Recommendations to Address Structural Problems in China's Basic Research

Consultation Group of the CAS Academic Divisions

A breakthrough in basic research often triggers a train of new technologies and inventions, giving rise to emerging industries and promoting major socioeconomic changes. Although there have been rapid advances in basic research in China in recent years, it is still far from meeting the needs of innovation-driven and innovation-led industrial development. The core components of China's high-tech industry have to be imported, most of Chinese firms are located at the low-end of the global industrial value chain, and no Chinese firm is world-known for S&T innovation even though the strength and overall level of basic research in this country have substantially enhanced with increasing research outputs, the largest R&D human resources, and the second largest number of SCI papers published in the world. For example, synthetic biology generally remains at the stage of basic research in China although its share of research papers worldwide in the field ranks second. By contrast, nearly 1,000 firms have been set up in related fields in the US, and national planning has been formulated for the industrialization of relevant research results in the UK. It is of paramount importance to pay due attention to the structural problems in China's basic research, because these problems are having significant impact on the direction selection and output efficacy of basic research in the country.

I. Notable Manifestations of Structural Problems in Basic Research

The structure determines the output. There exists a structural imbalance in China's basic research, which is manifest in the following.

1.1 A Marked Absence of Firms from Basic Research Activities

Basic research in China is primarily carried out by government research institutes and, in particular, universities. Since 2007, the share of universities has accounted for more than 50% of the total national expenditure on basic research. At the same time, the corporate share taken by business sector in this regard has been decreasing, which was merely 1.6% in 2014 (Zhao, *et al*., 2017), a sharp contrast with the equivalent share of 24.2% in 2013 in the US, which made business the second largest financing body for basic research in this country. In Japan, although universities were the major player of basic research in 1981, their expenditure in the area has kept shrinking thereafter and expenditure by enterprises kept growing. In 2014, the share of basic research expenditure by Japanese firms was 42.7% of the national total, outstripping that of universities. The situation is similar in the Republic of Korea (ROK). Since 1996, the basic research expenditure by ROK business sector constituted more than 40% of the national total, and in the years from 2004 to 2006, the figure was even reaching 60% (OECD, 2016).

1.2 Excessively Homogeneous Funding Channel for Basic Research

Recent years have witnessed a growing investment in basic research in China, which chiefly comes from natural science funds and post-doctoral science funds at various levels, and governmental departments of education, science and technology. Of them, the National Natural Science Fund has been a key funding body. The high priority placed on basic research by the government is mainly manifested by the rapid growth of the National Natural Science Fund, about a 300-fold increase over 30 years from 80 million yuan in 1986 to 24.8 billion yuan in 2016 (Website of China's Information Office, 2016), with a growth rate doubling or even tripling that of China's GDP in recent years. Characterized by free application and peer review, the Fund mostly supports research in fundamental disciplines with research results mainly in the form of published papers. In 2017, for instance, the National Natural Science Foundation of China (NSFC), which administrates the Fund on behalf of the central government, had supported, by August, 40,860 projects with a total direct funding up to 19.97 billion yuan, accounting for 78.29% of its annual funding budget (Cao, 2017). In 2015, 62.1% of SCI papers authored by Chinese researchers were tagged with the note "being financially supported by National Natural Science Fund" (Website of China's Information Office, 2017).

At the same time, China's natural science funding system also supports many disciplines closely related to applied research. In addition, it is difficult to completely separate basic and applied research. The leap and bound development of some disciplines over a dozen years is largely benefited from the close integration and mutual support between the two.

At present, China's basic research is mainly supported by the government with emphasis on the social welfare and public good of its results. Its homogeneous funding channel is the main reason behind the homogeneous evaluation standards of its results. The ever enforcing "paper-oriented" assessment metrics in recent years has impelled an increasing number of researchers to participate in the "paper competition". Under this circumstance, their research results are increasingly presented in the form of published works. What is more serious is that this kind of metrics, which gives unique importance to paper publication, has led to the negligence of systematic support to basic research, of the technological reservation and accumulation, of the system gap of technological innovation, of new research directions, and of the original research of frontier technologies.

