Structure of National Science and Technology Competitiveness: A Methodological and Empirical Study

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Abstract

This paper clearly defines the concepts of the national competitiveness, the national S&T competitiveness, and the national S&T competitiveness structure. It develops an evaluation framework with three dimensions: the national S&T competitive potential, the national S&T competitive strength and the national S&T competitive effectiveness. This paper proposes a structure analysis method and depicts the national S&T competitiveness structure of 35 countries in an empirical research. Apart from the definitions and the structure analysis method, this paper mainly draws the following conclusions: (1) In the one-dimensional national S&T competitiveness structure, the top 5 countries were all developed countries in 2015, while the developing countries generally performed better than developed countries considering the average annual growth rate of the national S&T competitiveness index. The 35 countries are clustered into 4 categories using the two-dimensional structure analysis method. For example, based on the ranking of the national S&T competitive strength index and the national S&T competitive effectiveness index of the 35 countries in 2015, the 35 countries are clustered into four categories: high-strength and high-effectiveness, low-strength and high-effectiveness, low-strength and low-effectiveness, and high-strength and low-effectiveness. (2) To a large extent, there is a significant correlation between the national S&T competitiveness index score and the GDP per capita value. And to a certain extent, there is some correlation between the national S&T competitiveness index score and the GDP value. Moreover, under the background of strength and effectiveness combination, or under the background of strength and potential combination, the national S&T competitiveness structure and GDP or GDP per capita show significant relationship.

Keywords

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1. Background

At present, global science and technology (S&T) innovation has entered an unprecedented intensive and active period, and human society is experiencing a far-reaching and extensive S&T revolution and industrial change. The changes of the national competitiveness of major countries are promoting the structure reconstruction of the world competition, and the national S&T competitiveness has become a new decisive factor in the international competitiveness (Mu, 2000). Major countries in the world have been adjusting their strategies and policies, trying to seize the strategic opportunities brought by the new round of S&T revolution as well as industrial transformation, relying on S&T innovation to occupy the rare opportunity in the process of the structure reconstruction, so as to achieve the qualitative improvement of the national S&T competitiveness and effectively guarantee the sustainable national development (Vietor, 2007). In this context, it is necessary to conduct a systematic study on a comprehensive and objective characterization of the national S&T competitiveness structure, so as to expand the research consensus, and to guide the formulation of national development strategies.

First of all, a thorough depiction of the national S&T competitiveness structure depends on an understanding of the concept of the national S&T competitiveness. In academic communities, especially in the field of economy, business as well as policy research, competitiveness is a longstanding concern. The research on national competitiveness can be traced back to 1841, when List (1841) came up with the concept of "national productivity". It held that comprehensive national strength is composed of factors, such as the national S&T development level, citizen quality, political system, social situation, natural resources, material means of production and others, and put the S&T development level in an important position of the national competitiveness. Farmer and Richman (1964) took politics and law, education, social culture and economy as independent variables, and employed a matrix method to study competitiveness. Since the end of the 20th century, the International Institute for Management Development (IMD) and the World Economic Forum (WEF) have been publishing annual reports on the comprehensive national competitiveness analysis and comparison of major economies in the world, and continually updated or revised their evaluation systems, becoming representative yardsticks of the international competitiveness research and evaluation at the national level for researchers and policy-makers. And both IMD and WEF take the national S&T competitiveness as an important dimension in the national competitiveness analysis. Porter (1990) noted that the factors of production, demand, related supportive industries, as well as corporate strategies and competition constitute the national competitive advantage, and pointed out that the S&T development level will gradually dominate the development of national competitiveness. The S&T contribution to national competitiveness is becoming more and more prominent (Fagerberg, 1996; Porter and Rivkin, 2012), which is rapidly changing the nature of competition and national strategies, and driving the world to a new competitive landscape (Bettis, 1995). However, up to now, there is no consensus on the concept definition or analysis paradigm of the national S&T competitiveness, and there is a lack of influential research results. Atkinson (2017) pointed out that at present, there is insufficient analysis and evaluation on the advantages, disadvantages, opportunities and threats of countries in competition, and few countries have formulated comprehensive competitiveness strategies to cope with global competition. Therefore, clearly defining the concept of the national S&T competitiveness sets the premise to comprehensively depict the national S&T competitiveness structure, which possesses important academic significance and necessity.

While the accurate evaluation of the national S&T competitiveness is the basis of depicting the

national S&T competitiveness structure, the existing research on systematic evaluation of the national S&T competitiveness is rarely involved. WEF's annual *Global Competitiveness Report* measures national competitiveness based on global competitiveness index (GCI). Although the GCI evaluation method emphasizes the importance of S&T development, it does not have specialized indicators for the S&T dimension. The evaluation of the national S&T competitiveness should not only consider the efficiency of resources transformation, but also consider the national scale and resources endowment. In addition, we argue that neither the contribution of comparative advantage of the national scale to national competitiveness, nor the contribution of comparative advantage of the resources mobilization capacity within national boundaries to national competitiveness should be ignored. In view of the absent issue in the existing research, this paper takes the national scale and the resources mobilization capacity within the national boundary into the evaluation dimension of the national S&T competitiveness, and analyzes the influence of the national comparative advantage on national S&T competitiveness structure at the same time.

At present, there is a lack of systematic study on the depiction of the national S&T competitiveness structure. On the one hand, it is not easy to accurately define the national S&T competitiveness structure, and the research on structure analysis method is insufficient. On the other hand, the framework of the evaluation index system for the S&T competitiveness is not complete. Based on the above analysis, a thorough grasp of the definition, evaluation, and analysis method of the national S&T competitiveness structure is the base in the comprehensively depiction of the national S&T competitiveness structure, so as to identify the advantages and disadvantages in one's national S&T competition, and to support the corresponding strategic decision-making and related policy-making. Based on the existing relevant research and previous work of our team, we present the definition of the national S&T competitiveness structure. An evaluation framework is then constructed from the national S&T competitive potential, the national S&T competitive strength and the national S&T competitive effectiveness, with 19 internationally commonly used indicators for the measurement. Structure analysis is proposed for the national S&T competitiveness structure. With the one-dimensional and two-dimensional structure analysis methods, this paper conducts an empirical analysis on 35 major countries in the world. Moreover, the comparative advantage of different countries is also included in consideration, and the paper analyzes the relationship between the competitiveness structure and GDP or GDP per capita. A study on a thorough definition, a comprehensive analysis and a systematic depiction of the national S&T competitiveness structure is thus realized.

This paper takes into account the S&T input, the S&T output as well as the efficiency of transforming the S&T input into the S&T output. It draws attention to the influence of national comparative advantage on the national S&T competitiveness structure, and tries to describe and analyze the national S&T competitiveness structure comprehensively and objectively, which is not only beneficial to accurately grasping the development tendency and international positioning in S&T innovation, but also of great significance for formulating the comprehensive and development strategies and the S&T diplomacy policies.

The rest of the article is arranged as follows. In Section 2, we discuss what may be called the "national competitiveness". Based on the redefinition of the national competitiveness, we clearly define the concepts of the national S&T competitiveness and the national S&T competitiveness structure. In Section 3, the theoretical and methodological basis of this study is introduced, and the evaluation system of the national S&T competitiveness structure is constructed. And the structure analysis method is introduced in details. Section 4 conducts an empirical study of the national S&T competitiveness structure. Section 5 presents concluding remarks.

2. Definitions

2.1. The national competitiveness

The concept of "competitiveness" emerged after the Second World War, and has been widely accepted and refined by scholars worldwide, but it has always been controversial and ill-defined (Mulatu, 2016). Since 1979, WEF has published t*he Global Competitiveness Report* once a year. Initially, *the Global Competitiveness Report* was jointly launched by WEF and IMD. However, differences in how to define and measure competitiveness led to the division of these two organizations. And since 1989, IMD has published a similar annual report called *the World Competitiveness Yearbook*. With the development of global economy, the attempts to update the definition of international competitiveness and to improve its measurement never stop. The early research on competitiveness mainly reflected economic and industrial development status of different countries, and focused on how to give full play to their own advantages to promote economic development after the War (Denison, 1967). In the 1990s, Porter's theory of competitive advantage (Porter, 1990) attracted the attention of scholars, and guided scholars to carry out research from micro-concerns about corporate competitiveness, meso-perspectives about industrial competitiveness to macro-perspectives about the international competitiveness. For example, *the Global Competitiveness Report* first launched by WEF in 1979 features the Global Competitiveness Index 4.0 (GCI 4.0) in the 2019 edition. In the 1980s, the reports defined competitiveness as market holding capacity, focusing on the micro-level of competitiveness. The reports in the 1990s began to emphasize the international competitiveness at the macro-level, such as the national profitability or the national economic growth capacity and the national environmental optimization ability. The 2019 edition announces that competitiveness refers to the attribute and qualities of an economy to achieve long-term economic growth and development by making more efficient use of factors of production.

Most definitions of competitiveness emphasize the efficiency of resource transformation. For example, the 2019 edition of *the Global Competitiveness Report* emphasizes the ability of economies to use factors of production more effectively. In fact, industrial competitiveness or corporate competitiveness basically follows this definition. For example, if the industry E of the country A can use the factors of production more effectively than those of the other countries, the industry E of the country A is thus more competitive than the industry E of other countries. Even if the scale of the industry E of the country A is smaller than those of the other countries, it may gradually become bigger and stronger through competition based on efficiency advantages. However, the international competitiveness at the national level (hereinafter referred to as national competitiveness) does not exactly follow this definition, and the national boundaries can never be changed by relying on competitive advantages. Therefore, the contribution of the comparative advantage of the national scale to national competitiveness cannot be ignored, neither can the contribution of the comparative advantage of the resources mobilization capacity within national boundaries to national competitiveness. Although the country A possessing relatively strong ability to mobilize resources within its border does not necessarily leads to its strong competitiveness, it is more likely to be more competitive compared with countries possessing relatively weak resources mobilization capacity. And here the resources mobilization capacity represents the potential competitiveness.

Considering the influence of the national scale, the resources mobilization capacity and the resource transformation efficiency, this paper holds that the national competitiveness refers to the ability of a country to mobilize and utilize resources more effectively and transform them into output in a certain international competitive environment, including the competitive potential, the competitive strength and the competitive effectiveness. The competitive potential represents the influence of the quantity of resources input, and

the more resources input than competitors, the greater competitive potential. The competitive strength represents the influence of the quantity of transforming the resources input into output, the more output than competitors, the stronger the competitive strength. The competitive effectiveness represents the influence of the efficiency of transforming the resources input into output, and the higher efficiency than competitors, the stronger competitive effectiveness. Compared with the traditional "chaotic and ill-defined" concept (Bristow, 2005), the definition of the national competitiveness proposed in this paper not only attaches importance to the efficiency of the resources transformation, but also takes into account the important influence of the national scale and the resources mobilization capacity.

2.2. The national S&T competitiveness

At present, the world is facing profound changes unseen in a century. The national S&T competitiveness has become a key force to grasp the opportunities of the new S&T revolution and industrial transformation, and to cope with the major challenges faced by the global political, economic, social and environmental development. It is also expected to be the key for the initiative of the international competition structure reconstruction, which has become the focus of attention of all sectors of society. In the 1980s, the S&T competitiveness began to attract the attention of scholars (Hatsopoulos and Krugman, 1987; Klein, 1988; Young, 1988), and gradually became the core of competitiveness research (Roessner *et al.,* 2002; Ashton *et al.,* 2006; Qian and Wang, 2017). It is a consensus for policy-makers and scholars to evaluate the S&T competitiveness to guide the formulation of national policies. For example, both IMD's *World Competitiveness Yearbook* (IMD, 2019) and WEF's *Global Competitiveness Report* (Schwab and World Economic Forum, 2019) take S&T competitiveness as an important dimension for analysis, although there are differences in the connotation and evaluation indicators between these two. So far, no consensus has achieved on how to evaluate the S&T competitiveness. The accurate evaluation of the national S&T competitiveness is the basis of grasping the evolution tendency of global S&T competitiveness structure, identifying the advantages and disadvantages of the national S&T competition, and supporting the corresponding strategic decision-making and related policy-making.

The national S&T competitiveness is one aspect of the national competitiveness. Based on the above definition of the national competitiveness, this paper defines the national S&T competitiveness as the ability of a country to mobilize and utilize S&T resources more effectively and transform them into S&T output under a certain international competitive environment, which includes three aspects: the national S&T competitive potential, the national S&T competitive strength and the national S&T competitive effectiveness. The national S&T competitive potential represents the influence of the quantity of S&T resources input, including financial and personnel input. The national S&T competitive strength represents the influence of the quantity of transforming S&T resources input into S&T output, including numbers of papers and patents. And the national S&T competitive effectiveness represents the influence of the efficiency of transforming S&T resources input into S&T output, including various types of products considered with the unit S&T input. It should be noted that the national S&T competitiveness defined in this paper not only considers the efficiency of the transformation of S&T resources input into S&T output, but also takes into account the important influence of the quantity of S&T output and the quantity of S&T resources input on national competitiveness.

