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National Innovation Capacity Index: A Cross-Country Comparative Analysis

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Abstract

The national innovation capacity (NIC) has received increasingly more attention from academia and policy makers. This study develops a methodology for measuring NIC with a view to provide the evidence for policy-making concerning national innovation capacity-building, and conducts a cross-country comparison based on the panel data of 2006-2015. (1) National innovation capacity index (NICI) is established to measure the performance of NIC from two perspectives, namely national innovation strength index (NISI) and national innovation effectiveness index (NIEI). (2) Developed countries usually perform better than developing countries in terms of the NICI if there is no huge gap in economic scale between two kinds of countries. (3) Emerging countries show greater imbalance between the NISI and the NIEI, and have generally higher average annual growth rate of the NISI and the NIEI than that of developed countries. (4) National innovation strength is closely related to national economic scale while national innovation effectiveness is closely related to national development level. Some theoretical considerations in this research may make contributions to innovation development studies. (1) NIC is regarded as the capacity for scientific discovery and technology invention, and for driving economic, social and environmental development, which emphasizes the driving effect and the influence of innovation on development. (2) The concepts such as the NISI and the NIEI are introduced to measure the NIC so as to distinguish the contribution of the size of innovation activities to the NIC and the contribution of the efficiency and efficacy of innovation-driven development to the NIC. (3) The indicator system of the NICI is designed from the perspective of the full spectrum of capacity-building process ranging from input to output by introducing the “innovation condition” as a broad sense “innovation input” and the “innovation outcome” as a broad sense “innovation output”.

Keywords

national innovation capacity; national innovation capacity index; cross-country comparison

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1. Introduction

The world is experiencing the new round of technology revolution and industry transformation, which will restructure global innovation development and competition pattern. Innovation as the significant driving force for development has become the core policy issue in both the developed and the developing world. On the one hand, innovation capacity has been recognized as the important foundation of national competitiveness. On the other hand, innovation capacity has become the internal driving force for the evolution of global innovation development structure. The world is also experiencing the transformation from the innovation policy to innovation development policy, which has profound impacts on the policy design and policy metrics. Therefore, both academia and policy makers have paid increasingly close attention to the measurement of national innovation capacity (NIC) so as to identify the policy issues related to national innovation development in general, and to national innovation strength and innovation effectiveness in particular.

The theoretical basis of the conceptual framework of NIC mainly comes from the theory of national innovation system (NIS). Freeman put forward the concept of NIS in 1987, and regarded NIS as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies (OECD, 1997). Thereafter, there are lots of researches on NIS from different perspectives. Lundvall (2010) emphasized the importance of knowledge and learning for innovation, and thought a system of innovation was constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge. According to Edquist (1997), innovation processes are influenced by many factors; they occur in interaction between institutional and organizational elements which together may be called ‘systems of innovation’. The book *National Innovation Systems: A Comparative Analysis* edited by Nelson (1993) reveals the important role of innovation system in economic growth through an international comparative analysis of innovation system in 15 countries (regions) with different income levels and scales. With the important role of innovation system in promoting economic growth being demonstrated, innovation capacity has gradually attracted increasingly more attention from scholars and policy makers. As Metcalfe and Ramlogan (2008) pointed out that successful economic development was intimately linked to a country’s capacity to acquire, absorb, disseminate, and apply modern technologies, a capacity embodied in its NIS. Therefore, continuously monitoring the NIC is of great significance for guiding the formulation of innovation-driven development policy so as to promote economic and social development.

Suarez-villa (1990) emphasized the connections between invention and innovation, and defined the NIC as the successful outcomes of all corporate and individual invention that could be measured by patent data. Neely and Hii (1998) regarded innovation capacity as the potential of a firm, region or nation to generate innovative output. Therefore, three different levels of innovation capacity were distinguished, namely national level, regional level and firm level. According to their research, the NIC was affected by education and training, S&T capabilities, industrial structure, interactions within the innovation system, and knowledge absorption from abroad (Neely and Hii, 1998). Based on ideas-driven endogenous growth theory, the cluster-based theory of national industrial competitive advantage, and research on national innovation systems, Furman, Porter and Stern (2002) developed a NIC framework (FP&S framework) to explore the determinants of

the NIC. They focused on the “new to the world” innovation production, and defined the NIC as country’s potential - as both an economic and political entity - to produce a stream of commercially relevant innovations. FP&S framework indicates that the NIC of a country is determined by the common pool of institutions, resource commitments, and policies that support innovation across the economy; the particular innovation environment in the nation’s industrial clusters; and the linkages between them (Furman *et al.*, 2002).

FP&S framework provides an effective explanation for the different performance in innovation capacity among countries, highlights the important role of government in enhancing innovation capacity and points out the way for policy makers to enhance the NIC from the perspective of innovation system, which becomes the main theoretical framework basis for the follow-up research on the NIC. For example, Furman and Hayes (2004) developed a production function to estimate national innovative productivity based on FP&S framework, and categorized countries into four groups according to their historical levels of NIC, namely, leading innovator countries; middle tier innovator countries; third tier innovator countries; and emerging innovator countries. Hu and Mathews (2005) extended the FP&S framework for measuring NIC by including public R&D, and applied it to the analysis of five East Asia countries and regions. Their results once again confirmed the conclusion of FP&S, and also showed the importance of public R&D expenditure for the latecomer countries to close the gap with developed countries. Mathews and Hu (2007) further distinguished the development goals of innovation-leading countries and latecomer countries, for the later, innovation means “new to the country” rather than “new to the world”, whose primary strategic goal is to catch up.

However, the FP&S framework doesn’t perform well when analyzing the components of NIC and their internal connections by just listing the elements of NIS, and the quality of linkages between innovation infrastructure and innovation environment is very difficult to measure, which leads to limited guidance for policy practice. To solve this problem, Mu *et al.* (2010) redefined the NIC from the perspective of innovation process and value creation, and regarded the NIC as the ability of a country to conduct scientific discovery, technological innovation and related commercialization activities, which consists of four aspects: the innovation input, the innovation condition, the innovation output and the innovation outcome. In a broad sense, NIC is the capability of a country to integrate innovation resources so as to transform them into fortune, which reflects an integrative capacity to promote economic and social development. Based on this definition, Mu and Fan (2011) constructed a three-dimensional conceptual framework for understanding NIC, namely, innovation elements, innovation actors and innovation activities (EAA framework), and proposed a national innovation capacity-building framework according to the EAA framework. The EAA framework integrates innovation process with innovation actors and elements from the national innovation system perspective, and provides a more systematic and comprehensive understanding of NIC, and an effective operational framework for innovation development policy practices.

The measurement of NIC has become the focus of innovation development policy and management research. Since the 1990s, the measurement of NIC has experienced a development process from single indicator approach to multi-dimensional indicator system approach. Earlier studies (*e.g.*, Suarez-Villa, 1990) used single indicator, such as patent data, to measure the NIC. Although it has the advantages of high availability of international data and simple data analysis methods, there are many shortcomings, such as the biased results which are not meaningful for policy practice. As a result, the single indicator

approach is gradually being phased out. Recently, the multi-dimensional indicator system has become the main approach for the measurement of NIC. Different scholars and institutes have developed various indicator systems for different evaluation goals with their own understandings of NIC. Representative studies can be divided into the following two categories.

The first category of researches tries to use a comprehensive set of indicators related to innovation to measure the NIC, including European Innovation Scoreboard (EIS), Global Innovation Scoreboard (GII) and The National Innovation Index proposed by Chinese Academy of Science and Technology for Development (NII-CASTED). The EIS provides a comparative assessment of the research and innovation performance of the EU Member States and the relative strengths and weaknesses of their research and innovation systems (European Commission, 2019). The EIS indicator system distinguishing between four types of indicators and ten innovation dimensions, capturing in total 27 different indicators. The four types of indicators consist of the framework conditions, the investments, the innovation activities, and the impacts. The GII provides detailed innovation metrics for 129 economies, and all economies covered represent 91.8% of the world's population and 96.8% of the world's GDP (Cornell University *et al.*, 2019). The GII indicator system is based on the input-output framework. The innovation input sub-index has five enabler pillars, including the institutions, the human capital and research, the infrastructure, the market sophistication, and the business sophistication. The innovation output sub-index has two enabler pillars, including the knowledge and technology outputs, and the creative outputs. These two sub-indices have the same weight in calculating the overall GII. The NII-CASTED measures national innovation index based on an indicator matrix comprising five pillars, including the innovation resources, the knowledge creation, the enterprise innovation, the innovation performance, and the innovation environment (Chinese Academy of Science and Technology for Development, 2018). The 30 second-level indicators of NII-CASTED are composed of 20 quantitative indicators which highlight innovation scale, quality, efficiency and international competitiveness while maintaining a balance between large and small countries, and 10 qualitative indicators which reflect the innovation environment. These indicator systems can generally reflect the innovation status of a country in a comprehensive way. However, they did not make a clear distinction between innovation capacity and innovation performance, which made it difficult to reveal the difference in innovation capacity between countries.

The second category of researches tries to develop a multi-dimensional indicator system specific to innovation capacity. The Global Competitiveness Report takes NIC as a part of the Global Competitiveness Index, and measures it from three aspects: the interaction and diversity, the research and development, and the commercialization (World Economic Forum, 2017). However, the measurement by World Economic Forum mainly focuses on the innovation environment and R&D, which is relatively simple and can't fully reflect the connotation and extension of NIC. Moreover, the use of subjective methods such as executive opinion survey to obtain data will reduce the reliability of international comparison. Porter and Stern (1999) proposed the National Innovation Index (NII) based on their understanding of NIS and the FP&S framework to measure the NIC, which highlights the resource commitments and policy choices that affect innovative output in the long run. The NII contains three aspects such as the quality of the common innovation infrastructure, the cluster-specific innovation environment, and the quality of linkages, and aims to monitor the innovation capacity of different countries and regions from multiple perspectives. However, the NII does not distinguish the

difference between the contribution of scale indicators and the contribution of efficiency indicators to NIC, which is very helpful for identifying and analyzing the policy issues related to innovation capacity-building.

