Application of bibliometric (scientometric) analysis and technology foresight in strategic planning of Chinese Academy of Sciences (CAS) and Chinese S&T Development

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Abstract
From 1949 to now, the CAS has changed the strategies three times and adjusted scientific fields according to the need of economic and social development. When CAS planned to shift the research fields of its institutes, the decision-maker would establish an expert group and hold several seminars or workshop to scan the frontier fields of sciences and so on. In 1998 (during the Ninth Five-Year-Plan period), CAS intended to adapt a new strategy facing the development of information/knowledge economy. So we have analyzed the structures of output and input of CAS and compared with different countries’ institutes, and pointed out that output and input structure of CAS were quite different from the developed countries. We compared the situations of 22 scientific fields between China and major developed countries using the bibliometric data. We found that the most important research fields of CAS did not match with the directions of other countries and recommended that CAS should adjust the research directions and critical research fields. During the compilation of Tenth Five-Years-Plan of CAS in China, CAS has organized the foresight programs to scan the technology trends. The conclusions of technology foresight have been provided to the decision-maker and experts of the Long Term. At the end of this paper, we will discuss how to merge the bibliometrics and foresight with the strategic planning of research fields.

Keywords: strategic planning, strategic intelligence analysis, bibliometric analysis, technology foresight

1 Strategic Planning in the Knowledge Innovation Program of CAS

The CAS is an integrative research organization which was founded in 1949. It has evolved through several phases, from establishment, fast progress, stagnancy, reform to fast progress. The CAS has accomplished several strategy adjusting and reorientation successfully in its history.

In 1956, China put forward the slogan of “Marching for the Science”, constituted a serial of S&T policies creatively, and put forward the first S&T development plan in the history of China’s
S&T development. China established 57 main tasks and 616 central problems, including the emerging disciplines such as atomic energy, semiconductor, wireless, automatization technology and rocket pushing technology, and the basic disciplines such as mathematics, physics and chemistry in the way of “developing the discipline by task”. CAS acted as a “locomotive” in the making and implementation of the plan. This was the exemplar of Chinese government’s guide to the development of S&T and its macro management in S&T development.

In 1979, after ratifying the implementation of the Eight-Year Plan of S&T Development which was made in the effort of over 20 000 scientists, the government of China ratified the Development Agenda of Basic Science (1978 – 1985) which was constituted by CAS. The Agenda laid out 27 emphasis industries such as natural resource, agriculture, ocean and transport. It also established 108 emphasis research projects. CAS played an important role in the planning of China’s S&T development.

In 1998, after investigating the opportunities for S&T development brought by the globalization of economy and the development of knowledge economy, and investigating the construction of national innovation system and the more and more important role of S&T in the development of economy, CAS delivered to the government of China a report named Meet the Challenge of Knowledge Economy, and Construct the National Innovation System which laid out the development strategy of S&T of China in the first half of the 21st century. It then implemented the Knowledge Innovation Program (KIP), which started the most extensive reform since CAS was founded and readjusted the layout of science and research focus.

In 2006, after 8 years’ deeply reform, CAS commits itself to the construction of China’s S&T independent innovation ability in respondence to the construction of China’s national innovation system. As what the president of CAS has said, the government of China and the whole society have realized that S&T is the important fundamental resource for the development of economy and society as well as the leading force to lead future development. China is organizing and constituting the mid to long range plan of the national S&T development, and deploying the emphasis fields of China’s S&T development according to the needs of national economic and social development and the trends the world’s S&T development. The goal is to enter the range of middle developed countries at the whole S&T capability level by 2020. CAS needs to concentrate its strength to achieve some important breakthroughs in the fields such as life science, nanotechnology, quantum informatics, and brain and cognitive science as well as in information technology, biological engineering, space science, energy, new material and advanced manufacturing technology. And meanwhile, it should strengthen the R&D in the fields such as medicine and health, environment protection, ecological restoration and ocean.

It is a huge and systematic project to constitute any perfect S&T plan. The Chinese government has devoted a lot of manpower in all the previous S&T planning. For example, it organized 787 scientists and technicians from 23 institutes to constitute the S&T development plan in 1956, and there were over 20 000 scientists and technicians participated in workshops, symposiums, conferences and the drafting of the Plan of National Science and Technology Development (1978 – 1985) in 1978. There are also more than 20 000 scientists participated in the constitution of the Mid to Long Range S&T Development Plan and the Eleventh Five-Year-Plan which was completed in 2006.

