
AI translation · View original & related papers at
chinaxiv.org/items/chinaxiv-202310.03060

Review of Research on Evaluating Technological Innovation Capability in Patent-Intensive Industries: Postprint

Authors: Su Naiping, Zhang Xian, Dong Kun, Chen Xiujian

Date: 2023-10-08T00:00:00+00:00

Abstract

[Purpose/Significance] Systematically review and compare the current research status of technological innovation capability evaluation in patent-intensive industries, providing references for establishing and improving the evaluation system of technological innovation capability in China's patent-intensive industries. [Method/Process] This study, through domestic and foreign literature research and web surveys, and based on analyzing the connotation of patent-intensive industries, summarizes the current research status of technological innovation capability evaluation in patent-intensive industries from three aspects: evaluation indicator research, evaluation method research, and empirical research. [Results/Conclusion] Analysis based on existing research findings on industrial technological innovation capability evaluation reveals that: the pertinence and applicability of evaluation indicators for technological innovation capability in patent-intensive industries are not prominent enough; evaluation methods are relatively single, mostly employing DEA methods to measure innovation efficiency in patent-intensive industries; empirical data are predominantly secondary data limited to national economic statistics, and research perspectives are overly broad. It is recommended that future research fully consider the characteristics of patent-intensive industries regarding patent quantity density and dependence on the patent system, incorporating more evaluation indicators that reflect industrial patent strength and economic contributions; actively explore scientific, effective, and comprehensive evaluation methods to comprehensively assess the technological innovation capability of patent-intensive industries from multiple perspectives; excavate and integrate multi-source data for evaluating technological innovation capability in patent-intensive industries and other patent data reflecting patent quality and protection levels in patent-intensive industries, with empirical research conducted from regional and industry subdivision perspectives.

Full Text

Preamble

Review on the Evaluation of Technological Innovation Capabilities of Patent-Intensive Industries

Su Naping^{1,2}, Zhang Xian³, Dong Kun⁴, Chen Xiujuan^{2,3}

¹National Science Library, Chinese Academy of Sciences, Beijing 100190, China

²School of Economics and Management, University of Chinese Academy of Sciences, Beijing 100190, China

³Chengdu Library and Information Center, Chinese Academy of Sciences, Chengdu 610041, China

⁴Institute of Scientific & Technical Information, Shandong University of Technology, Zibo 255049, China

Abstract

[Purpose/Significance] This study systematically reviews and compares current research on evaluating technological innovation capabilities in patent-intensive industries to provide references for establishing and improving China's evaluation system for these capabilities. **[Method/Process]** Through a review of domestic and international literature and web-based investigation, this research first analyzes the connotation of patent-intensive industries, then summarizes the current state of research from three perspectives: evaluation indicators, evaluation methods, and empirical studies. **[Result/Conclusion]** Analysis of existing industrial technological innovation capability evaluation research reveals that current evaluation indicators for patent-intensive industries lack sufficient pertinence and applicability; evaluation methods are relatively monolithic, predominantly employing DEA to measure innovation efficiency; and empirical data mostly consists of secondary national economic data with overly broad research perspectives. Future research should fully consider the characteristics of patent-intensive industries—their high patent density and dependence on the patent system—by incorporating more indicators that reflect industrial patent strength and economic contribution; exploring scientific, effective, and comprehensive evaluation methods; mining and integrating multi-source data and other patent data reflecting patent quality and protection levels; and conducting empirical studies from regional and sub-industry perspectives.

Keywords: Patent-intensive industry; Technological innovation capabilities; Evaluation indicators; Evaluation methods; Empirical research

Classification Number: G306

Citation Format: Su Naping, Zhang Xian, Dong Kun, et al. Review on the Evaluation of Technological Innovation Capabilities of Patent-Intensive Industries[J/OL]. Knowledge Management Forum, 2019, 4(1): 10-19 [citation date].

<http://www.kmf.ac.cn/p/158/>.