Mu proposed a National Innovation Capacity Index (NICI) with two sub-indexes concerning the innovation strength and the innovation effectiveness so as to provide evidence for the formulation of innovation capacity-building policies. Both sub-indexes are measured from four aspects: the innovation input, the innovation output, the innovation condition and the innovation outcome in *The Report on Innovation Development in China 2009* (The Center for Innovation and Development of Chinese Academy of Sciences, 2009; see also Mu et al., 2010). However, it is necessary to improve the NICI indicator system continually so as to reflect the changes in scientific, technological, economic and social development and the transformation from innovation policy to innovation development policy. Firstly, new indicators should reflect the technology progress and development. For example, the indicators such as the internet users, replace the indicators such as the total number of telephones and personal computers in the previous indicator system so as to reflect the change in infrastructure for increasingly more important digital transformation nowadays. Secondly, new indicators should reflect our deeper understanding on innovation activities. For example, the indicators such as SCI, SSCI, and A&HCI paper citations are more suitable than the indicators such as the number of scientific and technical journal articles in the previous indicator system to measure innovation output. Because the SCI, SSCI, and A&HCI paper citations reflect not only the quantity of innovation output, but also to some extent the quality of innovation output. Thirdly, new indicators should reflect the emerging change in innovation development. We are experiencing the transformation of innovation policy research paradigm to innovation development policy research paradigm (Mu et al., 2019). The innovation development policy paradigm regards the creation and diffusion of scientific and technological knowledge as the power source of innovation development, and emphasizes the importance of knowledge accumulation and application, as well as social diffusion. Therefore, some indicators concerning knowledge accumulation and its economic and social impact should be included in the NICI so as to match the innovation development policy practice. For example, the patents in force would be an important indicator for innovation condition while the export of high-tech products would be an important indicator for innovation outcome.

This study attempts to reconstruct a multi-dimensional indicator system of the NICI from the perspective of innovation development ranging from S&T advancement to economic and social development, and to bridge the NIC measurement and the formulation of innovation development policy so as to guide innovation development policy practices in China. The rest of this paper is structured into three parts, namely: (1) to develop the methodology for measuring NIC and related sub-indexes by illustrating the connotation of NIC and the relationship between NIC indicator system and innovation policy practice, including the analytical framework for NIC and the NICI indicator system. (2) to conduct the cross-country comparison of NIC and related sub-indexes, focusing on the ranking of the NICI, the NISI and the NIEI as well as their evolution during 2006-2015. (3) to summarize the results of previous cross-country comparisons, conclude major contributions to innovation development studies by redefining key terms such as innovation, and innovation development as well as innovation development policy paradigm, and to discuss some implications for policy design and policy metrics, and the limitations in designing indicator system of NIC.

2. Methodology

2.1. Measurement indicator system

This study designs the indicator system of the NICI on the basis of our deeper understanding of the connotation of innovation and NIC. Innovation is a complicated social process of value creation, in the fields of science, technology, economy, society and culture, which concerns activities ranging from scientific discovery, technological invention to methodological innovation, and their applications as well as social diffusion (Mu and Fan, 2011). Therefore, innovation capacity is embedded in the entire value creation process and various types of value creation activities, including not only the capacity in scientific discovery and technology invention, but also the capacity to drive economic and social development. From the viewpoint of innovation development definition, the innovation capacity indicates the force driving development. Therefore, the measurement of innovation capacity should pay attention to the force's action on the object, namely the effect and influence of innovation on development.

From the perspective of innovation capacity building process, innovation capacity consists of innovation input capacity, innovation condition capacity, innovation output capacity and innovation outcome capacity. It is worthwhile to point out that innovation input capacity and innovation condition capacity represent the potential of the innovation capacity, while innovation output capacity and innovation outcome capacity are the external manifestation of innovation capacity. Innovation input capacity represents the capacity of financial and personnel input for innovation, while innovation condition capacity represents the capacity of knowledge base and infrastructure for innovation. Innovation output capacity measures the direct output of scientific discovery and technological invention activities while innovation outcome capacity measures the impact of innovation on economic and social development, including the commercialization and social diffusion of science, technology and innovation. It is assumed here that the change of national innovation

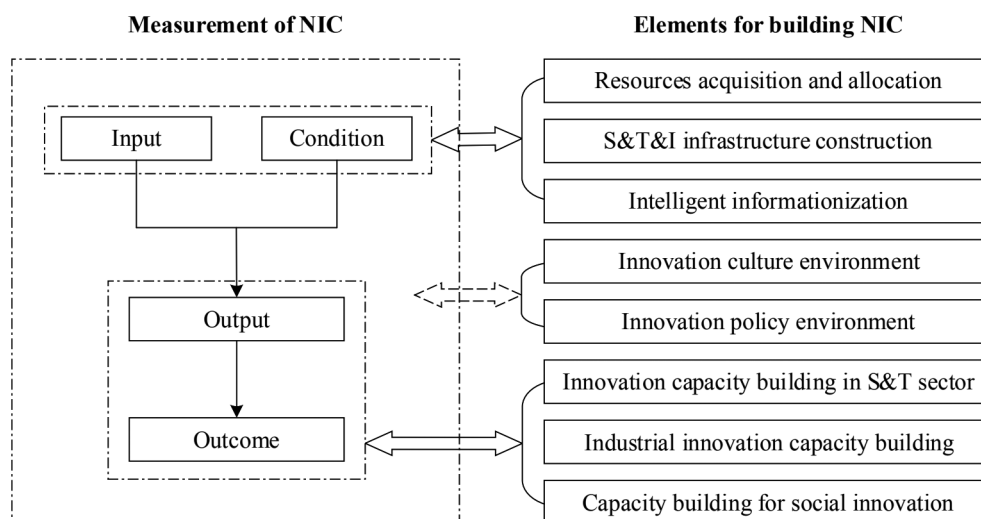


Fig. 1 Relationship between NIC indicator system and elements for building NIC

Adapted from Mu and Fan (2011)

capacity to a large extent resulted from the change of national innovation policy and cultural environment, which implies that the measurement of NIC provides indirect evidence for monitoring the changes in national innovation cultural environment. Therefore, the measurement of NIC and the cross-country comparison in details may provide lots evidences for designing and revising national innovation development policy through identifying the key policy issues related to innovation input-condition-output-outcome and cultural environment. The relationship between the indicator system of NIC and the elements for building NIC is shown in Fig. 1.

From the perspective of innovation capacity structure, the national innovation capacity consists of the national innovation strength and the national innovation effectiveness. National innovation strength emphasizes the contribution of the scale of innovation-driven development activities, while national innovation effectiveness emphasizes the contribution of the efficiency and efficacy of innovation-driven development activities. Therefore, the NIC measurement is very helpful to identify the key policy issues for designing and implementing suitable policies for innovation capacity-building. For example, the countries with large-scale innovation-driven development activities have stronger innovation capacity than those with small-scale innovation-driven development activities if there is no difference in innovation effectiveness among the countries, while the countries with higher innovation effectiveness may have stronger innovation capacity than those with lower innovation effectiveness if there is no difference in innovation strength among the countries.

This study develops a NIC analytical framework by integrating our understanding on innovation capacity from the perspectives of both the innovation capacity-building process and

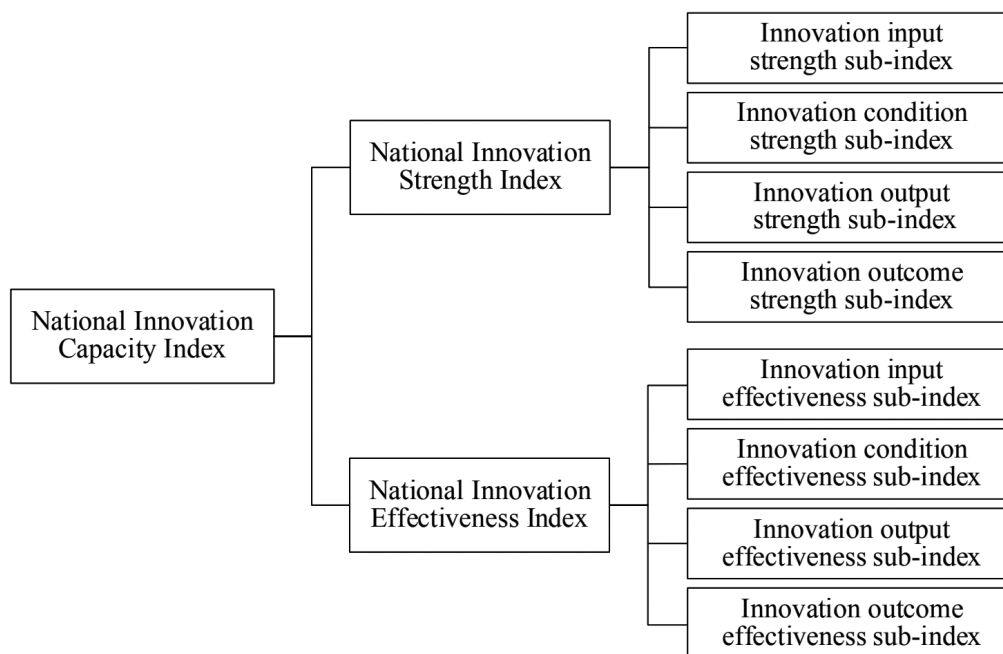


Fig. 2 The analytical framework for national innovation capacity

the innovation capacity structure, as shown in Fig. 2. The NIC analytical framework characterizes the NICI with national innovation strength index (NISI) and national innovation effectiveness index (NIEI), and develops the sub-indexes of the NISI and the NIEI from the perspective of input-condition-output-outcome. The NISI consists of four sub-indexes, namely: the innovation input strength sub-index, the innovation condition strength sub-index, the innovation output strength sub-index and the innovation outcome strength sub-index. The NIEI also consists of four sub-indexes, namely: the innovation input effectiveness sub-index, the innovation condition effectiveness sub-index, the innovation output effectiveness sub-index and the innovation outcome effectiveness sub-index.

According to the analytical framework for NIC, this study develops a NICI indicator system with 23 indicators as shown in Table 1. Compared with the NICI proposed by *The Report on Innovation Development in China 2009*, the new indicator system presented in this study replaces some indicators that are no longer applicable with some new suitable indicators, such as indicators that focus on knowledge accumulation and commercialization of innovation. When selecting the indicators, we follow three principles: (1) the principle of relevance, which requires the proxy indicators should effectively reflect the connotation of each sub-index; (2) the principle of comparability, which requires the proxy indicators should be comparable among selected countries; and (3) the principle of operability, which requires the proxy indicators should have continuous available data support.