Similar to the making of the scientific plan by Chinese government, the making of the development plan of CAS also uses expert groups. When making the development plan, CAS organizes the key scientists, academician and research management experts from different institutes of CAS. Workshops, symposium and conferences will be held on different topics to identify the development direction of each scientific field and consider the position and impact of
scientific research in the national economic construction of China. It will choose the key S&T problems and research fields, and constitute the Five-Year-Plan of S&T and the mid to long range S&T development plan. This method of plan making has much weakness as it may cause the development of S&T deviate from the needs of the development of the national economy and the industries.

During the period of the tenth and the eleventh Five-Year-Plan, CAS considered the needs of the national economic development for S&T adequately and analyzed the achievements of China’s S&T thoroughly when making the development plan. Based on the integrated consideration of the trends of the world’s S&T development and the distribution of scientific fields, it put forward the needs of China’s economic and social development for the development of S&T, and the development goal and main tasks for CAS. In this process, CAS made full use of the strategic experts, management experts and policy experts, and adopted many methods such as policy analysis, expert survey, bibliometric analysis, input/output analysis and expert forecasting.

2 Application of Bibliometric Analysis in Strategic Planning

The methods of strategic planning used by Chinese government and Chinese Academy of Sciences are a combination of expert survey and policy analysis. At the request of Chinese Academy of Sciences, The National Science Library of CAS carried out a research on the status of China’s science & technology in the world using bibliometric analysis in 1997. Through analysis and comparison, we concluded that China’s science & technology didn’t have a significant impact in the world. The development of different disciplines was unbalanced and the layout of disciplines was not appropriate. Especially China didn’t pay much attention to biology science and medical science which are hot topics in current world.

In that research, we compiled the bibliometric data on China’s science & technology papers from two sources. One is the analytic data Science Citation Index (SCI) (1983-1993) edited by T. Braun. The other is Institute of Scientific & Technical Information of China. The major indicators included counts of papers, citations, and average citations. T. Braun have classified scientific research into 27 scientific disciplines in his research. According to the traditional classification of science & technology in China, we have classified science research into 7 categories, that is, mathematics, physics, chemistry, geo-science, life science, medical science and engineering science. Through the overall analysis, we concluded that the shares of China’s scientific papers in the world was increasing. However, the number of citations and the cited rate were still at a low level. If we consider the number of scientific papers as an indicator of the scale of science research and the number of citations and the cited rate as indicators of the quality of scientific papers, the analysis indicates the status of China’s science in the world is decreasing and the quality and contribution of scientific papers of China still have a big gap with those in the developed countries.
Figure 1 shows the discipline structures of China’s science & technology are quite different from other countries in the world. China’s scientific papers concentrate on physics and chemistry fields. However, China has a low output in life science and medical science which other countries emphasize. This indicates China hasn’t completed her transformation in the research fields and hasn’t entered the big cycle of the world’s scientific research. As the same developing country as China, Brazil’s scientific papers’ disciplinary distribution is the same as the world’s average. This shows Brazil’s scientific research has a higher coherence with the developed countries.

In order to support the decision-making of Chinese Academy of Sciences on the drafting of strategic planning and the adjustment of disciplinary layout, we further investigated China’s scientific papers’ distribution in 27 disciplinary categories and identified those disciplines that China was still weak and had lower impact. We concluded that China held a weak competitive position in many scientific fields. In the perspective of the number of papers listed in SCI, the US, the UK, Japan, France and Germany were the top 5 countries and had an absolute advantage. Russia (former Soviet Union) had some advantage in certain scientific fields such as nuclear science, physical chemistry and solid physics. However, the development of China’s science was quite unbalanced. China had some relative advantage in mathematics, material science and classical physics, while lagged behind in life science and medical science, ranked No. 30 in the world (see table 1). The number of citations and cited rates of China’s scientific papers were in a similar situation with the number of papers.

Table 1: The profiles of Chinese scientific fields in all the countries (Numbers, Citations and Impact Factor (IF) in the period of 1989-1993)

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<td>Electronics</td>
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In the perspective of the disciplinary distribution of scientific papers in the world, biological engineering, public health, internal medicine, chemical engineering, solid physics and nerve medicine were the top 6 disciplines in the number of scientific papers, while China’s most scientific papers distributed in physics, solid physics, applied physics, material science, mathematics, physical chemistry. China’s scientific research had deviated from the trend of the international science development.

After a detailed analysis, we delivered our research findings to the Tenth Five-Year Science & Technology Planning Group of CAS: (1) There was a huge gap in science development between China and the developed countries; (2) The development of different disciplines was obviously unbalanced and the investment on life science and medical science research was distinctly insufficient in China; (3) The developed countries in science & technology had shifted their research priorities from physics and chemistry to life science and medical science. We recommended Chinese Academy of Sciences to adjust the disciplinary layout during its Tenth Five-Year Plan.

