to be a non-departmental public body is a rare opportunity which could improve the efficiency of the CSIST in many aspects. This spotlights a brighter future for the CSIST if the authorities take full advantage in the way forward to improving the national economy and creating optimal welfare.

5.4.1 Active reinforcements of benefits and strict management of IPs

The ultimate goal of DuTDPs is to positively affect industries and create socio-economic values. The socio-economic benefits resulted from R&D results are key factors that influence DuTDP performance. In this study, we find that aspects of the socio-economic efficiency of DuTDPs require substantial improvements. Competent authorities should actively improve such various aspects as cultivating national defense professionals, expanding marketing, integrating industrial needs, and strengthening IP management. Specifically, considering that civilian technologies are developed for profit purposes, the overall development of the social economy should be enhanced and strengthened through systematic integration and well marketed technology incentives.

5.4.2 Contemplation of organizational positioning and careful selection of DuTDPs

The CSIST is a national defense technology R&D institution in Taiwan that specializes in high-performance weaponry systems. It focuses on developing electronic and information technologies and manufacturing and integrating advanced weapons and related systems. However, its R&D is highly unstable. The number of employees at the CSIST stands at approximately 8,000, a huge drop from the initial 20,000. Besides, its employees are aging, and the CSIST cannot hire new people. In an effort to sustain R&D and production at the CSIST, this organization is considered as overloaded. Therefore, we suggest that the CSIST continue to develop defense technologies and national weaponry systems, which are the foundation of DuTDPs. In addition, the CSIST should carefully select topics or areas of focus for the DuTDPs and choose technologies that correspond to current policies regarding R&D in the national defense technology and the trend of global markets. Consequently, maximum results can be achieved.

The R&D and socio-economic efficiencies of the materials and chemical engineering category are comparatively high, indicating that this category is the top priority of DuTDPs. The socio-economic efficiency of the biotechnology and pharmaceutics category is substantially lower than its R&D efficiency, suggesting that this category is at infancy stage of development which needs its socio-economic values to be improved to address the social economy aspect. However, the CSIST does not necessarily have to develop the biotechnology and pharmaceutics category in spite of the importance of this category. Rather, it can assess and determine which other R&D units in Taiwan can effectively implement this development.

5.4.3 Support and promotion of organizational transformation

Since October 2010, the CSIST has been granted permission to be transformed into a non-departmental public body, according to the policies stipulated by the President of Taiwan and the Executive Yuan and the government policies regarding organizational restructuring. Subsequently, based on the development of scientific research institutions in other countries, the CSIST successfully completes this transformation. The purpose is to effectively improve the performance of the CSIST in human resources management, administration, budgeting, and procurement operation and to increase its operational management performance and competitiveness. By establishing an independent public body outside of traditional administrative authorities, the CSIST can incorporate business operation and management models to vitalize R&D in technologies. Furthermore, full or partial expenditures are still budgeted by the government, which enables the non-departmental public body to effectively implement public tasks and ensure the flexibility of organizational operations. This opportunity is rare and should be highly valued because it can contribute immensely to future prospects and organizational development and may lead to significant breakthrough. However, transformation is a challenging process that must pass through stringent legal processes and established systems. The CSIST has successfully undergone organizational transformation by cooperating with other parties and promoting national policies. In addition, through the system of non-departmental public bodies, the CSIST has created the core value of the national defense technology R&D institution and maximized the performance of the institution. Moreover, the CSIST will achieve the goal of strengthening autonomous national defense and improving the national economy, creating optimal welfare for the communities and citizens of Taiwan.

6. Conclusions

A management expert, Peter Dulac, indicates that measurement and evaluation are two of the fundamental elements in management. The performance and management of DuTDPs have received considerable attention because DuTDPs bring about spillover effects through R&D, enhance technological development in industries, and ultimately strengthen national economy. In this study, we apply the externality concept and utilize a network DEA with super-efficiency to analyze the R&D and socio-economic efficiencies of DuTDPs executed by the CSIST between 2004 and 2011.