National Innovation Strength Index (NISI). This study selects the absolute indicators to measure national innovation strength. Regarding financial and personnel input, the R&D expenditure and the number of researchers are regarded as two proxy indicators of innovation input strength. According to the accumulation of available knowledge resources and the level of intelligent informationization, the patents in force and the number of internet users are selected as two proxy indicators of innovation condition strength. Considering the direct output of scientific research and technological development, the SCI, SSCI, and A&HCI paper citations, the Patent grants (resident) and the PCT patent applications are selected as three proxy indicators of innovation output strength. Regarding the economic and social impact of innovation, we choose the charges for the use of intellectual property (receipts) and the export of high-tech products as two proxy indicators of innovation outcome strength.

National Innovation Effectiveness Index (NIEI). This study uses proportional indicators to measure the national innovation effectiveness. Innovation input effectiveness is measured by the R&D intensity, the number of researchers per million people and the R&D expenditure per researcher. Innovation condition effectiveness is measured by the patents in force per million people and the number of internet users per hundred people. Innovation output effectiveness is measured by the SCI, SSCI, and A&HCI paper citations per million researchers, the SCI, SSCI, and A&HCI paper citations per million R&D expenditure, the patent grants (resident) per million researchers, the patent grants (resident) per million R&D expenditure, the PCT patent applications per million researchers and the PCT patent applications per million R&D expenditure. Innovation outcome effectiveness is measured by the ratio of receipts to payments of charges for the use of intellectual property, the GDP per unit of energy use and the export of high-tech products as a percentage of manufactured exports.

Table 1 The indicator system for national innovation capacity index

Index	Sub-index	Indicator	Source
National Innovation Strength Index	Innovation input strength sub-index	R&D expenditure	WB
		The number of researchers	WB
	Innovation condition strength sub-index	Patents in force	WIPO
		The number of internet users	WB
	Innovation output strength sub-index	SCI, SSCI, and A&HCI paper citations	WOS
		Patent grants (resident)	WIPO
		PCT patent applications	WIPO
	Innovation outcome strength sub-index	Charges for the use of intellectual property (receipts)	WB
		The export of high-tech products	WB
National Innovation Effectiveness Index	Innovation input effectiveness sub-index	R&D intensity	WB
		The number of researchers per million people	WB
		R&D expenditure per researcher	WB
	Innovation condition effectiveness sub-index	Patents in force per million people	WB and WIPO
		The number of internet users per hundred people	WB
	Innovation output effectiveness sub-index	SCI, SSCI, and A&HCI paper citations per million researchers	WB and WOS
		SCI, SSCI, and A&HCI paper citations per million R&D expenditure	WB and WOS
		Patent grants (resident) per million researchers	WB and WIPO
		Patent grants (resident) per million R&D expenditure	WB and WIPO
		PCT patent applications per million researchers	WB and WIPO
		PCT patent applications per million R&D expenditure	WB and WIPO
	Innovation outcome effectiveness sub-index	The ratio of receipts to payments of charges for the use of intellectual property	WB
		GDP per unit of energy use	WB
		The export of high-tech products as a percentage of manufactured exports	WB

Note: WB is World Bank (data are from World Development Indicators); WOS is Web of Science (data are from InCites database); WIPO is World Intellectual Property Organization (data are from Intellectual Property Statistics).

2.2. Sample selection and data collection

This study aims to monitor the progress in innovation capacity-building so as to analyze the relationship between the innovation capacity and the economic performance of a country. There are two basic assumptions for selecting sample countries. Firstly, it is assumed that the innovation capacity of developed countries is stronger than that of developing countries if there is no difference in economic size between developed and developing countries. Secondly, it is assumed that the developing countries with bigger economic size confront more challenges than the developing countries with smaller economic size in innovation capacity-building. Therefore, it is necessary to select major developed countries and developing countries with great potential. This study selects 40 countries as the samples with the consideration of cross-country comparability and data availability, including major members of OECD, G20 countries, and BRICS countries. The combined GDP of these 40 countries accounted for more than 85% of the world total in 2015.

The data of this study are from the World Bank, the Web of Science, and the World Intellectual Property Organization. Specifically, the patent data come from the Intellectual Property Statistics, the publication data from InCites database and other basic data from the World Development Indicators. For the missing data, we use a 2-year averages to estimate the value in the intermediate missing year. In addition, for the missing data at the beginning or the end year of the time series, the data in the next five years or previous five years are used to estimate the missing year by trend extrapolation. Besides, some data of indicators such as patent grants (resident) per million researchers and PCT patent applications per million researchers can be obtained by simple calculation of the original basic data.

2.3. Normalization

In order to make the indicators of different measurement units comparable, the measured values of 23 basic indicators in the 40 countries are normalized with reference to the estimated values in 2020. The reason for choosing 2020 as the benchmarking year is that it is the milestone year for China's innovation development, namely: to become an innovation-driven country by 2020. This study uses linear dimensionless normalization and all the indicators are normalized into the range of [0, 100].

Z_{ijt} ($i=1,2, \dots, 40; j=1, 2, \dots, 23; t \in [2006, 2015]$) is the value of country i of indicator j in year t .

$\max Z_{ijt}$ ($i=1,2, \dots, 40; t \in [2006, 2020]$) is the maximum value of indicator j in 2006–2020 among 40 countries. The data of 2016–2020 is estimated by trend extrapolation of the previous observation data.

$\min Z_{ijt}$ ($i=1,2, \dots, 40; t \in [2006, 2020]$) is the minimum value of indicator j in 2006–2020 among 40 countries

\bar{Z}_{ijt} ($i=1,2, \dots, 40; j=1, 2, \dots, 23; t \in [2006, 2015]$) is the normalized value of country i of indicator j in year t . The normalized value of each indicator follows equation (1):

$$\bar{Z}_{ijt} = \frac{Z_{ijt} - \min Z_{ijt}}{\max Z_{ijt} - \min Z_{ijt}} \times 100 \quad (1)$$

2.4. Weight selection and index calculation

The indicator weight refers to the relative contribution of each indicator to NIC. In this study, the weight of each indicator was assigned based on expert judgment. In order to obtain the rational weight, this study allows experts with rich experience and better understanding of NIC to assign weight for each indicator and sub-index. The average weight is calculated as the weight of each sub-index and indicator.

The expert judgment is an experience-based method which gives a set of weights reflecting the expert's understanding on the indicator and the system of indicators as well as the policy orientation.

The scores of each sub-index can be calculated with the normalization data and their specific weights. Then, the scores of the NISI and the NIEI are calculated, and finally the score of the NICI is calculated based on the NISI and the NIEI scores.

w_j ($j=1, 2, \dots, 23$) is the weight of indicator j .

y_{ikt} ($i=1, 2, \dots, 40$; $k=1, 2, 3, \dots, 8$; $t \in [2006, 2015]$) is the score of sub-index k of country i in year t . Using equation (2), we obtain the score of each sub-index.

$$y_{ikt} = \sum w_j \bar{Z}_{ijkt} \quad (2)$$

W_k ($k=1, 2, 3, \dots, 8$) is the weight of sub-index k . For the sub-indexes of the NISI, $k=1, 2, 3, 4$; for the sub-indexes of the NIEI, $k=5, 6, 7, 8$. $W_1+W_2+W_3+W_4=W_5+W_6+W_7+W_8=1$.

Y_{it}^1 ($i=1, 2, \dots, 40$; $t \in [2006, 2015]$) is the score of the NISI of country i in year t .

Y_{it}^2 ($i=1, 2, \dots, 40$; $t \in [2006, 2015]$) is the score of the NIEI of country i in year t .

Using equation (3) and equation (4), we obtain the score of the NISI and the NIEI of country i in year t .

$$Y_{it}^1 = \sum W_k y_{ikt} \quad (k=1, 2, 3, 4) \quad (3)$$

$$Y_{it}^2 = \sum W_k y_{ikt} \quad (k=5, 6, 7, 8) \quad (4)$$

β_1 is the weight of the NISI, β_2 is the weight of the NIEI, $\beta_1+\beta_2=1$.

X_{it} ($i=1, 2, \dots, 40$; $t \in [2006, 2015]$) is the score of the NICI of country i in year t .

Using equation (5), we obtain the score of the NICI of country i in year t

$$X_{it} = \beta_1 Y_{it}^1 + \beta_2 Y_{it}^2 \quad (5)$$

3. Measurement Result Analysis

3.1. Cross-country comparison of the NICI

Developed countries usually perform better than developing countries in terms of the NICI scores, China is the only one developing country among the top 20 countries in the NICI ranking. The United States, Japan, South Korea, Germany, Denmark and the United Kingdom are generally stable among the top 10 in the NICI ranking during 2006 to 2015. In 2015, the United States was the super champion among the 40 countries in terms of the NICI score, while Japan, Switzerland and South Korea ranked the 2nd to 4th in terms of the NICI score respectively. Germany, Ireland, Sweden, Denmark, the Netherlands, and the United Kingdom ranked the 5th to the 10th in terms of the NICI score. China took the 25th place in 2006 and the 13th place in terms of the NICI score in 2015, and became the country with the fastest growth in the NICI score and the country with the largest improvement in the NICI ranking. Other BRICS countries such as Russia, South Africa, Brazil, and India have slightly changed their NICI ranking from 2006 to 2015, and ranked the 30th, the 36th, the 37th, and the 39th respectively in 2015. As shown in Fig. 3.