At the request of National Natural Science Foundation of China (NSFC), we carried out a research on the disciplinary layout of different countries in the world in 2004. The purpose of the research was to provide NSFC with background materials for the Eleventh Five-Year Planning and Mid to Long Range Planning of China’s science & technology development. We selected the scientific papers listed in SCI during the period 1993 to 2003 and analyzed the disciplinary structure and the change of the US, the UK, Japan, Australia, South Korea and China. For comparison, we analyzed the investment structure and the disciplinary distribution of the US, the UK, Japan, Germany and France, and further analyzed their emphasis areas and priority areas.

Through the analysis of the scientific papers during past 10 years in 22 scientific fields according to the SCI classification, chemistry, physics, clinical medicine, engineering and biology were the top 5 disciplines that produced most scientific papers.
The distribution of scientific fields was quite different in natural science in different countries because the resources and the development of different countries were different. The share of scientific papers of the top 5 disciplines was far higher in China and South Korea than in other countries and the development of different disciplines was relative unbalanced. The share of scientific papers of zoology, botany, geo-science and environment science was the highest in Australia because of its advantage of resources. Besides, countries like the US and the UK had a higher share of scientific papers of geo-science and environment science than other countries. And the share of material science papers was much higher in China, South Korea and Japan than in the US, the UK and Australia.

In each scientific field of chemistry, physics, engineering, material science, mathematics and computer science, China ranked top 10 in the total number of scientific papers in the world. We should focus on the development of other important disciplines such as biology, biological chemistry and clinical medicine, which were emphasized at the international level. Although the number of papers in these scientific fields was growing, the rank of the number of papers of biology and biological chemistry was still out of top 10. The rank of clinical medicine was even lower. Compared with the number of publications, the impact factors of China’s scientific papers listed in SCI were obviously low, even in the scientific fields of chemistry, physics, engineering, material science, mathematics and computer science mentioned above.

Through the analysis of the distribution of the investment in different scientific fields in different countries, we concluded that major developed countries paid a great attention to the development of life science. Public investment and research programs had grown in these scientific fields and the world-famous research institutions had adjusted their disciplinary layout. The share of R&D investment and the output of scientific papers in life science (biology and medical science) were much higher than in other disciplines in other countries. For example, the investment of the US in life science had grown during last several years and the share of research funding in life science was over 50%. Of the 63 institutes in natural science in Max Planck Society, there were 33 institutes in Biology and Medicine Section and there were 7 new established institutes in Biology and Medicine Section of all 9 new established institutes since 1995.

The research of information technology and nanotechnology has gained emphasis in major developed countries. There is a stable growth of investment in computer science in the US. The investment includes IT2 and Network and Information Technology R&D Program. The basic research of information technology has been the new investment hot topic of the US government. The Science and Technology Basic Plan (2001-2005) of Japan has established information and communication technologies as one of the priority areas of R&D investment and Japan has put forward its e-Japan Strategy. The French government considers the information technology and the development of digital society as the priority areas and CNRS has considered information and communication as one of the three emphasis research areas. The other two are life science and environment & energy. In the field of nanotechnology, the Bush government will continue to invest on the National Nanotechnology Initiative put forward by Clinton government in early 2000. The Department of Trade and Industry of the UK has established nanotechnology as one of the emphasis areas in the basic research fields.

3 Application of Technology Foresight in Strategic Planning
Technology foresight is a systematic study on science, technology, economy and social development over a comparatively long period in the future in order to determine research fields that are of strategic importance, and select critical technology clusters that can make great contributions to economic and social development. In October 2002, the Ministry of Science and Technology of China organized the first national technology foresight program in China and completed technology foresight and national critical technology selection in three key high-tech fields, that is, information technology, biotechnology and new materials at the initial phase. Scientific and normalized investigation and research enable us to comprehensively integrate the opinions of experts from all sectors of the society, understand the trend of China’s economic and social development in next ten years, seize the direction of S&T development in the future, and select critical technology clusters as priorities, thus providing fundamental information for the establishment of S&T policies, S&T development strategies and S&T planning.