2.3. The national S&T competitiveness structure

According to the Webster's dictionary[1], "structure" is defined as "organization of parts as

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[1] https://www.merriam-webster.com/dictionary/structure

dominated by the general character of the whole; coherent form or organization; the aggregate of elements of an entity in their relationships to each other". The national structure refers to the position of a country and its relations with other countries, based on certain character (some composite index or single index) within a spatial scope (*e.g.* the whole world, Asian countries) in a certain period of time.

Combined with our definition of the national S&T competitiveness, the national S&T competitiveness structure refers to the position of a country and its relations with other countries, based on the national S&T competitiveness (composite index such as the national S&T competitiveness index; single index such as the national S&T competitive potential index, the national S&T competitive strength index and the national S&T competitive effectiveness index), within a spatial scope (*e.g.* the whole world, Asian countries) in a certain period of time. An accurate and thorough analysis of the international S&T competitiveness structure and its evolution tendency is conducive to countries in their efforts to formulate and adjust foreign policy measures in time, take the initiative in international relationships, better develop their national interests, and promote better international partnerships, so as to realize the optimized global resources configuration. Overall, the promotion of the S&T innovation ability and the national S&T competitiveness is a positive sum game (Schwab and World Economic Forum, 2019).

3. Methodologies

3.1. Construction of evaluation framework and index system

The evaluation of the national S&T competitiveness should start with the dynamic system of the S&T activities, figuring out the key factors affecting S&T activities. Based on our definition of the national S&T competitiveness proposed in Section 2, the ranking of the national S&T competitiveness can reflect the overall situation of the national S&T competitiveness structure. Each of the three sub-indexes of the national S&T competitiveness evaluation can reflect one side of a country's S&T competitiveness activities. The aggregate of the ranking of the national S&T competitiveness, and the ranking and the pair-wise interrelationship of the three corresponding sub-indexes can thoroughly reflect the overall national S&T competitiveness structure of a country. This paper constructs an evaluation framework of the national S&T competitiveness from three dimensions, that is the national S&T competitive potential, the national S&T competitive strength and the national S&T competitive effectiveness, taking into account the S&T input, the S&T output as well as the efficiency of transforming the S&T input into the S&T output. As is shown in Figure 1. The national S&T competitive potential is the precondition of the S&T activities and represents the influence of the quantity of resources input. As for the specific indicators, human resources investment and financial investment are the two effective capital tools to support S&T activities, and greatly drive the output of the S&T strength and the transformation of the S&T effectiveness. The S&T competitive effectiveness is on the process side of the S&T activities, which belongs to a composite index, emphasizing the transformation and value-added from the S&T competitive potential to the S&T competitive strength. In terms of specific indicators, the S&T competitive effectiveness contains the unit S&T output from the unit S&T input, which is more conducive to measuring the operation efficiency of a country's S&T activities. The national S&T competitive strength is used to measure the achievements of a country's S&T activities, which belongs to the S&T input side. On the one hand, the S&T competitive strength should be supported by the S&T competitive potential. On the other hand, the national S&T competitive strength

as the most typical external embodiment of the achievements of S&T activities, is transformed from the S&T competitive effectiveness.
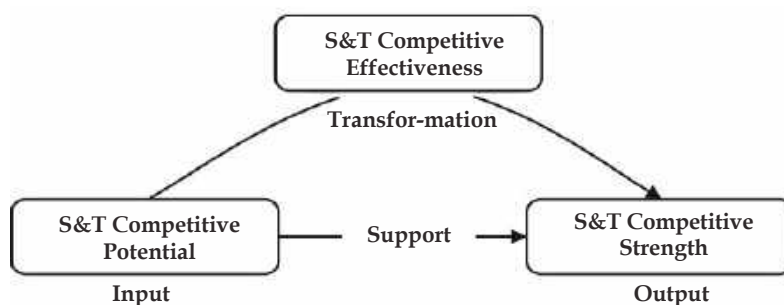

Fig. 1 The evaluation framework of the national S&T competitiveness

Based on the evaluation framework of the national S&T competitiveness, and in-depth consideration of the availability of related data, this paper constructs the evaluation index system of the national S&T competitiveness, and selects 19 internationally commonly used indicators to calculate and analyze these three indexes, including the national S&T competitive potential index (CPI), the national S&T competitive strength index (CSI) and the national S&T competitive effectiveness index (CEI). The indexes, indicators and the data sources for the evaluation are shown in Table 1.

Table 1 The indicator system for the national S&T competitiveness index

Index	Indicator	Source
National S&T Competitive Strength	SCI, SSCI and A&HCI paper publications	WOS
	SCI, SSCI and A&HCI paper citations	WOS
	Patent grants (resident)	WIPO
	Triadic patent grants	WIPO
	PCT patent applications	WIPO
	Charges for the use of intellectual property (receipts)	WB
National S&T Competitive Effectiveness	SCI, SSCI and A&HCI paper publications per million R&D expenditure	WB and WOS
	SCI, SSCI and A&HCI paper citations per million R&D expenditure	WB and WOS
	Patent grants (resident) per million R&D expenditure	WB and WIPO
	Triadic patent grants per million R&D expenditure	WB and WIPO
	PCT patent applications per million R&D expenditure	WB, WIPO
	Charges for the use of intellectual property (receipts) per million R&D expenditure	WB
	SCI, SSCI and A&HCI paper citations per SCI, SSCI and A&HCI paper	WOS
National S&T Competitive Potential	The number of researchers	WB
	R&D expenditure	WB
	R&D expenditure as a percentage of GDP	WB
	Researchers per million people	WB
	R&D expenditure per million people	WB
	R&D expenditure per million researchers	WB

3.2. The structure analysis method

Mu (2020) recently proposed a structure analysis method, which analyzes the structure and the subject relationship formed by some specified characters of the subjects in a certain space and a certain time period to identify the evolution direction of the national structure. The national structure analysis method is related to the number of the specified characters selected in the analysis of the national structure, and the latter directly determines the visualization form of the national structure. The analysis method of the national structure can be divided into two categories: the one-dimensional analysis method and the two-dimensional analysis method. The one-dimensional analysis method of the national structure refers to the method of classifying countries based on only one character (some composite index or single index), which can be presented in the form of the column or bar chart. The two-dimensional analysis method of the national structure refers to the method of classifying countries based on two characters (composite indexes or single indexes), which can be presented in the form of the scatter or bubble chart. Since the national scale and the resources mobilization capacity within the nation's border contribute to the national competitiveness, the influence of external factors, such as GDP that contributes to the national S&T competitiveness is also considered in the structure analysis. This paper discusses the relationship between the ranking of the national S&T competitiveness and GDP as well as GDP per capita. In the combined cluster distribution diagram of the two-dimensional analysis, GDP or GDP per capita is represented by bubble size, and the relationship between the national S&T competitiveness structure and GDP as well as GDP per capita is discussed, so as to realize a comprehensive depiction of the national S&T competitiveness structure.

3.2.1. The one-dimensional analysis method of the national S&T competitiveness structure

The one-dimensional analysis method of the national S&T competitiveness structure ranks the countries with the national S&T competitiveness index (or one of its sub-indexes) as the single character and to classify them according to a certain standard. It can be presented in the form of a column or bar chart. As is shown in Figure 2 and ten countries are ranked in the bar chart. A series of bars with the same width are used to represent the national S&T competitiveness index of different countries in a certain year or period. Based on the characteristics of the data, countries can be divided into several categories (for example, the 10 countries in Figure 2 are divided into 4 categories). In addition, more information such as the scores and the average annual growth rates of the national S&T competitiveness index (or one of its sub-indexes) in different years or periods, can also be presented in the bar chart.
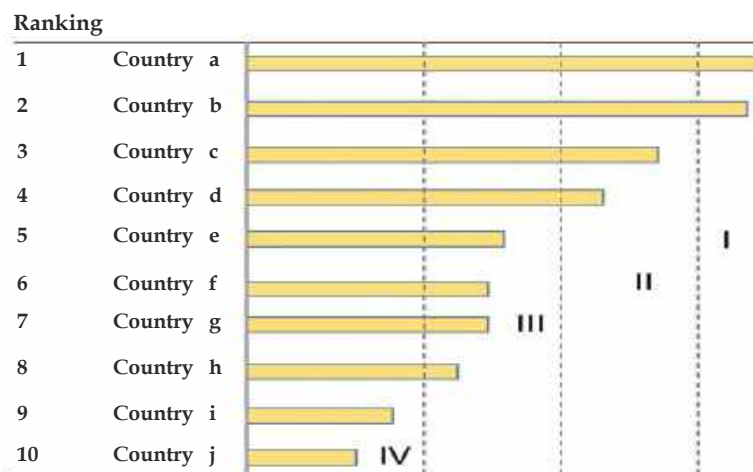

Fig. 2 Sketch map of the one-dimensional analysis method

3.2.2. The two-dimensional analysis method of the national S&T competitiveness structure

The essence of the two-dimensional analysis method of the national S&T competitiveness structure is to analyze the pair-wise interactive performance of the national S&T competitive potential, the national S&T competitive strength and the national S&T competitive effectiveness in the international competition environment, and to cluster countries into M categories (M ≥ 2). In order to present the pair-wise interactive performance of the three sub-indexes and classify countries more clearly, this paper holds that it is necessary to consider the classification needs and the situation of the method application, and creatively use the quadrant classification method, the clustering method and their combination to conduct the two-dimensional structure analysis. The following is an example of the national S&T competitiveness structure under the combination of strength and effectiveness.

(1) The quadrant classification method

The quadrant classification method divides all countries into several quadrants based on the distribution regions of the strength and effectiveness according to a certain standard, so as to obtain the multi-categories of countries distributed in different quadrants. The four-quadrant classification is an important method in management science. All countries are divided into the four quadrants based on the performance of their national S&T competitive strength and national S&T competitive effectiveness. As is shown in Figure 3 and twenty countries are clustered. In the coordinate system, in which the abscissa is for the national S&T competitive strength index (CSI) value ranking and the vertical coordinate is for the national S&T competitive effectiveness index (CEI) value ranking, the four-quadrant classification method divides the square into four quadrants, the countries falling in the Quadrant I are the countries with high national S&T competitive strength and high national S&T competitive effectiveness, referred to as high-strength and high-effectiveness countries. The countries falling in the Quadrant II are those with low national S&T competitive strength and high national S&T competitive effectiveness, referred to as low-strength and high-effectiveness countries. The countries in the Quadrant IV are those with high national S&T competitive strength and low national S&T competitive effectiveness, referred to as high-strength and low-effectiveness countries. The countries in the Quadrant III are those with low national S&T competitive strength and low national S&T competitive effectiveness, referred to as the low-strength and low-effectiveness countries.
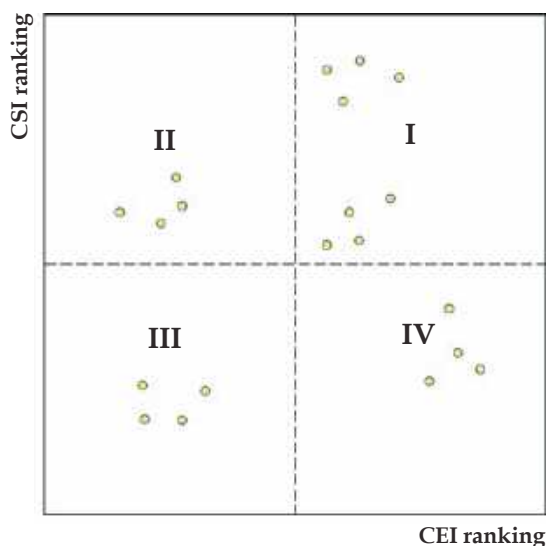

