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Modeling the relative efficiency of national innovation systems

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ABSTRACT

Although a large amount of past research has theorized about the character of national innovation systems (NISs), there has been limited process-oriented empirical investigation of this matter, possibly for methodological reasons. In this paper, we first propose a relational network data envelopment analysis (DEA) model for measuring the innovation efficiency of the NIS by decomposing the innovation process into a network with a two-stage innovation production framework, an upstream knowledge production process (KPP) and a downstream knowledge commercialization process (KCP). Although the concept of innovation efficiency is a simplification of the innovation process, it may be a useful tool for guiding policy decisions. We subsequently use a second-step partial least squares regression (PLSR) to examine the effects of policy-based institutional environment on innovation efficiency, considering statistical problems such as multicollinearity, small datasets and a small number of distribution assumptions. The hybrid two-step analytical procedure is used to consider 22 OECD (Organisation for Economic Co-operation and Development) countries. A significant rank difference, which indicates a non-coordinated relationship between upstream R&D (research and development) efficiency and downstream commercialization efficiency, is identified for most countries. The evidence also indicates that the overall innovation efficiency of an NIS is mainly subject to downstream commercial efficiency performance and that improving commercial efficiency should thus be a primary consideration in future innovation policy-making in most OECD countries. Finally, the results obtained using PLSR show that the various factors chosen to represent the embedded policy-based institutional environment have a significant influence on the efficiency performance of the two individual component processes, confirming the impact of public policy interventions undertaken by the government on the innovation performance of NISs. Based on these key findings, some country-specific and process-specific innovation policies have been suggested.

1. Introduction

The national innovation system (NIS) approach was introduced in the late 1980s (Freeman, 1987; Dosi et al., 1988) and further developed in the years that followed (Lundvall, 1992; Nelson, 1993; Edquist, 1997). It enjoys wide currency in both academic and policy-making contexts (Sharif, 2006) and is considered a useful and promising analytical tool for academic study and for the development of innovation policy-making, fostering an understanding of innovation processes and determinants (Edquist, 1997; Furman et al., 2002; Lundvall, 2007). Although no single definition of NISs has yet been adopted, a semantic core is common to most of the definitions used (Sharif, 2006). From a general perspective, an NIS results from the interaction between the knowledge innovation process (KIP) and the embedded[2] innovation environment represented by framework conditions and infrastructure related to government intervention (Furman et al., 2002; Faber and Hesen, 2004; OECD and EUROSTAT, 2005). As Edquist has pointed out, an institutional set-up geared toward innovation and an underlying production system are the basic characteristics of an NIS (Edquist, 1997). In terms of its physical composition, an NIS is a set of interacting institutions/actors (e.g., universities, industries and governments) that produce and implement knowledge innovation. These actors provide the national innovation production framework within which governments form and implement policies to influence the innovation process. Through interface

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[2] Cooke et al. (1998) used "embeddedness" to characterize the interdependent relationship between the innovation process system and the institutional milieu.

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structures (Molas-Gallart et al., 2008) or intermediate organizations (Howells, 2006), actors in different cultural and organizational contexts across an NIS are connected, and these connections tighten the institutionally embedded relationship between innovation production and the innovation environment.

The contributions of the extant literature regarding the NIS approach lead policy-makers to employ systematic thinking rather than linear thinking about innovation at the national level (Edquist, 1997; Edquist and Hommen, 1999; Groenewegen and van der Steen, 2006). The system thinking approach that supports a demand-side orientation in innovation policy (Edquist and Hommen, 1999) is a more holistic system perspective on innovation that focuses on the interdependencies among various agents, organizations and institutions (Groenewegen and van der Steen, 2006). In contrast to the traditional linear thinking approach, which supports a supply-side orientation in innovation policy (Edquist and Hommen, 1999), this alternative approach can better take into account the factors *influencing* innovation processes besides those *shaping* innovation processes, thus inspiring innovation policy-making. From a systems perspective, the NIS approach reminds policy-makers of the need to improve the collaboration among interacting institutions participating in the KIP and the influence of the innovation environment on the KIP. As national innovation policy-makers, governments mostly concern themselves with innovation efficiency as closely related to the innovation input/output ratio and emphasize the effect of public policy intervention on the innovation efficiency. Innovation efficiency is related to the concept of productivity, which is improved when the same amount of innovation input generates more innovation output or when less innovation input is needed to produce the same innovation output. This concept involves comparing the observed output to the maximum potential output obtainable from the input or, alternately, comparing the observed input to the minimum potential input required to produce the output. In this context, in the two comparisons, the optimum is defined in terms of production possibilities, and efficiency is technical (Fried et al., 2008, pp. 8). In this sense, efficient NISs are operating at their production possibility frontier (PPF) or "transformation curve", which indicates the maximum amount of innovation output that can be produced with a given input. Clearly, the innovation efficiency of an NIS is measured by the latter's ability to transform innovation input into output and generate profits.