The research is based on two rounds of Delphi surveys, and over 600 technical and economic social experts from research institutions, universities, enterprises and administrative departments of government have participated in the research and over 1000 experts in the discussion. Based on the data from the Delphi surveys, and through investigation on 222 technical projects that are likely to develop fast in the three fields of information technology, biotechnology and new materials, the research has systematically analyzed high technologies that could make significant scientific and technical breakthrough during the next 10 years, and industries that may get the leap-forward development with their key technologies. The report has also made an evaluation on the level of China’s R&D in the three fields and investigated the basis of R&D and the approaches for technology development in the three fields mentioned above, and probed into the relationship of technology and economy.

On the basis of the research findings of the technology foresight programs in the US, Japan, Germany and the UK, the group finished three phases’ research: the first stage was the analysis of China’s economic and social development trends and demands. At the same time, the technical tendency of information technology, biotechnology and new materials in China were also investigated. They had completed two reports of China’s economic and social development trends and demands for science and technology in next 10 years and Technical tendency in information technology, biotechnology and new materials in China in next 10 years.

The research findings show the technology demands of China’s economic and social development in the future are mainly presented in: transformation of the economic structure, harmonized development of the society, and resource, energy and environment. On the facet of economy, there are technical demands in manufacturing, agriculture, international trade and urbanization; on the facet of social development, there are technology demands in public health security, aging society, and employment pressure; and on the facet of resources, energy and environment, there are technology demands in water saving and water pollution control, raising the efficiency of using mineral resources, raising the efficiency of using energy resources and adjust the energy structure, improving the forest coverage-rate and desertification management.

Through the foresight of the technical tendency, it shows that during the first 30 years of the 21st century, information technology, biotechnology and nanotechnology will be the mainstream of the world’s technology development. China’s possible breakthroughs of science and technology in next 10 years will mainly happen in next generation mobile communication technology, NGN (Next Generation Network), nanoscale chip technology, Chinese information processing technology; human functional genomics, pharmaceutical biotechnology, bioinformatics, proteomics research, breeding technology of new agricultural breed; nano
materials and nanotechnology. Those research findings provided valuable reference for the making of Eleventh Five-Year Plan of Science and Technology Development.

In 2003, CAS started the research of the *Technology Foresight of China in next 20 years*, and its main tasks are to organize the research of technology foresight methods, technology demand analysis, Delphi survey, policy analysis and the methodology research of technology development trend tracking and monitoring. According to the picture of China’s social development in next 20 years such as globalization, informalization, urbanization, industrialization, recycling society and consumption-oriented society, they analyzed the national strategic demand, market demand and technology development trends, and deduced the technology demand clusters. Combined international technology develop trends with the picture of China’s social and economic development and technology trends in next 20 years, the research identified the technology demand of the national develop strategies and raised the policy advices. The initial project of technology foresight selected 31 sub-fields from the following four fields: CIT (communication and information technology) and electronic technology, biotechnology and medicine, material science and technology, and energy technology. They carried out two-round Delphi survey, and analyzed the importance, time requirement and possibility, leading countries with advanced technology and the level of China’s development, the limitation of technology development of 409 critical technology projects that were selected. There were 1880 experts participated in this research.

The research findings of technology foresight are of important reference when the CAS participated in making China’s *Eleventh Five-Year Plan* and the *Middle to Long Range Science and Technology Development Plan*. And the technology foresight research also provided stable information basis for further adjustment of disciplinary distribution in the Knowledge Innovation Program of the CAS.

4 Conclusion

Since 1956, China’s strategic planning of science and technology has been transferred successfully from the macro guideline (or profile) to micro adjustment (or project planning and management). In the early, China has made some general strategic planning and scanning the international frontiers of science and technology during the strategic planning of Science and Technology. Nowadays, China could make great efforts to the changing and tracing of the research fields or research directions in the S&T strategic planning. All those make the main aims of the Chinese science and technology planning to change from the imitation and study to the attending the international scientific research competition and independent innovation. So the development of the science and technology of China has broken the frameworks of tracing and studying completely, and established gradually the frame of scientific choice and original innovation. For example, in 1965, the planning of science and technology has taken the framework of realizing the research and development tasks of products or projects to propel the advance and adjustment of science research, accompanied by the tracing the frontiers of the international science and technology. In the near fifteen years, Chinese strategic planning have made the research fields choices and research directions choices.

When drafting the strategic planning, in the programme and methods, China has adapted the Delphi survey, scientometrics / bibliometrics, brain storm methods etc. Further, China has put more attention on the application of technology foresight, tendency analysis, need analysis,
technological economics analysis, and strategic planning analysis to make better planning. In the tendencies research of the international science and technology, China has make great efforts to compare and analysis the differences and gaps between China and developed countries, and scanned the research gaps or opportunities in some fields.

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