On October 21, 2016, China's Ministry of Industry and Information Technology issued the *Development Plan for Industrial Technological Innovation Capability (2016-2020)*, identifying the enhancement of industrial technological innovation capability as a crucial means and key support for transforming economic growth patterns and promoting industrial structure upgrading [1]. As a vital component of intellectual property-intensive industries, patent-intensive industries represent the leading sectors for China's industrial transformation, upgrading, and innovation-driven development, as well as the key to obtaining competitive advantages globally [2]. From 2010 to 2014, the added value of China's patent-intensive industries totaled 26.7 trillion yuan, accounting for 11.0% of GDP with an average annual real growth rate of 16.6%—more than double the 8% annual real growth rate of GDP during the same period [3].

In this context, national [4] and local governments [5-7] have successively issued multiple documents explicitly proposing goals and requirements for cultivating intellectual property-intensive industries. However, China's patent-intensive industries currently face challenges including insufficient R&D investment intensity, low industrial innovation efficiency, imperfect intellectual property protection and innovation incentive mechanisms, and underutilized patent advantages [8-9]. Strengthening technological innovation capability building has become urgent, and scientific, objective evaluation of these capabilities is a prerequisite and foundation for such efforts. Against this background, this paper draws from CNKI and Web of Science (WOS) for the period January 2012 to June 2018, using search terms including “patent-intensive industries,” “intellectual property-intensive industries,” and their English equivalents. Additionally, web-based investigations collected major research reports and policy documents in this field. The review reveals that current international research on evaluating technological innovation capabilities in patent-intensive industries is extremely limited, with domestic studies largely borrowing from general frameworks for industrial technological innovation capability evaluation. Therefore, this study focuses on domestic literature, organizing current research from three aspects: evaluation indicators, evaluation methods, and empirical studies. It then analyzes existing problems in current evaluation approaches and proposes targeted recommendations for future research based on the objectives and practical needs of evaluating technological innovation capabilities in patent-intensive industries.

1. Connotation of Patent-Intensive Industries

Reasonable industrial measurement forms the foundation for evaluating technological innovation capabilities in patent-intensive industries [2]. This study first organizes current domestic and international definitions of patent-intensive industries. As a new industrial concept, the intersection between patent-intensive industries and national key industries such as high-tech industries cannot be ig-

nored [2]. Comparing patent-intensive industries with high-tech industries can further clarify the conceptual basis for constructing more targeted and applicable evaluation indicator systems.

The United States first explicitly proposed the concept of intellectual property-intensive industries in 2012, defining patent-intensive industries as those with invention patent quantities per employee exceeding the average level across all industries [10]. This concept gained rapid recognition, with the European Union [11] and China [8,12] conducting related research, though definitions vary across countries due to differences in industrial classification standards and policies (specific criteria and explanations are provided in). Additionally, since technology, products, and industries all have distinct life cycles, the definition of patent-intensive industries is dynamic [13]. Broadly speaking, patent-intensive industries refer to those with patent density above average—industries that produce relatively more patents given a certain scale of input—characterized by high patent density, high added value, and high economic contribution, representing the fundamental direction of industrial innovation [14].

In terms of coverage, patent-intensive industries intersect with but differ significantly from high-tech industries in connotation. The *Patent-Intensive Industries Directory (2016 Trial)* [17] and the *High-Tech Industry (Manufacturing) Classification (2013)* [18] share a unified industry classification standard—the *2011 National Economic Industry Classification (GB/T 4754-2011)*. Based on this standard, patent-intensive industries encompass 48 medium categories comprising 179 sub-categories, while high-tech industries include 61 sub-categories, with 49 overlapping sub-categories. In other words, patent-intensive industries cover approximately three times the scope of high-tech industries, with nearly 80% of high-tech industries belonging to the patent-intensive category, as illustrated in [Figure 1: see original paper]. However, their defining criteria differ: high-tech industries (manufacturing) are defined by relatively high R&D intensity (ratio of R&D expenditure to main business revenue), representing R&D input-intensive industries [18]; whereas patent-intensive industries are defined by patent output density, particularly those highly dependent on patent protection systems [2,17,19]. Therefore, when constructing evaluation indicator systems for patent-intensive industries, researchers can draw from existing high-tech industry evaluation research but must emphasize characteristics of patent density and dependence on the patent system.

