Technological Forecasting & Social Change 112 (2016) 303–312

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

An actor-network perspective on evaluating the R&D linking efficiency of innovation ecosystems

Ping-Chuan Chen [a], Shiu-Wan Hung [b,*]

[a] Executive Master Program of Business Administration in Biotechnology, Taipei Medical University, Taipei 110, Taiwan
[b] Department of Business Administration National Central University, 320, Taiwan

ARTICLE INFO

Article history:
Received 18 September 2015
Received in revised form 11 August 2016
Accepted 15 September 2016
Available online 24 September 2016

Keywords:
R&D efficiency
Actor-network theory
Network data envelopment analysis
Performance measurement

ABSTRACT

Research and development (R&D) is one of the key factors contributing to the economic growths in both advanced and developing countries. Implementing technological innovation strategies to accelerate the research and development has thus become one of the most important industrial policies for governments. The R&D performance is highly influenced by the complexities of interactions among actors in an innovation system. An evaluation model that incorporates the influence of linking activities is highly desired. This study employed the actor-network theory to construct a three-stage R&D production framework that emphasizes the linking activities among basic research stage, technology translation stage, and system development stage. In addition, the network data envelopment analysis (DEA) method was used to evaluate the relative R&D efficiency across the global twenty-five countries. The analysis results screened out specialized efficient country at each sub-process and further constructed the efficiency group for benchmark-learning. This study also pointed to the importance of the research institution for technology commercialization. The potential application of network DEA and actor-network theory approach in assessing the efficiency of R&D activities were also highlighted.

1. Introduction

Research and development (R&D) have become key factors contributing to economic growth in both advanced and developing economies (Corrado et al., 2009; Falk, 2006; Mario, 2009; OECD, 2007; Schwab, 2012). The increase in a country's overall level of R&D efficiency leads to the corresponding increases in its competitive advantage (De Jorge and Suarez, 2011; Kang and Park, 2012; Sosa, 2012). Implementing technological innovation strategies to accelerate the research and development has thus become one of the most important industrial policies for governments. For example, the National Science and Technology Council of United States have been developing national strategic plan for advanced manufacturing to guide the federal program and activities in support of the research and development (Holdren, 2012). The council considered that the acceleration of innovation required the bridging of a number of gaps in the present innovation system, particularly the gap between R&D activities and the development of technological innovations in domestic production of goods. To achieve optimal effects, the decision-making and strategic planning of R&D investment needs to be well coordinated in evaluating the relative efficiency of the innovation system. However, the operation of innovation system is a multi-dimensional network and interconnected by actors in different organizational context (e.g. university, government and non-profit research institutions, and business enterprises). The complexities of innovation outcomes are strongly influenced by the interactions among actors in the innovation system (network) (Hoholm and Araujo, 2011). Despite previous researches have investigated the R&D performances, they neglected the existence and interacting effects of internal or linking activities, and thus could not evaluate the impact of sector-specific inefficiencies on the overall efficiency of the system as a whole (Färe and Grosskopf, 2000; Lewis and Sexton, 2004; Löthgren and Tambouur, 1999; Prieto and Zofio, 2007). Therefore, an evaluation model that takes into account the effects of actors' co-linking activities in the innovation process is highly desired.

The actor-network theory, proposed by researchers from the sociology of science (Latour, 1987; Callon, 1986; Law, 1992; Bijker and Law, 1992), examines the motivations of actors who form the elements, linked by association, of heterogeneous networks of aligned interests (Walsham and Sahay, 1999). The philosophy of actor-network theory has become widely acknowledged in recent years, particularly in the field of innovation research (Alcouffe et al., 2008; Donaldson et al., 2002; du Preez, 2012; Hoholm and Araujo, 2011; Miettinen, 1999; Prout, 2008; Remírez et al., 2011; Thrane et al., 2010; Yoo et al., 2005), and organizational studies and strategic management (Czarniawska, 2006; Durepos and Mills, 2012; Lagesen, 2012; Steen, 2010; Vickers and Fox, 2010; Whittle and Spicer, 2008). This study employed the

* Corresponding author at: Department of Business Administration National Central University, No. 300, Jung-Da Road, Jung-Li city, Tao-Yuan 320, Taiwan.
E-mail address: shiuwan@mgt.ncu.edu.tw (S.-W. Hung).

http://dx.doi.org/10.1016/j.techfore.2016.09.016
0040-1625/

actor-network theory to illustrate how the dynamic mechanism of innovation emerges and unfolds at the national level in practice.

According to the literature, the innovation processes are highly situated and contingent (Pavitt, 2005) with linkages among actors, organization, industrial network and other distant sectors. The national innovation system is a set of interacting actors (e.g. university, government and non-profit research institutions, and business enterprises) that create scientific knowledge. All actors in the innovation system need to collaborate in formal and informal networks not only to generate new knowledge but also to strategically create and shape supportive system resources. Cohen and Levinthal (1989) proposed that the purposeful establishment of selective interactions within networks can promote firms to access complementary knowledge. Griliches (1979) demonstrated that the generation of knowledge may be viewed as the outcome of a knowledge production process. The production of new knowledge requires the access to external knowledge as a source of new ideas either to improve existing technologies or to provide the basis for brand new ones. Previous studies have highlighted the effect of knowledge spillovers on the total factor productivity (TFP) growth (Dumais et al., 2002; Jones, 1995; Krammer, 2015; Romer, 1990; Thompson, 2006). Romer (1990), Jones (1995) and others adopted the endogenous growth model of profit-seeking firms' investments in R&D and demonstrated that the firm's R&D not only raises its profits, but also has a positive externality on other firms' R&D productivity. Although the importance of externalities in knowledge or R&D had been recognized, there is an ongoing debate as to what extent knowledge spillovers can actually increase long-term per capita growth (Gehringer, 2016; Jones, 1995; Romer, 1990). These knowledge creation and transfer processes are, however, characterized by uncertainty and controversy, particularly in the interactions among actors in the network and the exploration of knowledge. Antonelli et al. (2011) indicated that the intentional interactions among innovative agents are important to the success of knowledge production processes. Since the R&D performance of the innovation system is a complex phenomenon situated within a network of interconnected processes, the linkages in the network should tighten the institutionally embedded relationship between innovation production and environment (Guan and Chen, 2012; Hoholm and Araujo, 2011). This study aimed to re-construct the innovation system from the actor-network theory perspective and further examine the relative R&D efficiency from a multi-dimensional viewpoint.