The NISI ranking of the developed countries with bigger economic size such as the United States, Japan and Germany is usually higher than that of the developed countries with smaller economic size. Switzerland is the exception among the top 10 countries in the NISI ranking. The NIEI ranking of the developed countries with smaller economic size such as the Switzerland, Ireland and Sweden is usually higher than that of the developed countries with bigger economic size. Japan and South

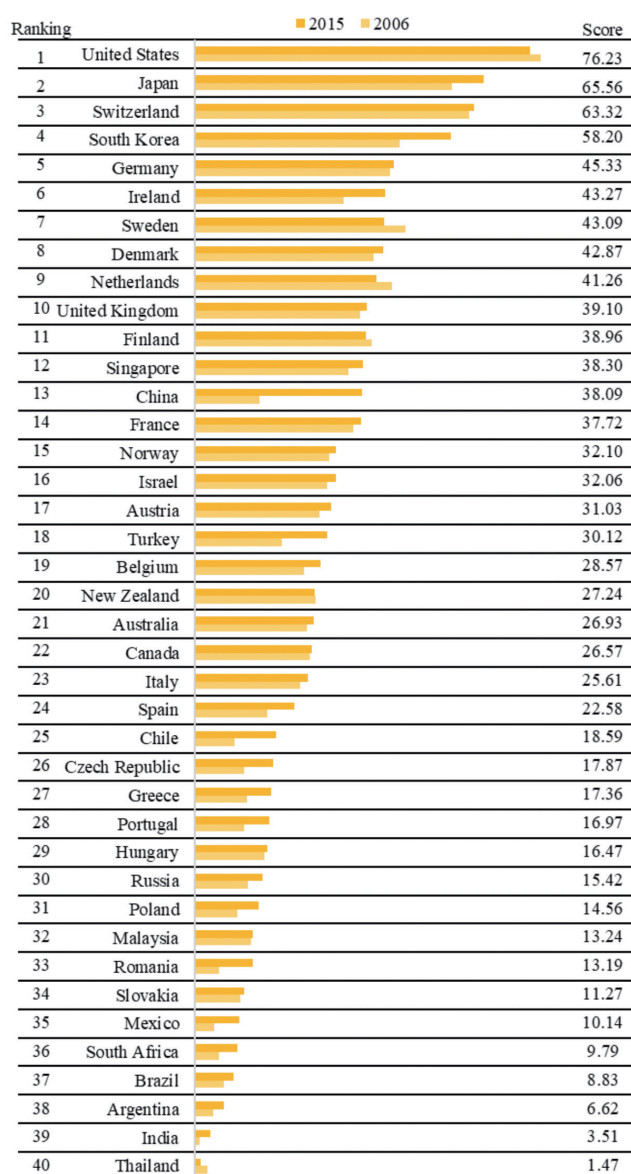


Fig. 3 Ranking of national innovation capacity index

Korea are the two exceptions among the top 10 countries in the NIEI ranking. Japan shows a very good balance between the ranking of the NISI and the NIEI, both ranked the 3rd place in 2015. Some developed countries such as Switzerland, Ireland, Denmark, Finland, the United States and Germany show great imbalance between the NISI and the NIEI. For example, Switzerland ranked the 1st in the NIEI and the 10th in the NISI among the 40 countries in 2015, while the United States took the 1st place in the NISI and the 10th in the NIEI. The NISI ranking of big developing countries in terms of economic size such as Brazil, Russian, Indian and China is usually higher than that of small developing countries. Besides, big developing countries may show greater imbalance between the innovation strength and the innovation effectiveness than small countries. For example, China is a typical country with high innovation strength index and low innovation effectiveness index, and took

Table 2 Rankings and scores of the NICI, the NISI and the NIEI in 2006 and 2015

Country	NICI				NISI				NIEI			
	2006		2015		2006		2015		2006		2015	
	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking
United States	78.47	1	76.23	1	52.80	1	72.27	1	30.21	8	32.49	10
Japan	58.42	3	65.56	2	24.36	2	33.05	3	31.2	5	39.78	3
Switzerland	62.26	2	63.32	3	3.07	12	6.17	10	44.15	1	48.13	1
South Korea	46.59	5	58.20	4	7.24	7	15.04	5	31.96	3	41.52	2
Germany	44.44	7	45.33	5	11.74	4	16.43	4	28.36	9	32.54	9
Ireland	33.86	13	43.27	6	0.85	26	2.42	20	26.85	11	36.30	5
Sweden	47.95	4	43.09	7	2.64	13	3.97	14	35.09	2	35.62	6
Denmark	40.63	8	42.87	8	1.02	22	1.68	23	31.15	6	36.30	4
Netherlands	44.69	6	41.26	9	6.24	8	10.46	8	31.22	4	32.04	11
United Kingdom	37.61	10	39.1	10	9.68	5	12.28	6	24.95	12	29.95	12
Finland	40.22	9	38.96	11	1.29	20	1.49	26	30.76	7	33.81	7
Singapore	35.02	12	38.3	12	1.63	18	3.02	19	27.22	10	32.81	8
China	14.86	25	38.09	13	13.56	3	43.06	2	8.31	36	18.05	29
France	35.96	11	37.72	14	8.04	6	11.74	7	24.69	14	29.25	14
Norway	30.54	14	32.10	15	0.53	29	0.87	30	24.86	13	29.52	13
Israel	30.20	15	32.06	16	1.01	23	1.56	24	24.41	15	29.24	15
Austria	28.32	16	31.03	17	0.91	25	1.47	27	23.24	16	28.59	16
Turkey	19.70	22	30.12	18	1.39	19	3.22	18	17.42	22	27.35	17
Belgium	24.85	20	28.57	19	1.21	21	2.23	21	20.84	19	26.70	18
New Zealand	27.57	17	27.24	20	0.31	37	0.55	37	23.05	17	26.44	19
Australia	25.59	19	26.93	21	1.99	15	3.32	16	20.94	18	25.22	20
Canada	26.17	18	26.57	22	3.72	10	5.18	12	20.46	20	24.30	21
Italy	24.01	21	25.61	23	3.42	11	4.63	13	19.21	21	23.87	22
Spain	16.44	23	22.58	24	1.99	14	3.31	17	15.01	24	22.36	23
Chile	9.12	33	18.59	25	0.10	39	0.31	39	11.21	31	20.83	24
Czech Republic	11.20	30	17.87	26	0.38	33	0.84	32	12.42	28	20.16	25
Greece	11.89	28	17.36	27	0.32	35	0.59	36	12.89	26	19.92	26
Portugal	11.26	29	16.97	28	0.36	34	0.66	35	12.46	27	19.64	27
Hungary	15.80	24	16.47	29	0.44	31	0.84	33	15.36	23	19.24	28
Russia	12.09	27	15.42	30	4.15	9	5.66	11	11.14	32	16.79	33
Poland	9.73	32	14.56	31	0.73	28	1.55	25	11.29	30	17.72	30
Malaysia	12.75	26	13.24	32	0.84	27	1.35	28	13.19	25	16.93	32
Romania	5.57	36	13.19	33	0.17	38	0.44	38	8.87	33	17.23	31
Slovakia	10.41	31	11.27	34	0.09	40	0.19	40	12.04	29	16.05	34
Mexico	4.52	37	10.14	35	1.01	24	2.06	22	7.78	38	14.63	36
South Africa	5.65	35	9.79	36	0.39	32	0.86	31	8.82	34	14.84	35
Brazil	6.54	34	8.83	37	1.69	17	3.47	15	8.75	35	13.25	37
Argentina	4.13	38	6.62	38	0.31	36	0.82	34	7.87	37	12.76	38
India	1.24	40	3.51	39	1.72	16	6.52	9	5.30	40	8.64	40
Thailand	2.86	39	1.47	40	0.47	30	1.12	29	6.97	39	9.27	39

Note: The countries in the table are ranked by the NICI in 2015

the 2nd place in the NISI and the 29th in the NIEI in 2015, which shows that there is a huge gap between China's rankings in the NISI and the NIEI. Among other BRICS countries, due to the economic and population scale advantages, Brazil, India and Russia ranked among the top 15 in the NISI in 2015, but their rankings in the NIEI are all below 30. South Africa performs relatively poorly both in innovation strength and innovation effectiveness. As shown in Table 2.

3.2. Cross-country comparison of the NISI

The ranking of the NISI score shows a structure characterized by the combination of one superpower with several strong countries. In 2015, the United States was the super champion among the 40 countries in terms of the NISI score, while China and Japan ranked the 2nd with score 43.06 and the 3rd with score 33.05 in terms of the NISI score respectively, their scores are significantly lower than that of the United States (72.27). Germany, South Korea, the United Kingdom, France, the Netherlands,

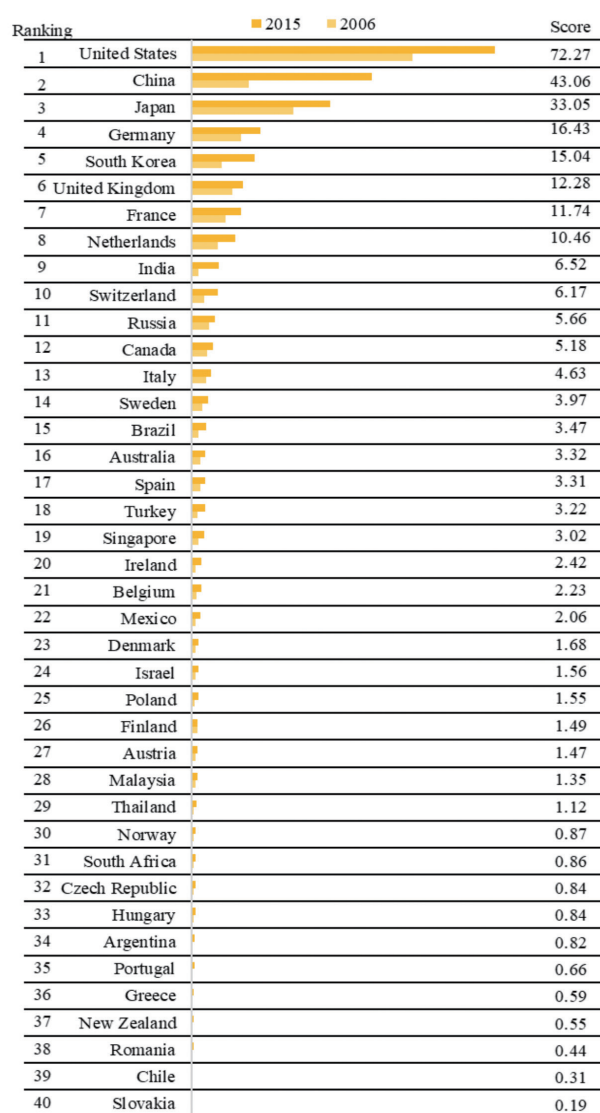


Fig. 4 Ranking of national innovation strength index

India and Switzerland ranked from the 4th to the 10th in terms of the NISI score, but their scores were all below 20. Countries with bigger economic and population size usually perform better than developed countries with smaller economic and population size in terms of the NISI scores. China, India, Russia and Brazil ranked the 2nd, the 9th, the 11th and the 15th in terms of the NISI score due to their comparative advantages in population and economic scale. Among the top 10 countries in terms of the NISI score, 8 countries are developed countries, and 7 countries are among the top 10 countries in terms of GDP size, which implies that both the economic size and economic development level have significant impacts on the NISI. It is worthwhile to point out that there is a huge gap between the United States and China in terms of the NISI score. As shown in Fig. 4.

