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Measuring relative efficiency of government-sponsored R&D projects: A three-stage approach

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ABSTRACT

Without considering differences in operating environment, traditional methods of efficiency evaluation are suffering from external environmental influences. This study presents an alternative approach for assessing the relative efficiency of government-sponsored research and development projects (GSP). A three-stage approach employing data envelopment analysis to evaluate efficiency and Tobit regression to control external variables was applied to 110 projects over 9 years. This study finds that firm size, industry, and ratio of public subsidy on research and development (R&D) budget of recipient firm significantly influences the technical efficiency of GSP in Taiwan. After controlling these external variables, the mean value of technical efficiency in the third stage increases and becomes significantly different to that in the first stage. Most GSPs increase their returns when their projects are scaled up. Furthermore, government policy makers must establish the upper-limit ratio of subsidies on R&D budgets of recipient firms to avoid inefficient use of public funds.

1. Introduction

As increased attention is paid to governmental support for private sector research and development (R&D), policy makers must offer an economic rationale for their support of public–private technology partnerships, and to require methods of performance evaluation to determine efficiency of R&D projects (Revilla, Sarkis, & Modrego, 2003). Through promulgating the Government Performance and Results Act (GPRA) of 1993 in the United States, which stressed the accountability of performance, agencies have been required to pay serious attention to evaluate impact of government subsidy (Corley, 2007). Public subsidies intended to stimulate the R&D progress of firms are wasted if resources are not used efficiently.

Previous studies of R&D project evaluation tended to focus on just one aspect of performance and have been criticized for failing to provide an overall and aggregate assessment of relative performance (Farris, Groesbeck, Van-Aken, & Letens, 2006). Inherent contradiction has occurred between the multi-faceted and multidimensional nature of contemporary R&D activity and unidimensional approaches to its measurement (Mark, Henry, & Julnes, 2000). Since each measure represents a partial component of multidimensional manifolds, excessive emphasis on any partial dimension of performance will lead to distort assessments of innovation performance (Backes-Gellner & Sadowski, 1990). Furthermore, previous government-sponsored R&D project (GSP) performance evaluation relied mainly on outputs rather than project inputs, such as project scope, technical complexity, and staffing, all of which influenced project performance and initiated a need for output/input comparisons, that is efficiency (e.g., Bach, Conde-Molist, Ledoux, & Schaeffer, 1995; Georghiou, 1999; Ruegg & Feller, 2003; Walwyn, 2007). To solve these problems, a more elaborate method of assessing efficiency is necessary for determining GSP performance.

Farrell (1957) was the first to use frontier production functions to measure technical efficiency (TE). Technical efficiency of a production unit indicates the maximization of potential output based on given inputs, considering physical production relationships (Iraizoz, Rapun, & Zabaleta, 2003; Sohn & Moon, 2004). Data envelopment analysis (DEA) was one of the main methods used to measure technical efficiency. DEA, initially proposed by Charnes, Cooper, and Rhodes (1978), has been widely used to estimate frontier production function to calculate the maximum output that can be achievable by each production unit for a given combination of inputs by applying

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Linear Programming (Coelli, Prasada-Rao, O'Donnell, & Battese, 1998). Decision-making units (DMUs) that are technically efficient are located at the frontier, while those that are not technically efficient appear below the frontier, since their output falls below the technically possible maximum.

The DEA technique possesses several advantages in assessing the technical efficiency of R&D activities versus other parametric methods.[2] These attractive features have inspired researchers to apply DEA techniques to assess R&D efficiency, assess performance in new product development, and select R&D projects (Farris et al., 2006; Glass, McCallion, & McKillop, 2006; Linton, Walsh, & Morabito, 2002). Technical efficiency and operating environment influence production unit ability to transform inputs into outputs. However, in typical DEA studies, the influence of external operating environmental variables was neglected (Fried, Schmidt, & Yaisawarng, 1999). Therefore, separating the management component of inefficiency from the external variables to clarify the nature of efficiency or inefficiency of GSP is essential for developing policies for improving public sector resource allocation.

