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R&D in China: the scale and specifics of the innovation process

La investigación científica en China: el alcance y los detalles del proceso de innovación

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ABSTRACT:
This article covers an important topic, which is relevant to the development of innovation processes in one of the most rapidly developing countries, China. Considering the scale, structure and dynamics of research and development activities (R&D) it is a main tool for assessing the development of the country's innovation process. The purpose of this study is to examine the scale and specifics of modern innovation processes in China by considering relevant basic indicators of the R&D development in China. The authors determined China's place in the global innovation investment process, presented and analyzed a wide range of statistical data, which describes the resource intensity and results of the R&D in this country. This analysis was carried out in an institutional context featured by separate consideration of development indicators of research, education and business components of the R&D.
Keywords: Innovations in China, innovation process, national economy, R&D financing.

RESUMEN:
El artículo está relacionado con el desarrollo de procesos de innovación en uno de los países en desarrollo más activos del mundo: China. La consideración de la escala, estructura y dinámica de la implementación de la investigación y el desarrollo (I+D) son las herramientas para evaluar el desarrollo del proceso de innovación en dicho país. El propósito es estudiar el alcance y los aspectos específicos de los procesos modernos de innovación en China, considerando los indicadores básicos relevantes del desarrollo de su área de investigación. Los autores determinan el lugar que ocupa China en el proceso global de inversión en innovación, presentan y analizan los extensos datos estadísticos que caracterizan la intensidad de recursos y los resultados de la I + D en ese país. Este análisis se lleva a cabo en un contexto institucional: los indicadores del desarrollo del sector de investigación, la esfera científica y educativa y el componente de negocios de I + D se consideran por separado.
Palabras clave: Innovación china, Proceso de innovación, economía nacional, financiamiento de I+D.

1. Introduction

The crucial tendency of modern global economic development is a sustainable growth of innovation processes that are expressed in multiple features and signs. Since 1960s positive

changes in the innovation activity in both developed and developing countries has provided the basis for the development of production powers of their economies, notably such countries as the USA, Germany, South Korea, China etc. The interrelation between the innovation process and economic growth is the reason behind innovation-related issues going beyond the scope of science or business only, thus gaining national importance for each of developing countries (*Nikonova, 2016*).

Examination of country specifics of innovation processes allows to detect the most effective models of innovation development and accumulate and use a valuable experience of others' successes and mistakes. The combination of basic science development and applied studies is a continuous innovation process, which is taking place in modern developing countries. One of such developing countries is China, dubbed a «hot spot» of global innovations by the World Intellectual Property Organization (WIPO). Two areas, which were leading by their numbers of international patent applications in 2011-2015, were identified as those of the highest level of innovation activity: Shenzhen-Honk Kong (2nd place in the world, 41200 applications) and Beijing (7th place in the world, 15200 applications) (*WIPO, 2017*).

The interest in the innovation process, which exists in China, is quite logical: China is among global leaders in terms of both amount of R&D financing and performance of the innovation process. During the recent decade the issues relevant to Chinese innovation development have attracted close attention of scientists from various countries. In particular, Chinese scientists consider factors of the innovation development and types and sources of R&D financing. They put an emphasis on their national human potential as a crucial strategic resource that ensures China's national competitiveness in the global economy (*Hu* et al., *2007*). Russian scientists point to substantial growth of the global scientific potential of China and its readiness and possibility to occupy leading positions in global science and innovations and also analyze the issues and the consequences of such powerful innovation process (*Berger, 2017*; *Krasova, 2016*). Scientists of the University of Cambridge and other Western universities detect statistical links between innovation and economic development in their various aspects (*Whalley* et al., *2010*; *Wen* et al., *2018*; *Chen* et al., *2018*). Justin Yifu Lin, a well-known Chinese economist, highlights R&D financing, capital accumulation, industrial modernization and new technologies as the factors of transition to the «advanced market economy» (*Lin, 2012*).

Yet Chinese innovation process and its research component, scale and specifics still constitute a relevant subject of consideration due to the changes in domestic and external conditions, state policy directions and other factors. The purpose of this study is to examine the scale and specifics of modern innovation processes in China by using relevant basic indicators of Chinese research development. The subject of this study is the scale and specifics of the innovation process in modern China, while its scope is the scope and structure of R&D being conducted, which are studied in terms of national economic development.

2. Methodology

Methodological basis of this article comprises is formed by general provisions of modern economics, notably modern macroeconomic theory, global economic development theory, innovation development concept, human capital theory and general adaptation theory applied by means of system analysis. In terms of its methods the study is based on economic and institutional analyses, comparative studies, expert assessments, structural and statistical analyses, socioeconomic forecast and also approaches that are globally used for making management decisions.