2. Evaluation of Technological Innovation Capabilities in Patent-Intensive Industries

The key to evaluating technological innovation capabilities lies in selecting scientifically feasible indicators and effective evaluation methods [21]. Since the concept of patent-intensive industries emerged, scholars have conducted empirical studies on their technological innovation capability evaluation [22-27]. This section summarizes and compares current research from three aspects: evaluation indicators, evaluation methods, and empirical studies.

2.1 Current Status of Evaluation Indicator Research

Selecting sensitive and representative indicators is essential for constructing evaluation indicator systems [28]. Current evaluation indicators for industrial technological innovation capability are typically designed based on input-output perspectives [29-30]. This study organizes and interprets relevant indicators for patent-intensive industries from these two dimensions.

2.1.1 Technological Innovation Input Indicators Technological innovation input refers to the quantity and quality of all tangible and intangible resources invested in innovation activities, generally categorized into human, material, and financial aspects [31]. Current studies primarily adopt two types of input indicators: human resource input and financial input.

Human resource input indicators commonly include the number or proportion of R&D personnel [21-26], with some scholars also using average industry employment numbers [27]. Financial input indicators focus on three components: independent R&D expenditure, technology acquisition costs, and technological transformation expenses. Independent R&D expenditure indicators include R&D funding [22-26], equipment expenditure [24], and new product development expenditure or proportion [22,24-25]. Technology acquisition indicators include technology import expenditure [22,24-25] and domestic technology purchase expenditure [24]. Technological transformation indicators primarily include technological transformation expenditure [25]. Additionally, some scholars incorporate fixed asset investment [22], number of R&D institutions [24], and new product development project numbers [26] as input indicators.

2.1.2 Technological Innovation Output Indicators Technological innovation output refers to the results of innovation resource input, reflecting the benefits and scale of innovation activities [29,31]. Current studies adopt two main types of output indicators: knowledge output and economic output.

Knowledge output indicators primarily include patent-related metrics such as patent application numbers [23-24], invention patent application numbers [23,26], valid invention patent numbers [22], and invention patent grants [25]. Economic output indicators consider market share, profitability, and export capacity, commonly using new product sales revenue or output value [22-25], new product export sales revenue [24,27], and profit [23,27]. Some scholars also include total industrial output value [23] and main business revenue [27] as output indicators.

Common evaluation indicators for patent-intensive industry technological innovation capabilities and their interpretations are summarized in .

2.2 Current Status of Evaluation Method Research

Selecting scientifically effective evaluation methods is crucial [21]. Existing research on patent-intensive industries primarily employs Data Envelopment Anal-

ysis (DEA) to measure innovation efficiency (see). Proposed by A. Charnes et al. in 1978, DEA is a non-parametric method for analyzing relative efficiency of decision-making units with multiple inputs and outputs. Its advantages include not requiring specific production frontier function forms, processing data without dimensions, or making weight assumptions, making it relatively simple and objective. Its disadvantage is providing limited explanatory information about decision-making units, leading some scholars to combine DEA with other methods [33-34].

Current applications of DEA in patent-intensive industry evaluation include two categories:

First, single-stage or multi-stage DEA methods evaluate innovation efficiency. Single-stage DEA treats innovation as a “black box,” evaluating decision-making units using only initial inputs and final outputs while ignoring intermediate processes, thus failing to reveal internal stage efficiencies and their influencing factors. To better uncover internal development patterns, multi-stage DEA methods are widely applied [35]. For instance, Jiang Nan [23] divided the innovation system into “technology” and “economy” stages to compare innovation efficiency differences between patent-intensive and non-patent-intensive industries, while Wang Liying et al. [24] used a three-stage DEA approach based on the innovation value chain (technology output, materialization output, and value output) to examine Zhejiang province’s patent-intensive industries (see).