1.3 Unbalanced Structure of Total R&D Expenditure

Whereas China has continuously increased its R&D investment since 2012 when the strategy of innovation-driven development began to implement, making it the second largest country in terms of R&D expenditure, the share of its basic research in total R&D spending has maintained at about 5%, as compared to the long-time stable figure of 12%–20% in countries like the US, Japan and ROK, and 17% in OECD countries in 2013. In addition, the figures in countries like the US, Japan, ROK have shown an uptrend every year. For instance, it has grown from 13.4% in 1980 to 17% in 2017 in the US, and from 12.5% in 1995 to 14.5% in 2017 in ROK (OECD, 2019). This further widens the gap between China and developed economies such as the US, Japan and South Korea.

In general, due to this prominent structural problem, the financial and human resources are likely to be channeled into the low-efficient research activities, leading to the mismatch of quality scarce resources. Therefore, it is important to grapple with the problem by starting from optimizing basic research structure and improving its quality.

II. The Possibility of Addressing the Structural Problem in China's Basic Research

2.1 The Feasibility of Increasing Enterprises' Investment in Basic Research

As latecomers, the trajectory of Japanese and ROK enterprises during the stage of economic catch-up could be used as a reference in this regard. And an analysis of the status quo and trending developments of China's industry shows the potential of domestic firms to invest in basic research.

2.1.1 The experience of increasing investment in basic research by industry in Japan and ROK

While the share of R&D expenditure in national GDP showed an upward trend in Japan and ROK in the economic catch-up, their growing percentage of basic research spending in total R&D expenditure tended toward leveling off. This mirrored the process in which the era of government-dominant S&T and basic research investment gave way to the era of increased investment in research and development and basic research by enterprises. Finally the proportion of basic research spending in gross R&D budget has maintained at about 15%.

Basic research investment by business in Japan and ROK featured with being dominated by a few large corporations and significantly influenced by economic cycles. For example, the basic research by Japanese corporations slowed down during the two worldwide oil crises and the bust of the Japanese bubble economy. An outstanding feature in ROK is that its basic research is mainly performed by enterprises, which is followed by national research institutes and universities. At the later stage of the economic catch-up, the basic research spending by the business sector in ROK made up about 50% of the national total. By contrast, the development of basic research in Japanese universities is on a par with that of enterprises. The significant role of the Japanese business sector in basic research development is closely related with the high-speed economic growth after the Second World War.

The two driving forces behind the increased investment by enterprises in basic research in the two countries are the following:

a) As the competitiveness of their enterprises has reached or are approaching the world frontier level, they look to basic research for further strengthening their technological capacities and maintaining their competitive edge.

b) Enterprises make long-term strategic planning to sharpen their technological advantages by capitalizing upon the development of their advantageous industries and of advantageous resources housed by domestic research institutes and universities.

The experiences of the two countries show that the driving forces behind the business investment in basic research lie in their own strategic consideration and market pressure. One of the key features is that the market mechanism plays a decisive role in R&D activities when the development of enterprises has attained or approached world advanced level and the related industries have competitive advantages in the world.

2.1.2 The potential of Chinese enterprises for increasing investment in basic research

Nowadays China's economic development has reached a new stage in which some industries are entering "a sensitive period" in terms of competition. It will be difficult to maintain their competitive edge without innovation and basic research. Therefore, there is a great potential for Chinese firms to increase their investment in basic research.

a) Chinese firms are deeply involved in international competition. With the added-value of their products going up to some extent in the world, they are in a critical period of moving upward along the industrial chain. China's exports have maintained the world's first since 2009, and its share amounted to 13.8% of the world total in 2015 (Liu, 2016). Starting from 2014, China's Outward Foreign Direct Investment (OFDI) has exceeded its Foreign Direct Investment (FDI). In 2015, China became the second largest OFDI country after the US with Chinese private enterprises playing an important part. In 2017, the number of Chinese firms kept increasing in Fortune Global 500 for 14 years in a row, reaching 115, including China Telecom, Alibaba and Tecent.

b) Chinese firms have become more competitive in the world. The number of patents granted to Chinese firms by the US Patent and Trade Mark Office has been remarkably increased, from 274 in 2000 to 12,221 in 2016, with the percentage of patents granted to Chinese applicants in the total number granted to foreign countries in the country rising from 0.16% to 83.3% in the same period. In 2016 the number of patents granted to Chinese applicants in Europe exceeded that of ROK for the first time.

c) There exists structural problem in basic research investment by Chinese enterprises. Although firms spend the biggest chunk of China's R&D money, accounting for 77.1% of the national total in 2015, their share in basic research is very low, only about 1% of the national

total, much lower than that of the US, Japan and ROK. Furthermore, in spite of the continuous increase of China's investment in basic research, its percentage in total R&D budget has kept at about 5%. In China, about 80% of investment in basic research comes from the central government, far higher than that of the US. Compared with their counterparts in the US, Japan, South Korea and Russia, Chinese enterprises pay more attention to experimental development, comprising more than 95% of their R&D budget since 2007. Actually, the total spending of Chinese firms on basic research in 2014 was far lower than that of Japanese and American counterparts in 1981 (using purchasing power parity at that time) (OECD, 2016).