The empirical results are summarized as follows. (a) The average R&D efficiency of the DuTDPs is substantially higher than the average socio-economic efficiency, indicating that the invested resources are effectively applied. However, the socio-economic benefits should be expanded and strengthened to achieve the dual-effect value of national economy enhancement and autonomous national defense improvement. (b) Regarding various applied categories, the materials and chemical engineering category performs relatively efficient in terms of the R&D and socio-economic efficiencies causing its overall efficiency to be the highest among other categories. The R&D efficiency of the biotechnology and pharmaceutics category is greater than its socio-economic efficiency, showing that this category has achieved its initial goal but still needs improvement in transforming the R&D benefits into social welfare. This analysis provides future references for selecting DuTDP topics or areas of focus. In summary, governments should constantly invest and appropriately allocate R&D resources to achieve the dual-use goal of improving the R&D and socio-economic efficiencies.

An important implication of this area of research is that this study has potential in making an empirical contribution. Specifically, the application of DEA in assessing the performance of DuTDPs may serves as a good reference for researchers and even the policy makers in the area. Apart from IRCE, IRON, and IROT, they may consider using DEA in the real-world application in the future. Furthermore, the efficiency scores and the super-efficiency ranking may generate further empirical contributions in that the DEA outcomes of this study support the reliability of the DEA models used.

Finally, this study has thrown up some questions for future studies. First, the methods used in this study differ (different types and numbers of indicators) from those applied by the CSIST for empirical concerns, which possibly created differences in ranking results. Therefore, future research may follow the CSIST to evaluate DuTDPs. Second, note that the key to an effective DEA analysis is selecting appropriate research

DMUs and indicators. Although we select indicators based on prior literature, future studies may adopt other indicators to obtain alternative analysis results that will increase the accuracy of performance evaluations.

References

[1] Benoit E. Growth and defense in developing countries. Economic Development and Cultural Change. 1978:271-80.

[2] Aizenman J, Glick R. Military expenditure, threats, and growth. Journal of International Trade and Economic Development. 2006;15:129-55.

[3] Alptekin A, Levine P. Military expenditure and economic growth: A meta-analysis. European Journal of Political Economy. 2012;28:636-50.

[4] Yilgör M, Karagöl ET, Saygili ÇA. Panel causality analysis between defence expenditure and economic growth in developed countries. Defence and Peace Economics. 2014;25:193-203.

[5] Linton JD, Walsh ST, Morabito J. Analysis, ranking and selection of R&D projects in a portfolio. R&D Management. 2002;32:139-48.

[6] Linton JD, Morabito J, Yeomans JS. An extension to a DEA support system used for assessing R&D projects. R&D Management. 2007;37:29-36.

[7] Lu W-M, Hung S-W. Assessing the performance of a vertically disintegrated chain by the DEA approach–a case study of Taiwanese semiconductor firms. International Journal of Production Research. 2010;48:1155-70.

[8] Lu W-M, Hung S-W. Exploring the operating efficiency of Technology Development Programs by an intellectual capital perspective—A case study of Taiwan. Technovation. 2011;31:374-83.

[9] Lu W-M, Wang W-K, Kweh QL. Intellectual capital and performance in the Chinese life insurance industry. Omega. 2014;42:65-74.

[10] Wang W-K, Lu W-M, Kweh QL, Lai H-W. Does corporate social responsibility influence the corporate performance of the U.S. telecommunications industry? Telecommunications Policy. 2014.

[11] Seiford LM, Zhu J. Infeasibility of super-efficiency data envelopment analysis models. INFOR. 1999;37:174-87.

[12] Zhu J. Multi-factor performance measure model with an application to Fortune 500 companies. European Journal of Operational Research. 2000;123:105-24.

[13] Sexton TR, Lewis HF. Two-stage DEA: An application to major league baseball. Journal of Productivity Analysis. 2003;19:227-49.

[14] Kao C, Hwang S-N. Efficiency decomposition in two-stage data envelopment analysis: An application to non-life insurance companies in Taiwan. European Journal of Operational Research. 2008;185:418-29.

[15] Lo S-F. Performance evaluation for sustainable business: A profitability and marketability framework. Corporate Social Responsibility and Environmental Management. 2010;17:311-9.

