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Performance evaluation of China's high-tech innovation process: Analysis based on the innovation value chain

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ABSTRACT

The Chinese high-tech industry has developed greatly since the beginning of China's "National High-tech R&D (863) Program" and "China Torch Program". This paper introduces a conceptual model extended from the innovation value chain model to simultaneously estimate the R&D and commercialization efficiencies for the high-tech industries of 29 provincial-level regions in China. To match reality, a network DEA incorporating both shared inputs and additional intermediate inputs is constructed to open the "black box" view of decision making units used in single-stage DEA. This study is the first attempt to link the R&D and commercialization with a solid theoretical foundation and feasible mathematical methods. The empirical findings show that most of the 29 regions have low efficiency in the commercialization sub-process compared to the R&D sub-process, although there are regional differences in China's high-tech industry. Pearson correlation shows that the R&D sub-process is not closely correlated to the commercialization sub-process in terms of efficiency. Our analysis can provide information for the formulation of policies to achieve high innovation efficiency.

1. Introduction

With the advent of the "Third Industrial Revolution", high-tech innovation has reached a highwater mark. On the international stage, the USA launched its "Star Wars Program" officially called the "Strategic Defense Initiative" (SDI); France put forward the industrial innovation plan "create tomorrow's products"; Germany introduced its "2020 - innovation partnership" and "standard innovation plan"; both the UK and Singapore launched an "innovation voucher program" (IVS); and Japan proposed a "digital Japanese innovation plan" (ICT). Having a transitional economy, China has paid increasing attention to the development of high-tech industry. The "Chinese High-tech R&D (863) Program", "China Torch Program", and "Made in China 2025 initiative" have introduced industrial policies to encourage high-tech industry development. Against this background, within the analytical framework of innovation value chain, this study endeavors to analyze the innovation efficiency so as to study the improvement path of China's high-tech industry innovation.

The growth and development of China's high-tech industry gives evidence that China's commitment is paying off. However, there is still some way to go before China catches up with high-income countries such as the USA and Japan. For illustration, Table 1 and Table 2 show the R&D intensity and the value added respectively. One of the major scientific and technological development goals of China's 12th Five-Year Plan (2011–2015) is that "the ratio of value added of high-tech industry to that of Manufacturing reaches 18%", which was achieved in the USA in 2005. The "global competitiveness report 2014–2015", issued by World Economic Forum, points out that China is in the efficiency-driven stage. The low rate of transformation to productivity and low level of high-tech industrialization hinder the China's innovation-driven strategy.

Relevant studies on measurement-oriented high-tech industry activities are burgeoning in the literature. Most of the studies focus on R&D investment and firm performance. Lin et al. (2006) and Lin et al. (2008) examined the factors influencing firm performance. Hu (2001) developed an empirical model to study the relationship between government R&D, private R&D, and productivity in Chinese enterprises. Hong et al. (2015) applied a stochastic frontier analysis model to explore the relationship of government grants, private R&D funding, and innovation efficiency of China's high-tech industry. Zhang et al. (2003) investigated the influence of ownership on the R&D efficiency of Chinese firms. Most of the efficiency evaluation studies use a "black-box" framework, which is not consistent with the theory that innovation is a multistage sequential process (Hage and Hollingsworth, 2000; Hansen and Birkinshaw, 2007; Porter and Millar, 1985). Porter (2008) proposed that the "value chain" divides a company's activities into design, production, marketing, delivery, and other related strategic activities; it is not a collection of independent activities, but rather a system of

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Table 1
R&D intensity of high-tech industry in selected countries.
Source: National Bureau of Statistics, China Statistics Yearbook on High Technology Industry (2013).

China (2012)	USA (2009)	Japan (2008)	Germany (2007)	UK (2006)	Korea (2006)
1.68	19.74	10.5	6.87	11.1	5.86

Note: R&D intensity is calculated as the ratio of R&D expenditure to Gross Industrial Output Value of high-tech industry.

Table 2
Ratio of value added of high-tech Industry to that of Manufacturing in selected countries.
Source: National Bureau of Statistics, China Statistics Yearbook on High Technology Industry (2013).

China (2007)	USA (2009)	Japan (2008)	Germany (2007)	UK (2007)	Korea (2006)
12.7	21.2	15.4	12.8	17.1	23

interdependent activities. Hage and Hollingsworth (2000) developed the concept of the "idea innovation network", which has six areas reflecting research: basic research, applied research, product development research, production research, quality control research, and commercialization/marketing research. Hansen and Birkinshaw (2007) proposed the "Innovation Value Chain" and recommended viewing innovation as a sequential, three-phase process that involves idea generation, idea development, and the diffusion of developed concepts. Therefore, it is necessary to identify different components of the strengths and weaknesses in the innovation process.