Second, DEA-Malmquist index methods measure changes in innovation efficiency over time, requiring continuous and independent indicator data to ensure objective results [22,36]. Chen Wei et al. [22] used DEA-Malmquist to analyze China’s nine major patent-intensive industries at the industry level, while Jiang Nan et al. [26] compared innovation efficiency between patent-intensive and non-patent-intensive industries using this method (see).

2.3 Current Status of Empirical Research

Based on different data sources and research perspectives, scholars have conducted empirical studies on patent-intensive industry technological innovation capability evaluation (see). Regarding data sources, most studies rely on existing statistical data from sources like the *China Statistical Yearbook* and *China Science and Technology Statistical Yearbook*, primarily comprising national economic data [22-27]. From a methodological perspective, research predominantly adopts a national viewpoint to compare technological innovation capabilities between patent-intensive and non-patent-intensive industries [22,24,26]. Evaluation results indicate that patent-intensive industries have not yet fully leveraged their competitive advantages, suffering from input redundancy and low output efficiency. Multi-stage DEA analyses reveal that the primary stage determining overall innovation efficiency is the transformation of intellectual property elements like patents into economic performance [23-24].

3. Review of Current Research

Current research on patent-intensive industry technological innovation capability evaluation remains limited. However, extensive studies have evaluated technological innovation capabilities in high-tech industries [37-41]. As a new industrial concept, patent-intensive industries possess both unique characteristics and common industrial features. Given the high overlap between high-tech and patent-intensive industries, existing research—particularly on high-tech industries—provides valuable references for constructing evaluation indicator systems for patent-intensive industries. Based on existing research and the characteristics of patent-intensive industries, this study summarizes the strengths and weaknesses of current evaluation research:

First, regarding evaluation indicators, existing industrial technological innovation capability research emphasizes R&D investment, patent and new product output, and economic benefits [42-43], such as R&D funding and personnel input, patent numbers, new product quantities, and sales revenue. Patent-intensive industry evaluation indicators also follow this framework from financial input, human input, knowledge output, and economic output perspectives. However, most studies fail to incorporate the characteristics of high patent density and patent system dependence, resulting in insufficient pertinence and applicability. For example, knowledge output indicators only focus on quantitative metrics like patent application numbers, while patent-intensive industries already possess patent quantity advantages. To better reflect innovation competitiveness, more attention should be paid to patent quality and economic driving effects. In summary, current research borrows general frameworks but ignores patent-intensive industry characteristics, lacking exploration of indicators that reflect patent strength, which hinders revealing development patterns.

Second, regarding evaluation methods, common approaches in industrial technological innovation capability research include Analytic Hierarchy Process [44], Principal Component Analysis [45-46], Factor Analysis [47-49], Entropy Method [38,50], and DEA [51-53], with different methods providing different information and weight assignments that affect results. Current patent-intensive industry research predominantly uses DEA to measure innovation efficiency, which only reflects the transformation capability from input to output while ignoring actual input and output levels. Although DEA is mature for efficiency evaluation, innovation efficiency represents only one aspect of technological innovation capability. To understand the internal structure of China's patent-intensive industries, comprehensive evaluation of overall capability levels is needed. In summary, the monolithic methodological approach yields incomplete and unreliable results.

Third, regarding empirical research, data sources fall into two categories: survey data obtained through questionnaires or interviews [38,54-55], which is costly but timely and flexible; and existing statistical data from yearbooks and databases [48-50,56], which is less costly but often outdated and limiting for indicator selection. Research perspectives can be national [49], regional [46,48,51],

or industrial [29]. Current patent-intensive industry research primarily uses secondary statistical data limited to national economic data, lacking in-depth mining of patent data. Research perspectives are overly broad, focusing on national-level comparisons between patent-intensive and non-patent-intensive industries, which prevents detailed analysis of regional and sub-industry differences. This limits the accurate revelation of development status.

