

# International Comparison of Scientific and Technological Innovation -Input and Output

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**Abstract.** Strengthening the country with science and technology is a new strategy for China's economic development. However, lack of core technology in many fields limits the development of China's innovation. This paper collects and analyzes the data on the input and output of scientific and technological innovation in China, the United States, Japan and other major countries, then puts forward suggestions on how to improve the structure of public financial expenditure on science and technology, how to obtain scientific and technological funds through multiple channels, and how to adjust the structure of personnel engaged in R&D activities.

**Keywords:** Scientific and Technological Innovation Output; Scientific and Technological Innovation Input; Scientific and Technological Expense; Human Resources.

## 1. Introduction

Technological innovation is the strategy for economic development of major developed countries. It can also change the low-end industrial structure, the lack of competitiveness of products and the destruction of the ecological environment formed by the early economic development model of China. However, under the increasingly fierce competition between China and the USA in recent years, the US's policy has evolved to suppress Chinese technology companies. The dilemma that China faces under the trade war exposes that we are still controlled by some other countries in key technologies such as special materials and major components.

General Secretary Xi emphasized the need to strengthen basic research in his report to the 19th National Congress of the Communist Party of China, which requires absolute support from human, financial and policy resources. There are still many problems such as insufficient scientific research funds, low efficiency of output of technology expenditure. In addition, the high risk and difficulties in financing for small and medium-sized enterprises resulting in the reliance on government investment, tax incentives and fiscal subsidy.

## 2. Review on Literature

Scientific and technological innovation is the main development strategy of developed countries at present. However, different economic systems and social structures require different models. Dong Xin (2016) compared the innovation models from strategy, law, finance and talent of the developed countries, and suggested that China should improve the legal system of intellectual property protection, adjust the allocation of human resources and implement financial policies.

Empirical research on the role of China's fiscal expenditure on S&T (scientific and technological) output shows that the former does have a significant effect on promoting the latter, and the fiscal expenditure should maintain a long-term effect. Zhang Weilin (2016) analyzed the effect of fiscal S&T expenditure on local economic development in Fujian province, found that the effect in short term was weak, but after 10 years it began to have a lasting and steady impact. Xinglin and Sun Zhenzhen (2018) analyzed the dynamic relationship between S&T input and output in Qingdao, using R&D personnel and funding as input, and R&D Awards and invention patents as output. He found that there is a 4-year time lag between input and output, and suggested to optimize the allocation of S&T input and human resources to increase efficiency. Using VAR model, Cao Yijun and Hou Yuqiao (2021) proved that fiscal input to science and technology has a positive effect on the long-

term stability of innovation. Therefore, the fiscal investment should continue to focus on the key areas, and improve of quality of R&D personnel rather than to increase quantity.

The above research shows that fiscal investment is indispensable for S&T innovation. But some scholars revealed that the use of fiscal funds in China is unreasonable in some area, resulting in inefficiency of fiscal input. Cheng Li and Hu Diancheng (2018) found that, although the overall growth rate of Chongqing's local financial technology investment budget is large, there are still problems mentioned above, and he suggested to improve the overall allocation mechanism for S&T resources, increase investment in basic research, environmental protection, and agriculture, cutting-edge and high-tech fields. An Huaxuan et al. (2018) found that a large amount of fiscal S&T funds were used in non S&T fields in Yunnan Province.

The input of S&T is not only from government, but also from financial institutions, capital markets, and venture capital. Some scholars have verified the relationship between market funding and technology output. Zhou Tianyun et al. (2014) did an empirical study on the relationship between financial development and economic development in several different regions in China, and found that the development of financial centers played a significant role in promoting regional economic growth in both short-term and long-term. However, scholars also generally found that China's S&T funding from market is insufficient. Yang Nenxiao and An Zetong (2021) constructed a synergy index to measure the coordinated development of technological finance and technological innovation based on data from Shanxi Province, which showed a low-level. So they proposed to speed up the reform of technological finance, and increase the intensity of tax incentives, financial subsidies, and rewards for the transformation of scientific achievements.