From previous studies, approaches used to measure technical efficiency in operating environment could be classified into three categories: frontier separation approach, all-in-one approach, and two-stage approach (Fried et al., 1999). These approaches examined differences in efficiency among DMUs by relating measures of inefficiency to characteristics of the external operating environment. However, these approaches could not clarify the effects of external conditions on the efficient use of each individual input or output. The essence of inefficiency is essential to policy making for improving the effectiveness of resource allocation. Consequently, a fourth approach, the three-stage approach,[3] was introduced (Fried et al., 1999). Three-stage approach has been applied to evaluate relative efficiency in numerous areas, including manufacturing (Chapelle & Plane, 2005), banks (Drake, Gall, & Simper, 2006), and the public sector (Wang & Huang, 2007). However, no study has applied the three-stage approach to evaluate the relative efficiency of GSPs. Inspired by Fried et al. (1999), this study proposes a three-stage approach that applies DEA to estimate GSP efficiency and adjusts efficiency scores by considering the effect of external environmental variables. The findings of this study provide useful feedback for improving GSP fund effectiveness. The remainder of this paper is organized as follows. Section 2 reviews input measures, output measures, and external environmental variables of GSPs. Section 3 then introduces the GSP context in Taiwan and explains the three-stage approach with data collection. Next, Section 4 summarizes the investigation results. Finally, the last section presents the conclusion and empirical implications.

[2] First, DEA technique does not require the assumption of a functional form for the specification of input–output relation. Second, based on best practice, DEA technique does not need a priori factor weights to be specified in the evaluation process. This advantage is valuable in the context of empirical analysis where little is known of production function and behavior of recipients (Chapelle & Plane, 2005). Third, in contrast to parametric analysis, where it is assumed that the single optimized regression equation applies to each empirical observation, the DEA method calculates the performance of each DMU with regard to a specific peer group reflecting the best practice for the observation (Seiford & Zhu, 1999). Finally, DEA naturally deals with the simultaneous occurrence of several inputs and several outputs.

[3] The three-stage approach used by this study, in contrast to other approaches, has several advantages. First, it fully uses the information on slack estimates generated in the initial DEA model. Second, its result is an input slack measure of technical efficiency with conventional interpretations. Third, it is not necessary to classify the external variables into input and output categories prior to the all-in-one DEA approach. Finally, it can ascertain the influence of external variables on the efficient use of each input (Fried et al., 1999).

2. Literature review

2.1. Government-sponsored R&D project performance

The performance evaluation of GSP innovation[4] should serve multiple objectives, and appropriate indicators can be selected for different objectives (Ruegg & Feller, 2003; Sohn, Joo, & Han, 2007). Consequently, to fit the objectives of different stakeholders, GSP performance must be assessed by using different measures in different dimensions (Bach et al., 1995; Georghiou, 1999; Revilla et al., 2003; Ruegg & Feller, 2003; Sohn et al., 2007). Previous studies have mainly proposed two or three dimensions for measuring GSP performance.

Revilla et al. (2003) suggested that the traditional approach to performance evaluation is based on quantitative indicators and includes short-term and long-term dimensions of performance evaluation. Short-term performance generally describes the more concrete effects of a project on firm productivity. Meanwhile, long-term performance is typically less tangible, and hence difficult to quantify. One such long-term performance is the value of experience-based learning. This definition resembles that employed by Bach et al. (1995), which included both direct and indirect effects.

Georghiou (1999) reviewed the operation of GSP evaluation at a European level and addressed a schema of outputs and effects resulting from GSPs including intermediate output, final output and long-term impact. Measures of GSP performance range from scientific outputs such as publications, through "intermediate" outputs such as patents and prototypes, and then to "final" outputs such as new or improved products, processes or services and long-term impacts resulting from interaction between the outputs and the economy or society.

In a study of the National Institute of Standards and Technology (NIST), Ruegg and Feller (2003) proposed output, outcome and impact dimensions of performance to evaluate GSP based on a review of 45 studies of the Advanced Technology Program (1990–2000) of the USA. As defined by Ruegg and Feller, GSP inputs provide a budget for convening staff to administer the process. The principal outputs include publications, patents, models, algorithms, prototype products and processes. Meanwhile, the main outcomes include sales of new and improved products, processes, and productivity effects on firms. Long-term impacts relate to the social goals that drove the emergence of GSP for increasing GDP and employment, and improving the international competitiveness of industry.

According to the definition of performance used by Ruegg and Feller (2003) and Sohn et al. (2007) propose a structural equation model incorporating Likert-scale measures to assess GSP performance in three respects: output, outcome and impact. However, Sohn et al. (2007) further defined output as GSP technological performance; outcome as business performance, management performance, and manufacturing performance; impact as long-term effect in improving national competitiveness and broadly based benefits. Based on consideration of microeconomic and quantifiable measures, this study adopted the definition of GSP performance used by Georghiou (1999) and Ruegg and Feller (2003), which includes intermediate output and final output but excludes long-term impact.

Regarding the issues related to the application of DEA in R&D projects, numerous studies have identified various measures for describing project inputs and outputs and evaluating relative efficiency (e.g., Farris et al., 2006; Linton et al., 2002; Revilla et al.,

[4] The Oslo manual (OECD, 1997) defines an innovation as the commercial introduction of a new or significantly improved product or process to the market.