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Gaps in the Relative Efficiency of National Innovation Systems and Growth Performance across OECD and BRICS Countries[1]

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8.1 Introduction

The aim of this chapter is to analyze how the relative performance of National Innovation Systems (NIS) in the Organization for Economic Cooperation and Development (OECD) and the BRICS countries of Brazil, the Russian Federation, India, China, and South Africa could impact countries' long-run economic growth rates. To that end, we first estimated the relative efficiency of national innovation systems and their main objectives in those countries, creation, diffusion, and utilization, using Data Envelopment Analysis (DEA) software. Then we analyzed how relative NIS performance (efficiency) could impact each country's economic growth.

This research has two main influences. The first is from authors who recognize that technological progress is a fundamental factor in explaining economic growth (Schumpeter 1934 and Solow 1957, in neoclassical theory, and Romer 1990, in the new endogenous growth theory). The second comes from authors whose research has

[1] We are grateful for the collaboration of master's degree student Juan Carlos Vilchis in researching statistical information and estimates of DEA models.

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focused on NIS (Freeman 1987, 1995; Lundvall 1992; Nelson 1993; Metcalfe 1995; and Niosi 2002, among others).

Despite their theoretical differences, Schumpeter, Solow, and Romer recognize the key role of innovation or technological progress in economic growth. Sources of innovation include human capital and R&D (Research and Development). According to Romer (1990), dissimilar R&D levels (population involved in R&D activities) and uneven productivity performance in the research sector explain per capita income differentials across countries. Although Romer considers patents a key factor in his research sector analysis, he does not include various institutional factors that can influence decisions to increase countries' R&D efforts. Nelson (1993) points out how the new endogenous growth theory does not include in its models certain institutional variables that a growing number of authors have already accepted as essential to analyze economic growth. In this sense, the second theoretical group has pointed out that the systemic approach provides relevant and additional elements to assess success in generating new ideas (innovation) through the combined efforts of various institutions and agents, whose activities and interactions create, modify, and disseminate new technologies (Freeman 1987), and also includes the utilization of new, economically useful knowledge (Lundvall 1992).

This study estimates the national innovation system's relative efficiency index (NIS-REI) in OECD and BRICS countries, using DEA methodology (Charnes, Cooper and Rhodes 1978; Ramanathan 2009).[3] A subsequent estimate is made of the effect of this

[3] DEA was created as a mathematical technique based on linear programming models to measure the relative performance of a set of similar units. However, today the scope of its scientific use is larger, as developed by different authors, evolving to encompass many more extensions and finding a number of practical applications. In the 1980s and 1990s, Charnes and Cooper et al. made interesting contributions in the DEA

performance on countries' long-term economic growth. Most studies on this topic have focused on estimating whether a system is efficient as a whole. Unlike previous studies (Nasierowski and Arcelus 2003; Lee and Park 2005; Hollanders and Celikel 2007; Pan 2007; Pan, Hung and Lu 2010; Cai 2011; Cai and Hanley 2012), our goal is to contribute to measuring NIS-REI by objectives, in addition to assessing its global efficiency. We considered it appropriate for the NIS-REI measurement to be based on the achievement of each central NIS objective: creating, disseminating, and using new knowledge (Whitley 2001).

The OECD has contributed to the performance analysis of individual and comparative NIS of its member states and of other emerging nations – such as the BRICS. As our contribution to such NIS analyses, we have estimated the NIS-REI of thirty-nine OECD (thirty-five) and BRIC (four) countries. We sought to measure relative NIS efficiency across OECD and non-OECD emerging countries, such as Brazil, China, India, the Russian Federation, and South Africa. We also sought to explain how the systemic performance of innovation might impact each country's long-term economic growth. We asked whether countries with a weak R&D sector and disjointed NIS could have positive relative efficiency compared with countries that have built strong technological capabilities and appear to have institutional and social agents interacting to foster innovative efforts, and how their innovation performance impacts their economic growth rate. In other words, we asked whether it is possible for countries lacking a strong research sector and which are dependent on technology transfer or

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applications, such as DEA to measure the efficiency of maintenance units in the US Air Force and large commercial banks. An interesting article in the field of microeconomics is Charnes, A., Cooper, W. W., Golany, B., Seiford, L., and Stutz, J. (1985b). Foundations of data envelopment analysis for Pareto-Koopmans efficient empirical production functions, *Journal of Econometrics* 30 (1/2): 91-107 (Cited by Ramanathan 2009).

importing capital goods to produce new ideas. We also asked if such countries could create, disseminate, and use new technological knowledge efficiently, compared with countries that possess a research sector and entrepreneurs linked to the innovation frontier. Finally, we asked whether those countries could link new ideas and technological knowledge to their growth performance.

The key questions in this research are: do countries, which invest the most in each of the three NIS objectives, achieve higher relative efficiency? Even if some NIS are efficient in achieving one or two of their objectives, might they be inefficient in achieving the others? How does this relative NIS performance affect long-term economic growth? As a hypothesis, we propose that OECD and BRICS countries with the greatest GDP results derived from investing most heavily in the three core NIS objectives should achieve greater NIS-REI levels than those countries channeling fewer resources into that area. We also expected that some NIS are relatively efficient in relation to some objectives but inefficient in relation to others. Finally, we expected that those countries with better relative NIS performance would report higher sustained economic growth.

