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Evaluating the efficiency of dual-use technology development programs from the R&D and socio-economic perspectives ☆

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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.

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 well-being. 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

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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 analyzes 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 and 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 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

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