4. Future Research Prospects

Establishing a more scientific and reasonable evaluation indicator system for patent-intensive industry technological innovation capabilities helps understand the economic characteristics and development patterns of these industries, thereby exploring the contribution of patent innovation to industrial economic development and providing references for industrial transformation and upgrading. This study's review of evaluation indicators, methods, and empirical research reveals that domestic research remains in the exploratory stage, primarily borrowing general frameworks from other industries. Main problems include: (1) insufficient pertinence and applicability of evaluation indicators; (2) monolithic evaluation methods focusing on DEA for efficiency measurement; and (3) reliance on secondary national economic data with broad research perspectives.

Based on evaluation objectives and practical needs, future research should address these issues through the following recommendations:

First, regarding evaluation indicators, research should strengthen pertinence by incorporating more indicators reflecting industrial patent strength beyond simple patent counts. For example, patent technology maturity indicators (calculated as $\alpha = a/(a + b)$ [57], where a represents annual invention patent applications and b represents annual utility model applications, with decreasing α values over time reflecting technological maturation) can evaluate the degree of transformation into actual products. Invention patent growth rate indicators ($v = a/A$ [57], where a is as above and A is the cumulative invention patent applications over five years) can assess changing trends in innovation activities and technological reserves in specific fields. Additionally, more indicators reflecting economic contribution should be added, such as total asset contribution rate and net profit margin to evaluate asset profitability and earning capacity, thereby better revealing the economic value generated when R&D achievements are transformed into marketable new products.

Second, regarding evaluation methods, to comprehensively and accurately reveal development levels, future research should explore the applicability of other methods such as Entropy Method, Analytic Hierarchy Process, and Factor Analysis, or comprehensively apply multiple methods to evaluate technological innovation capabilities from various angles.

Third, regarding empirical research, obtaining large amounts of relevant data provides informational support for evaluation. Future studies should mine and

integrate multi-source data based on research purposes, scope, and available resources. Additional patent data can be obtained from the National Intellectual Property Administration or commercial patent databases, such as invention patent grants and invalidation requests. Meanwhile, given regional economic imbalances and differences in leading industries, future research should adopt more regional perspectives and investigate differences among sub-industries to better support empirical evaluation of patent-intensive industry technological innovation capabilities.

References

- [1] Ministry of Industry and Information Technology. Development Plan for Industrial Technological Innovation Capability (2016-2020) [EB/OL]. [2018-02-15]. <http://www.miit.gov.cn/n1146295/n1652858/n1652930/n4509650/c5331368/content.html>.
- [2] Mao Hao. Local Path of Patent-Intensive Industry Development [J]. *Electronics Intellectual Property*, 2017(7): 65-75.
- [3] Development Planning Department, State Intellectual Property Office. Main Statistical Data Report on China's Patent-Intensive Industries (2015) [EB/OL]. [2018-12-03]. <http://www.sipo.gov.cn/docs/pub/old/tjxx/yjcg/201610/P020161028632217319768.pdf>.
- [4] Central People's Government of the People's Republic of China. Several Opinions of the State Council on Accelerating the Construction of an Intellectual Property Powerhouse under New Circumstances (Guofa [2015] No. 71) [EB/OL]. [2017-11-16]. http://www.gov.cn/zhengce/content/2015-12/22/content_{10468}.html.
- [5] Jiangsu Provincial Intellectual Property Office. Provincial Government Notice on Accelerating Intellectual Property Powerhouse Construction Policies and Measures [EB/OL]. [2018-03-06]. http://www.jsip.gov.cn/zwgk/gfwj/xgzc/201704/t20170407_{38662}.html.
- [6] State Intellectual Property Office. Guangxi Accelerates Development of Patent-Intensive Industries [EB/OL]. [2018-12-03]. <http://www.sipo.gov.cn/dtxx/1105601.htm>.
- [7] Henan Science and Technology Network. Henan Province Patent Development "13th Five-Year" Plan [EB/OL]. [2018-12-19]. <http://www.hnkjt.gov.cn/2017/03/08/1488981586586.html>.
- [8] Li Fengxin, Liu Lei, Ni Ping. Statistical Report on Patent Intensity of Chinese Industries [J]. *Science Focus*, 2014, 9(1): 7-24.
- [9] Zhu Chengliang, Liu Ruiming, Wang Hongwei. Evaluation and Improvement Path of Green Innovation Performance in Patent-Intensive Industries [J]. *Journal of Quantitative & Technological Economics*, 2018, 35(4): 61-79.
- [10] Economics and Statistics Administration and United States Patent and Trademark Office. Intellectual Property and the U.S. Economy: Industries in Focus [EB/OL]. [2018-03-26]. <https://www.uspto.gov/learning-and-resources/ip-motion/intellectual-property-and-us-economy>.