The authors followed the concept, which determines the leading role of innovations in economic growth of modern developed and developing countries, and considered outstripping amounts of R&D financing as the main basis for the innovation process, Thus, the authors paid close attention to the analysis of amount and structure of R&D expenditures in both research and education fields and in business.

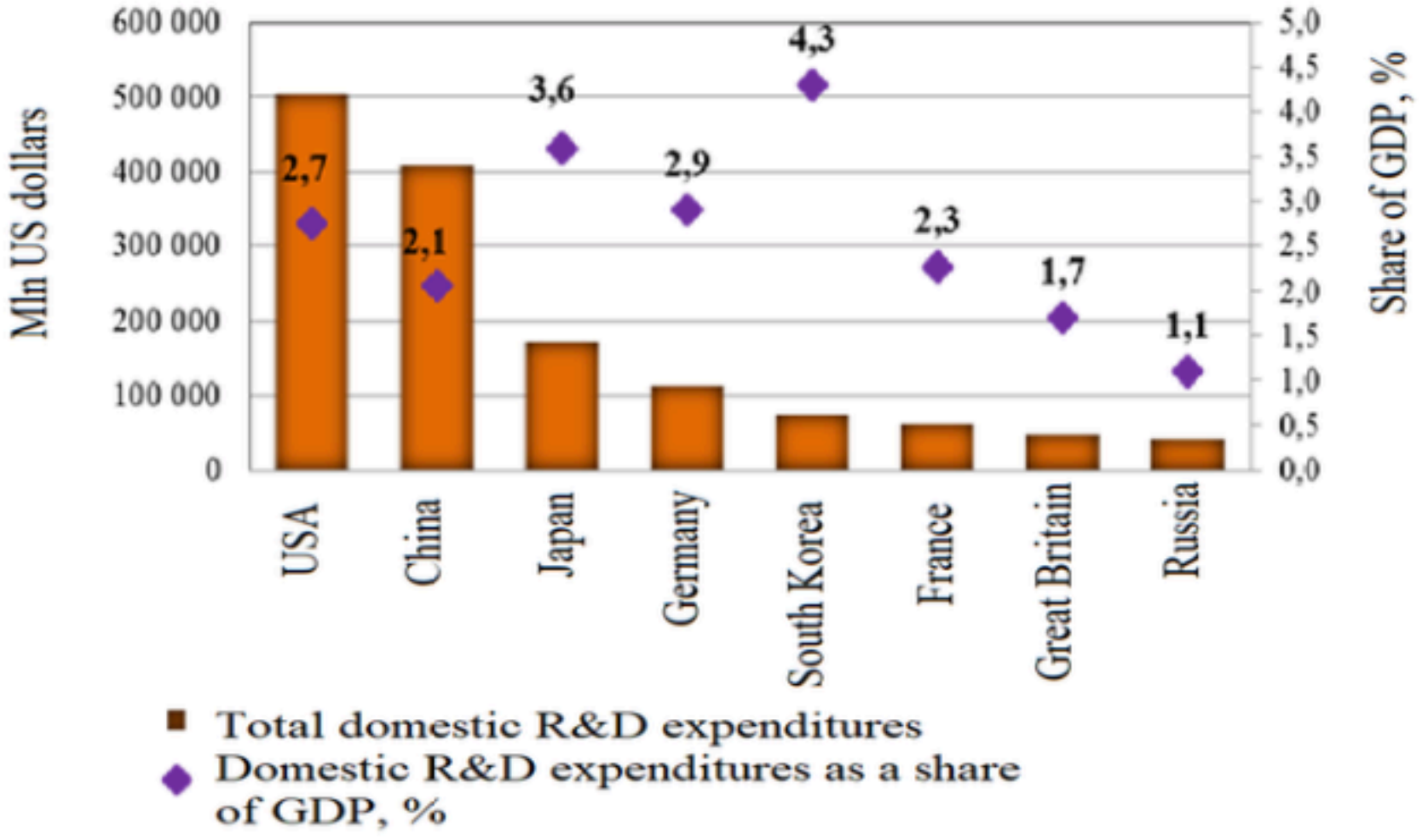
3. Results

3.1. General trends in Chinese innovation development

According to the «Main Science and Technology Indicators» data of the Organization for Economic Cooperation and Development, the USA, China, Japan, Russia, Germany and South Korea are global leaders in terms of aggregated amount of domestic R&D expenditures (by their absolute cost values). Continuous positive dynamics of increase in R&D expenditures during 2004-2016 were confirmed in all of these countries and also some other ones. In terms of the absolute amount of R&D expenditures made the USA is leading the field, with its relevant annual expenditures being several times as large as those in Germany, Russia, South Korea, France and the Great Britain combined. In 2016 annual R&D expenditures in the USA exceeded 500 bln dollars, thus setting an absolute record that remains unbeaten. The 2nd place has been firmly occupied by China since 2010, which is gradually getting closer to the USA in terms of innovation financing. During the recent decade the USA has increased the annual amount of its R&D expenditures by 50% (175 bln dollars), while the same increase in China was 4.7 times (322 bln dollars) (*OECD, 2017*). It is also worth noting that R&D expenditures as a share of GDP in the USA remains stable at 2.75%, while in China it is gradually increasing: from 1.32% in 2005 to 2.05% in 2016 г. (*FSSS, 2017*). With that fact in mind, nowadays the USA can hardly be called a leader of innovation development, since it shares its leading positions with China. Other countries are still lagging behind the leaders in terms of the amount of financing, though some of them show considerable increase in innovation quality (Figure 1).

Figure 1

Amount of R&D financing in the innovation-leading countries, 2016



Source: compiled by the author on the basis of (OECD, 2017).

The amount of financing is not the only indicator of a national economy's leaning towards innovation. A number of respected scientific and academic organizations constitute the Global Innovation Index, an integrated rating indicator that is calculated for each country and takes into account the amount and quality of available resources, innovation environment and also the efficiency of innovation and innovation activity. In 2017 24 out of the top 25 places were occupied by the countries with high income-per-capita levels, with the exception of China (21st place). In 2016 China became the first country with middle income level to join the top 25 countries of the innovation ranking (*GII, 2017*).