[16] Tone K, Tsutsui M. Network DEA: A slacks-based measure approach. European Journal of Operational Research. 2009;197:243-52.

[17] Du J, Liang L, Zhu J. A slacks-based measure of super-efficiency in data envelopment analysis: A comment. European Journal of Operational Research. 2010;204:694-7.

[18] FAS. Chungshan Institute of Science and Technology. The Federation of American Scientists. 1999.

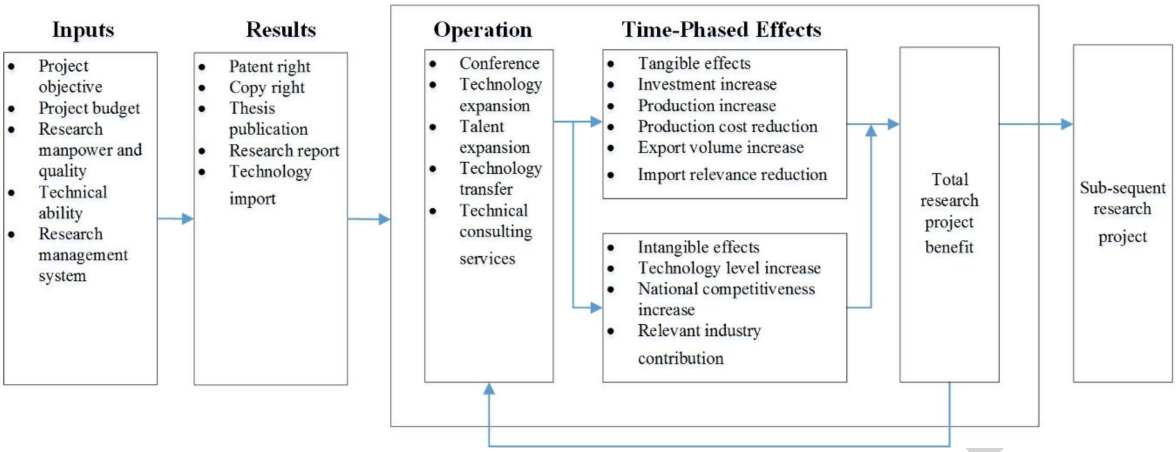
[19] Jan T-S, Jan C-G. Development of weapon systems in developing countries: a case study of long range strategies in Taiwan. Journal of the Operational Research society.

2000:1041-50.
[20] Mulvenon J. Taiwan and the Revolution in Military Affairs. In The Information Revolution in Military Affairs in Asia. Palgrave Macmillan2004. p. 139-65.
[21] Ken Y, Liu Y-C, Hsueh C-C, Chang S-M, Chen S-J. Exploring the evaluation method of technology program: Taiwan and U.S.A. (written in Chinese). Sci-Tech Policy Review. 2008;1:53-68.
[22] Swink M, Talluri S, Pandejpong T. Faster, better, cheaper: A study of NPD project efficiency and performance tradeoffs. Journal of Operations Management. 2006;24:542-62.
[23] Liu JS, Lu W-M. Network-based method for ranking of efficient units in two-stage DEA models. Journal of the Operational Research Society. 2012;63:1153-64.
[24] Kocher MG, Luptacik M, Sutter M. Measuring productivity of research in economics: A cross-country study using DEA. Socio-Economic Planning Sciences. 2006;40:314-32.
[25] Wang EC, Huang W. Relative efficiency of R&D activities: A cross-country study accounting for environmental factors in the DEA approach. Research Policy. 2007;36:260-73.
[26] Wu W-Y, Tsai H-J, Cheng K-Y, Lai M. Assessment of intellectual capital management in Taiwanese IC design companies: Using DEA and the Malmquist productivity index. R&D Management. 2006;36:531-45.
[27] Sánchez AM, Pérez MP. R&D project efficiency management in the Spanish industry. International Journal of Project Management. 2002;20:545-60.
[28] Lee SK, Mogi G, Lee SK, Hui K, Kim JW. Econometric analysis of the R&D performance in the national hydrogen energy technology development for measuring relative efficiency: The fuzzy AHP/DEA integrated model approach. International journal of hydrogen energy. 2010;35:2236-46.
[29] Eilat H, Golany B, Shtub A. R&D project evaluation: An integrated DEA and balanced scorecard approach. Omega. 2008;36:895-912.
[30] Rousseau S, Rousseau R. The scientific wealth of European nations: taking effectiveness into account. Scientometrics. 1998;42:75-87.
[31] Verma D, Sinha KK. Toward a theory of project interdependencies in high tech R&D environments. Journal of Operations Management. 2002;20:451-68.
[32] Cherchye L, Abeele PV. On research efficiency: A micro-analysis of Dutch university research in Economics and Business Management. Research policy. 2005;34:495-516.
[33] Schmookler J. Invention and economic growth. Cambridge: Harvard University Press; 1966.
[34] Jaffe AB. Technological opportunity and spillovers of R&D: evidence from firms' patents, profits and market value. USA: National Bureau of Economic Research Cambridge, Mass.; 1986.
[35] Nieto M, Quevedo P. Absorptive capacity, technological opportunity, knowledge spillovers, and innovative effort. Technovation. 2005;25:1141-57.
[36] Griliches Z. The search for R&D spillovers. NBER Working Papers Series (No 3768): National Bureau of Economic Research; 1992.
[37] Cohen WM, Goto A, Nagata A, Nelson RR, Walsh JP. R&D spillovers, patents and the incentives to innovate in Japan and the United States. Research Policy. 2002;31:1349-67.
[38] Nadiri MI. Innovations and technological spillovers. National Bureau of Economic