- [11] European Patent Office and the Office for Harmonization in the Internal Market. Intellectual Property Rights Intensive Industries: Contribution to Economic Performance and Employment in the European Union [EB/OL]. [2018-12-18]. https://euipo.europa.eu/tunnel-web/secure/webdav/guest/document_{library}/observatory/documents/contribution-study-chinese.pdf.
- [12] Development Planning Department, State Intellectual Property Office. Statistical Report on Regional Patent Intensity of Chinese Industries [EB/OL]. [2018-07-09]. <http://www.sipo.gov.cn/docs/20180212175748107427.pdf>.
- [13] Liu Dan. Research on Measurement of China's Patent-Intensive Industries [D]. Zhenjiang: Jiangsu University, 2014.
- [14] Jiang Nan. Research on Differences in Cooperative Relationships of Patent Right Holders in Patent-Intensive Industries [J]. Journal of Intelligence, 2016, 35(4): 87-91.
- [15] Economics and Statistics Administration and United States Patent and Trademark Office. Intellectual Property and the U.S. Economy: 2016 Update [EB/OL]. [2017-11-15]. <https://www.uspto.gov/sites/default/files/documents/IPandtheUSEconomySept2016.pdf>.
- [16] European Patent Office and the European Union Intellectual Property Office. Intellectual Property Rights Intensive Industries and Economic Performance in the European Union [EB/OL]. [2018-12-18]. https://euipo.europa.eu/tunnel-web/secure/webdav/guest/document_{library}/observatory/documents/IPContributionStudy/full_{report}.pdf.
- [17] Development Planning Department, State Intellectual Property Office. Patent-Intensive Industries Directory (2016) (Trial) [EB/OL]. [2017-10-30]. <http://www.sipo.gov.cn/zscqgz/2016/201610/P020161028559513716647.pdf>.
- [18] National Bureau of Statistics. High-Tech Industry (Manufacturing) Classification (2013) [EB/OL]. [2018-01-15]. http://www.stats.gov.cn/statsinfo/auto2073/201310/t20131030_{450341}.pdf.
- [19] Liu Qian, Jiang Nan, Dai Fengyan. New Path to Break “Low-End Lock-In” : Review and Prospect of Patent-Intensive Industry Research [J]. Science & Technology Progress and Policy, 2017, 34(19): 154-160.
- [20] Shi Qingqi. Research on China's Industrial Technological Innovation Capability [M]. Beijing: China Light Industry Press, 2000: 3-5.
- [21] Zhao Yulin, Cheng Ping. Empirical Analysis of Technological Innovation Capability of High-Tech Industries in Chinese Provincial Regions [J]. Business Economics and Administration, 2013, 1(6): 77-85.
- [22] Chen Wei, Jing Rui, Xu Ruihu, et al. Evaluation of Technological Innovation Efficiency of High Patent-Intensive Industries in China [J]. Journal of Harbin Engineering University, 2017, 38(3): 489-494.
- [23] Jiang Nan. Evaluation System for Innovation Efficiency of Patent-Intensive Industries [J]. Scientific Research, 2014, 32(7): 1003-1011.