The foregoing expert opinion is backed by a wide range of statistical data on research development in China, which show a continuous development of the innovation process and active involvement of even larger amount of workforce, equipment, materials and other resources in this process by all indicators and areas of the innovation activity. The innovation process in China is also featured by qualitative institutional component, which means that a number of research and educational institutions rapidly increases and extends in accordance with additional functions and areas of studies. Table 1 shows general data on innovation institution development in China.

Table 1
The most relevant indicators of the research component
of Chinese innovation process, 2011–2016

Indicator	Unit	2011	2016	Change, %
Research labor input, including those of:	1000 person-year	2883	3878	134,51%
- basic studies	1000 person-year	193	275	142,49%
- applied studies	1000 person-year	353	439	124,36%
- experimental and laboratory studies	1000 person-year	2337	3164	135,39%
R&D expenditures, including those on:	bln yuan	868,7	1567,7	180,47%
- basic studies	bln yuan	41,2	82,3	199,76%
- applied studies	bln yuan	102,8	161,1	156,71%
- experimental and laboratory studies	bln yuan	724,7	1324,3	182,74%
Total amount of state budget expenditures	bln yuan	188,3	314,1	166,81%
Total amount of private investor expenditures	bln yuan	642,1	1192,4	185,70%
R&D expenditures as a share of GDP, %	%	1,78	2,11	118,54%

Source: compiled by the author on the basis of (NBSC, 2017)

As Table 1 shows, the amount of expenditures on and labor input of all types of studies, including basic, applied, experimental and laboratory ones, are growing at substantial rates. In terms of the labor input, i.e. the number of participating staff, the largest share (81) belongs to experimental and laboratory studies, which reflects a trend towards an active commercialization of scientific results and development of new things the economy actually needs: new types of materials, resources, products etc. As for fundamental and applied studies, their share of labor input is only 19%, yet they too demonstrate sustainable growth rates, since all types of studies are carried out simultaneously.

Yuan-denominated R&D expenditures too show the prevalence of experimental and

laboratory studies as a share of the total amount of expenditures (84%), which points to their key importance to Chinese economy.

Of the total amount of R&D expenditures in 2016, the largest share belonged to those borne by private sources, which brings China closer to the level of developed countries: according to Chinese data, such share was 76.1% of the total amount of expenditures. R&D expenditures as a share of GDP calculated on the basis of Chinese statistical data correlates with those of global statistical data and currently slightly exceed 2%.

Nowadays China pays particular attention to the efficiency and performance of the R&D. The performance of scientific studies can be measured by the following indicators: number of published academic papers, number of received awards and respected academic prizes, number of approved grants etc. (Table 2).