Fig. 3 Sketch map of the quadrant classification method

(2) The clustering method

The clustering method is based on a certain clustering standard to classify all countries based on the strength and effectiveness. Different from the quadrant classification method, the clustering method focuses on the relative distance between countries. Therefore, the clustering method aims to divide all countries into multi-categories according to similar national S&T competitiveness. The K-means clustering method is one of the most classical clustering algorithms. All countries can be classified into K categories based on the performance of the national S&T competitive strength and the national S&T competitive effectiveness. And the classification results can be obtained directly. As is shown in Figure 4 and twenty countries are clustered into K categories (in Figure 4, K equals to 4). The K value is generally determined according to the intuitive number of columns and classification requirements. In the actual use, there are cases that while some samples are classified into one category according to the clustering algorithm, they are classified into another according to some actual situation.
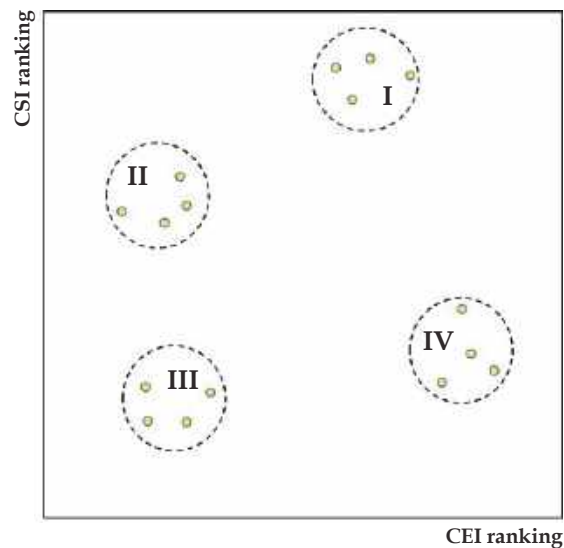
Fig. 4 Sketch map of the clustering method

3.2.3. External factors of the national S&T competitiveness structure

It is necessary to identify the external factors that influence the national S&T competitiveness structure in the structure analysis. As is discussed in Section 2, the contribution of the national scale to the national competitiveness cannot be ignored, neither can the contribution of the resources mobilization capacity within the nation's border to the national competitiveness. It is supposed that the influence of external factors, such as GDP that contributes to the national S&T competitiveness, will influence the national S&T competitiveness structure. Based on the analysis of the national S&T competitiveness structure, this paper discusses the relationship between the national S&T competitiveness structure and GDP or GDP per capita. Therefore, on the basis of the one-dimensional structure analysis, this paper uses the combination quadrant diagram of the scatter chart to analyze the relationship. On the basis of the two-dimensional structure analysis, this paper employs the bubble chart instead of the scatter chart in the combination cluster distribution map (as is shown in Figure 5), with GDP or GDP per capita as the external character, so as to further identify the relationship between the national S&T competitiveness structure and GDP or GPD per capita under the combination of the pair-wise sub-indexes of the national S&T competitiveness.
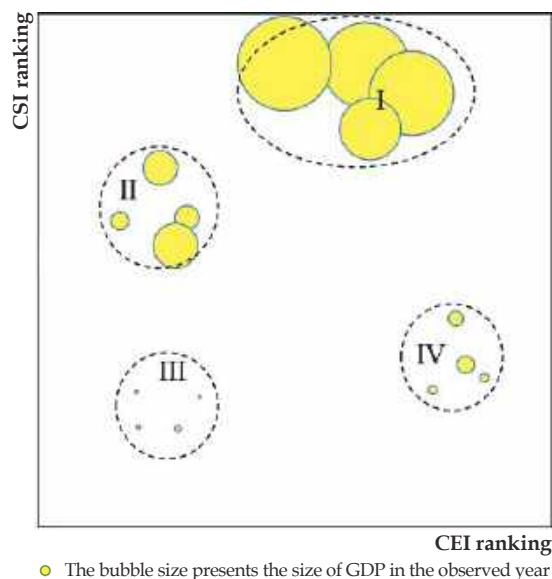
CEI ranking

○ The bubble size presents the size of GDP in the observed year

Fig. 5 Sketch map of relationship analysis between the national S&T competitiveness structure and GDP

4. Empirical Analysis: National S&T Competitiveness Structure

4.1. The one-dimensional analysis of national S&T competitiveness structure

In general, from 2006 to 2015, the national S&T competitiveness of developed countries performed better than most of the developing countries. In particular, the national S&T competitiveness index scores of the United States and Japan maintained the first and second place, respectively. As for emerging economies represented by BRICS countries, except China, their index scores of the national S&T competitiveness were significantly lower than those of the major S&T powers, and the index scores of the above-mentioned emerging economies were all lower than the average value of the 35 countries. Specifically, South Africa, Russia, India and Brazil were in the bottom of the 35 participating countries (ranking the 29th, 31st, 32[ed] and 33rd, respectively). Among them, the scores of Russia and South Africa even showed a downward tendency. Russia's national S&T competitiveness ranking dropped from the 24th in 2006 to the 31st in 2015. As is shown in Figure 6.

According to Figure 6, from 2006 to 2015, the average annual growth rates[2] of the national S&T competitiveness index scores of developing countries were generally higher than those of developed countries. The average annual growth rates of Finland, Sweden, Germany, Russia and Israel were all lower than 1%, and Israel was the one even with a negative annual growth rate (-1.42%). In contrast, with the scale comparative advantage brought by the rapid growth of S&T investment, China's national S&T competitiveness index ranking rose by 13 places from 2006 to 2015, and the annual growth rate of the index score was 11.46%, which showed the fastest growth among the 35 participating countries. In 2015, the countries ranked from the 4th to the 10th for the national S&T competitiveness index were the Netherlands, Germany, South Korea, Sweden, China, Denmark and the United Kingdom. The national

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[2] The algorithm used to calculate the annual growth rate K from A to B is $K = {}^{(B-A)}\sqrt{(Y_B/Y_A)} - 1$, where Y_a and Y_b are the index values of Year A and Year B, respectively.

S&T competitiveness index scores were 31.00, 25.18, 23.99, 23.42, 22.56, 20.42 and 20.18, respectively. Although China's national S&T competitiveness index ranked the 8th, there was still a big gap compared with major developed countries. Its index score was only 44.80% of that of the United States.
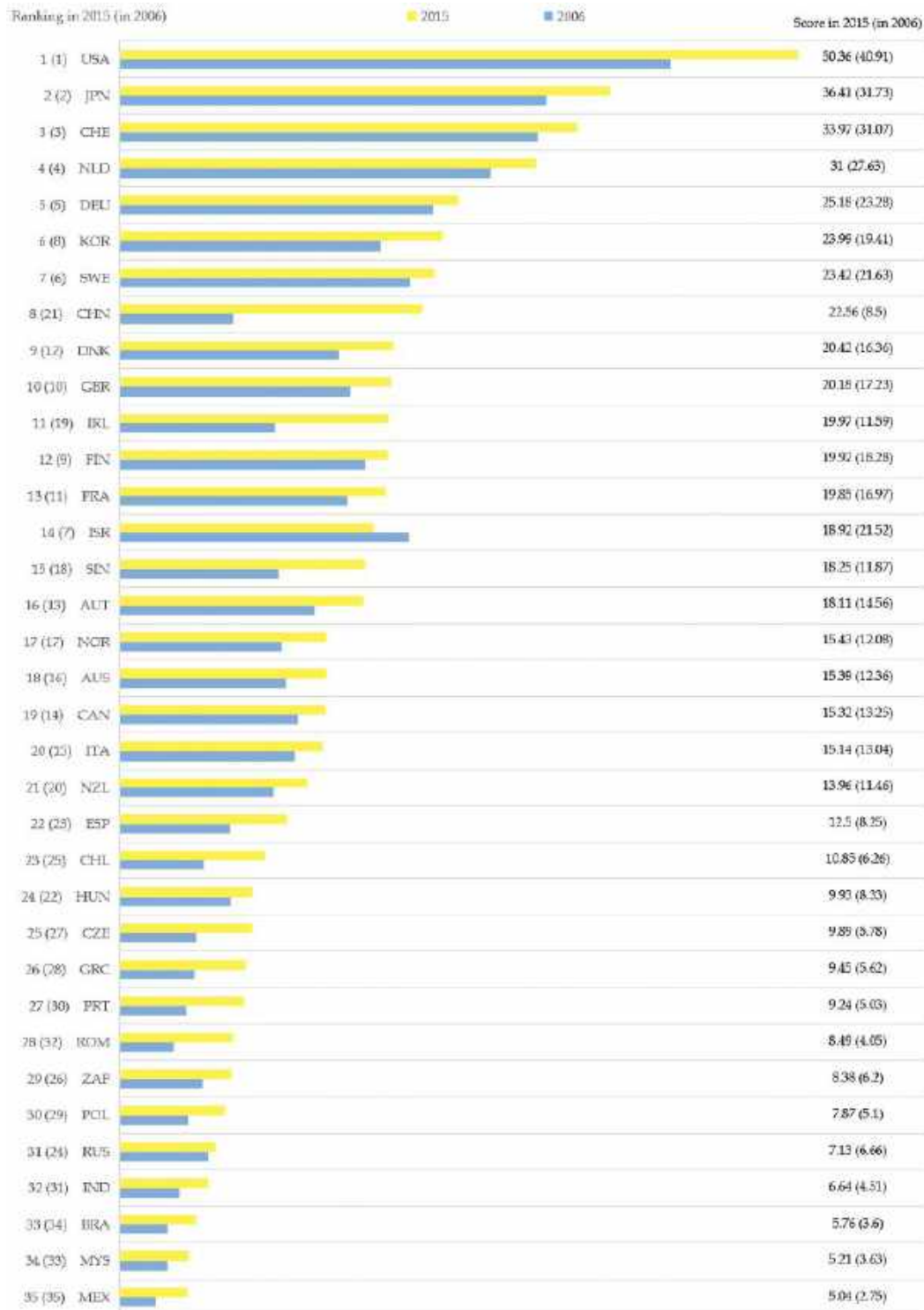

Fig. 6 The ranking of the national S&T competitiveness index

4.2. The two-dimensional analysis of national S&T competitiveness structure

   4.2.1. National S&T competitiveness structure under the combination of strength and effectiveness

In order to more clearly depict the national S&T competitiveness structure of the 35 countries under the combination of strength and effectiveness, this paper uses the ranking combination of the national S&T competitive strength index (CSI) and the national S&T competitive effectiveness index (CEI), and employs the four-quadrant classification method and the K-means clustering method to analyze the ranking combination, respectively.