The average annual growth rate of the NISI score in developing countries is generally higher than that of developed countries. The top 10 countries in terms of the average annual growth rate of the NISI during 2006-2015 were India, China, Chile, Ireland, Argentina, Romania, Thailand, Turkey, Czech Republic, and South Africa. Among them, India is the fastest growing country with a growth rate of 15.95%. China ranks the 2nd with an average annual growth rate of 13.96%. Other countries with an average annual growth rate of more than 10% include Chile (13.34%), Ireland (12.32%), Argentina (11.26%), Romania (11.09%) and Thailand (10.09%). Most of developed countries have a relatively low average annual growth rate of the NISI. For example, the average annual growth rate of both the United States and Japan during the decade is 3.55% and 3.45% respectively. As shown in Fig. 5.

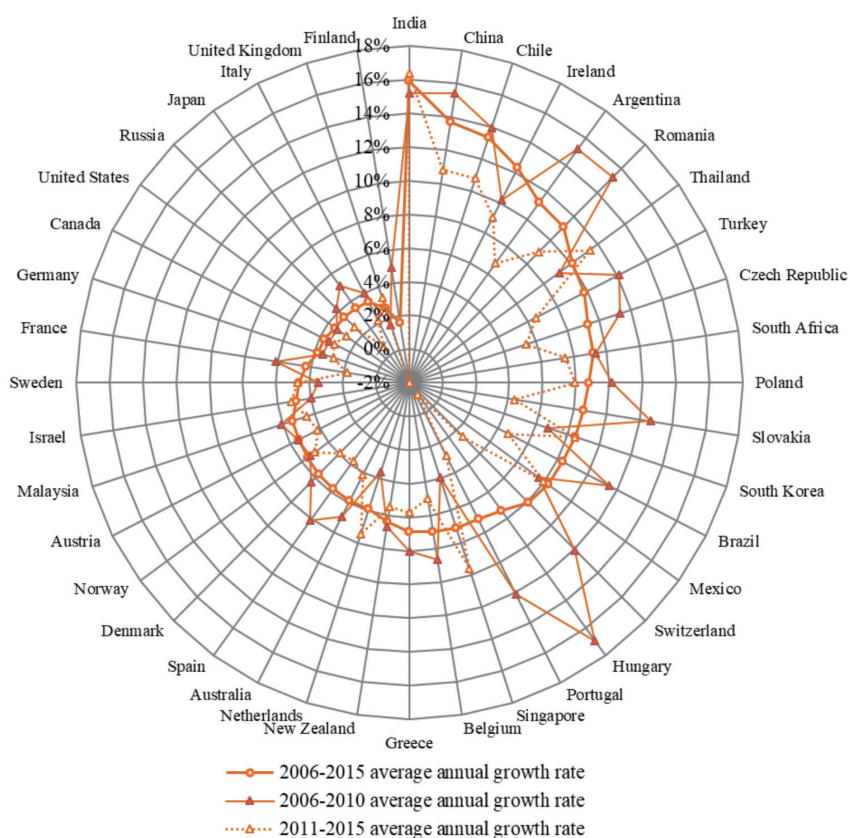


Fig. 5 Average annual growth rate of national innovation strength index

Note: The countries in the figure are sorted clockwise by the value of average annual growth rate of 2006-2015

In order to identify the detailed advantages and disadvantages of the NISI among leading developed countries and influential developing countries with great potential, this study selects two groups of countries and compares their performance in the sub-indexes of the NISI. Group one countries, regarded as leading developed countries, consists of the United States, Japan, Germany, South Korea and the United Kingdom. Group two countries, regarded as influential developing countries with great potential, consists of five BRICS countries, namely: Brazil, Russian, Indian, China and South Africa. Countries in Group one influence the structure of global innovation capacity and competitiveness, while countries in Group two, to a large extent, shape the direction of restructuring global innovation capacity and competitiveness.

Compared with the average of the 40 countries, the five countries in the first group have outstanding advantages in four sub-indexes of the NISI. However, there exists a huge gap among these five countries. The United States shows its super-advantages in all four sub-indexes compared with other four countries, and determines the maximum value of three sub-indexes of the NISI, including the innovation input strength sub-index, the innovation output strength sub-index and the innovation outcome strength sub-index. Japan performs significantly better than Germany, the United Kingdom and South Korea in all four sub-indexes, as shown in Fig. 6.

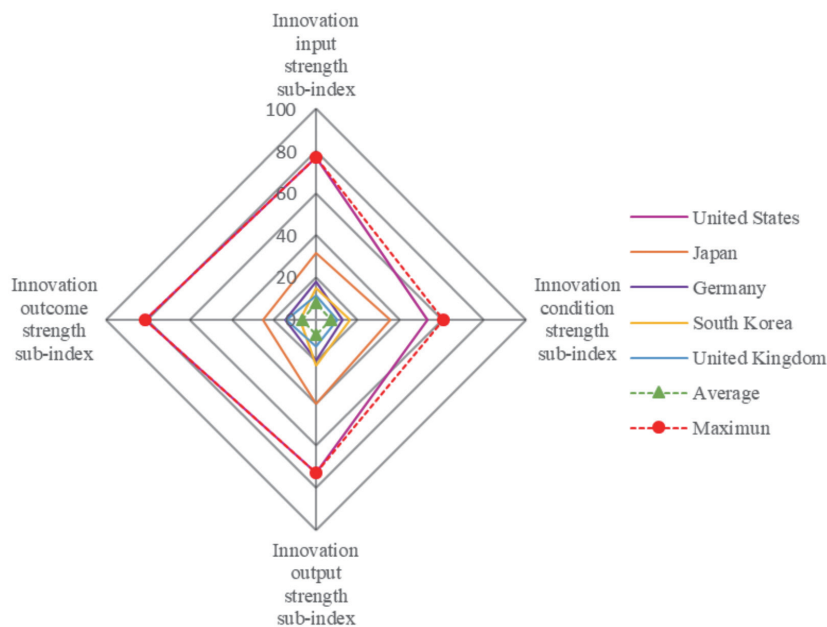


Fig. 6 The sub-index comparison of the NISI of developed countries in 2015

The BRICS countries perform relatively well in the innovation input sub-index and the innovation condition sub-index rather than the innovation output sub-index and the innovation outcome sub-index. China determines the maximum value of the innovation condition strength sub-index of the 40 countries due to its large scale of the internet users. Compared with the other four BRICS countries, China has a great advantage in all four sub-indexes, but still has a huge gap compared with the United States, which mainly reflected in the innovation output strength and the innovation outcome strength.

India, Russia and Brazil also perform relatively well in the innovation input sub-index and the innovation condition sub-index. However, the BRICS countries, except for China, all have significantly lower score in the innovation output strength sub-index and the innovation outcome strength sub-index than that of the average of the 40 countries, as shown in Fig. 7.

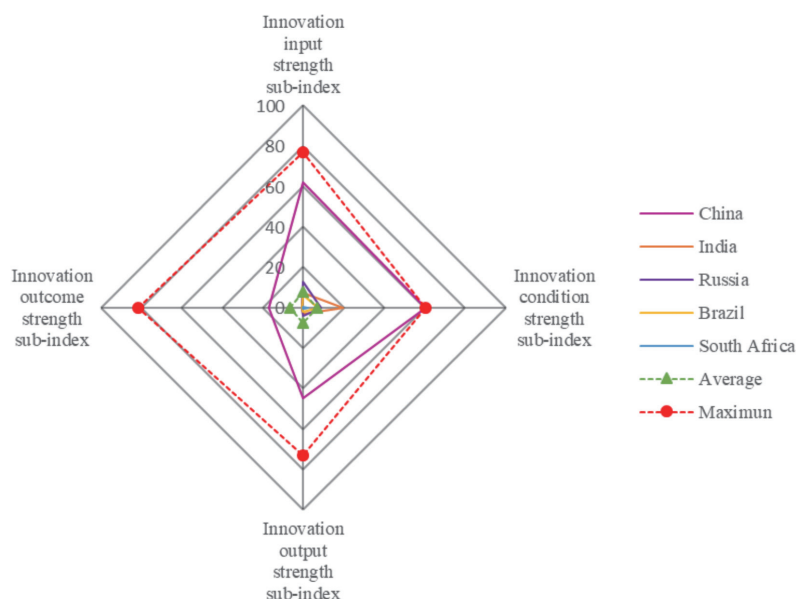


Fig. 7 The sub-index comparison of the NISI of BRICS countries in 2015

3.3. Cross-country comparison of the NIEI

The developed countries with smaller population and economic scale such as Switzerland and Denmark perform better than countries with bigger population and economic size in the NIEI, as shown in Fig. 8. Switzerland, South Korea, Japan, Denmark, Ireland, Sweden, Finland, Singapore, Germany, and the United States ranked among the top 10 in the NIEI ranking in 2015, and with relatively stable NIEI scores during 2006-2015. Among them, 6 countries are small developed countries. In the contrast, the NIEI scores of developing countries are generally very low. For example, the NIEI ranking of China has been rising from the 36th in 2006 to the 29th in 2015, but still far behind the developed countries such as South Korea, Japan and the United States. Other BRICS countries, Russia, South Africa, Brazil and India ranked the 33rd, the 35th, the 37th and the 40th respectively in 2015.

The average annual growth rate of the NIEI in emerging countries is generally higher than that of developed countries as shown in Fig. 9. China, Romania, Mexico, Chile, South Africa, India, Czech Republic, Argentina, Portugal and Turkey ranked among the top 10 in the average annual growth rate of the NIEI during 2006-2015. For example, China's average annual growth rate is 9.01%, much higher than that of the United States (0.81%) and Germany (1.54%).