In the second of the five parts comprising this chapter, we analyzed the relevance of NIS and their comparative evaluation. In the third, we briefly described the Data Envelopment Analysis (DEA) methodology and outlined some findings in measuring NIS with DEA. In the fourth part, we estimated the efficiency indices of each of the following objectives: creation, diffusion, and utilization, using XLDEA software. Part five is a study of the impact of relative NIS efficiency on economic growth across countries by means of an econometric model. In conclusion, we summarize our main findings.

8.2 Why Are National Innovation Systems Important and How Can We Measure Their Relative Efficiency?

The National Innovation Systems approach provides the theoretical tools to analyze all the components that combine to make innovation possible. This holistic[4] approach assumes that firms join efforts with other organizations in an institutional framework in order to create, disseminate, and use technological knowledge (Edquist 1997; Soete, Verspagen, and Weel 2009).[5] Institutions and organizations as a whole are key in arriving at innovation events (Balzat 2002; Balzat and Hanusch 2004). Their importance differs depending on whether countries have developed an institutional framework, cultural heritage, and policies to foster innovation.[6]

Although this approach emphasizes the national dimension within a nation-state's geographic boundaries (OECD 1997; Lundvall 1992; Niosi 2002), today, international institutions and organizations interact with national agents, increasing

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[4] Holistic means that every system's property depends on each part of the whole system. It outlines the multidisciplinary innovation study by taking into account social, political, organizational, and developmental elements.

[5] Development, absorption, and diffusion have been identified as the core that organizations and institutions could influence in a national innovation system framework (Lundvall 1992), Lundvall and Tomlinson 2002; and Nooteboom 2000). Specifically, Edquist (1997) considers that an innovation system is made up of "all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations" (Edquist 1997: 14).

[6] The OECD (2002) considers that the main NIS agents' interactions include competitions, transactions or agreements, and network creation.

their influence on national science, technology, and innovation policy.[7] In the context of globalization processes, international trade agreements (or other kinds of arrangements) or the enactment of international legislation, such as the TRIPS, seem to affect some countries' NIS performance, either in whole systems or in parts of systems. However, it is relevant to analyze those national factors, and also international factors affecting endogenous systemic elements, their properties, and their ties to key NIS objectives (such as foreign direct investment (FDI), technology transfer (TT), and information and communications technology (ICT) imports).

There are various approaches to analyze innovative performance and national innovative capacity (Furman, Porter and Stern. 2002; Porter and Stern 2001). For this study, we chose to analyze NIS efficiency based on three main objectives: (i) creation, (ii) diffusion, and (iii) utilization (Whitley 2001).[8]

8.3 Measuring Relative NIS Efficiency with the DEA Model

Data Envelopment Analysis (DEA) is a useful tool for evaluating the relative efficiency of a set of decision-making units (DMUs). The DEA uses a variety of inputs (means) to achieve the production of goods and services (ends). The tool takes as reference the

[7] In the specific case of OECD countries, constant observation has been implemented to suggest policies orientation regarding what can and should be done for a catching up process.

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most efficient DMUs, to which it assigns an efficiency index of one, and evaluates the relative performance of the least efficient DMU, which it values between zero and one (Niosi 2002) (See Annex).

We evaluated relative NIS efficiency by means of DEA, using Science & Technology (S&T) indicators, which can be quantitative or qualitative, and may be used as input or output. According to Grupp and Schubert (2010), the methodology for choosing indicators is a multidisciplinary decision based on two main ideas. The first is that innovation is a process that, when successful, may generate monopolistic profits. The second is that statistics validate the performance of each step of the innovation process. The individual indicators could be partial, not measuring innovation as a whole, and often are indirect because innovation is sometimes intangible. But there are also indicators intended to generate statistics on innovation, such as R&D expenditure and patents, among others.[9]

Different studies on the relative efficiency of NIS through DEA models use R&D expenditure as input (Nasierowski and Arcelus 2003; Lee and Park 2005; Hollanders and Celikel 2007; Pan 2007; Pan, Hung, and Lu 2010; Cai 2011; Cai and Hanley 2012); differentiate between public R&D (Matei and Aldea 2012) and private R&D (Zhang 2013), or R&D capital stocks (Guang and Chen 2012; Zhang 2013; Hu, Yang, and Chen 2014). All those authors take human capital into account as input under different specific variables. As output variables, it is common that the authors use patents granted by different offices (WIPO, USPTO, EPO, JPO) and scientific and technical journal articles. The authors use different output variables, such as royalty and licensing fees (Nasierowski and Arcelus 2003; Hu, Yang and Chen 2014); high-technology export

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[9] There is a great variety of DEA programs to calculate efficiency (see Barr 2004).

and national productivity (Zhang 2013), especially ICT products (Cai 2011) or medium and high-tech product exports as % total product exports (Matei and Aldea 2012); employment in knowledge-intensive activities (manufacturing services) as % of total employment; knowledge-intensive services exports as % total service exports (Matei and Aldea 2012), and computers per capita (Afzal 2014) (See Table 8.1).