Some scholars compared the use of S&T funds in developed countries with China, and pointed out that the China's S&T expenditures is not very effective. For example, Tian Yuan and Zhou Shujun (2017) believed that although the contribution of scientific and technological progress have increased significantly in recent years, the proportion of investment on basic research was still low, conversion rate of scientific and technological achievements was low, and school-enterprise synergy effect was insignificant. Chen Yaping and Wang Shenghua (2021) made a statistical analysis of the scale and structure of China's financial expenditure on S&T, which showed that although the overall scale of current financial investment on S&T was increasing, the structure was unreasonable, especially in the the proportion of investment in basic research, which is too low compared with other major countries. In addition, the authors also pointed out that although the quantity of China's scientific and technological output is leading in the world, the quality and output per unit of expenditure are still relatively low.

In addition to financial resources, human resource is another important factor for innovation. Gu Junjian and Zhao Yulin (2021) showed that the synergy of S&T innovation and human capital can promote manufacturing productivity based on empirical analysis. They believed that the low proportion of scientific researchers was the reason why China's S&T innovation was difficult to break through. Therefore, it is suggested that more attention should be paid to the investment of R&D personnel and to raise the salary of the innovation department to attract high-end talents.

The current scholars' general view on the development of science and technology is that China's current innovation strength has made great progress, but there are some deficiencies in quality. Funding sources, structure of fiscal expenditure on S&T, tax policies and subsidy policies need to be improved. This paper will compare the scientific and technological input and output among China and several technologically advanced countries based on the real data in recent years, and put forward advice on how to adjust the allocation of S&T input and output.

### **3. International Comparison of Scientific and Technological Output**

#### **3.1 PCT international patent applications**

PCT (Patent Cooperation Treaty) is an international cooperation treaty in the field of patents. The number of PCT patent applications accepted refers to the number of PCT patent applications accepted

by the State Intellectual Property Office. Table 1 below is the PCT patent data of major countries in the world since 2010. All the data are sourced from "China Statistical Yearbook Science and Technology".

**Table 1.** The number of PCT patent applications in major countries in recent years.

Country (Region)	China	USA	France	Germany	Japan	Korea	UK
2010	12300	45088	7230	17560	32216	9604	4892
2011	16396	49206	7406	18846	38864	10357	4874
2012	18616	51857	7801	18749	43523	11787	4918
2013	21506	57451	7905	17922	43772	12381	4849
2014	25542	61488	8260	17983	42381	13119	5267
2015	29837	57132	8420	18004	44053	14564	5291
2016	43092	56592	8210	18308	45210	15555	5504
2017	48904	56685	8014	18951	48205	15751	5568
2018	53352	56156	7919	19748	49708	17013	5634
2019	59050	57692	7938	19327	52686	19075	5770
2020	68764	58730	7765	18538	50559	20054	5900

As can be seen from the above table, since 2019, the number of applications from China has ranked first among countries. In 2021, it will account for more than a quarter of all with 69,540 applications, surpassing the 59,570 in the United States and 50,260 in Japan. China's technological innovation strength has grown rapidly in recent years.

### 3.2 Scientific research papers

In recent years, the number of scientific research papers in China has increased significantly. The number of scientific papers and the number of citations are shown in Table 2, according to the Essential Science Indicators database, from January 2011 to September 9, 2021.

**Table 2.** Top 10 countries and regions by number of ESI papers.

Rank	Country	Number of Papers	Cited Times
1	USA	4379730	87553897
2	China	3465661	45591820
3	UK	1396742	29822342
4	GermanyG	1186919	22824920
5	Japan	875069	12290608
6	France	802799	15205668
7	Italy	758293	13434758
8	Canada	751647	14517245
9	India	725360	8132863
10	Australia	690031	13270891

In terms of the number of scientific papers and the frequency of citations, China is ranking second, just after the United States. The number of papers is relatively close, but the gap between the number of citations and the United States is still large, indicating that China's scientific research papers are still far less widely referenced than in the United States.

## 4. International Comparison of Investment in Scientific and Technological Innovation

S&T investment mainly includes financial investment and human investment. Usually, R&D expenditure is used to express a country's investment in scientific research, and it is measured by the number of R&D personnel.

### 4.1 R&D expenditure

Research and experimental development is the first step of scientific and technological innovation. R&D expenditure is an important financial guarantee for innovation, it can show how much the importance a country attach to scientific and technological innovation. The table below shows the R&D expenditures of major countries from 2010 to 2019 (the data after 2020 is not available except for China). Due to the different sizes of countries, we use the proportion of R&D expenditures to GDP to make a comparison horizontally.

