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A scale-independent analysis of the performance of the Chinese innovation system

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ABSTRACT

In this paper we use scale-independent indicators to explore the performance of the Chinese innovation system from an economic and from a science and technology point of view, and compare it with 21 other nations. Some important developments in the Chinese innovation system, hidden by rankings by conventional performance indicators, were revealed. We find that gross domestic expenditure on R&D (GERD) & gross domestic product (GDP) and GDP & POP (population) all exhibit strong 'Matthew effects', measured by their scaling factors. This means that the Chinese R&D intensity (GERD/GDP) and national wealth (GDP per capita) are growing significantly with the increase of the GDP. Also pairs such as citations & papers, papers & GDP, citations & GDP, and paper & GERD exhibit these 'Matthew effects'. This observation points to the fact that in China scientific outputs and impacts are growing faster than economic growth and research investment. However, according to another scale-independent indicator, namely the adjusted relative citation impact (ARCI), China ranks on the bottom of the list, but the growth rate of the ARCI is the highest among these countries (comparing the periods 1995–1999 and 2001–2005). To sum up, we interpret these findings to mean that the scientific outputs and impacts of China show a real tendency of catching up with its economic growth. It is expected that with an increase of its GDP and R&D intensity China will show a sustained increase in indicators related to science and technology. Similarly, there are very strong 'Matthew effects' between the outputs of technology (patents) and economic growth and research investment. This means that the outputs of technology are expected to increase considerably with an increase of GDP and R&D expenditure. Furthermore, in the Chinese innovation system the government intramural expenditure on R&D (GOVERD) has a stronger non-linear impact on patent productivity than business enterprise expenditure on R&D (BERD). This shows that in China research institutions financed by the government play a more important role than enterprises.

1. Introduction

An innovation system is a social construct, composed of individuals and organizations that directly and indirectly invest time and energy in the production of scientific and technical knowledge (Katz, 2006). The innovation capacity of a country is widely regarded as the principal driving force behind its competitiveness and economic growth. However, for different

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nations it takes a different time to reach the technological frontier where innovation becomes a basic driving force. Innovation in the case of latecomer countries needs to be understood in a way that is rather different from innovation in the case of leaders (Hu & Mathews, 2005).

Most, if not all, complex systems have a propensity to exhibit scaling properties. A scaling property is characterized by a power law correlation or distribution, and is common to physical systems, natural systems and social systems (Christensen, Danon, Scanlon, & Bak, 2002; Katz & Katz, 1999; Newman, Watts, & Strogatz, 2002; van Raan, 2008a; Wagner & Leydesdorff, 2005). A power law is one of the signatures of non-linear dynamical processes and is also indicative of the existence of scale-independence or self-similarity. Like most complex systems, innovation systems display characteristic power law correlations or distributions (Jin & Rousseau, 2005a; Katz, 1999, 2000; Katz & Cothey, 2006; van Raan, 2008b). These scaling correlations can be used to construct scale-independent indicators that are properly normalized for the sizes of the members of the system (Katz, 2000, 2006). The differences between the ranks by scale-independent indicators and by conventional (scale dependent) indicators can result in a shift in perspective about the performance of members of an innovation system.

Since 1978 China has undergone profound economic and organizational reforms. One objective of the reforms is to increase efficiency by replacing the central planning system of resource allocation by a free market mechanism. Significant achievements have been made in the latest three decades. The government has decentralized fiscal and managerial control, redefined public and private ownership, and encouraged new linkages between research and industry. Organizational boundaries related to innovation activities have changed considerably, and primary actors in innovation activities have become more autonomous and functionally diversified (Liu & White, 2001). Typical aspects of China's innovation system continue to emerge from the interactions between its regional innovation systems and other ones.

Quantitative and qualitative measures of input and output are frequently applied to construct performance indicators used to inform decision makers. However, some of these performance indicators derived from ratios, are not normalized for size. As a result, some important developments are kept hidden from view, and decision makers can be misled. For example, King (2004) used performance indicators derived from ratios, such as 'wealth intensity' (GDP per person), 'citation intensity' (citation per GDP), scientific impact (citation/paper), publications per researcher, etc., to measure the quantity and quality of science in different nations. In his rankings China lags behind scientific giants such as the US, UK, Germany and Japan. But he also points out that simple citation rankings can hide important developments, particularly in countries such as China and India, which have developed their science base rapidly and effectively over the past years. This paper focuses on finding important developments in China's innovation system which are otherwise hidden by rankings based on conventional performance indicators. This goal is reached by using a scale-independent approach. Further, based on these scale-independent indicators, the performance of China's innovation system will be illustrated and compared with 21 other countries.

The paper is organized as follows. In Section 2, a description of the data source and the methodology is provided. Based on scale-independent indicators, a thorough investigation of many aspects of the Chinese innovation system including economic, scientific and technological aspects is presented in Section 3. The policy relevance of the findings is summarized in the final section.

2. Data source and methodology

This section will explore the data source and the methodology that is applied in this research.

2.1. Data source

In this paper we make a comparison between China and 21 countries (the comparator group) including the G7 group (italicized) and the 15 countries of the European Union (EU15). The countries are: Austria, Australia, Belgium, *Canada*, Denmark, Finland, *France*, *Germany*, Greece, India, *Italy*, *Japan*, the Netherlands, Portugal, Ireland, South Korea, Spain, Sweden, Switzerland, *the United Kingdom* and *the United States*. Except for China and India, the other countries are all OECD countries, and most of them can be described as innovation-typed countries. We note that over the past years China and India have been engaged in technology based economics growth, competing with each other in many sectors (Bhattacharya, 2004). Therefore, we consider it of interest to include and compare the innovation systems of these two important emerging economies.

The following measures are used to construct scale-independent indicators: GDP, gross domestic expenditure on R&D (GERD), higher education expenditure on R&D (HERD), business enterprise expenditure on R&D (BERD), government intramural expenditure on R&D (GOVERD), population (POP), number of scientific papers, citations to papers and patents. The above measures can be roughly classified into three groups: economic indicators (GDP, GERD, HERD, BERD, GOVERD, POP), output and impact of science research (scientific papers and citation to papers), and the output of technological innovation (patents). Here the term "scientific papers" refers to publications covered by the *Science Citation Index* (SCI) and the *Social Science Citation Index* (SSCI). The SCI and SSCI provide reasonably comprehensive coverage of the significant contributions in most scientific areas. As for patents, three categories are identified for each country: the number of patent applications to the US Patent and Trademark Office (USPTO), the number of patent applications to the European Patent Office (EPO) and the number of triadic patent families (TPF).

As we use a broad range of measures in this paper, the corresponding data sources are also relatively complicated. The economic data for China and 20 OECD countries come from the *Main Science and Technology Indicators* (1998–2007) produced