- [24] Wang Liying, Wang Jiamin, Yu Weijia. Evaluation and Improvement Path of Regional Patent-Intensive Industry Innovation Efficiency—A Case Study of Zhejiang Province [J]. *Science Research Management*, 2017, 38(3): 29-37.
- [25] Sun Lei, Chen Wei, Liu Jinzhi, et al. Evaluation of Technological Innovation Efficiency of China' s Patent-Intensive Industries [J]. *Science and Technology Management Research*, 2016, 36(19): 52-55.
- [26] Jiang Nan. R&D Performance Evaluation of Patent-Intensive Industries—Based on DEA-Malmquist Index Method [J]. *Science of Science and Management of S.&T.*, 2014, 35(3): 99-107.
- [27] Zhang Jun. Efficiency Analysis of Jiangsu Province' s Patent-Intensive Industries During the “12th Five-Year” Period—Based on Manufacturing Data [J]. *Tianjin Science & Technology*, 2015, 42(11): 25-28.
- [28] Wu Youjun. Research on Evaluation Indicator System for Industrial Technological Innovation Capability [J]. *Commercial Research*, 2004(11): 27-29.
- [29] Wang Hongqing, Hou Yi. Evaluation of Technological Innovation Capability of China' s High-Tech Industries [J]. *China Science and Technology Forum*, 2017(3): 58-63.
- [30] Yi Ming, Peng Jiachao, Yu Yanxia. Evaluation and Improvement Countermeasures of Technological Innovation Efficiency of China' s High-Tech Industries [J]. *Macroeconomics*, 2017(11): 73-80.
- [31] Zeng Zhaoning, Fan Wen. Research on Evaluation Indicator System for High-Tech Industry Technological Innovation Capability [J]. *Journal of Xi' an Shiyou University (Social Science Edition)*, 2014, 23(1): 6-10.
- [32] Charnes A, Cooper W W, Rhodes E. Measuring the Efficiency of Decision Making Units [J]. *European Journal of Operational Research*, 1978, 2(6): 429-444.
- [33] Wei Quanling. *Data Envelopment Analysis (DEA)* [M]. Beijing: Science Press, 2006.
- [34] Yuan Qun. Review of Data Envelopment Analysis Application Research [J]. *Economic Research Guide*, 2009(19): 201-203.
- [35] Feng Zhijun, Chen Wei. R&D Innovation Efficiency of China' s High-Tech Industries—A New Perspective Based on Resource-Constrained Two-Stage DEA Method [J]. *Systems Engineering—Theory & Practice*, 2014(5): 1202-1212.
- [36] Liu F H F, Wang P H. DEA Malmquist Productivity Measure: Taiwanese Semiconductor Companies [J]. *International Journal of Production Economics*, 2008, 112(1): 367-379.
- [37] Di Xiaoyan, Zhang Chidong. Analysis of Innovation Capability of Intelligent Industry from the Perspective of Industrial Innovation Chain: A Case Study of Big Data Industry [J]. *China Soft Science*, 2018(5): 39-48.