In order to have a further comparison of the performance in the sub-indexes of the NIEI among countries, we choose three typical groups of countries to compare with the average and the maximum values of the 40 countries in 2015. The first group country, regarded as developed countries with smaller economic scale, consists of Switzerland, Denmark, Ireland, Sweden and Finland, all of them perform excellently in the NIEI. The second group country, regarded as developed countries with

bigger economic scale, consists of South Korea, Japan, Germany, the United States and the United Kingdom, all of them perform well in the NIEI. The third group consists of five BRICS countries, all of them are developing countries with great potential and represent the catching-up emerging

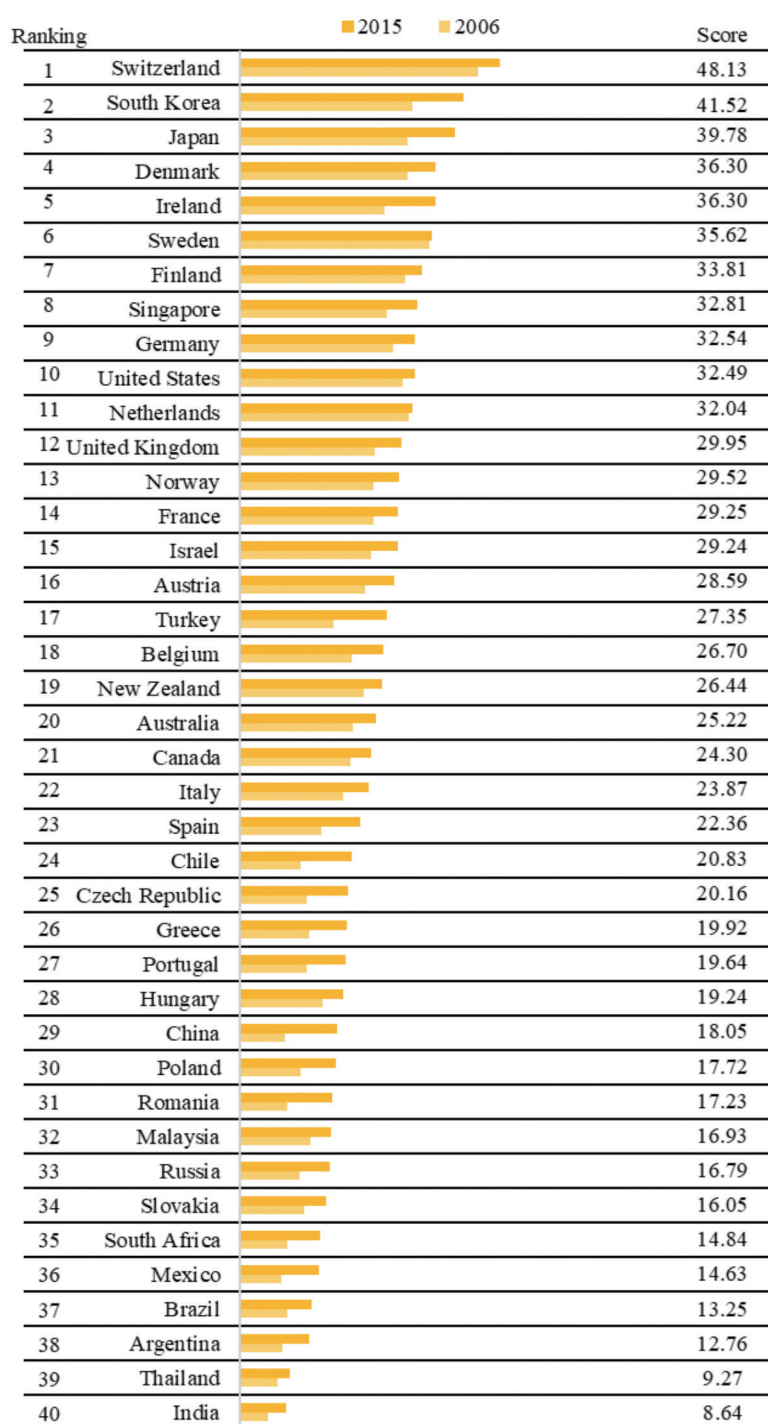


Fig. 8 Ranking of national innovation effectiveness index

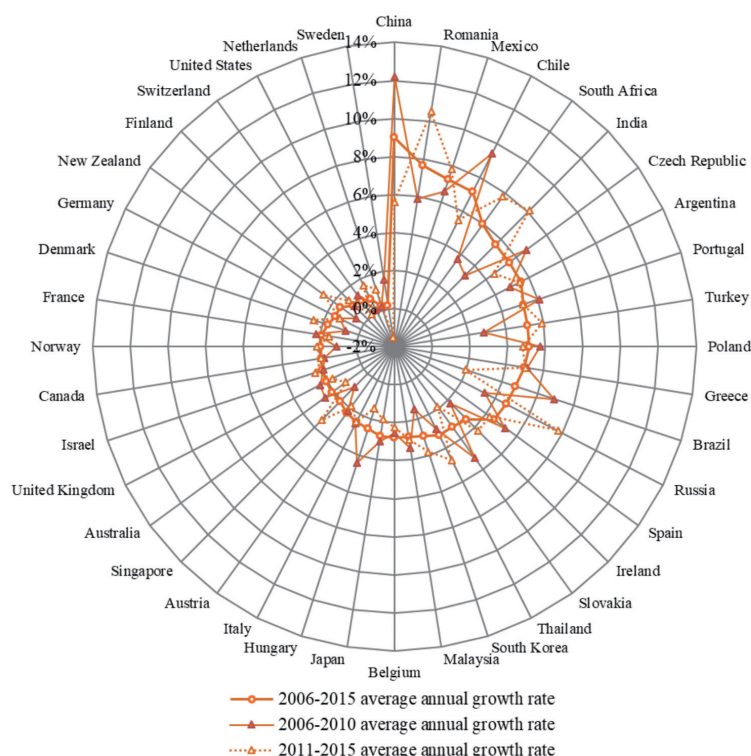


Fig. 9 Average annual growth rate of national innovation effectiveness index

Note: The countries in the figure are sorted clockwise by the value of average annual growth rate of 2006-2015

economics.

The first group countries show outstanding performance in various sub-indexes of the NIEI in contrast to the average among the 40 countries. Switzerland, which ranked the 1st in the NIEI, determines the maximum value of the innovation input effectiveness sub-index and the innovation output effectiveness sub-index, while Ireland determines the maximum value of the innovation condition effectiveness sub-index, as shown in Fig. 10. It is necessary to discuss in detail that Turkey determines the maximum value of the innovation outcome effectiveness sub-index in 2015. The indicator “charges for the use of intellectual property (receipts)” to a large extent results in the unexpected maximum value because the charges for the use of intellectual property (receipts) of Turkey was overestimated based on the value of the average of other 39 countries, which may result in an extremely high ratio of receipts to payments of charges for the use of intellectual property in 2015. In practice, the charges for the use of intellectual property (payments) of Turkey was only 682 million US\$ in 2015, which ranked the 36th in 40 countries.

The second group countries also achieve good results in the score of various sub-indexes of the NIEI. Most sub-indexes of the second group countries show better performance than that of the average of the 40 countries, except for the innovation outcome effectiveness sub-index of South Korea. However, South Korea gets higher scores than the other four countries in terms of the innovation input effectiveness sub-index, the innovation condition effectiveness sub-index and the innovation output effectiveness sub-index, as shown in Fig. 11. The main reason for this unexpected result is

that the GDP per unit of energy use of South Korea is extremely low, which ranked 36th among the 40 countries. Therefore, the innovation outcome effectiveness, especially the environment innovation development should become the key policy issue for South Korea to strength national innovation

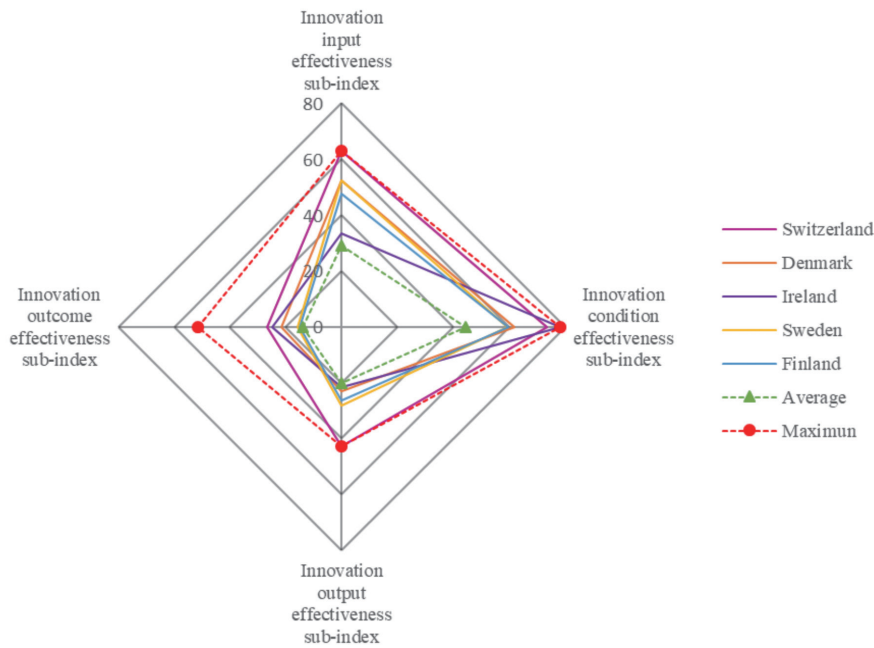


Fig. 10 The sub-index comparison of the NIEI of small-size developed countries in 2015

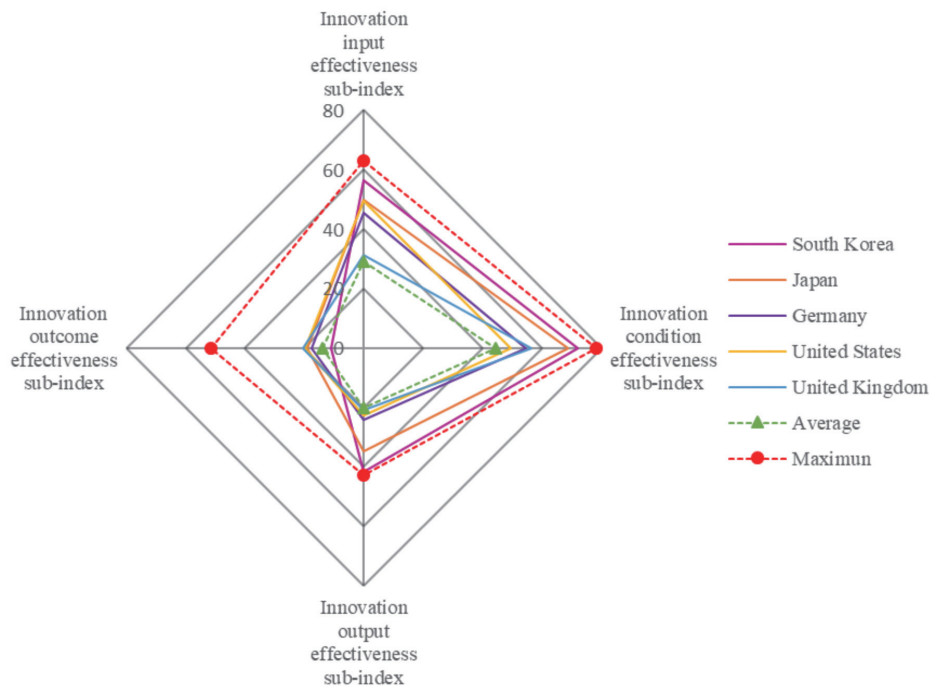


Fig. 11 The sub-index comparison of the NIEI of large-size developed countries in 2015

effectiveness so as to improve overall performance of the NIC.