First of all, using the four-quadrant classification method, this paper draws the combined quadrant chart of the ranking of 35 countries' CSI and CEI in 2006 and 2015. As is shown in Figure 7. The 35 countries are divided into four quadrants according to the two dashed lines of CSI ranking and CEI ranking equal to 18. The countries in the Quadrant I are called countries with high CSI and high CEI, referred to as high-strength and high-effectiveness countries. The countries in the Quadrant II are called countries with low CSI and high CEI, referred to as low-strength and high-effectiveness countries. The countries in the Quadrant III are called countries with low CSI and low CEI, referred to as low-strength and low-effectiveness countries. And the countries in the Quadrant IV are called countries with high CSI and low CEI, referred to as high-strength and low-effectiveness countries.
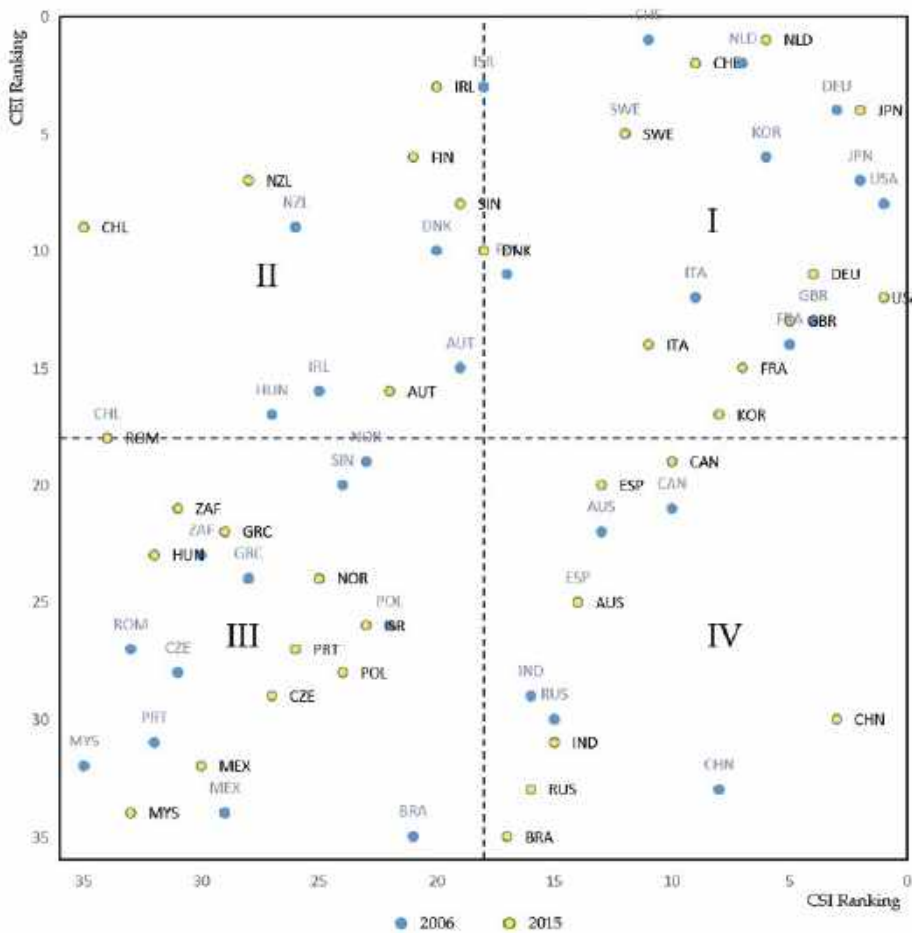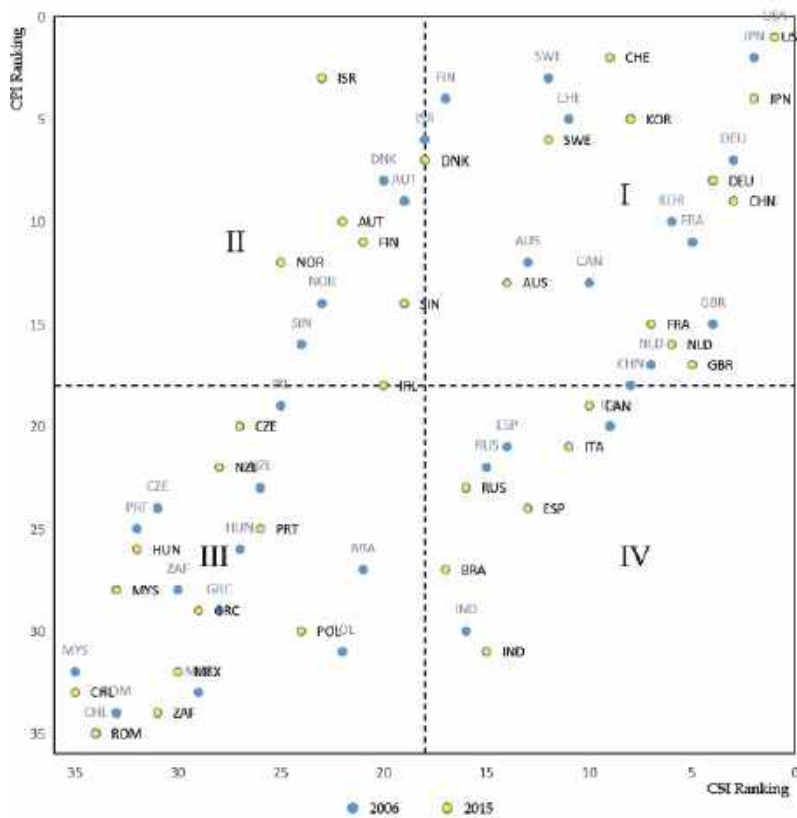

Fig. 7 The combined quadrant chart of the national S&T competitiveness structure under the combination of strength and effectiveness (2006 vs. 2015)

According to Figure 7, 12 countries with high CSI and high CEI were clustered in Quadrant I, including the United States, Japan, Germany and the United Kingdom in 2006. Most of these countries remained their state in 2015, and Israel dropped into Quadrant III as a low-strength and low-effectiveness country. In 2015, Chile, New Zealand and Ireland were among the 7 low-strength and high-effectiveness countries, among which, Singapore and Romania were in Quadrant III in 2006. There were 10 low-strength and low-effectiveness countries in 2015, Malaysia, South Africa, Czech Republic and Greece included. Brazil, Russia, India and China, four of the BRICS countries, were high-strength and low-effectiveness countries with the other 4 countries classified in Quadrant IV in 2015, while Brazil was among the low-strength and low-effectiveness countries in 2006. As is shown in Table 2.

Table 2 Four-quadrant classification results of 35 countries (based on CSI and CEI rankings)

Category	Countries distribution in 2006	Countries distribution in 2015
I (High-strength and high-effectiveness)	USA, Japan, Germany, UK, France, South Korea, the Netherlands, Italy, Switzerland, Sweden, Finland, Israel	USA, Japan, Germany, UK, the Netherlands, France, South Korea, Switzerland, Italy, Sweden, Denmark
II (Low-strength and high-effectiveness)	Austria, Denmark, Ireland, New Zealand, Hungary, Chile	Singapore, Ireland, Finland, Austria, New Zealand, Romania, Chile
III (Low-strength and low-effectiveness)	Brazil, Poland, Norway, Singapore, Greece, Mexico, South Africa, Czech Republic, Portugal, Romania, Malaysia	Israel, Poland, Norway, Portugal, South Africa, Greece, Mexico, Czech Republic, Hungary, Malaysia
IV (High-strength and low-effectiveness)	China, Canada, Australia, Spain, Russia, India	China, Canada, Spain, Australia, India, Russia, Brazil

Note: The countries in the table are listed in order of the CSI ranking, from high to low

To further characterize the classification from different perspectives, the K-means clustering method is used to cluster the ranking combination of CSI and CEI of 35 countries in 2006 and 2015, which are divided into four categories. In 2015, there were 10 countries in Category I, including the United States, the United Kingdom and Japan, among which, both Spain and Canada were in Category IV in 2006. There were 7 countries in Category II in 2015, Switzerland, Sweden and Denmark included. Austria was in Category II in 2006 and moved to Category III in 2015 with the other 8 countries there, including South Africa, Chile and Greece. Brazil, Russia, India and China were always in Category IV both in 2006 and in 2015. As is shown in Table 3. Comparing the two classification results, it is found that the classification results of the four-quadrant classification and the K-means clustering are almost the same.

Table 3 K-means clustering classification results of 35 countries (based on CSI and CEI rankings)

Category	Countries distribution in 2006	Countries distribution in 2015
I	USA, Japan, Germany, UK, France, South Korea, the Netherlands, Italy	USA, Japan, Germany, UK, the Netherlands, France, South Korea, Canada, Italy, Spain
II	Switzerland, Sweden, Finland, Israel, Austria, Denmark, New Zealand	Switzerland, Sweden, Denmark, Singapore, Ireland, Finland, New Zealand
III	Norway, Singapore, Ireland, Hungary, Greece, South Africa, Czech Republic, Portugal, Romania, Chile, Malaysia	Austria, Norway, Portugal, Greece, South Africa, Hungary, Malaysia, Romania, Chile
IV	China, Canada, Australia, Spain, Russia, India, Brazil, Poland, Mexico	China, Australia, India, Russia, Brazil, Israel, Poland, Czech Republic, Mexico

Note: The countries in the table are listed in order of the CSI ranking, from high to low

4.2.2. National S&T competitiveness structure under the combination of strength and potential

In order to more clearly depict the national S&T competitiveness structure of the 35 countries under the combination of strength and potential, this paper uses the ranking combination of the national S&T competitive strength index (CSI) and the national S&T competitive potential index (CPI), and employs the four-quadrant classification method and the K-means clustering method to analyze the ranking combination, respectively.

First of all, using the four-quadrant classification method, this paper draws the combined quadrant chart of the ranking of the 35 countries' CSI and CPI in 2006 and 2015. As is shown in Figure 8. And the 35 countries are divided into four quadrants according to the two dashed lines of CSI ranking and CPI ranking equal to 18. The countries in the Quadrant I are called countries with high CSI and high CPI, referred to as high-strength and high-potential countries. The countries in the Quadrant II are called countries with low CSI and high CPI, referred to as low-strength and high-potential countries. The countries in the Quadrant III are called countries with low CSI and low CPI, referred to as low-strength and low-potential countries. And the countries in the Quadrant IV are called countries with high CSI and low CPI, referred to as high-strength and low-potential countries.

Fig. 8 Combined quadrant chart of the national S&T competitiveness structure under the combination of strength and potential (2006 vs. 2015)

According to Figure 8, in 2015, USA, Japan, Germany, China, South Korea, Switzerland, Sweden, France, UK, the Netherlands with Switzerland were the 11 countries with high CSI and high CPI. And it should be noted that China was in Quadrant IV in 2006, while Canada was in this quadrant in 2006 and dropped to the quadrant IV in 2015. Israel, Denmark, Austria, Finland, Norway and Singapore were the 6 low-strength and

high-potential countries in 2015 with Finland moving from the high-strength and high-potential quadrant in 2006. Canada, India, Spain and Russia were among the 6 high-strength and low-potential countries in 2015. Portugal, Hungary, Malaysia, Greece, Mexico, South Africa, Chile and Romania with the other 4 were low-strength and low-potential countries set in the Quadrant III in 2015. As is shown in Table 4.

Table 4 Four-quadrant classification results of 35 countries (based on CSI and CPI rankings)

Category	Countries distribution in 2006	Countries distribution in 2015
I (High-strength and high-potential)	USA, Japan, Germany, UK, France, South Korea, the Netherlands, Canada, Switzerland, Sweden, Australia, Finland	USA, Japan, China, Germany, UK, the Netherlands, France, South Korea, Switzerland, Spain, Australia
II (Low-strength and high-potential)	Israel, Austria, Denmark, Norway, Singapore	Denmark, Singapore, Finland, Austria, Israel, Norway
III (Low-strength and low-potential)	Brazil, Poland, Ireland, New Zealand, Hungary, Greece, Mexico, South Africa, Czech Republic, Portugal, Romania, Chile, Malaysia	Ireland, Poland, Portugal, Czech Republic, New Zealand, Greece, Mexico, South Africa, Hungary, Malaysia, Romania, Chile
IV (High-strength and low-potential)	China, Italy, Spain, Russia, India	Canada, Italy, Spain, India, Russia, Brazil

Note: The countries in the table are listed in order of the CSI ranking, from high to low

To further characterize the classification from different perspectives, the K-means clustering method is used to cluster the ranking combination of CSI and CPI of the 35 countries in 2006 and 2015, which are divided into four categories. While there were only 6 countries in Category I in 2006, there were 10 in 2015. UK, the Netherlands, South Korea, France and China moved in from Category IV in 2006 and Finland moved to Category II in 2015. There were 10 countries in Category II, Israel, Denmark, Austria, Finland, Norway and Singapore included. 8 countries were in Category III, including Greece, South Africa and Chile. Canada, Italy, Russia, Spain, Brazil, India with Poland were the 7 countries in Category IV. As is shown in Table 5. Comparing the two classification results, it is found that the classification results of the four-quadrant classification and the K-means clustering are almost the same.

Table 5 K-means clustering classification results of 35 countries (based on CSI and CPI rankings)

Category	Countries distribution in 2006	Countries distribution in 2015
I	USA, Japan, Germany, Switzerland, Sweden, Finland	USA, Japan, China, Germany, UK, the Netherlands, France, South Korea, Switzerland, Sweden, Finland
II	India, Israel, Austria, Denmark, Brazil, Poland, Norway, Singapore, Ireland, New Zealand, Hungary, Czech Republic, Portugal	Australia, Denmark, Singapore, Ireland, Finland, Austria, Israel, Norway, Czech Republic, New Zealand
III	Greece, Mexico, South Africa, Romania, Chile, Malaysia	Portugal, Greece, Mexico, South Africa, Hungary, Malaysia, Romania, Chile
IV	UK, France, South Korea, the Netherlands, China, Italy, Canada, Australia, Spain, Russia	Canada, Italy, Spain, India, Russia, Brazil, Poland

Note: The countries in the table are listed in order of the CSI ranking, from high to low

4.2.3. National S&T competitiveness structure under the combination of effectiveness and potential

In order to more clearly depict the national S&T competitiveness structure of the 35 countries under the combination of effectiveness and potential, this paper uses the ranking combination of CEI and CPI, and employs the four-quadrant classification method and the K-means clustering method to analyze the ranking combination, respectively.

