ARTICLE IN PRESS
TFS-18633; No of Pages 10
Technological Forecasting & Social Change xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Technological Forecasting & Social Change

Technology foresight in China: Academic studies, governmental practices and policy applications

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ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form 5 August 2016
Accepted 9 August 2016
Available online xxxx

Keywords:
Technology foresight
Academic studies
Governmental practices
Policy applications
China

ABSTRACT

Technology foresight has received increasing attention in China among academic scholars and policy makers. This paper, based on an analysis of global technology foresight features, systematically summarizes and discusses academic studies, governmental practices, and policy applications regarding technology foresight in China, associated with bibliometrics, expert interviews, and desk research methods. The evidence of both theoretical studies and practical activities indicates that technology foresight has rapidly developed in China. This development process can be divided into three periods: the exploration, rapid development, and maturation periods. Technology foresight activities in China enable stakeholders to consult with each other, which leads to a technology foresight culture. Further, many problems in developing and planning with science, technology, and innovation can be solved when comprehensive approaches are adopted to conduct technology foresight activities, including large-scale Delphi survey, scenario analysis, technology roadmap, and bibliometrics, among others. Currently, technology foresight is not only an essential instrument, but is also widely applied in China to develop planning and policies regarding science, technology, and innovation activities. Alternatively, the methodology of Chinese technology foresight and its application to science and technology planning must further improve.

1. Introduction

Motivators for science and technology progress are increasingly complicated. This trend has changed, from "internal factors of the technology system determine the trajectory of technology development" to "interaction between technology and social and economic development determines the trajectory of technology development," which then evolved to "the technology trajectory has multiple possibilities and the future trajectory can be selected through present policies" (Research Group of Technology Foresight towards 2020 in China, 2006). At the same time, confronted with increasing global economic competition, policy-makers and scientists are grappling with the problem of how to select the most promising research areas and emerging technologies on which to target resources and, hence, derive the greatest benefits (Martin, 1995). To develop oriented-future policies in this situation of complex driving forces, technology foresight (TF) has been considered an appropriate method to manage science, technology and innovation activities (Georghiou, 2013). The term "Technology Foresight" took off in the 1990s, as European, and then other, countries sought new policy tools to deal with problems in their science, technology and innovation systems (Miles, 2010). Technology foresight activities and studies effectively assist in planning and managing uncertainty levels, which have received more and more attention in emerging countries.

Technology foresight has gradually become the focus of academic research and policy-making, which is particularly significant in China, as this large emerging country requires science and technology strategies to realize advancing development based on innovation. An increasing number of scholars and policymakers in China consider technology foresight as an integrated, comprehensive platform for developing science and technology (S&T) planning and policies. They regard technology foresight as a crucial approach to identifying national strategic demands, and grasping the trend of innovative, global science and technology. Recently, technology foresight has reached a new peak to meet S&T planning and demands in implementing China's innovation-driven development strategy, and has been applied to dynamically adjust S&T strategies and policies to optimize resource allocation.

Technology foresight provides an approach of developing policy in the complex context. It is imperative to discover more scientific, reasonable ways to develop science, technology and innovation policies when facing social and economic development uncertainties amid increasingly complicated international situations. As links between modern S&T and socioeconomic development have tightened, and science and

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http://dx.doi.org/10.1016/j.techfore.2016.08.010
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technology discussion topics have penetrated various social and economic fields, features differ in developing and implementing long-term S&T planning, compared to previous periods. For example, science and technology policies have integrated with policies in other fields, such as agriculture and industry, in various ways. In spite of those in science and technology circles, the policy development process has begun to involve more stakeholders, including enterprises and the public. Therefore, the policy-making process requires each stakeholder's participation and consultation (Grupp and Linstone, 1999). Before technology foresight exercises in policy-making, decisions were commonly made by a few elites based on their unique personal insights. Technology foresight provides an interactive policy-making process and participation of different parties. As are argued in Martin (1995), foresight is a ‘process’, not just a set of techniques, and involves consultative procedures to ensure feedback to and from relevant actors. We should note that foresight does not predict a predetermined future, but actively shapes the future through the involvement of players and decisions in the present (Cachia et al., 2007; Meissner, 2012).