**Table 3.** Proportion of research and experimental development (R&D) in major countries to GDP.

Country (Region)	China	USA	Japan	UK	Francee	Germany	Swedenn	Korea
2010	1.71	2.74	3.10	1.64	2.18	2.73	3.17	3.32
2011	1.78	2.77	3.21	1.65	2.19	2.81	3.19	3.59
2012	1.91	2.68	3.17	1.58	2.23	2.88	3.23	3.85
2013	2.00	2.71	3.28	1.62	2.24	2.84	3.26	3.95
2014	2.02	2.72	3.37	1.64	2.28	2.88	3.10	4.08
2015	2.06	2.72	3.24	1.65	2.27	2.93	3.22	3.98
2016	2.10	2.79	3.11	1.66	2.22	2.94	3.25	3.99
2017	2.12	2.85	3.17	1.68	2.20	3.05	3.36	4.29
2018	2.14	2.95	3.22	1.73	2.19	3.12	3.32	4.52
2019	2.24	3.07	3.20	1.76	2.20	3.19	3.39	4.64

China's R&D expenditure has been increasing in recent years, but there is still a certain gap compared with the United States, Japan, Germany and other scientific and technological powers. In 2019, many countries surpassed China in the proportion of R&D expenditure to GDP, such as the United States, Japan, Germany, Sweden, and South Korea, as well as Austria, Belgium, Denmark, Finland, and Singapore, which are not included in the table due to space limitations. Compared with China's entire economy, there is still a lot of space for improvement in scientific research funding.

### 4.2 Source of R&D funding

The source of R&D funding can show the financial contribution of the government and the market in the R&D stage. The table below shows the proportion of each component of R&D expenditure on technological innovation in major countries. Due to the different time of the latest data obtained for each country, the table indicates the year of each country's data.

**Table 4.** Proportion for each department of R&D funding sources in major countries (%).

Country	China	USA	Japan	UK	Francee	Germany	Swedenn	Korea
year	2020	2019	2019	2018	2019	2019	2017	2019
corporate funds	77.5	63.3	78.9	54.8	56.7	64.5	60.8	76.9
government funds	19.8	25.9	14.7	25.9	32.5	27.8	25.0	20.7
Other funds	2.8	10.7	6.4	19.3	10.8	7.7	14.2	2.4

As can be seen from the above table, most of China's R&D funds come from the enterprises themselves, the proportion of R&D funds from the government is lower than that of other countries except for Japan. R&D funds from financial institutions and capital market accounted for only 2.8%,

significantly lower than other countries except South Korea. These show that my China's scientific and technological innovation mainly relies on the support of enterprises themselves and part of the government, while market funds are not giving a strong support. The reason of this situation may be that China's financial institutions and capital market funds are obvious risk averse to new products development, and this creates the funding pressure for scientific and technological enterprises and lead to insufficient innovation support and limited development.

### 4.3 R&D Funds Execution Department

From the proportion of funds executed by different departments in each country, we can see the comparison of the main users of R&D funds.

**Table 5.** Proportion of R&D expenditure of each part of the executive department (%).

Country	China	USA	Japan	UK	Francee	Germany	Swedenn	Korea
Year	2020	2019	2019	2019	2019	2019	2019	2019
Enterprises	76.6	73.9	79.2	66.6	65.8	63.2	71.7	80.3
Government	14.0	9.9	7.8	6.6	12.4	12.6	4.5	10.0
Higher education sector	7.7	12.0	11.7	23.1	20.1	22.5	23.7	8.3
Other departments	1.8	4.2	1.4	3.7	1.7	1.7	0.1	1.4

The main executive departments of China's R&D expenditures, like most countries, are enterprises. However, the proportion of R&D expenditure executed by the higher education department is the lowest among the listed countries, and the proportion of the government sector is the highest among the listed countries. Except for South Korea, the proportion that executed by higher education departments in other countries is significantly higher than that of government departments. But in China, the latter is nearly twice of the former. This is mainly due to the fact that a lot of R&D funds from Chinese government are used on enterprises as subsidies and investment in innovative activities. However, colleges and universities are important incubators of scientific and technological innovation achievements, and are important in the contribution in the first stage of scientific and technological output. Without sufficient financial support, the development of scientific research will be hampered.