Research; 1993.
[39] Piric A, Reeve N. Evaluation of public investment in R&D-towards a contingency analysis. Policy Evaluation in Innovation and Technology: Toward best practices Cap. 1997;5.
[40] Farrell MJ. The measurement of productive efficiency. Journal of the Royal Statistical Society Series A (General). 1957;120:253-90.
[41] Cook WD, Harrison J, Imanirad R, Rouse P, Zhu J. Data Envelopment Analysis with Nonhomogeneous DMUs. Operations Research. 2013;61:666-76.
[42] Du J, Chen Y, Huo J. DEA for non-homogenous parallel networks. Omega. 2015;56:122-32.
[43] Golany B, Roll Y. An application procedure for DEA. OMEGA. 1989;17:237-50.
[44] Ho M-C, Liu J, Lu W-M, Huang C-C. A new perspective to explore the technology transfer efficiencies in US universities. The Journal of Technology Transfer. 2014;39:247-75.
[45] Sun S. Measuring the relative efficiency of police precincts using data envelopment analysis. Socio-Economic Planning Sciences. 2002;36:51-71.
[46] Lewin AY, Morey RC, Cook TJ. Evaluating the administrative efficiency of courts. Omega. 1982;10:401-11.
[47] Kim B, Oh H. An effective R&D performance measurement system: survey of Korean R&D researchers. Omega. 2002;30:19-31.
[48] Olson EM, Walker OC, Ruekerf RW, Bonnerd JM. Patterns of cooperation during new product development among marketing, operations and R&D: Implications for project performance. Journal of Product Innovation Management. 2001;18:258-71.
[49] Hsu F-M, Hsueh C-C. Measuring relative efficiency of government-sponsored R&D projects: A three-stage approach. Evaluation and Program Planning. 2009;32:178-86.
[50] Chiou Y-C, Lan LW, Yen BT. A joint measurement of efficiency and effectiveness for non-storable commodities: Integrated data envelopment analysis approaches. European Journal of Operational Research. 2010;201:477-89.
[51] Karlaftis MG. A DEA approach for evaluating the efficiency and effectiveness of urban transit systems. European Journal of Operational Research. 2004;152:354-64.
[52] Chiou Y-C, Chen Y-H. Route-based performance evaluation of Taiwanese domestic airlines using data envelopment analysis. Transportation Research Part E: Logistics and Transportation Review. 2006;42:116-27.
[53] Keh HT, Chu S, Xu J. Efficiency, effectiveness and productivity of marketing in services. European Journal of Operational Research. 2006;170:265-76.
[54] Yu M-M. Assessing the technical efficiency, service effectiveness, and technical effectiveness of the world’s railways through NDEA analysis. Transportation Research Part A: Policy and Practice. 2008;42:1283-94.
[55] Yu M-M, Lin ET. Efficiency and effectiveness in railway performance using a multi-activity network DEA model. OMEGA. 2008;36:1005-17.
[56] Kao C. Efficiency decomposition in network data envelopment analysis: A relational model. European Journal of Operational Research. 2009;192:949-62.
[57] Chen Y, Cook WD, Li N, Zhu J. Additive efficiency decomposition in two-stage DEA. European Journal of Operational Research. 2009;196:1170-6.
[58] Cook WD, Zhu J, Bi G, Yang F. Network DEA: Additive efficiency decomposition. European Journal of Operational Research. 2010;207:1122-9.
[59] Cook WD, Liang L, Zhu J. Measuring performance of two-stage network structures