The Innovation Value Chain (IVC) is an effective instrument applied to analyze innovation activities (Hansen and Birkinshaw, 2007; Roper and Arvanitis, 2012; Roper et al., 2008). For the convenience of evaluation, based on the fundamental characteristics of China's high-tech innovation process, this paper simplifies the innovation activity into two sub-processes: the "R&D process" and the "commercialization process". The R&D process generates knowledge and applies the knowledge to innovation including basic research, applied research, and product development research, as detailed in China's *National Bureau of Statistics*. R&D activity is a catalyst for innovative industrial activities and ultimately it is responsible for the growth in productivity and total revenue (Shefer and Frenkel, 2005). The "R&D process" can be treated as the linkage of "idea generation" and "idea conversion". The commercialization process is viewed as introducing innovations into the market, involving economic activities such as manufacturing and marketing. The commercialization stage can be treated as the linkage of "idea conversion" and "idea diffusion".

Considering that tacit and asymmetric knowledge is hindered by regional boundaries (Li and Tellis, 2016) and that the social culture and the specific governance rules in China vary from one region to another, the regional innovation system (RIS) gives insight into using administrative regions as the unit of analysis. RIS is an innovation network in which the innovation actors in a geographic area interact with each other to achieve knowledge generation, diffusion, and exploitation, involving various innovation activities operating under the innovation environment shaped by formal and informal institutions. Originating from the national innovation system (NIS), RIS, proposed by Cooke (1992), has been an adequate approach for exploring innovation activities of geographical entities (Buesa et al., 2010, 2006; Fritsch, 2002; Wang et al., 2015). Previous studies demonstrate the significance of conducting research in subnational regions (Guan and Chen, 2010; Li, 2009; Wang et al., 2015). From a practical point view, the statistical data for innovation activities are available in the provincial-level regions. Following the common practice, this paper studies the innovation disparity of the high-tech industries in provincial-level regions of China.

To evaluate efficiency, there are two main approaches in the prior studies: the stochastic frontier analysis (SFA) approach and the data envelopment analysis (DEA) approach. Both methodologies are frequently used in empirical analysis and have their individual strengths and limitations. SFA is only applied to the scenarios with a concrete form for the production function (Aigner et al., 1977; Battese and Corra, 1977; Meeusen and Van den Broeck, 1977). Data envelopment analysis (DEA), proposed by Charnes et al. (1978), is a mathematical programming approach for analyzing the relative efficiency of peer decision making units (DMUs) which have multiple inputs and multiple outputs. As a nonparametric technique, DEA has been applied in the efficiency analysis in various areas including commercial banks, regional innovation, agricultural economics, hospitals, and enterprises (Chen et al., 2012; Fu et al., 2007; Guan and Chen, 2010; Liang et al., 2006). The traditional single-stage DEA model treats the DMUs as a "black box" without consideration of the internal structure. Due to the complex internal structure of the DMUs, a number of scholars have endeavored to develop models with a two-stage internal structure. In recent years especially, the emerging literature has put forward approaches for two-stage DEA modeling from various perspectives. The extended or modified models include the linear DEA models (Chen et al., 2006), network DEA models (Cook et al., 2010; Halkos et al., 2015; Kao, 2014; Liu et al., 2013), value-chain DEA models (Chen and Zhu, 2004; Chiu et al., 2012), and relational two-stage DEA models (Chen and Guan, 2012; Kao, 2009; Liang et al., 2006). Given the flexibility of the DEA model, in this paper, we select DEA for the evaluation of R&D and commercialization efficiency of the high-tech industries in 29 Chinese provincial-level regions based on the concept of innovation value chain.

The integrated conceptual framework in this paper expands the theory and the method of innovation research and provides a new perspective on the evaluation of innovation performance of the high-tech industry. By comparing innovation performance between regions and identifying the determinants of innovation efficiency, this paper draws upon and contributes to three streams of research: innovation value chain, high-tech innovation efficiency at the regional level, and network DEA. The remaining parts of this paper are organized as follows. Section 2 presents the literature review and constructs the conceptual framework of high-tech industry innovation. Section 3 provides a two-stage DEA model for our study. In Section 4, the innovation performance of the high-tech industries of China's 29 provincial-level regions is analyzed. Section 5 discussed the implications to theory, practice and policy. Conclusions are summarized in Section 6.

2. Literature review and conceptual framework

2.1. Literature review

Since the pioneering work of Schumpeter (1934) who placed innovation at the core of his "Theory of Economic Development", many scholars have endeavored to explore innovation activities. An emerging body of literature suggests that innovation is vital to creating substantial and sustainable competitive advantages. The innovation literature covers various levels such as firms, industries, and areas (Bernstein and Singh, 2006; Hong et al., 2015; Lee et al., 2014; Wang et al., 2015). Yang and Liu (2006) found that the adoption of innovation diffusion in high-tech firms was significantly related to the competition intent of these firms including aggressive technology posture and product development frequency. Tseng et al. (2009) identified a new set of financial and nonfinancial performance indicators and developed a business performance evaluation model to measure business performance in Taiwan's high-tech manufacturing industry. Zhang and Lv (2012) applied the quantile regression model to investigate various relevant factors that impact the innovation performance of high-tech enterprises. The results showed the discriminate impact of factors such as enterprise scale, R&D expenditure, net assets debts ratio, and