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Relative efficiency of R&D activities: A cross-country study accounting for environmental factors in the DEA approach

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Abstract

This paper applies the production framework associated with the data envelopment analysis (DEA) method to evaluate the relative efficiency of R&D activities across countries. R&D capital stocks and manpower are treated as inputs while patents and academic publications are considered as outputs. A three-stage approach, which involves using DEA for evaluating efficiency and using Tobit regressions for controlling the external environment, is applied to 30 countries in recent years. The results show that less than one-half of the countries are fully efficient in R&D activities and that more than two-thirds are at the stage of increasing returns to scale. Most countries have a more significant advantage in producing SCI cum EI publications than in generating patents.

Keywords: R&D; Efficiency; Data envelopment analysis; Tobit regression

1. Introduction

R&D activity is a well-organized process of knowledge creation, production, diffusion, and application. It entails innovation in scientific technology, in management measures, and in social and political systems, etc. OECD (2003) defined the investment in knowledge as the sum of R&D expenditure, expenditure for higher education and investment in software. Since R&D investment is one of the most crucial elements in promoting scientific and technological progress, any country that uses the resources inefficiently could bear a penalty in the form of achieving a much slower progress. Furthermore, if R&D resources are not used effectively, additional investment may be of little help in stimulating progress. However, the relevant literature has focused primarily on efforts at new R&D investment and comparatively little attention has been given to the effective use of the resources, particularly at the national level, once they are in place. This is a potentially important omission, since the very conditions responsible for scientific and economic backwardness may operate through the poor management of R&D activities. Understanding the nature of R&D efficiency/inefficiency is important for designing policies to improve resource allocation.

In this paper, we attempt to fill in this gap by examining the efficiency of national R&D activities. We propose a three-stage approach, which involves applying data envelopment analysis (DEA) for estimating

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efficiency and Tobit regressions for controlling the external environment. Following Pakes and Griliches (1984) and Griliches (1990), this paper considers R&D to be a production process and regards each country as a decision-making unit (DMU) conducting R&D. By setting up an inter-country R&D innovation production framework and using the DEA model and Tobit regression iteratively, our three-stage approach can identify and separate the intrinsic technical inefficiency in the R&D process from the external effects stemming from the operating environment, which differs substantially from country to country.[1] The sample in this paper consists of thirty (30) countries that engage in R&D activities intensively. In addition, slack and advantage analyses provide detailed assessments on each country's R&D resource allocation.

There has been a large amount of literature devoted to discussing the effects of R&D investment on raising productivity and profits at the firm and industry levels. Mansfield (1980, 1988), Terleckyj (1982), Griliches (1986), Meliciani (2000), Hartmann (2003), Timmer (2003), and Gonzalez and Gascon (2004) provided evidence from many industries in various countries. Feller (1990) and Adams and Griliches (2000) emphasized the importance of the productivity of basic research in universities.

Only in recent years have a few examples in the literature discussed R&D efficiency by using quantitative approaches with regard to R&D at the firm level, Zhang et al. (2003) applied the stochastic frontier analysis (SFA) approach to the R&D efforts of Chinese firms to examine the difference in efficiency among various types of ownership. As for academic research, Korhonen et al. (2001) and Cherchye and Vanden Abeele (2005) applied the DEA technique to evaluate the efficiency of university R&D in Finland and the Netherlands, respectively.

The rest of the paper is organized as follows. Section 2 presents a summary of the overall methodology and discusses the R&D production framework and the DEA model of the efficiency measure. Section 3 gives a description of the data management and the hypotheses tested in the paper. Section 4 presents the empirical results of the three-stage approach. A comparison of the relative efficiency scores for Stage I and Stage III as well as advantage analysis are also performed in this section. The final section provides a summary and the conclusion.

[1] The impact of the environment on production efficiency was first considered in Charnes et al. (1981). Fried et al. (1999,2002) proposed a series of approaches for controlling external effects and statistical noise in order to achieve a more accurate efficiency measure.

2. The analytical framework of R&D efficiency

2.1. An overall summary of the methodology

This paper sets up an inter-country innovation production framework for R&D activities in 30 countries. Each country is regarded as a DMU that employs R&D manpower and physical resources as inputs to produce countable outputs. Inspired by Fried et al. (1999), we propose a three-stage approach to analyze the relative efficiency of R&D production. In the first stage, the input-oriented DEA model is applied to estimate the inter-country efficiency frontier of R&D activities. Technical efficiency scores as well as input slacks are calculated and analyzed for each country. In the second stage, Tobit estimation equations are specified in which the dependent variable for each equation is the sum of the radial and non-radial input slacks.[2] The independent variables are those that represent the external operating environment within which R&D activities are carried out. These equations identify inefficiencies attributable to factors beyond the control of R&D agencies. Finally, in the third stage, parameter estimates from the second stage are used to predict the total input slacks. These predicted values represent the allowable slack due to the operating environment and are used to calculate the adjusted values for the primary R&D inputs. These adjusted input data are used to rerun the DEA model under the initial output specification. Since the new efficiency scores are obtained from the above processes that control for external influences, they represent the net component of R&D efficiency.[3]

2.2. The innovation production framework

This paper considers the R&D/knowledge generation activity in each country as a production process. Pakes and Griliches (1984) and Griliches (1990) illustrated

[2] For the meanings of radial and non-radial input slacks, see Coelli et al. (1998), pp. 142–145.

[3] Fried et al. (1999) reviewed previous approaches to treating the external operating environment. Three categories mentioned are the frontier separation approach, the all-in-one approach, and the two-stage approach. The three-stage approach of this paper, in contrast to previous approaches in the existing literature, has four advantages. First, it gives a radial measure of technical efficiency with the conventional intuitive interpretations. Second, it avoids the risk of arbitrary classification of an external variable as either an input or an output prior to analysis as in the case of the previous all-in-one approach. Third, it can ascertain the influence of the external variables on the efficient use of each input. Fourth, it fully utilizes the information on slack estimates generated in the initial DEA model.