by DEA: a review and future perspective. Omega. 2010;38:423-30.
[60] Du J, Liang L, Chen Y, Cook WD, Zhu J. A bargaining game model for measuring performance of two-stage network structures. European Journal of Operational Research. 2011;210:390-7.
[61] Sahoo BK, Zhu J, Tone K, Klemen BM. Decomposing technical efficiency and scale elasticity in two-stage network DEA. European Journal of Operational Research. 2014;233:584-94.
[62] Banker RD, Charnes A, Cooper WW. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management science. 1984;30:1078-92.
[63] Tone K. A slacks-based measure of efficiency in data envelopment analysis. European journal of operational research. 2001;130:498-509.
[64] Du J, Wang J, Chen Y, Chou S-Y, Zhu J. Incorporating health outcomes in Pennsylvania hospital efficiency: An additive super-efficiency DEA approach. Annals of Operations Research. 2014;221:161-72.

Appendix



IROT Model
Source: Extracted from Ken et al. [15].

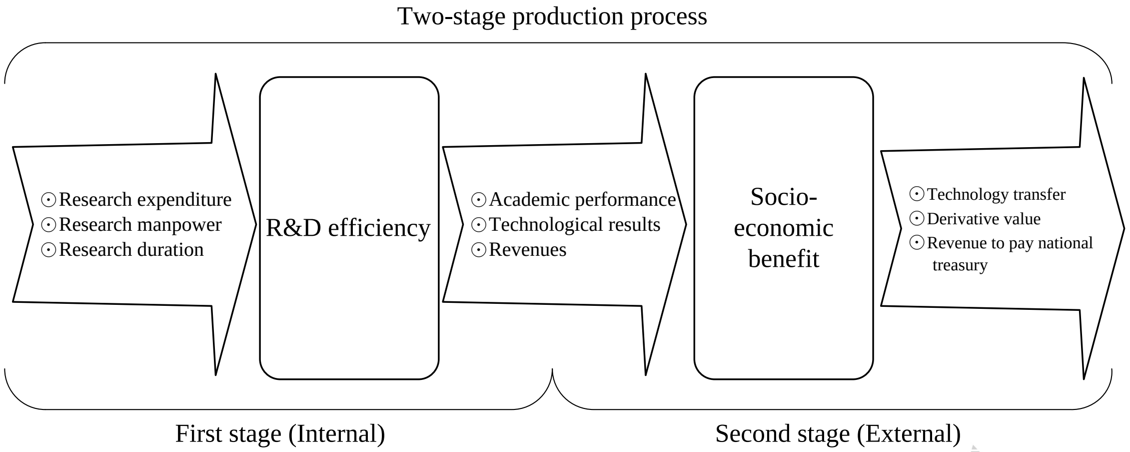


Figure 1 Two-stage network production processes for DuTDPs

Table 1 Indicator definition

Indicators and attributes	Definition	Unit
Research expenditure (input)	The investment amount in R&D expenditures during program execution.	Thousand NT$
Research manpower (input)	The number of workers during program execution.	Number of person
Research duration (input)	The period of time used for program execution.	Number of month
Academic performance (output /input)	The number of domestic and international published papers and research reports attributable to program execution.	Unit
Technological results (output /input)	The number of domestic and international patents granted for programs.	Unit
Revenues (output /input)	Income obtained from technology transfer and patent output of programs.	Thousand NT$
Technology transfer (output)	The number of technology transferred, technology licensing, etc. to the domestic and international industries.	Unit
Derivative value (output)	The amount of investment in the industry.	Thousand NT$
Revenue to pay national treasury (output)	Income from the R&D outcomes paid to the Taiwanese treasury.	Thousand NT$