Along with the increasing enhancement of enterprise's S&T and economic strength and the continuous expansion of scientific frontiers, technological progress becomes more dependent on scientific research, and the over-dependency on experimental development has unable to meet the enterprises' need of innovation-driven development. For example, the global deployment of basic research by Huawei demonstrates Chinese firm's need of basic research after gradually approaching global competitive frontiers. In addition, after rapid enhancement of their competitiveness, dozens of Chinese Internet companies, such as Alibaba, Tecent, Baidu and Jingdong, are paying increase attention to basic research. However, there are obvious differences among firms in terms of R&D investment. In 2013, the R&D investment in industries such as computers, communications and other electronic equipment was the largest, mounting to 125.2 billion yuan (at current price), about 15% of the total R&D expenditure in this country, followed by electronic machinery and equipment manufacturing (81.5 billion RMB) and automobile industry (68 billion RMB) (Innovation Development Department of Chinese Ministry of Science and Technology, 2015). China is active in R&D investment in high-speed railway, communications, electronic machinery and equipment manufacturing and automobile industries with obvious market advantages. It is quite possible for China to further its investment intensity to make preparation for strengthening the competitiveness of its enterprises.

In summary, compared with the US, Japan and ROK, China lags behind in terms of basic research investment and much room remains for improvement. At present, as the global competition in key and core technological areas becomes fiercer, China should make forward-looking and strategic planning in order to head toward an economic and S&T powerhouse.

2.2 Learning from the Category-specific Management System of Basic Research in the World

Category-specific management is an important starting point to address the structural problem in basic research. In this regard, there is much to learn from the management system of basic research in countries with developed basic research such as the US, Japan and Germany. Taking the US as an example, its basic research management system features a clear structure and responsibilities. There are different research priorities, funding channels and administrations as to different kinds of basic research there. The basic research budget mostly comes from federal government and the business sector, among which the federal government makes up about 60% of the national total. Within the federal government departments, the largest funding agency is the National Institutes of Health (NIH), which is followed by the National Science Foundation, Department of Energy (DOE), National Agency of Space Administration, and Department of Defense. Different organizations are responsible for various basic research projects with different focus and categories. NIH is mainly to support the basic research in medicine and biology, including various research projects and training programs related to human health. NSF aims at expanding knowledge frontiers, and laying foundation for the country's long-term economic growth by forming an innovation-driven economy and training globally competitive labor forces. It mainly supports research projects in biological sciences, computer and information science and engineering, engineering geology, mathematics and physical science, sociology, behavior and economics and other interdisciplinary research areas. DOE is dedicated to the development of new energy sources with emphasis on clean energy technology and new technology transfer, supporting basic research in fundamental research in energy, high energy physics, nuclear physics, computing and network capacity and fusion energy.

III. Major Recommendations

To address the current structural problems facing China's basic research, the first thing to do is to encourage enterprises to increase their input in this regard. This is not only out of their own development needs, more importantly, the changes in investment structure could make the goals of basic research more significant: not simply to attain a higher ranking in paper publication, but to promote more "well-rooted" innovations, enhance global industrial competitiveness, and put into practice the innovation-driven development strategy in earnest.

3.1 Establish an Industry-University-Research "Ensemble"

It is advisable to encourage the establishment of a research consortium consisting of enterprises, universities and research institutes, a new model of intensive collaboration among the business sector and academia. The new institution could help people from enterprises, universities and research institutes joining forces to address common, fundamental and critical issues in scientific research, to encourage the mutual support and cooperation between the "people producing knowledge" and those "putting knowledge into practice." While tackling difficult problems, a good job could be done in training a large group of people good at the transformation and combination of innovation elements.

Efforts should be made to set up a system encouraging industrialists to approach research labs. It is important to put in place a mechanism facilitating the constant communications between scientists and entrepreneurs. While strengthening the links between scientific research and the needs of entrepreneurs, the move will promote a rapid application of novel knowledge into practice.