Contrast with their performance in the NICI, the BRICS countries perform relatively poorly in the NIEI. Except for the innovation output effectiveness sub-index of South Africa, the value of four sub-indexes of BRICS countries are all lower than the average of 40 countries, as shown in Fig. 12, which indicates there is a huge gap between developed countries and the BRICS countries. It is worthwhile to point out that most of the BRICS countries have one or two sub-indexes showing weakness. For example, Brazil ranked the 27th in both the innovation input effectiveness sub-index and the innovation outcome effectiveness sub-index among the 40 countries in 2015, but the 40th in the innovation output effectiveness sub-index, which greatly restricts the promotion of Brazil's ranking in the NIEI.

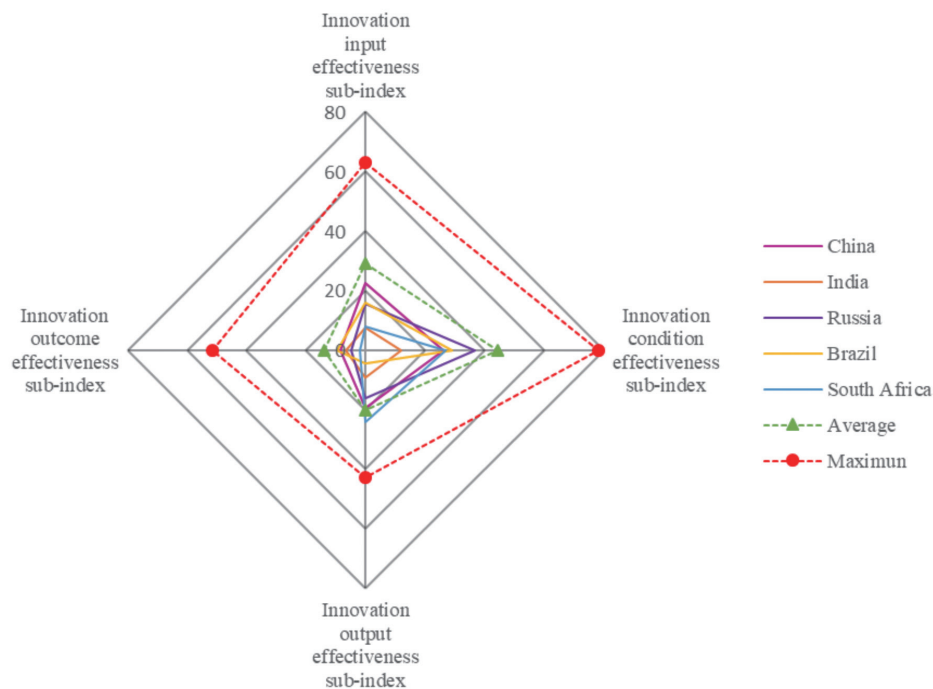


Fig. 12 The sub-index comparison of the NIEI of BRICS countries in 2015

3.4. Structure analysis of the NIC

Based on the ranking of the NISI and the NIEI, the 40 countries can be classified into four groups by using K-means clustering method. The first group, regarded as NIC leading country, consists of the countries with high ranking both in the NISI and the NIEI, including the United States, Japan, Switzerland, South Korea, Germany, Sweden, the Netherlands, the United Kingdom and France. The second group, regarded as NIC advanced country, consists of the countries with relatively higher ranking in the NISI and the NIEI, including Ireland, Denmark, Finland, Singapore, Norway, Israel, Austria, Turkey, Belgium, Australia, Canada, Italy and Spain. The third group, regarded as NIC unbalanced catching-up country, consists of the countries with relatively higher NISI ranking but lower NIEI ranking, including China, Russia, Mexico, Brazil and India. The fourth group, regarded as NIC catching-up country, consists of the countries with low ranking both in the NISI and the

NIEI, including New Zealand, Chile, Czech Republic, Greece, Portugal, Hungary, Poland, Malaysia, Romania, Slovakia, South Africa, Argentina, Thailand, as shown in Fig. 14. Both NIC leading country and NIC advanced country are all developed countries, while NIC unbalanced catching-up country consists of emerging countries with great potential. The structure of national innovation capacity is relatively stable during 2006-2015.

By introducing the auxiliary variables such as GDP and GDP per capita, the cross-country comparison shows that countries with bigger economic scale, as measured by GDP, usually have a correspondingly higher ranking of the NISI as shown in Fig. 13, while developed countries with higher economic development level, as measured by GDP per capita, usually have a corresponding higher ranking of the NIEI as shown in Fig. 14. Among the 40 countries, seven of the top 10 countries in GDP also ranked the top 10 in the NISI, i.e., the United States, China, Japan, Germany, the United Kingdom, France and India. However, South Korea, the Netherlands and Switzerland ranked higher in the NISI than their ranking in GDP, which means these three countries attach great importance to the expansion of the scale of innovation activities. Six of the top 10 countries in GDP per capita also ranked the top ten in the NIEI, i.e., Switzerland, Denmark, Ireland, Sweden, Singapore, and the United States. Japan, South Korea, Finland and Germany ranked higher in the NIEI than their ranking in GDP per capita, which means these four countries perform well in efficiency and efficacy of innovation activities.

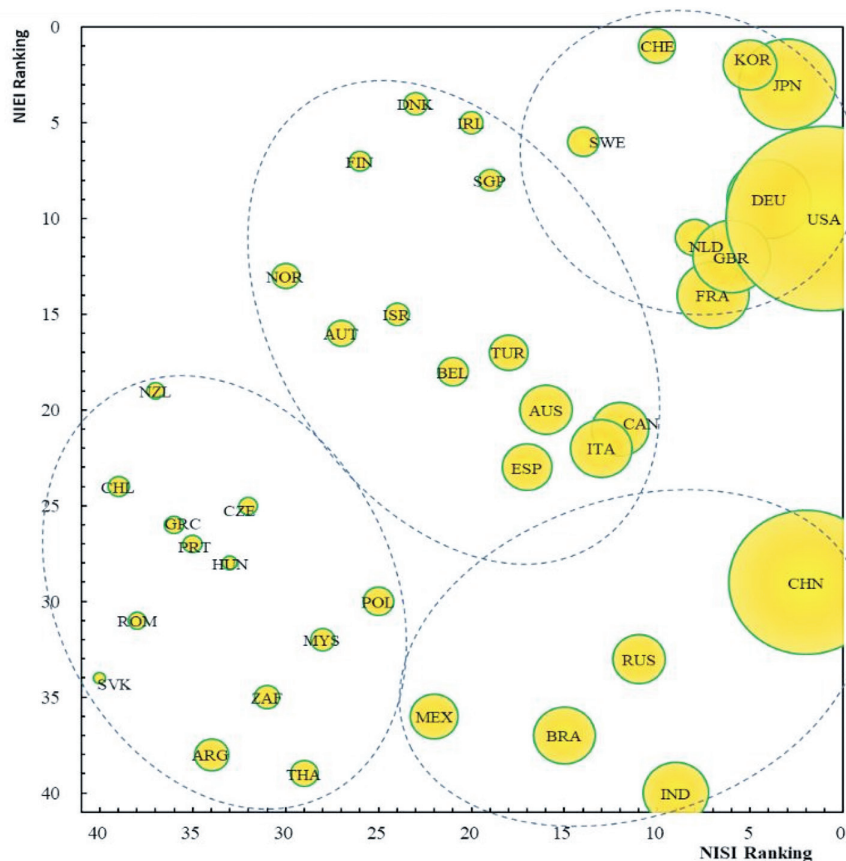


Fig. 13 Economic size and the structure of innovation capacity in 2015

Note: The bubble area presents the size of GDP (2015 current price)

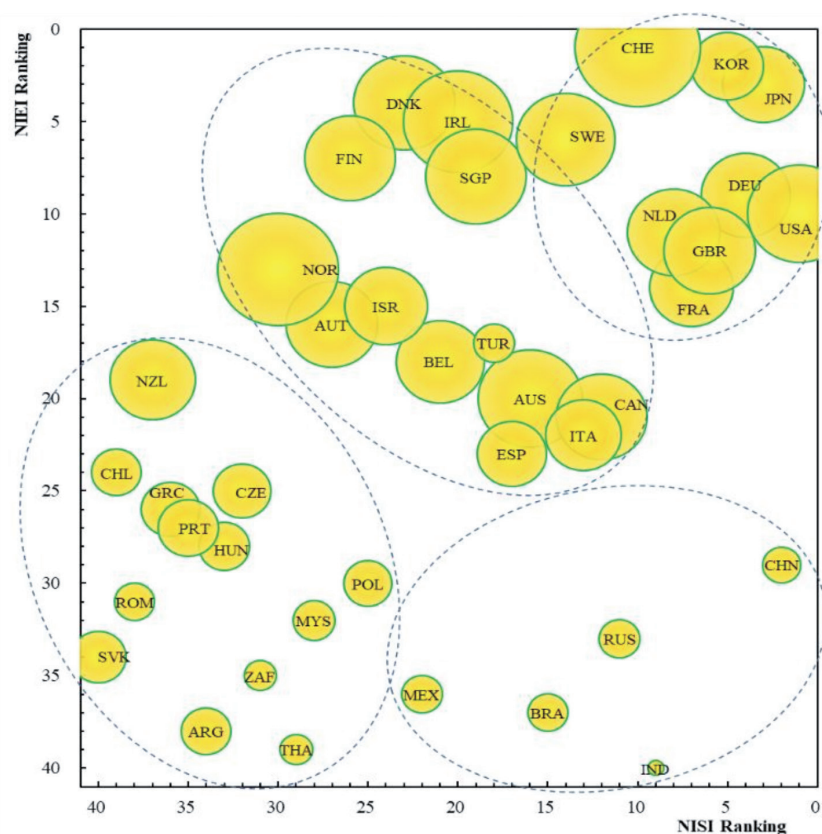


Fig. 14 Economic development level and the structure of innovation capacity in 2015

Note: The bubble area presents the size of GDP per capita (2015 current price)

4. Major Conclusions and Policy Implications

4.1. Major conclusions

Previous studies have tried to measure national innovation activities or national innovation capacity by developing a multi-dimensional indicator system with a comprehensive set of indicators related to innovation for innovation capacity. Most of them have to face the difficulties in identifying and explaining the impact of the scale and the effectiveness of a country's innovation activities on the NIC. This study has developed a new methodology for measuring national innovation capacity by redefining the terms related to the innovation and the innovation development, and exploring the new perspectives to understand the national innovation capacity. The major conclusions are as follows.