First of all, using the four-quadrant classification method, this paper draws the combined quadrant chart of the ranking of the 35 countries' CEI and CPI in 2006 and 2015. As is shown in Figure 9. And these countries are divided into four-quadrant according to the two dashed lines of CEI ranking and CPI ranking equal to 18. The countries in the quadrant I are called countries with high CEI and high CPI, referred to as high-effectiveness and high-potential countries. The countries in the Quadrant II are called countries with low CEI and high CPI, referred to as low-effectiveness and high-potential countries. The countries in the Quadrant III are called countries with low CEI and low CPI, referred to as low-effectiveness and low-potential countries. And the countries in the Quadrant IV are called countries with high CEI and low CPI, referred to as high-effectiveness and low-potential countries.
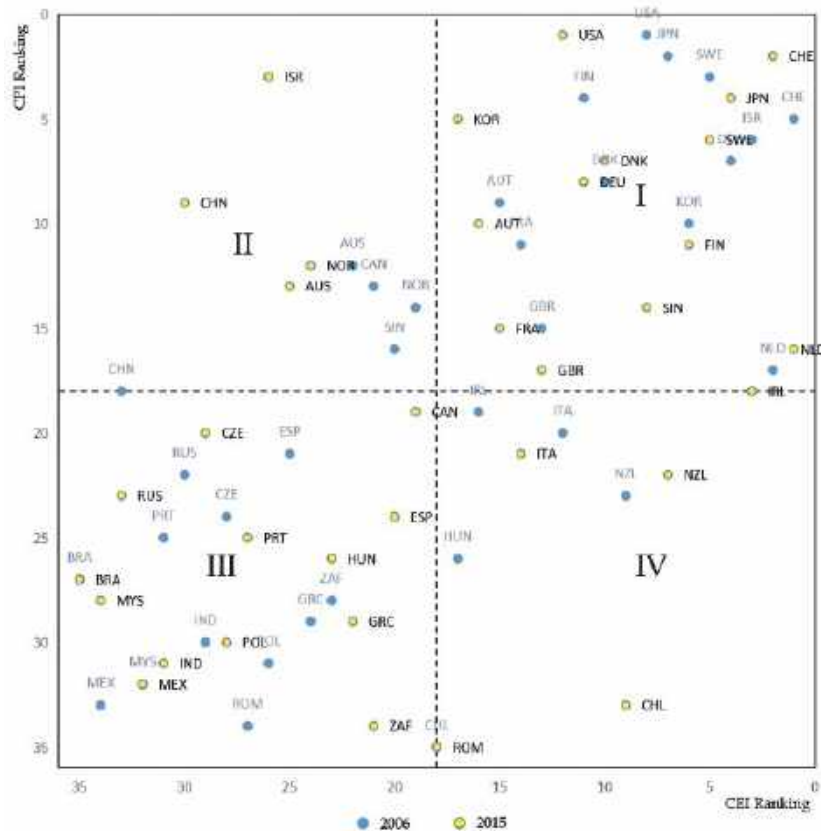
Fig. 9 Combined quadrant chart of the national S&T competitiveness structure under the combination of effectiveness and effectiveness (2006 vs. 2015)

According to Figure 9, in 2015, there were 13 countries with high CEI and high CPI, with Singapore moving from the low-effectiveness and high-potential Category in 2006. Israel moved from Category I in 2006 to Category II. And Israel, China, Australia and Norway were the 4 low-effectiveness and high-potential countries in 2015. New Zealand, Italy, Ireland, Hungary and Chile were the 5 high-effectiveness

and low-potential countries in Category IV in 2006, while Hungary moved to Category III in 2015. 14 countries were in Quadrant III with low CEI and low CPI in 2015, including Russia, Brazil, India and South Africa, which were among the BRICS countries. As is shown in Table 6.

Table 6 Four-quadrant classification results of 35 countries (based on CEI and CPI rankings)

Category	Countries distribution in 2006	Countries distribution in 2015
I (High-effectiveness and high-potential)	Switzerland, the Netherlands, Israel, Germany, Sweden, South Korea, Japan, USA, Denmark, Finland, UK, France, Austria	the Netherlands, Switzerland, Japan, Sweden, Finland, Singapore, Denmark, Germany, USA, UK, France, Austria, South Korea
II (Low-effectiveness and high-potential)	Norway, Singapore, Canada, Australia	Norway, Israel, China, Australia
III (Low-effectiveness and low-potential)	South Africa, Greece, Spain, Poland, Romania, Czech Republic, India, Russia, Portugal, Malaysia, China, Mexico, Brazil	Romania, Canada, Spain, South Africa, Greece, Hungary, Portugal, Poland, Czech Republic, India, Mexico, Russia, Malaysia, Brazil
IV (High-effectiveness and low-potential)	New Zealand, Italy, Ireland, Hungary, Chile	Ireland, New Zealand, Chile, Italy

Note: The countries in the table are listed in order of the CEI ranking, from high to low

To further characterize the classification from different perspectives, the K-means clustering method is used to cluster the ranking combination of CEI and CPI of the 35 countries in 2006 and 2015, which are divided into four categories. In 2015, there were 10 countries in Category I, with Singapore moving in from Category IV in 2006. South Korea, Israel, France and Austria were in Category I in 2006 and moved to Category II in 2015. And there were 5 more countries in Category II in 2015, with China, Australia and Norway included, as the four high-effectiveness and low-potential countries. 10 countries were in Category III in 2015, including four of the BRICS countries, Russia, Brazil, India and South Africa, and Brazil moved from Category II in 2006. As is shown in Table 7. Comparing the two classification results, it is found that the classification results of the four-quadrant classification and the K-means clustering are almost the same.

Table 7 K-means clustering classification results of 35 countries (based on CEI and CPI rankings)

Category	Countries distribution in 2006	Countries distribution in 2015
I	Switzerland, Israel, Germany, Sweden, South Korea, Japan, USA, Denmark, Finland, France, Austria	the Netherlands, Switzerland, Ireland, Japan, Sweden, Finland, Singapore, Denmark, Germany, USA
II	Canada, Australia, Spain, Czech Republic, Russia, Portugal, China, Brazil	France, Austria, South Korea, Canada, Norway, Australia, Israel, Czech Republic, China
III	Chile, South Africa, Greece, Poland, Romania, India, Malaysia, Mexico	South Africa, Greece, Hungary, Portugal, Poland, India, Mexico, Russia, Malaysia, Brazil
IV	the Netherlands, New Zealand, Italy, UK, Ireland, Hungary, Norway, Singapore	New Zealand, Chile, UK, Italy, Romania, Spain

Note: The countries in the table are listed in order of the CEI ranking, from high to low

4.3. GDP as an external variable for the national S&T competitiveness structure

4.3.1. The relationship between the national S&T competitiveness structure and GDP or GDP per capita

(1) The relationship between the national S&T competitiveness structure and GDP

The Pearson correlation coefficient between the index value of the national S&T competitiveness and the standardized value of GDP[3] of 35 countries in 2015 was 0.625** (Spearman correlation coefficient was 0.370*)[4], which indicates that there was a significant correlation between the index score of the national S&T competitiveness (NCI score) and the standardized value of GDP. As is shown in Figure 10. The 35 countries were distributed around the fitting line for the year of 2006 as well as for the year of 2015, indicating a roughly linear trend. However, with the exception of the United States and China which possessed relatively prominent GDP, the other 33 countries were clustered in the third quadrant. The United States was almost in the first quadrant in 2015 because of its excellent performance in the national S&T competitiveness index in 2015 (NCI score equal to 50.36), while China's national S&T competitiveness performance was relatively
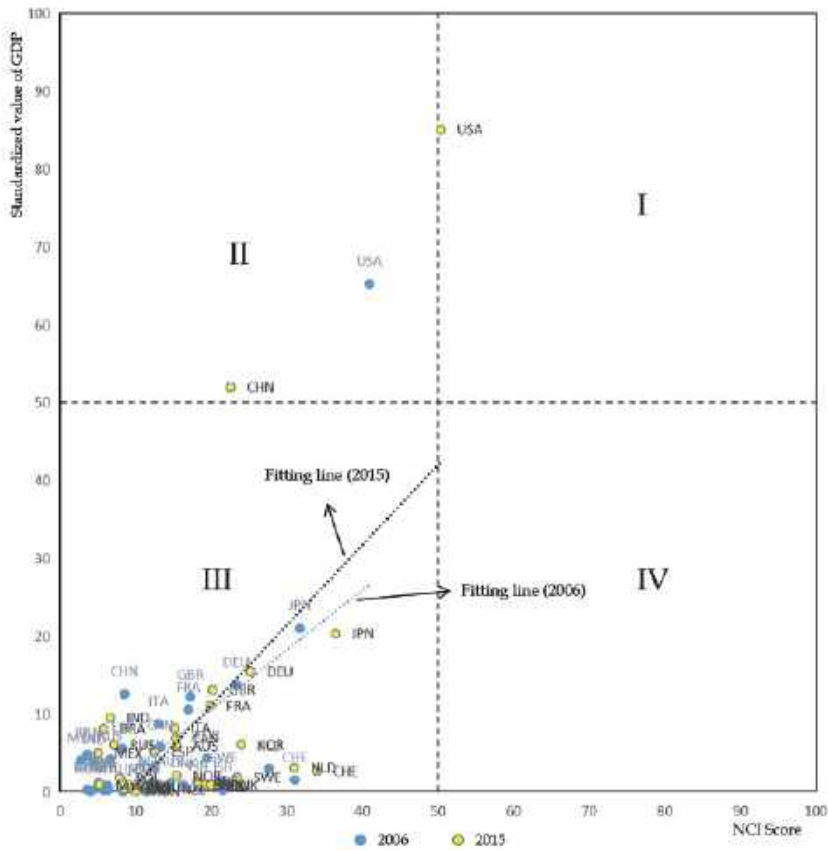
Fig. 10 Combined quadrant chart with the national S&T competitiveness index (NCI) score and the standardized value of GDP (2006 vs. 2015)

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[3] The algorithm used to standardize GDP or GDP per capita of the country C, among the 35 countries in 2006 or 2015, is $G_{Ct} = \frac{G_C - G_{min}}{G_{max} - G_{min}} \times 100$, where GCt is the GDP (or GDP per capita) value of the country C in the year of t; Gmin and Gmax are the minimum GDP (or GDP per capita) value and maximum GDP (or GDP per capita) value, respectively, in 2006-2020 among the 35 countries. The data in 2020 is estimated by trend extrapolation of the previous observation data.

[4] In this paper, * indicates that the correlation is significant at the level of 0.05 and ** indicates that the correlation is significant at the level of 0.01.

poor (NCI score equal to 22.56, 44.80% to the NCI score of the United States), sat in the third quadrant in 2006 and in the second quadrant in 2015 because of its increased GDP. Moreover, it is reminded from the details that there is much room for improvement for the United States, which possessed the best national S&T competitiveness, when facing needs for ideal long-term development.