- [38] Yam R C M, Guan J C, Pun K F, et al. An Audit of Technological Innovation Capabilities in Chinese Firms: Some Empirical Findings in Beijing, China [J]. *Research Policy*, 2004, 33(8): 1123-1140.
- [39] Vicente M, Abrantes J L, Teixeira M S. Measuring Innovation Capability in Exporting Firms: The INNOVSCALE [J]. *International Marketing Review*, 2015, 32(1): 29-51.
- [40] Luo R, Chanaron J J. Innovation Capabilities of Hi-Tech Small and Medium-Sized Enterprises (SMES): A Comparative Analysis Between China and France [J]. 2017, 14(3): 77-111.
- [41] Edison H, Ali N B, Torkar R. Towards Innovation Measurement in the Software Industry [J]. *Journal of Systems and Software*, 2013, 86(5): 1390-1407.
- [42] Daniel L, Saenz L. Innovation and Development [EB/OL]. [2018-12-19]. <http://documents.worldbank.org/curated/en/205791468315566096/pdf/wps3774.pdf>.
- [43] Hagedoorn J, Cloudt M. Measuring Innovative Performance: Is There an Advantage in Using Multiple Indicators? [J]. *Research Policy*, 2004, 32(8): 1365-1379.
- [44] Kim S K. Analytic Hierarchy Process Expansion for Innovation Performance Measurement Framework [EB/OL]. [2018-12-19]. <https://www.hindawi.com/journals/je/2013/632845/cta/>.
- [45] Li Jinlan, Zheng Shurong. Evaluation of High-Tech Industry Technological Innovation Capability Based on PCA—A Case Study of Quanzhou [J]. *Science & Technology Progress and Policy*, 2010, 27(16): 126-130.
- [46] Jiang Hong, Zhao Shukuan, Li Jinjin. Regional Industrial Technological Innovation Capability Evaluation Method and Application Research [J]. *Information Science*, 2009(10): 1538-1541.
- [47] Zhu X, Li Z. Evaluation of Regional Technological Innovation Capability in Guangxi Based on Factor Analysis [EB/OL]. [2018-12-19]. <https://www.atlantis-press.com/proceedings/ermm-15/20916>.
- [48] Duan Jie, Liang Qiqi. Research on Industrial Technological Innovation Performance Evaluation Based on Factor Analysis—A Case Study of Shaanxi Equipment Manufacturing Industry [J]. *Science and Technology Management Research*, 2014, 34(14): 53-57.
- [49] Xu Ling, Wu Fengchai. Evaluation of Technological Innovation Capability of China's High-Tech Industries [J]. *Science & Technology Progress and Policy*, 2011, 28(2): 128-132.
- [50] Li Li, Zhu Weiwei. Research on Measurement and Evaluation of Industrial Technological Innovation Capability—A Case Study of Guangdong's High-Tech Industries [J]. *Productivity Research*, 2009(24): 145-147.
- [51] Jian C G. A Study of the Relationship Between Competitiveness and Technological Innovation Capability Based on DEA Models [J]. *European Journal*

of Operational Research, 2006, 170(3): 971-986.

[52] Wang Juntao, Zhang Jianhui. Research on Technological Innovation Efficiency Evaluation and Resource Allocation of Shanxi' s High-Tech Industries Based on CCA-DEA [J]. Science and Technology Management Research, 2014, 34(3): 53-56.

[53] Chen Wei, Zhang Changxiao, Li Chuanyun, et al. Evaluation of Technological Innovation Efficiency of High-Tech Industries Based on DEA-Malmquist Index [J]. Science and Technology Management Research, 2017(23): 79-84.

[54] Cruz-Cázares C, Bayona-Sáez C, García-Marco T. You Can' t Manage Right What You Can' t Measure Well: Technological Innovation Efficiency [J]. Research Policy, 2013, 42(6/7): 1239-1250.

[55] Yam R C M, Lo W, Tang E P Y, et al. Analysis of Sources of Innovation, Technological Innovation Capabilities, and Performance: An Empirical Study of Hong Kong Manufacturing Industries [J]. Research Policy, 2011, 40(3): 391-402.

[56] Guan J, Chen K. Measuring the Innovation Production Process: A Cross-Region Empirical Study of China' s High-Tech Innovations [J]. Technovation, 2010, 30(5): 348-358.

[57] Yang Wu. Research on the Role of Patent Data in Measuring Innovative Technological Changes [J]. Science and Technology Management Research, 2006(7): 54-56.

Author Contributions

Su Naping: Conducted research material investigation, collation, and analysis; drafted and revised the paper;

Zhang Xian: Proposed research ideas, participated in paper review and revision;

Dong Kun: Participated in paper revision;

Chen Xiujuan: Participated in paper revision.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv –Machine translation. Verify with original.