Table 2 Spearman's rho correlation coefficients among inputs and outputs

	Research expenditure	Research manpower	Research duration	Academic performance	Technological results	Revenues	Technology transfer	Derivative value	Revenue to pay national treasury
Research expenditure	1								
Research manpower	.843***	1							
Research duration	.808***	.697***	1						
Academic performance	.900***	.832***	.772***	1					
Technological results	.709***	.600***	.641***	.692***	1				
Revenues	.945***	.869***	.813***	.895***	.720***	1			
Technology transfer	.830***	.759***	.800***	.869***	.722***	.885***	1		
Derivative value	.666***	.628***	.614***	.597***	.538***	.724***	.618***	1	
Revenue to pay national treasury	.943***	.870***	.821***	.886***	.696***	.988***	.873***	.713***	1

***. Correlation is significant at the 0.01 level (2-tailed).

Table 3 Regression results on input and output indicators

First stage				Second stage			
Input factors	Output measures			Input factors	Output measures		
	Academic performance	Technological results	Revenues		Technology transfer	Derivative value	Revenue to pay national treasury
Research expenditure	0.740***	0.683***	0.924***	Academic performance	0.369**	-0.430	-0.039
Research manpower	0.187**	-0.132	0.029	Technological results	0.259**	0.083	-0.016
Research duration	0.049	0.169	0.025	Revenues	0.281*	0.882***	1.043***
R^2	0.899	0.511	0.940	R^2	0.749	0.332	0.993
F	104.086***	12.191***	182.853***	F	34.741***	5.792***	1673.446***

***. Significant at the 0.01 level.
**. Significant at the 0.05 level.
*. Significant at the 0.1 level.

Table 4 Network efficiency values

Number	Title	R&D efficiency	Rank	Socio-economic efficiency	Rank	Overall efficiency	Rank
1	KTAS	1	-	0.9996	10	0.9998	8
2	ASVSIPTD	0.9292	22	0.6689	12	0.7732	12
3	MSCOI	1	-	0.9999	4	0.9999	5
4	MAT	0.9713	16	0.1692	23	0.2852	22
5	MSMCI	0.9995	12	0.9999	5	0.9997	9
6	BMCSIT	0.9509	19	0.3795	17	0.5367	16
7	FIBCTD	1	-	0.9999	6	0.9999	5
8	ARDFM	0.9376	20	0.5334	14	0.6740	13
9	BDTD	0.9106	24	0.1055	31	0.1824	31
10	OPESKTRD	0.7651	36	0.1920	22	0.2843	23
11	OIOMAT	0.8501	31	0.1966	20	0.3039	21
12	IMMTDP	0.9585	18	0.1570	24	0.2658	24
13	NGEMDKT	0.7987	34	0.5534	13	0.6408	14
14	LACKSITA	0.9667	17	0.1095	29	0.1941	28
15	CASRTI	0.8388	32	0.0697	33	0.1198	33
16	VSSKTD	0.8894	26	0.1084	30	0.1848	30
17	IPMTDC	0.8803	27	0.1961	21	0.3083	20
18	ATDAC	0.8133	33	0.9999	7	0.9066	10
19	MMT	1	-	0.9999	8	0.9999	-
20	NGMCSRKTD	0.9773	14	0.0773	32	0.1419	32
21	DHWCT	1	-	1	-	1	-
22	VGPKTD	0.6569	39	0.0116	38	0.0190	38
23	VATIV	0.9999	11	0.9999	9	0.9999	5
24	VCSSDKT	0.7209	37	0.0379	35	0.0629	35
25	ARDSMM	1	-	1	-	1	-
26	KRRESED	0.9906	13	0.1101	28	0.1974	27
27	KTLEV	1	-	1	-	1	-
28	DLPRAT	0.8651	29	0.2163	19	0.3317	19
29	TIHVA	0.6772	38	0.4395	16	0.5121	17
30	HCIRRR	0.8680	28	0.0307	37	0.0556	37
31	TFSMMEKT	0.9123	23	0.0337	36	0.0624	36
32	BMDTD	0.9729	15	0.0065	39	0.0128	39
33	PSIMAT	0.9065	25	0.1447	25	0.2410	25
34	NMPTD	1	-	0.1295	26	0.2293	26
35	VETRDI	0.7956	35	0.0565	34	0.0960	34
36	IVRDVKT	0.8599	30	0.1157	27	0.1928	29
37	PESPISI	1	-	0.6995	11	0.8232	11
38	SRRFIIAC	0.9334	21	0.4751	15	0.6227	15
39	DKTNEG	1	-	0.2303	18	0.3743	18
	Mean	0.9127		0.4167		0.4778	