### 4.4 R&D personnel

China has being paying great attention to education after solving the problem of food and clothing. At the same time, the national economic development made the national income increase year by year. No matter from government or family, the investment in education is steadily increasing. The number of people with higher education is increasing rapidly, which can be the reserve of scientific researchers.

As can be seen from Table 6, the absolute number of researchers engaged in R&D in China in recent years exceeds 5.23 million in 2020, including more than 2.2 million specialized researchers. However, compared with other countries, the ratio of researchers to R&D staff is the lowest among all the listed countries, and the gap is large. Of course, a country's R&D personnel do not necessarily need to grow proportionally with total population if their quality is sufficient to support the development of science and technology.

In addition, we calculated the proportion of researchers among R&D personnel. In China, it is about 43%, while more than 60% in other countries, even more than 80% in Sweden and South Korea. According to the classification of the State Administration of Taxation of China, the composition of research and development personnel is divided into three categories: researchers, technical personnel and auxiliary personnel. It shows that technical personnel and auxiliary personnel are much more than researchers, who can really creat scientific innovation.

**Table 6.** Number of R&D personnel in major countries.

Country	China	USA	Japan	UK	Francee	Germany	Swedenn	Korea
Year	2020	2018	2019	2019	2019	2019	2019	2019
Personnel engaged in R&D activities (thousand)	5234.5	-	903.4	486.1	463.7	735.6	91.2	525.7
Researchers among the above	2281.1	155.5	681.8	317.5	314.1	450.7	77.6	430.7
Personnel engaged in R&D activities per 10,000 employers	70	-	130	148	163	163	178	194
Researchers among the above	30	98	98	97	110	100	151	159
The ratio of researchers to R&D staff	43.58%	-	75.47%	65.32%	67.74%	61.27%	85.09%	81.93%

## 5. Summary and Suggestions

### 5.1 Improve the quality of China's scientific and technological innovation output

Judging from the number of PCT patent applications mentioned above, its absolute value has already ranked first in the world, and its growth rate is also faster than that of other countries, indicating that China's S&T innovation will be ranked first in the world for at least the next several years. In terms of the scientific research papers, the total number of papers in China is second only after the United States, and has been increasing obvious in recent years. Even the number of new additions every year has a trend of surpassing the United States. However, in contrast, the number of citations of papers from Chinese scholars is only about half of the US, which shows that the innovative value provided by papers from China is generally not high and not been used widely as reference. In fact, most of the content, methods and viewpoints of scientific research papers in China are highly repetitive, but there are not too many new ideas. As the first-stage output of scientific and technological innovation, the innovative value of scientific papers is very important. Therefore, the current environment of scientific research in China needs to be improved. It is necessary to encourage more creative research and reduce constraints. Quality and innovative value should be given more importance, rather than the accumulation of quantity.

### 5.2 Improve resource allocation for scientific and technological innovation investment

As can be seen, the proportion of China's R&D expenditure in GDP is relatively low among the major countries except for UK, and far lower than the United States in absolute value. The main course of the lack of funding is mainly due to the weak of mobilization of technology funds in the market.

In addition, the proportion of S&T funds implemented by different departments in China is unreasonable. The higher education sector, where scientific researchers gather, should take up more funds. The proportion of expense used by higher education sector is higher than by government in other major countries except for South Korea, while expense used by higher education sector only accounts for about half of the government.

The absolute number of scientific researchers in China far exceeds that of other countries, and the scientific research funds per personnel is much less than that of other countries, resulting in

insufficient financial support for basic research. In the current stage of national economic transformation, many important matters of national economy and people's livelihood needs financial support, so the government should encourage the development of market-sourced S&T funds, use various favorable policies to attract social investment, and leverage idle private funds. Those funds will give great financial support to the scientific and technological innovation.

At last, the proportion of R&D personnel in China who specialize in research is much lower than that of other countries. Most of the personnel engaged in R&D activities are not capable of making breakthroughs in basic research, which may lead to slow development of innovation. Therefore, reducing the proportion of auxiliary personnel and technical personnel, introducing high-end talents with innovative strength, and providing a sufficient research environment are the keys to improving my country's innovation strength.

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