Table 2
Statistical data on research performance
in China, 2011–2016

Indicator	Unit	2011	2016	Change, %
Number of published academic papers	ths units	1500	1650	110,00%
Number of published papers on science and technology	ths units	45,5	53,3	117,14%
Number of achievement in high-priority fields of science and technology	ths units	44,2	58,8	133,03%
Number of received national invention awards	unit	55	66	120,00%
Number of received national awards relevant to scientific progress	unit	283	171	60,42%
Number of obtained patents	ths units	1633,3	3464,8	212,13%
Number of approved grants	ths units	960,5	1753,8	182,59%

Source: compiled by the author on the basis of (NBSC, 2017)

As Table 2 shows, the number of obtained patents and the number of approved grants showed the largest increase in terms of research performance, 212.1% and 182.6% respectively. It closely correlates with the amount of labor and financial expenditures aimed at experimental and laboratory studies. In terms of the number of academic papers published and the number of inventions China is in the top ranks in the world, with the number of published papers (both domestic and international ones), patents and inventions keeping growing.

Comparison between particular indicators of research performance and basic indicators of socioeconomic development leads to the following conclusion: nowadays there are on average 2 to 3 persons, who are involved in the research process, per 1000 Chinese people. Russian scientists argue that «China is persistently and rapidly boosting the numbers of its academic elite. In 1985–2005 the growth rate of the number of researches in Chinese economy was 2.25 times as higher as population growth rate, comparing with 1.25 times in Japan over the same period, 1.71 times in the USA (1980–2000 гг.) and 0,.9 times in Russia (1995–2005)» (*Leonov* et al., *2008*).

In 2016 Chinese scientists published 426 000 academic and engineering papers, which amount to 19% of the total number of global academic papers. The number of published papers equals to about 44% of the science-related staff, i.e. roughly the half of such staff are actively involved in the publication activity. Such number for the first time exceed the number of published papers by American authors (about 409 ths). American scientists still occupy leading positions in numerous scientific fields, notably medicine and humanitarian sciences, by the number of papers, yet they lag behind their Chinese colleagues in terms of the number of papers on chemistry and engineering sciences (*NSF, 2016*). A number of Chinese scientists point out that there is a dependency between a country's share of the total number of published academic papers and the amount of R&D financing (*Zhou* et al., *2006*).

An important indicator of high demand for intellectual products of Chinese scientists and researches is the citation rate of their papers. According to 2017 data, academic papers of Chinese researches, that were published in the global academic database, were cited 506654 times, including 52.4% of citations by SCI, or Science Citation Index and 40.3% of them by El, or Engineering Index. The remaining 36853 citations were registered by CPCI-S, or Conference Proceedings Citation Index Science. The largest number of citations was related to chemistry (17.6% of the total number of SCI citations), followed by clinical medicine (13.2%), physics (11.3%), biology (10.8%) and medicine (*NBSC, 2017*).

3.2 Institutional aspect of Chinese innovation development

When considering an institutional structure of innovations more closely, it is possible to point to the two directions the innovation process unfolds in: via research institutions as such and academic ones. Both structures are developing in China, with numerous indicators of these fields of activity showing the increase in process and performance indices, which outpaces the growth in a number of industries. Main indicators of activity of research institutions are shown in Table 3.

Table 3
Main indicators of activity of Chinese research institutions, 2011-2016

Indicator	Unit	2011	2016	Change, %
Number of research institutions, including:	unit	3673	3611	98,31%
- national level (controlled by the Chinese Government)	unit	686	734	107,00%
- regional level (controlled by provincial government authorities)	unit	2987	2877	96,32%
Number of staff	ths people	362	450	124,31%
Labor input of research institution staff, including:	1000 person-year	316	390	123,42%
Total amount of state budget expenditures	bln yuan	130,7	226	172,92%
Total amount of private investor expenditures	bln yuan	110,6	185,2	167,45%

Source: compiled by the author on the basis of (NBSC, 2017).

As Table 3 shows, there are currently 3560 operating research institutions in China, with 4360 ths people involved in their activity. The largest financial burden for ensuring their activity is carried out by the state budget: 84.4% of the total amount of expenditures is borne either by the Chinese Government or provincial government authorities. It is plausible to describe R&D and the crucial application area of state interests and funds, which is expressed in the form of the state indicating its biggest interest in developing basic and applied science and being can active participant in domestic R&D activity. In general R&D amounts to 10.2% of the total labor input of Chinese innovations and 15.1% of expenditures on the innovation activity.