To describe the relationship between the national S&T competitiveness and GDP of different countries more clearly, the ranking combination distribution map of the 35 countries in 2006 and 2015 in two dimensions is drawn (as shown in Figure 11). It can be seen that the traditional S&T powers, such as the United States, France, Germany, the United Kingdom and Japan, were all located in the upper right corner of the first quadrant, while the emerging economies, such as India, Brazil, Russia and other
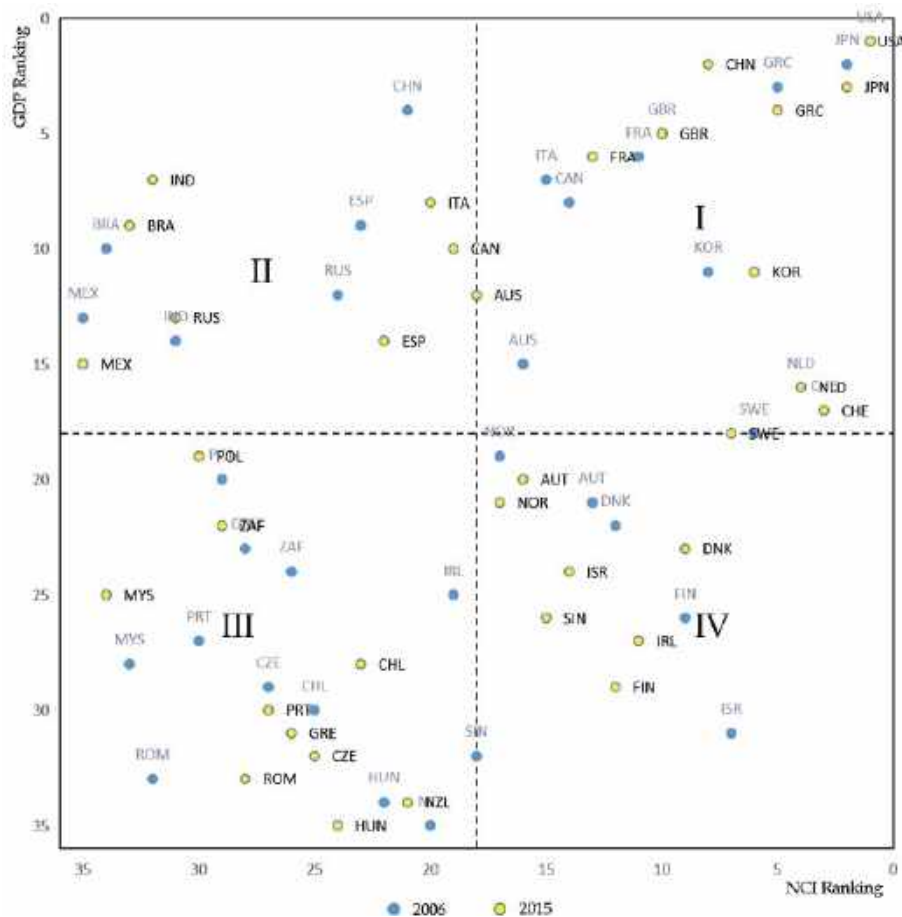
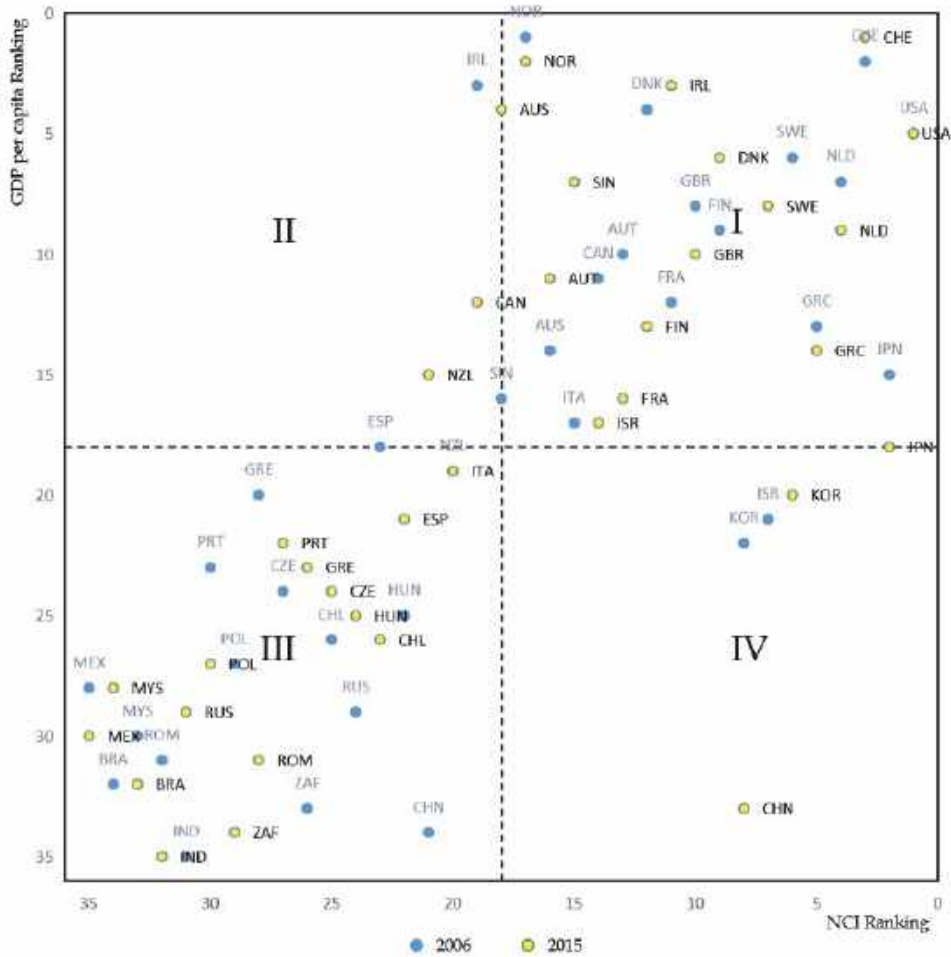**Fig. 11 Combined quadrant chart with the national S&T competitiveness index (NCI) ranking and the GDP ranking (2006 vs. 2015)**

countries with a dominant economic aggregate were mainly distributed in the second quadrant due to their weak national S&T competitiveness. Among them, China's performance was relatively prominent, and it leaped from the second quadrant in 2006 to the upper right corner of the first quadrant in 2015.

(2) The relationship between the national S&T competitiveness structure and GDP per capita

The Pearson correlation coefficient between the index value of the national S&T competitiveness and

the standardized value of GDP per capita of the 35 countries in 2015 was 0.577** (Spearman correlation coefficient was 0.705**), which indicates that there was a significant correlation between the index value of the national S&T competitiveness and the standardized value of GDP per capita. As is shown in Figure 12. These countries were distributed around the fitting line, indicating a roughly linear trend, with the exception of Norway, which was driven by its GDP per capita. The United States which possessed strong national S&T competitiveness (the index value equal to 50.36) deviated from the fitting line and set in Quadrant I, while most countries were clustered in the third quadrant, and the index value of the national
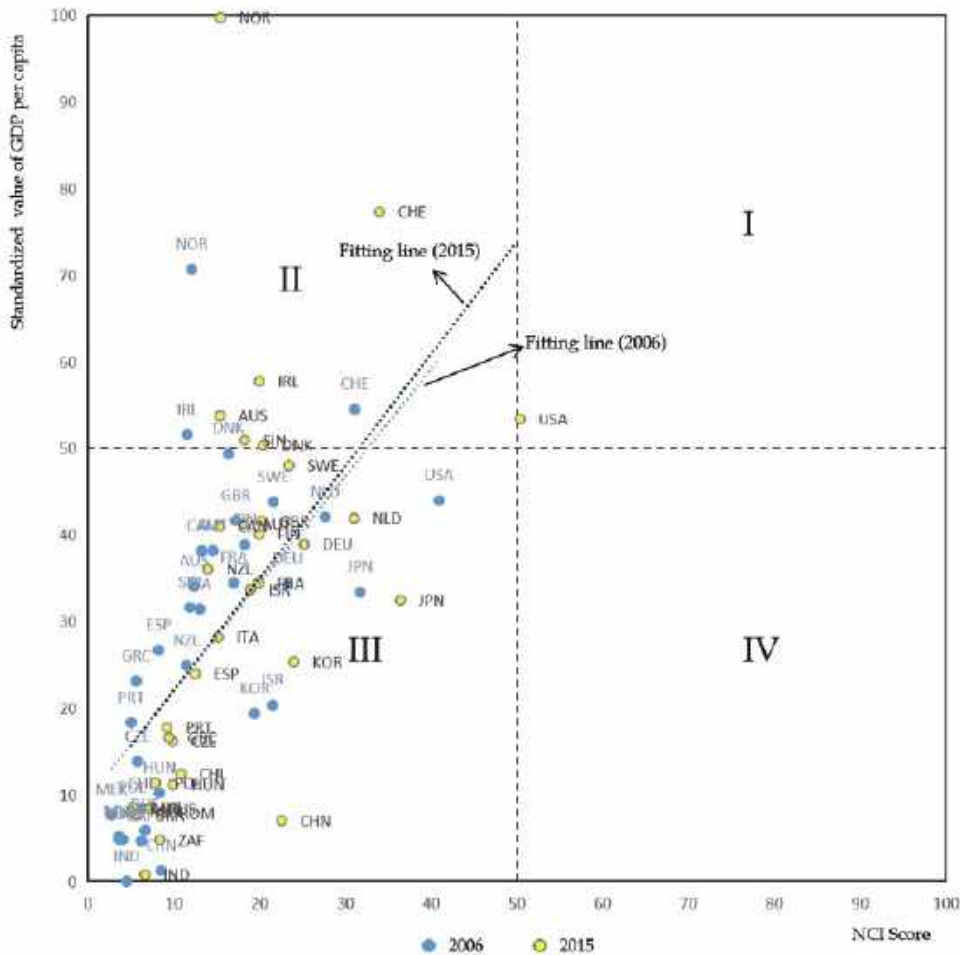
Fig. 12 Combined quadrant chart with the national S&T competitiveness index (NCI) score and the standardized value of GDP per capita (2006 vs. 2015)

S&T competitiveness was obviously low. In addition, most of the developed countries were in the upper part of the third quadrant or in the second quadrant due to their high GDP per capita. China's national S&T competitiveness was outstanding among emerging economies, but affected by factors such as large population size, its performance in GDP per capita was poor. On the whole, facing 2020, the level of the national S&T competitiveness of all these 35 major countries needs to be further improved.

To describe the relationship between the national S&T competitiveness and GDP per capita of different countries more clearly, the ranking combination distribution map of the 35 countries in 2006 and

Fig. 13 Combined quadrant chart with the national S&T competitiveness index (NCI) ranking and the GDP per capita ranking (2006 vs. 2015)

2015 in two dimensions is drawn. As is shown in Figure 13. It can be seen that the traditional S&T powers, such as the United States, Switzerland, France, Germany and Sweden, were all located in the upper right corner of the first quadrant, while emerging economies, such as India, Brazil, Russia and other countries with a dominant economic aggregate were mainly distributed in the third quadrant due to their large population size. Among them, China's performance was relatively prominent, and it leaped from the third quadrant in 2006 to the fourth quadrant in 2015. It should also be noted that while China's GDP per capita ranking has been improved slowly, and its economic construction still needs to be strengthened.

4.3.2. The influence of GDP or GDP per capita under the combination of strength and effectiveness

In order to further identify the relationship between the national S&T competitiveness structure and GDP and GPD per capita under the combination of strength and effectiveness, this paper employs the bubble chart with the abscissa for the CSI ranking, the vertical coordinate for the CEI ranking, and the bubble size as the external character for the standardized value of GDP or GDP per capita. As is shown in Figures 14-17. It can be seen that under the background of strength and effectiveness combination, the national S&T competitiveness structure has a significant relationship with GDP or GDP per capita.
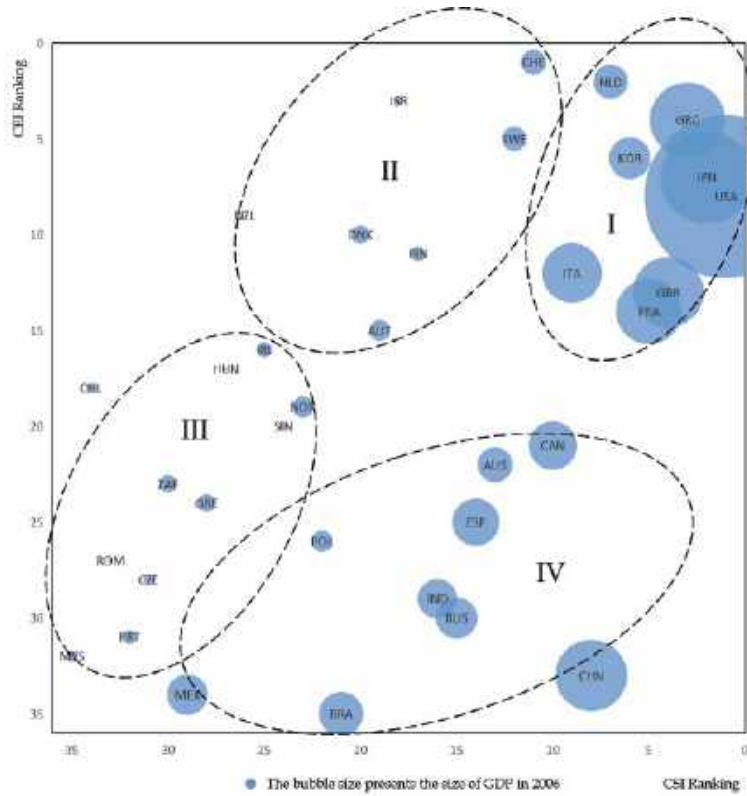
Fig. 14 Combined clustering distribution chart with the combination of CSI ranking and CEI ranking (2006)
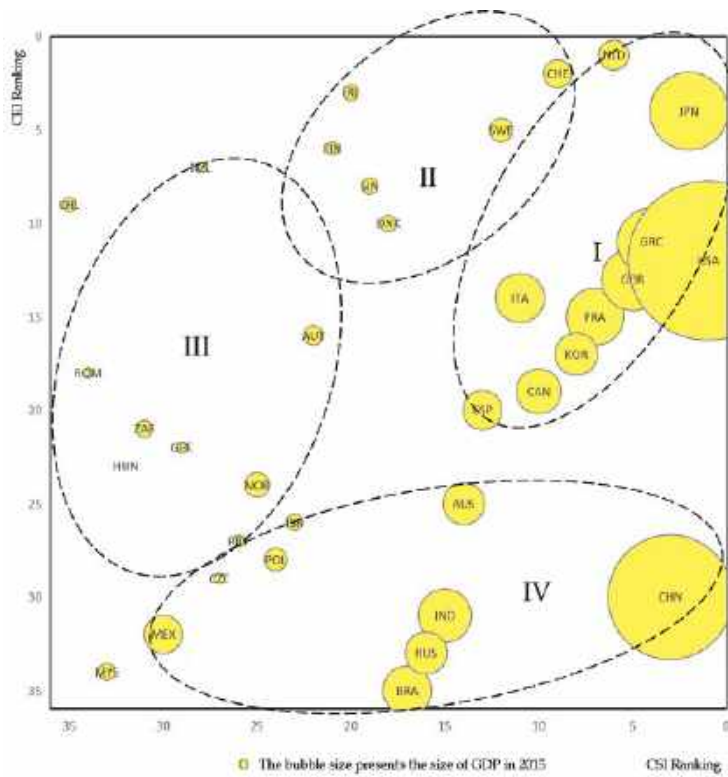