Firstly, this study develops a NICI from the perspectives of the innovation capacity-building process, the innovation capacity structure, and our understanding on the terms such as the "innovation" and the "innovation development". The NICI and related sub-indexes can be used to monitor the evolution of the national innovation capacity and the global innovation capacity structure, which could provide evidences for analyzing national innovation-driven development strategy and policy related to the innovation resources allocation, the science and technology infrastructure

construction.

Secondly, the cross-country comparison shows that developed countries usually perform better than developing countries in terms of the NICI scores if there is no huge gap in the economic scale between two kinds of countries. The United States, Japan, South Korea, Germany, Denmark and the United Kingdom are generally stable in their top-10 positions in the NICI ranking during 2006 to 2015. The United States was the super champion among the 40 countries in terms of the NICI score, while Japan, Switzerland and South Korea ranked from the 2nd to the 4th in terms of the NICI score respectively. China is the only one developing country among the top 20 countries in the NICI ranking and the fastest growth in the NICI score because of its advantages in the size of innovation activity.

Thirdly, the cross-country comparison shows that the ranking of the NISI score shows the structure with one superpower and several strong countries, and countries with bigger economic size usually perform better than developed countries with smaller economic size in the NISI scores, developed countries with smaller economic scales usually perform better than those with bigger economic size in the NIEI score. In 2015, the United States was the super champion among the 40 countries in terms of the NISI score, while China and Japan took the 2nd place and the 3rd place in the NICI score respectively. Among the top 10 countries in terms of the NISI score, 7 countries are among the top 10 in GDP. Among the top 10 countries in the NIEI ranking, 6 are small developed countries.

Fourthly, the cross-country comparison shows that the average annual growth rate of both the NISI score and the NIEI score in emerging countries are generally higher than that of developed countries. Among the top 10 (India, China, Chile, Ireland, Argentina, Romania, Thailand, Turkey, Czech Republic, and South Africa) in the average annual growth rate of the NISI during 2006-2015, Ireland is the only one developed country among the top 20 countries in the NISI ranking in 2015. Among the top 10 countries (China, Romania, Mexico, Chile, South Africa, India, Czech Republic, Argentina, Portugal and Turkey) in the average annual growth rate of the NIEI during 2006-2015, China's average annual growth rate is 9.01%, much higher than that of the United States (0.81%) and Germany (1.54%).

Fifthly, this study has classified the 40 countries into four groups according to their performance in the NISI and the NIEI, namely: NIC leading country with excellent performance in two sub-indexes, NIC advanced country with good performance in two sub-indexes, NIC unbalanced catching-up country with huge gap between two indexes, and NIC catching-up country with poor performance in two indexes. NIC leading country consists of the United States, Japan, Switzerland, South Korea, Germany, Sweden, the Netherlands, the United Kingdom and France. NIC advanced country consists of Ireland, Denmark, Finland, Singapore, Norway, Israel, Austria, Turkey, Belgium, Australia, Canada, Italy and Spain. NIC unbalanced catching-up country consists of China, Russia, Mexico, Brazil and India. NIC catching-up country consists of New Zealand, Chile, Czech Republic, Greece, Portugal, Hungary, Poland, Malaysia, Romania, Slovakia, South Africa, Argentina and Thailand.

4.2. Policy implications

The NIC measurement and related cross-country comparison could provide very useful and necessary evidences for policymaking and innovation development policy analysis. On the basis of major conclusion above, there are five policy implications as follows:

Firstly, the cross-country comparison shows that developed countries usually perform better than

developing countries in terms of the NICI scores, which implies that there is a significant positive correlation between the NIC and national economic development level. Therefore, innovation capacity-building should be taken as the core policy issue in the process of innovation development policy by developing countries. In practice, China has effectively implemented a series of innovation develop policies such as the Five Year Plan for National Innovation Capacity-building, the Medium and Long Term Plan for National Major Science and Technology Infrastructure Construction, and etc. since 2006, and become the country with the fastest growth in the NICI score, the largest improvement in the NICI ranking from the 25th place in 2006 to the 13th place in 2015, and the only one developing country among the top 20 in the NICI ranking.

Secondly, the cross-country comparison shows that the NIC leading country with excellent performance in the NISI and the NIEI consists of developed countries such as the United States, Japan, Switzerland, South Korea, Germany, Sweden, the Netherlands, the United Kingdom and France, which implies that both the NISI ranking and the NIEI ranking to a large extent indicate the level of the comprehensive economic and social development. Therefore, the NISI and the NIEI should be included in the development goals of catching-up countries so as to construct a well-balanced innovation-driven country, and be taken into the policymaking process of innovation capacity-building so as to choose effective policy measures by analyzing the advantages and the disadvantages according to the NISI and the NIEI as well as the specific indicators if necessary.

Thirdly, the cross-country comparison shows that the NIC unbalanced catching-up country consists of developing countries with great potential such as China, Russia, Mexico, Brazil and India, which implies that it is of great importance for these emerging countries to strengthen both national innovation strength and national innovation effectiveness and to promote the coordinated development of innovation strength and innovation effectiveness by setting the priority of policy measures and implementing a series of innovation development policies. For example, it is necessary for China to give the highest priority to national innovation effectiveness capacity-building in the policy agenda so as to support national development pattern shifting from quantitative growth model to qualitative development paradigm in general, and to realize the regional coordinated development in particular.

Fourthly, the cross-country comparison shows that the average annual growth rate of both the NISI score and the NIEI score in emerging countries are generally higher than that of developed countries, which implies that it is necessary for emerging countries to monitor the development trend and the progress in national innovation capacity-building according to the average annual growth rate of two sub-indexes, to keep the balance between the NISI and the NIEI by implementing innovation policy targeting to the NISI and the NIEI separately. For example, it is necessary for countries with great imbalance in innovation strength and innovation effectiveness to narrow the gap between the two sub-indexes by implementing special policies targeting the disadvantages in the NISI or the NIEI.

Fifthly, the cross-country comparison shows that the NIC unbalanced catching-up country usually performs relatively better in the innovation input and the innovation condition than in the innovation output and the innovation outcome, which implies that the innovation development policy in the NIC unbalanced catching-up country should focus on the transformation process from the innovation input and the innovation condition to the innovation output and the innovation outcome by integrating the policies related to the capacity-building for science & technology development, the industrial innovation capacity-building, the social innovation capacity-building and the environmental

innovation capacity-building, and by innovation cultural and environmental formation.

4.3. *Theoretical contributions and limitations*

This study has three theoretical contributions to innovation development studies in general and to measuring the NIC in particular.

Firstly, this study starts from our previous definition of the term “innovation” and “innovation development”. The term “innovation” emphasizes that innovation is a value creation process, including scientific and technological value, the economic and social value as well as the cultural value, which implies that innovation capacity consists of the capacity for scientific discovery and technology invention, the capacity to drive economic and social development. The term “innovation development” further emphasizes the driving effect and the influence of innovation on development, and concerns the efficiency, effectiveness, and efficacy of innovation-driven development activities, which enriched the academic understanding of the connotation of innovation development. Therefore, the measurement of innovation capacity should consider the force’s action on the object, namely the effect and influence of innovation on development. These definitions provide theoretical framework for designing the indicator system related to the NIC and the related sub-indexes.

Secondly, the NIC is defined from two perspectives such as the national innovation strength and the national innovation effectiveness. The former reflects the contribution of the size of innovation activities to the NIC, while the latter reflects the contribution of the efficiency and efficacy of innovation-driven development to the NIC. Therefore, this study can distinguish the impact of the innovation scale and the innovation efficiency on innovation capability, and explain that small countries such as Switzerland, Ireland, Sweden and Denmark usually rank higher in the NIEI than big countries such as the United States, China, Brazil and Indian, while big countries such as the United States, China, Japan and Germany usually rank higher in the NISI than small countries such as Switzerland, Ireland, Sweden and Denmark.

Thirdly, the NICI is designed from the perspective of the capacity building process ranging from innovation input to innovation output, namely: the innovation input capacity, the innovation condition capacity, the innovation output capacity and the innovation outcome capacity. In practice, both the innovation condition as innovation input in a broad sense and the innovation outcome as innovation output in a broad sense are often neglected in the measurement of national innovation capacity. The results that BRICS countries perform better in national innovation condition capacity than in national innovation outcome capacity imply that the three E (efficiency, effectiveness and efficacy) may be the core issues for innovation development policy in developing countries, especially the BRICS countries.

Restricted by the availability of data, there are some limitations in designing indicator system. For example, in addition to the Internet users and Patents in force, the innovation condition strength also reflected in the hardware facilities and institutional environment of a country, such as large S&T infrastructure and fair competitive environment. However, it is difficult to obtain the reliable and comparable data for indicators related to S&T infrastructure and fair competitive environment in the 40 countries. Therefore, it is necessary for the follow-up research to develop a more comprehensive indicator system of the NICI so as to measure national innovation capacity by combining statistical data and survey data.

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