Table 5 Results of additive super-efficiency for R&D efficient projects

Number	Title	Super-efficiency	Rank	Slacks					
				t_1^{1-*}	t_2^{1-*}	t_3^{1-*}	t_1^{1+*}	t_2^{1+*}	t_3^{1+*}
1	KTAS	1.133	6	577.575	0	0	0	9.771	0
3	MSCOI	1.127	7	0	0	0	0	0	25772.299
7	FIBCTD	1.576	2	0	9.860	0	76.561	0	0
19	MMT	1.145	5	0	0	0	0	0	21258.333
21	DHWCT	1.399	4	0	0	4.830	0	2.648	2188.611
25	ARDSMM	1.032	8	17417.784	0	0	0	0	0
27	KTLEV	1.448	3	5300.900	0	0	0	1.000	0
34	NMPTD	0.997	9	0	0	0	0	0.248	0
37	PESPISI	1.591	1	3723.844	1.366	0	12.603	0.756	0
39	DKTNEG	0.632	10	14664.579	0	0	0	8.225	3971.927

Table 6 Results of additive super-efficiency for Socio-economic efficient projects

Number	Title	Super-efficiency	Rank	Slacks					
				t_1^{2-*}	t_2^{2-*}	t_3^{2-*}	t_1^{2+*}	t_2^{2+*}	t_3^{2+*}
21	DHWCT	1.279	3	0	0	0	0	3275489.745	0
25	ARDSMM	1.291	2	0	0	0	0	16447476.408	0
27	KTLEV	2.659	1	2.037	0	913.889	0	0	0

Table 7 Efficiency value of each application fields

Field	R&D efficiency			Socio-economic benefit			Overall efficiency		
	Mean	Efficiency	Inefficiency	Mean	Efficiency	Inefficiency	Mean	Efficiency	Inefficiency
Mechanics and transportation	0.9015	6 (26%)	17 (74%)	0.3789	1 (4%)	22 (96%)	0.4402	1 (4%)	22 (96%)
Communication and optoelectronics	0.9288	2 (9%)	21 (91%)	0.4895	1 (4%)	22 (96%)	0.5689	1 (4%)	22 (96%)
Materials and chemical engineering	0.9258	2 (9%)	21 (%91)	0.5612	1 (4%)	22 (96%)	0.6126	1 (4%)	22 (96%)
Biotechnology and pharmaceutics	0.9418	0 (0%)	23 (100%)	0.0560	0 (0%)	23 (100%)	0.0976	0 (0%)	23 (100%)

Evaluating the Efficiency of Dual-Use Technology Development Programs from the R&D and Socio-Economic Perspectives

Highlights

- We apply a network data envelopment analysis model called network slacks-based measure (NSBM).
- We examine the R&D and socio-economic efficiencies of Taiwan's dual-use technology development programs.
- We employ the additive super-efficiency model to distinguish benchmark programs at different stages.
- We conduct an analysis on the strengths and weaknesses of internal resource utilization.