Fig. 15 Combined clustering distribution chart with the combination of CSI ranking and CEI ranking (2015)
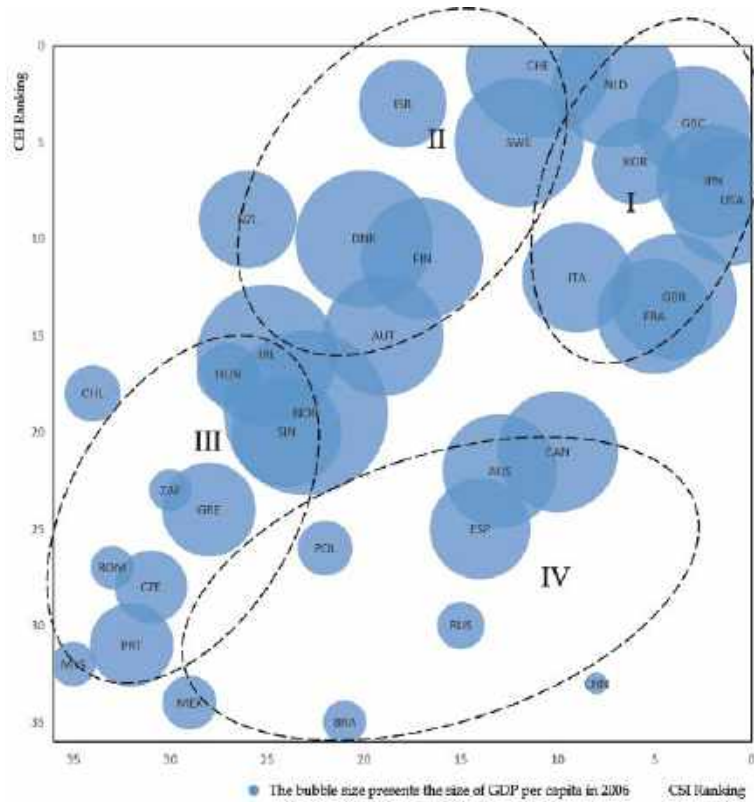
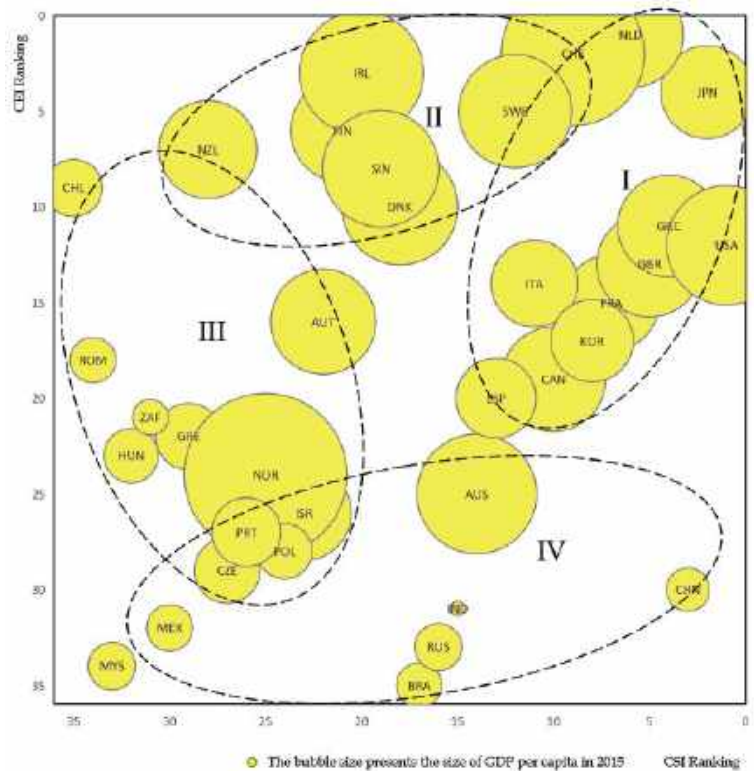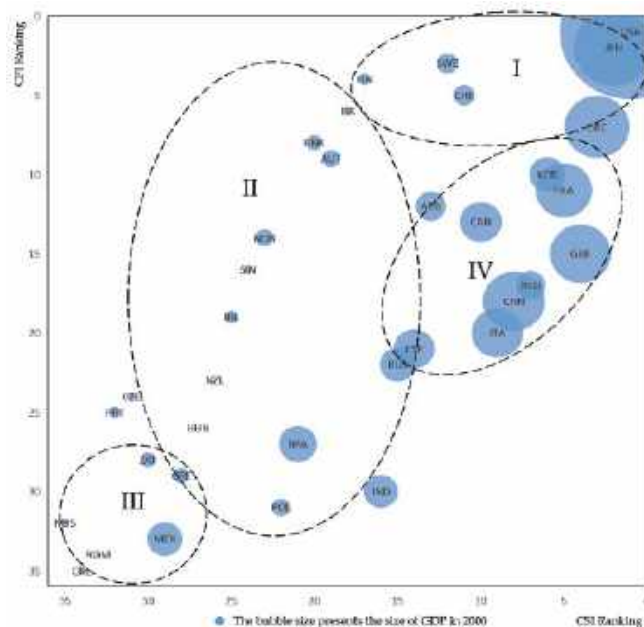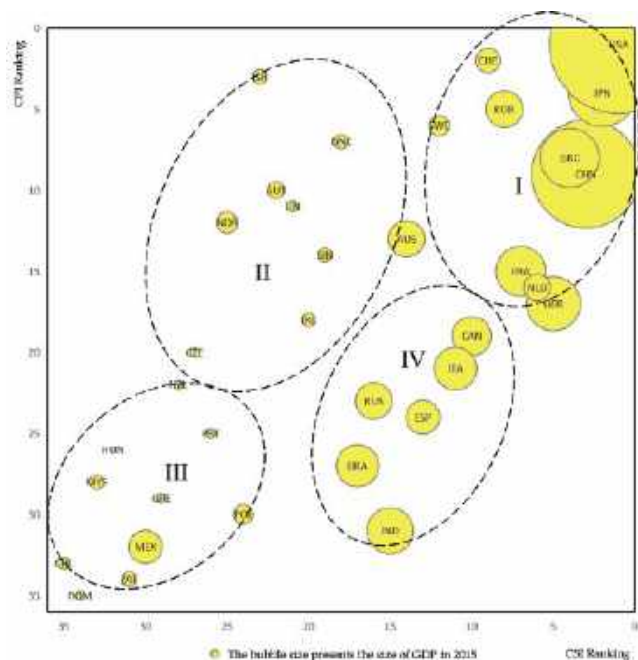**Fig. 16 Combined clustering distribution chart with the combination of CSI ranking and CEI ranking (2006)**

Fig. 17 Combined clustering distribution chart with the combination of CSI ranking and CEI ranking (2015)
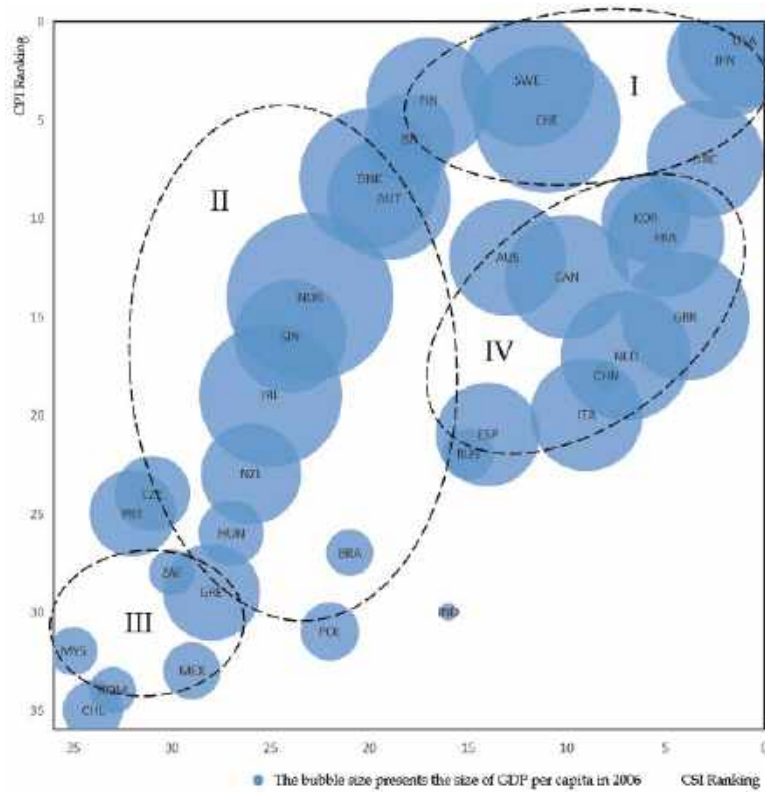
4.3.3. The influence of GDP or GDP per capita under the combination of strength and potential

In order to further identify the relationship between the national S&T competitiveness structure and GDP and GPD per capita under the combination of strength and potential, this paper employs the bubble chart with the abscissa for the CSI ranking, the vertical coordinate for the CPI ranking, and the bubble size as the external character for the standardized value of GDP or GDP per capita. As is shown in Figures 18-21. It can be seen that under the background of strength and effectiveness combination, the national S&T competitiveness structure has a significant relationship with GDP or GDP per capita, and the correlation is especially obvious with the former.

Fig. 18 Combined clustering distribution chart with the combination of CSI ranking and CPI ranking (2006)

Fig. 19 Combined clustering distribution chart with the combination of CSI ranking and CPI ranking (2015)

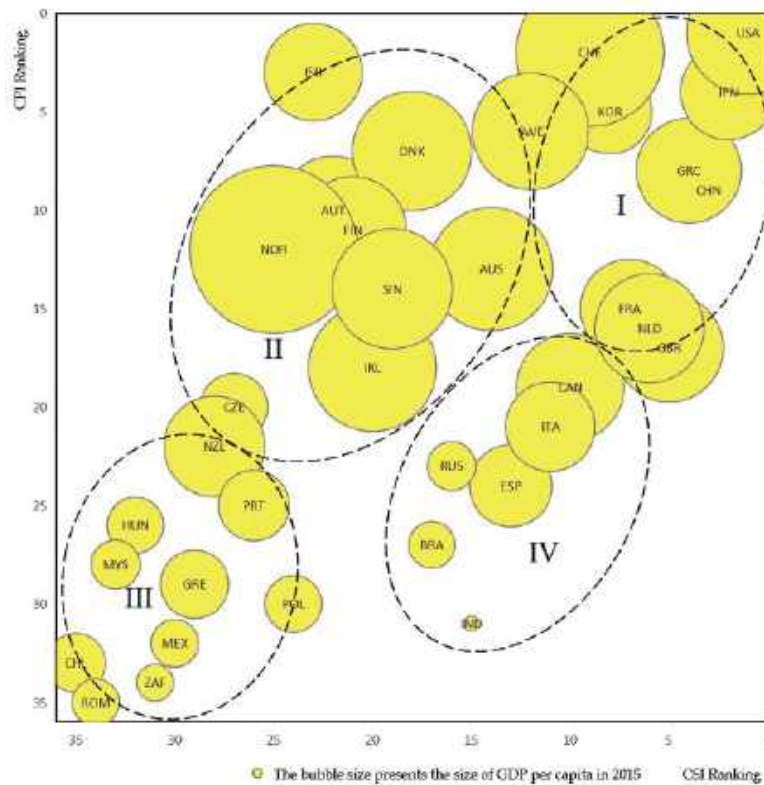**Fig. 20 Combined clustering distribution chart with the combination of CSI ranking and CPI ranking (2006)**

Fig. 21 Combined clustering distribution chart with the combination of CSI ranking and CPI ranking (2015)