As a field of innovation activity, the higher education (education field), by and large, does not lag behind purely research activity in terms of its growth rates. Alongside with research institutions this field has a large-scale academic infrastructure and remains one of the leaders of Chinese innovation process. In general education institutions accumulate 65.8% of the total academic potential of China, 9.4% of the total labor input of its R&D and 7% of the total amount of R&D expenditures. A small share of education-related R&D expenditures is due to the fact that the main purpose of higher education institutions remains to be personnel training for real economy, not generation of innovations. State funds play an important role in the structure of financial sources, amounting to 63.8% of the total amount of the relevant funds. Comparing to research institutions, the amount of financing of innovation activity of education ones is 53% less, and in case of state funds only – 46.4% less. The integration of higher education institutions' science and business activity remains to be an important element of the national innovation system (*Osipov* et al., *2015*).

Chinese government authorities are also establishing business community-oriented environment, infrastructure and conditions, which promote the innovation activity of domestic manufactures of high technology products. According to expert observations, the companies of the science-and-technology field are widely provided with land plots in addition to tax breaks and subsidies. The area of such land plots exceeds the one needed for factory and plant construction. Companies use these additional areas to build residential buildings or hotel, which generate revenues that, in turn, are invested into R&D to compensate for the factory losses. State-owned banks provide innovating companies with loans at low interest rates, and local government authorities often reimburse them interest payments due to such loans (*Xu* et al., *2017*).

Up to 2000s Chinese companies used to be giant factories using purely industrial and mostly extensive methods of raising their production output and extending their range of activity. Such companies could hardly be called as innovative and technologically advanced one. Back in 1990s and in the beginning of 200s the innovation process of most Chinese companies was an adoption of foreign product samples, production methods and techniques and applied technologies. The modern stage of their development is featured by sustainable shift towards new production quality bases on either own or advanced imported technologies and product distribution with refer to the international standards.

Chinese statistical data clearly show unprecedented rates of growth of national companies' interest in innovations regardless of their scale and industry. The innovation development of Chinese business environment during two five-year periods in a row can be described as active (Table 4).

Table 4
The most relevant indications of development of the business component of Chinese innovation process, 2004–2016

Indicator and unit	2004	2009	2016	Change, %	
				2016 against 2004	2016 against 2009
Number of companies using innovations, unit	17075	36387	86891	508,88%	238,80%

The foregoing companies' share of the total number of domestic companies	6,2	8,5	23,0	370,97%	270,59%
Labor input of innovations, 1000 person-year	542	1447	2702	498,52%	186,73%
R&D expenditures by business entities, bln. yuan	110,5	377,6	1094,5	990,50%	289,86%
R&D expenditures as a share of sales revenue, %	0,56	0,69	0,94	167,86%	136,23%
Number of innovative business projects, ths units	53,6	194,4	361	673,51%	185,70%

Source: compiled by the author on the basis of (NBSC, 2017).

As Table 4 shows, during the recent decade the number of companies using innovations and making innovative products has increased 5.1 times, while the labor input of innovations, the total amount of R&D expenditures by business entities and the number of innovative projects generated by the business environment have increased 5.0 times, 9.9 times and 6.7 times respectively. In general, the labor input to R&D of business entities as a share of the total national innovation-related labor input is 70.7%. The number of research staff of companies and organizations is 2702 ths people, which is 2.5 times as large as that of research and education institutions combined. The total amount of research expenditures by business entities is 2.2 times as large as that of similar expenditures by research and education institutions combined. Thus, the business environment has turned into the crucial customer and sponsor of innovations, which are featured by successful practical implementation.

4. Conclusions

As a summary of this study it is possible to mention that innovations are the crucial factor of sustainable economic development of modern China and major condition of bringing back outstripping rates of economic growth China enjoyed during 1990s and 2000s. The innovation process in such developing country as China is featured by the following trends and features:

1. China is the second largest country after the USA in terms of the amount of R&D financing and the largest country in terms of innovation financing among developing countries. The amount of R&D expenditures in 2016 was about 1.5 trln yuan (250 bln US dollars). Outstripping increase in investments aimed at innovations provide basis for further China's shift towards global scientific, technological and economic domination.

2. Just like in other developing countries, the innovation process in China is executed by developing research activity, education field and business innovations. In 2010s the business structures, with their share of total amount of resources spent on innovations exceeding two thirds, started to play a leading role, thus bringing China close to the innovation level of developed countries.

3. Active development and implementation of innovations in the production is reflected by substantial growth and improvement of virtually all indicators of the innovation development of Chinese national economy, such as number of scientific achievement; number of inventions, patents and grants; and increase in science-intense products' share of the total amount of production output and export. The basic science development in China based on strategic benchmarks of economic growth is combined with the results of practical implementation of intellectual products.

4. China is currently at the second stage of its innovation development, which is based on practical implementation of the latest results of research activity.

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