The study proposed a three-stage R&D production framework, including the basic research stage, the technology translation stage, and the system development stage, to analyze the R&D performance of different countries. The linking activities among actors were considered (Levinthal and Myatt, 1994; Nelson, 1995). By using the network data envelopment analysis (DEA) method, this study evaluated three-stage performance models, namely, research efficiency, translation efficiency and economic efficiency. Since its introduction in late 1970s, data envelopment analysis (DEA) has been a popular method for measuring the relative efficiency of decision-making units (DMUs) with multiple inputs and outputs (Charnes et al., 1978). DEA is a linear programming based technique that converts multiple input and output measures into a single comprehensive measure of performance. The application of DEA is strongly supported in the multitude of empirical analyses methods which inherently regards tradeoffs among various quantity measures for evaluating the relative R&D efficiency at the firm, industry and national levels (Garcia-Valderrama et al., 2009; Guan and Chen, 2012; Hashimoto and Haneda, 2008; Kumbhakar et al., 2012; Lu and Hung, 2011; Sharma, 2012; Sharma and Thomas, 2008).

This study regarded R&D generation activity as a production process, and considered each country as a decision-making unit (DMU) which conducts R&D activities within the innovation system. By employing the actor-network theory, this study offered an alternative perspective and characterization of the divisional efficiencies of the innovation system via a three-stage process that emphasizes the effect of linking activities. We "followed the actor" (Latour, 1987) where the R&D production happened to unfold in each different actor-network, and set up three different R&D production stages, including developing novel ideas into scientific knowledge by academia during the basic research stage, transforming the scientific knowledge into industrial practice by research institute during the technology translation stage, and implementing the innovation into economic outcome and commercializing by business enterprises during the system development stage. In addition, the linking activities among actors were also considered in the study, including joint research, technology transfer, and university-industry collaboration. By constructing an inter-country R&D production framework, the actor-network theory approach of this study could be used to identify the transformation of innovation context in which actors get involved.

This paper is organized as follows. An overview of R&D performance evaluation and actor-network theory is given in Section 2. In Section 3, we present the conceptual performance model of actor-network innovation system. The data selection and research methodology are also addressed in Section 3. Section 4 presents the empirical results and discussion. Finally, Section 5 concludes with the finding of this study and provides implications for policy makers with insight into resource allocation and strategic decision-making.

2. Literature review

2.1. R&D performance evaluation

Various literatures devoted to the investigation of R&D performance at the firm and industry levels. Kumbhakar et al. (2012) applied the stochastic frontier analysis approach to examine the impact of corporate R&D activities on firm performance, comprised of top European R&D investors over the period 2000–2005. De Jorge and Suarez (2011) provided evidence of the effects of subsidies for R&D activities on technical efficiency from Spanish manufacturers during the period 1993–2002. Zhang et al. (2003) investigated the influence of ownership on the R&D efficiency of Chinese firms. Moreover, several other studies also examined R&D performance at the industry level (Gonzalez and Gascon, 2004; Hartmann, 2003; Hashimoto and Haneda, 2008; Meliciani, 2000; Sharma, 2012). Sharma (2012) investigated the impact of R&D activities on firm performance of the Indian pharmaceutical industry. Hashimoto and Haneda (2008) used the data envelopment analysis (DEA) and Malmquist index method for measuring the change in R&D efficiency at both firm and industrial levels. In addition, Gonzalez and Gascon (2004) analyzed the evolution of the productive patterns in a sample of 80 pharmaceutical laboratories that operated in Spain from 1994 to 2000. Meliciani (2000) examined the effect of research and investment activities on patents across industries.

Meanwhile, other studies have investigated the relative efficiency of R&D performance across countries (Guan and Chen, 2012; Lu and Hung, 2011; Pan et al., 2010; Garcia-Valderrama et al., 2009; Lee et al., 2009; Sharma and Thomas, 2008). Guan and Chen (2012) emphasized the effects of policy-based institutional environment on the relative efficiency of various innovation systems. Pan et al. (2010) reconciled diverse efficiency measures to characterize the operating performance of the national innovation system across countries. Lee et al. (2009) evaluated the national R&D programs focusing on R&D policy and resource allocation. Lu and Hung (2011) also pointed to the importance of intellectual capital in achieving high level of efficiency of national technology development program. Sharma and Thomas (2008) explored the inter-country R&D efficiency using the DEA approach and highlighted the inefficiency in the R&D resource usage.

Most of these studies used the factors of manpower, R&D expenditures, publications and patents for evaluating the effects of the R&D investment at the firm, industrial and national levels. Furthermore, despite various studies had used the DEA method which inherently