It is advisable to explore the establishment of "professional foundations" with the joint efforts of private and public sectors. The new funding mechanism, such as bio-medical research fund, food agriculture research fund, industrial technological innovation fund, and resource, energy and eco-environment fund, will be conducive to enhancing the comprehensive and professional level of resource matching. Starting from fundamental research oriented to industry and application, efforts should be made to link up and complement the systems of knowledge, technology and industrial innovation, and to form a novel pattern of synergic innovation between industries, universities and research institutes.

3.2 Launch Special S&T Program to Support Disruptive Innovation

At present, NSFC usually gives preference to projects with considerable research basis. Although it will also provide one-year small-amount grant to some exploratory research with "unrestrained thinking topics" and launched a special program to support "controversial projects," however, very limited number of people could receive such support. The reason is that some of the research proposals are "highly-risky" and disruptive, posing challenges to the existing research paradigms, which usually goes beyond the background of application reviewers or fails to satisfy the specific requirements of funding programs in academic disciplines. In addition, as some very innovative ideas are often preliminary at the beginning, the applicants may not be able to submit a "mature and nice" application proposal. Fortunately, the NSFC has realized that it is difficult for the existing mechanism to select "good" topics for controversial projects.

It is advisable to adjust the existing model for funding high-risk projects by establishing special programs to support disruptive innovations. The management model for this kind of programs should be different from the conventional ones with emphasis on risk management. When giving support to high-risk projects, it is important to make serious analysis of "unsuccessful" projects and try to find scientific value in them. The government's support to research activities featured with high risks could help enterprises avoid the risk of industrial innovation, and is conducive to innovation exploration.

3.3 Dovetail the Management of Basic Research with the Management of National Key R&D Program

It is advisable to set up new funds for the basic

research that is directly related to R&D projects in key technological R&D programs, major programs and the areas supported with significant S&T resources, and give the management power to competent authorities. Although the central government is making large amount of investment in key technological R&D programs with significant impact, it fails to give enough consideration to related basic research, leaving these programs short of powerful "internal core" of basic research. As a result, they are "big but not strong." For example, to achieve its mission, China's Mars exploration program needs to conduct many basic research projects. However, the department responsible for the program, China National Space Administration, does not have the function or funds to support such basic research. Therefore, some basic research highly related to, and urgently needed by the program is unable to be efficiently planned or conducted. Had the exploration program set up a component to support basic research to be managed under the Administration, it would be more efficient to complete the program. It is advisable to set up basic research projects in many civil-military integration programs.

3.4 Enhance the Flexibility in Using Basic Research Funds from Enterprises

It is advisable to adopt operational category-specific management according to different funding channels. At present, some basic research projects are funded jointly by the government and enterprises. During the process of the research performed in universities and research institutes, the part of funding from enterprises is subject to the management of government regulations concerning the public appropriation, leading to the lack of fund-using autonomy of enterprises and affecting their enthusiasm of making investment in basic research. Efforts should be made to set up special accounts for enterprise investment in government-enterprise joint basic research, give them the controlling power to use their investment in basic research. It is important to ensure the funds from enterprises are used for their intended purposes, to ensure principle researchers have the power to put the resources into good use under the financial regulations and budget. Work should be done to guarantee the autonomy and flexibility of enterprise investment while safeguarding the efficiency of public appropriation. As to the projects invested by

local governments, the investors should be able to use them flexibly. As basic research is an exploratory activity with great uncertainty, to avoid disjoining the funding administration from the project operation, it is advisable to allow the adjustment of fund spending to some extent at some specific conditions, so as to increase the enthusiasm of enterprises for investing in basic research.

3.5 Adjust the Existing Statistical Coverage of Basic Research

The vague definition, overlapping usage and cognitive difference of the concept of basic research in China have led to statistic errors in the four aspects of military investment, R&D human costs, infrastructure investment and corporate investment, making it possible to either overestimate or underestimate the basic research investment in this country. Especially during the process of data collection, basic research and applied research are differentiated on the basis of their unique or specific applications, leading to considerable part of application-oriented basic research cannot be classified into basic research, which actually underestimates the basic research investment of enterprises.

It is advisable to make explorations into differentiating applied basic research and basic research from the perspective of anticipated application time (long-term or short-term). In this way, the mid- and long-term research projects and applied basic research projects carried out by firms could be included in the statistical coverage of basic research, so as to avoid statistical errors as much as possible and make statistic operation more scientific, standardized and precise.

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