4.3.4. The influence of GDP or GDP per capita under the combination of effectiveness and potential

In order to further identify the relationship between the national S&T competitiveness structure and GDP and GPD per capita under the combination of effectiveness and potential, this paper employs the bubble chart with the abscissa for the CEI ranking, the vertical coordinate for the CPI ranking, and the bubble size as the external character for the standardized value of GDP or GDP per capita. As is shown in Figures 22-25. It can be seen that under the background of effectiveness and potential combination, the national S&T competitiveness structure has no obvious relationship with GDP nor GDP per capita.
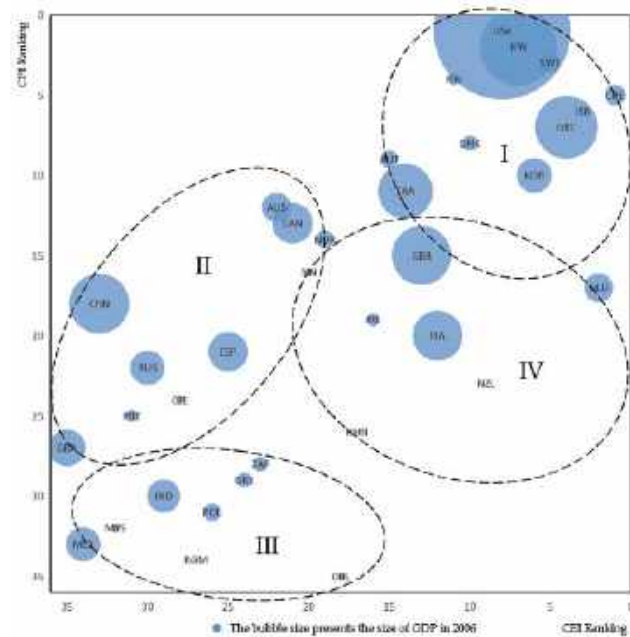

Fig. 22 Combined clustering distribution chart with the combination of CEI ranking and CPI ranking (2006)
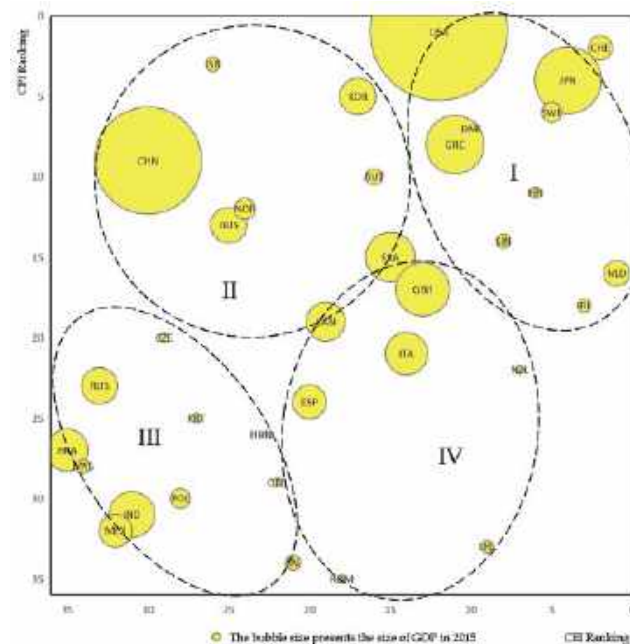

Fig. 23 Combined clustering distribution chart with the combination of CEI ranking and CPI ranking (2015)
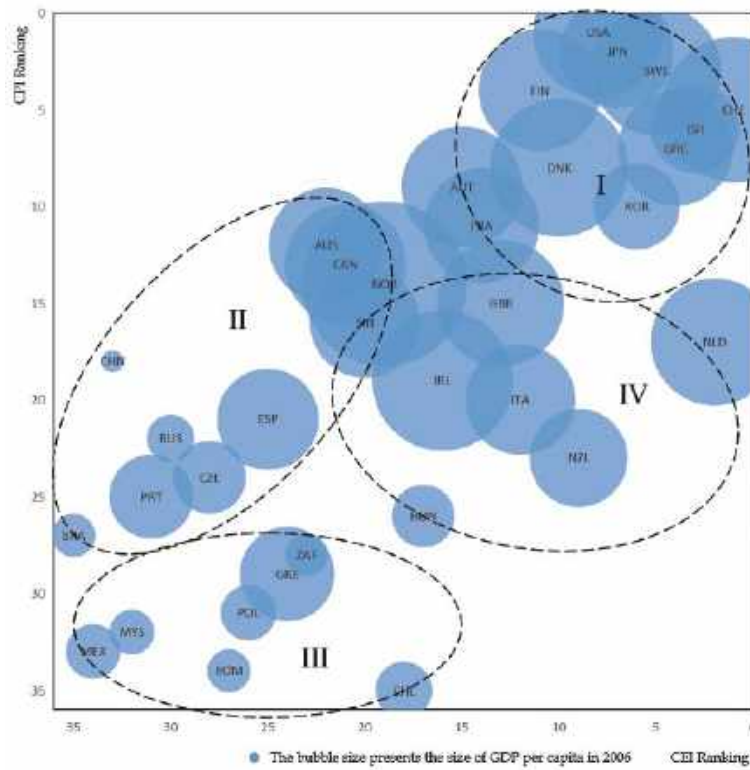
Fig. 24 Combined clustering distribution chart with the combination of CEI ranking and CPI ranking (2006)
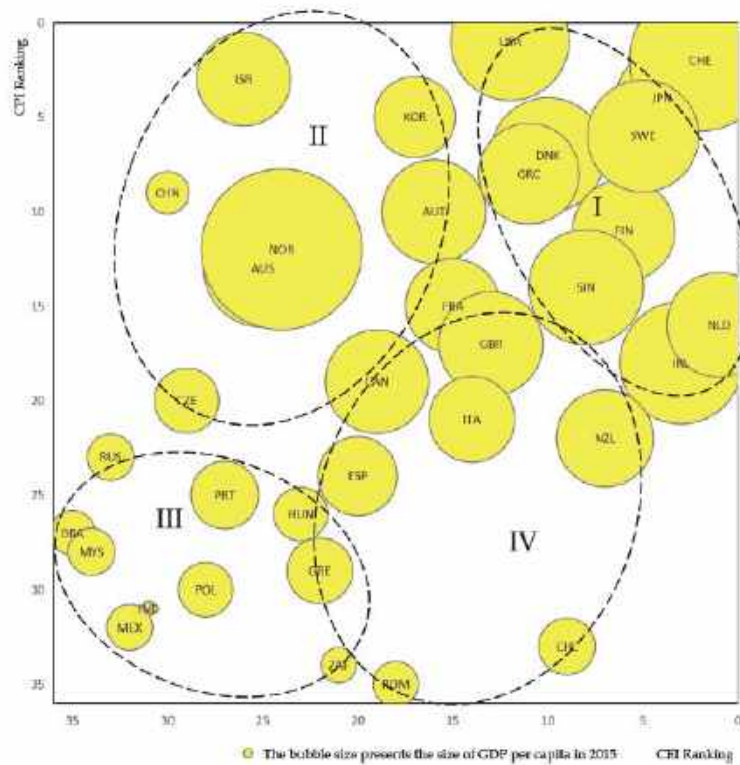

Fig. 25 Combined clustering distribution chart with the combination of CEI ranking and CPI ranking (2015)

5. Conclusion and Implications

This paper clearly defines the national S&T competitiveness structure and constructs an evaluation framework of the national S&T competitiveness from three indexes: the national S&T competitive potential index, the national S&T competitive strength index and the national S&T competitive effectiveness index. It takes into account the S&T input, the S&T output as well as the efficiency of transforming the S&T input into the S&T output. Then the structure analysis method is proposed and an empirical research is conducted with related data of 35 major countries. It draws attention to the influence of national comparative advantage on the national S&T competitiveness structure, and depicts and analyzes the national S&T competitiveness structure comprehensively and objectively, which is not only beneficial to accurately grasping the development tendency and international positioning in S&T innovation, but also of great significance to formulating national development strategies.

5.1. Conclusions

Firstly, this paper defines national S&T competitiveness as the ability of a country to mobilize, utilize and transform S&T resources under a certain international competitive environment, which can be described by three factors: the national S&T competitive potential, the national S&T competitive strength and the national S&T competitive effectiveness. The national S&T competitiveness structure refers to the position of a country and its relations with other countries, based on the national S&T competitiveness (composite index such as the national S&T competitiveness index; single index such as the national S&T competitive potential index, the national S&T competitive strength index and the national S&T competitive effectiveness index), within a spatial scope (*e.g.* the whole world, Asian countries) in a certain period of time. The definition of the national S&T competitiveness proposed in this paper not only attaches importance to the efficiency of the S&T resources transformation, but also takes into account the important influence of the national S&T activities' scale and the S&T resources mobilization capacity.

Secondly, the paper develops an evaluation framework of the national S&T competitiveness with three dimensions: the national S&T competitive potential, the national S&T competitive strength and the national S&T competitive effectiveness. The national S&T competitive potential is the precondition of the S&T activities and represents the influence of the quantity of S&T resources input. The national S&T competitive effectiveness emphasizes the transformation and value-added from the national S&T competitive potential to the national S&T competitive strength. As the most typical external embodiment of the achievements of S&T activities, the national S&T competitive strength is supported by the S&T competitive potential and is transformed from the S&T competitive effectiveness.

Thirdly, the paper develops a structure analysis method, which is used to analyze the national S&T competitiveness structure of 35 countries in the period of 2006-2015. The essence of the two-dimensional structure analysis method is to analyze the pair-wise interactive performance of the national S&T competitive potential, the national S&T competitive strength and the national S&T competitive effectiveness in the international competition environment, and to cluster the countries into M categories (M ≥ 2).

Fourthly, in the one-dimensional national S&T competitiveness structure, the top 5 countries were all developed countries in 2015, while developing countries generally performed better than developed countries considering the average annual growth rate of the national S&T competitiveness index. The two-dimensional structure analysis method clusters the countries into 4 categories under the pair-

wise interactive performance of the sub-indexes. For example, based on their ranking of the national S&T competitive strength index and the national S&T competitive effectiveness index in 2015, the 35 countries are clustered into four categories: high-strength and high-effectiveness, low-strength and high-effectiveness, low-strength and low-effectiveness, and high-strength and low-effectiveness, depicting the national S&T competitiveness structure.

Furthermore, to a large extent, there is a significant correlation between the national S&T competitiveness index score and the GDP per capita value. And to a certain extent, there is some correlation between the national S&T competitiveness index score and the GDP value. Moreover, it is found that under the background of strength and effectiveness combination, or under the background of strength and potential combination, the national S&T competitiveness structure and GDP or GDP per capita show significant relationship.

5.2. Policy implications

The structure analysis results show that the rapid promotion of the S&T competitiveness of China is mainly contributed by the fast scale expansion of S&T activities, while its S&T competitive effectiveness is still far behind that of developed countries. From 2006 to 2015, China's S&T competitiveness index ranking rose from the 21st to the 8th among the 35 countries, and took the first place in terms of the growth rate. China's S&T competitive strength index ranking rose from the 8th to the 3rd, and the S&T competitive potential index ranking rose from the 18th to the 9th. However, China's S&T competitive effectiveness index ranking only rose from the 33rd to the 30th, which implies that the improvement of efficiency, effectiveness and efficacy should be the core issue of the S&T policies of China in the future. Therefore, three policy implementations are proposed as following.

First of all, it is necessary to strengthen the guidance of science and technology policies. It is advisable to identify and select the most valuable research fields by conducting S&T development priorities-setting so as to make a forward-looking layout of strategic high-tech, basic science, technological science and engineering science research in the national science and technology programs. Secondly, it is necessary to strengthen the S&T performance administration. National science and technology programs should pay attention to the performance management for the national S&T projects and grants so as to optimize the allocation of S&T resources and guide innovators to improve the quality of scientific research output and the efficiency of S&T activities. Thirdly, it is necessary to strengthen the management of intellectual properties. There is a need for policy to improve the ability of intellectual property development and strategic management of innovators such as universities, public research institutes and enterprises subjects, and to improve the laws & regulations related to intellectual property protection so as to develop the value of intellectual property.

In short, this study on competitiveness and competitiveness structure offers a good reference for countries to understand their own competitive advantages and disadvantages, so as to formulate strategic policies to improve their S&T competitiveness. As *the Global Competitiveness Report* (Schwab and World Economic Forum, 2019) put it,"Competitiveness is not a zero-sum game between countries— it is achievable for all countries." The national S&T competitiveness emphasizes the comparison of scale, quality, efficiency and influence. To pursue competitiveness is a process to rise to the top. The structure analysis method proposed in this study offers implications for research on the industrial and regional competitiveness structure. However, there are still some limitations in this study due to the data availability and the complexity of the competitiveness issues.

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