Assessing innovation efficiency helps both to identify the best innovation practitioners for benchmarking and to shed light on ways to improve efficiency by highlighting areas of weakness. In empirical management, in countries seeking to enhance policy learning and thus develop more appropriate policy recommendations, examples of "best practices" are currently employed. Additionally, the effect of innovation environment on the innovation process is related to the effectiveness of the innovation policy instruments formed by governments. If the aim is to foster effective innovation policy-making, it is advisable to further investigate the effect of factors embedded in the innovation environment on the efficiency of the KIP based on system thinking. Prior studies (Freeman, 1987; Dosi et al., 1988; Furman et al., 2002; Lundvall, 1992; Nelson, 1993; Edquist, 1997; Fernández-de-Lucio et al., 2001, 2003; Fritsch and Slavtchev, 2007, 2009) have indicated or empirically demonstrated that the differences in the innovation performance of geographic units are closely related to variation in the innovation environment embedding the innovation process.

To obtain effective information for innovation policy-makers, it is important to choose an appropriate modeling/mythological framework to accommodate the production structure of the KIP and its embeddedness in the institutional environment. As an emerging current of thought in the economics of innovation, the innovation systems approach provides a useful analytical tool for the development of innovation policy-making for geographic units (e.g., nation or regions) (Edquist and Hommen, 1999). However, simply grasping the conceptual structure of innovation systems does not allow one to control the operational quality of innovation systems via specific empirical management, which depends on measuring innovation performance and exploring its determinants. This means that the innovation systems approach mainly promotes our understanding of what relevant factors innovation policy-makers should consider. However, to understand what to do to improve innovation performance and how to do it requires (1) the construction of a new measurement framework for benchmarking the innovation performance of geographic units in comparison to "best innovation practitioners" and (2) the creation of an examination framework for exploring the determinants of cross-unit differentials. It becomes necessary to use a two-step integrated analytical framework for this purpose. Possibly for methodological reasons, there has been little formal empirical investigation of these two issues. As Balzat and Hanusch (2004) have argued, the NIS approach still lacks coherent theoretical backing and the methodology necessary to allow for more systemic, empirical comparisons among countries. Using novel modeling tools, this study aims to construct an integrated analytical framework for quantitatively investigating the NIS, taking into account the internal physical transformation structure of the KIP and the embeddedness of the KIP in the external institutional environment.

The rest of this paper is organized as follows. Section 2 defines the conceptual production framework of a typical NIS within which the KIP operates under the influence of the innovation environment. Section 3 is devoted to constructing our modeling methodology. Section 4 provides an empirical analysis based on the innovation activities of 22 OECD countries. Finally, Section 5 offers concluding remarks.

2. Conceptual process-oriented framework of national innovation systems

An increasing number of studies (e.g., Edquist, 1997; Furman et al., 2002; Doloreux, 2002; Lundvall, 2007) shows that it is more meaningful to explore trajectories of innovation within a system framework. However, an economic innovation is accomplished only with the first commercial transaction (Freeman and Soete, 1987). This means that an innovation is usually accompanied by a business process. Although the innovation systems approach leads to non-linear thinking about complex innovation mechanisms, a "linear" view of innovation is still dominant from a production point of view. In this, the development of an innovation production activity is seen as a process made up of sequential stages that are temporally and conceptually distinct and characterized by unidirectional causal relationships (Rossi and Emila, 2002). It is no wonder that the process-oriented perspective on innovation systems is attractive in both the academic and the policy-making context. Relevant studies of innovation activities from a process-oriented perspective are becoming more frequent in the literature (e.g., Rothwell, 1994; Rogers, 1995; Brown and Svenson, 1998; Bernstein and Singh, 2006; Galanakis, 2006). The innovation process-oriented perspective frequently has been visible in previous studies at various levels, with typical innovation production frameworks such as the "flow diagram of R&D project" (Geisler, 1995), the "R&D process diagram" based on a typical R&D laboratory (Brown and Svenson, 1998) and the "knowledge production function diagram" based on technological R&D activities (Pakes and Griliches, 1980; Griliches, 1990). As Dvir and Pasher (2004) have indicated, innovation is the process of converting knowledge and ideas into benefit value.

We have used Fig. 1 to describe the consecutive production framework from the initial (innovative and non-innovative)