Technology foresight provides an interactive and communicative platform among all kinds of stakeholders in policy-making. Foresight exercises are seldom limited to small expert groups, and are participatory, involving a wide range of stakeholders. This opens stakeholders' minds to new possibilities for the future (Cachia et al., 2007; Meissner, 2012). The technology foresight process enables all stakeholders to discuss how to shape society in the future. Each group communicates during this process to reach a consensus for future directions, which creates a mechanism and network for realizing future development. Researchers from institutes and colleges, as well as personages from both enterprises and the public, participate in this process, which facilitates the efficient communication of opinions from different perspectives to agree on the key issues in developing relative policies. As this process can reduce risk and avoid incorrect decisions as to the technology development trajectory as much as possible, it enhances scientific, reasonable approaches to developing innovative policies for science and technology (Ren, 2008; Fan, 2003). Policymakers using technology foresight results can clearly indicate to the science, technology, and innovation communities that they are broadly considering a bottom-up approach, rather than purely top-down (Meissner, 2013, p.59).

Although technology foresight techniques have obtained much progress, the review research of practices or applications in the specific-country context is rare in the extant literature. Some relevant researches are focused on the advanced countries (see, Georghiou et al., 2008), and few literature gives attention to the development and applications of technology foresight in emerging countries. China is one of emerging countries earlier introducing and applying technology foresight to develop S&T planning and policies. However, current literature lacks a systematic summary of academic research and its latest applications, as well as how it supports S&T planning and formulation. A review of technology foresight activities in China is needed and attractive in terms of governmental practices and policy applications, which may provide some potential implications for technology foresight practices and studies in future. Since technology foresight can't escape from the social-economic factors in one country, some interesting and specific findings are expected in the specific context of China. This paper provides a comprehensive summary of the methods, academic research, and policy applications of technology foresight as adopted in China. It also conducts a comparison and analysis of technology foresight from an international perspective, and aims to provide a reference for technology foresight in China.

The rest of this paper is organized as follows: Section 2 analyzes global trends in journal articles and technology foresight practices, as well as global technology foresight features. Section 3 discusses domestic developmental trends in journal articles and governmental practices of technology foresight in China. Section 4 reviews and analyzes Chinese technology foresight methods. Section 5 illustrates the latest national technology foresight activities in China since 2013. Section 6 discusses how technology foresight impacts and supports S&T planning and formulation in China. Finally, Section 7 provides a summary and some directions for future research.

2. A summary of international studies and practices in technology foresight

International trends in technology foresight are analyzed in this study from two aspects: journal articles and practices. The former is observed through the number of journal articles relevant to technology foresight by searching the SSCI (Social Sciences Citation Index) periodical database, adapted to retrieve international articles. As the manner of technology foresight presentation differs in international articles, the retrieval is conduced according to subjects containing “technology foresight,” “technology forecasting,” “technological foresight,” “technology forecast,” “technological forecasting,” or “technological forecast.” This provides the greatest extent of comprehensive coverage, and 416 journal articles are obtained (1967– 2015).

Combining technology foresight practices and research trends as illustrated in Fig. 1, global technology foresight exercises can be divided into two stages. First, the exploratory stage occurs before 1990, when technology foresight activities initially began, and few countries organized and conducted such exercises. Moreover, Japan's technology foresight was the most representative. The number of journal articles from 1971 to 1990 regularly fluctuated once every five years, which parallels Japan's conducting of technology foresight activities every five years. This means that Japan's technology activity guided the global academic study of technology foresight prior to 1990.

The high-speed development stage ranges from 1990 to the present. From 1990 to the early twenty-first century, academia and various countries' governments gradually began to discover the importance of technology foresight. Many countries, including the United Kingdom, China, France, Germany, Italy, India, and Korea, launched technology foresight activities, and the number of countries performing technology foresight activities significantly increased. After the early twenty-first century, the number of countries conducting technology foresight activities still increased worldwide, and the annual average number of journal articles was at its peak (see also Fig. 1). As a result, technology foresight's importance reached a new height. Significant technology topics and their development trends, identified by technology foresight activities, are essential references for grasping the development trends in science and technology, and for nationally cultivating new competitive advantages. Presently, countries' technology foresight activities have five basic features, as follows:

First, technology foresight closely focuses on not only the development of future science and technology, but also the market's pull. Technology foresight, in other words, includes the selection of critical technologies as well as the recognition of economic and societal demands. For example, future vision research studies have been prioritized by several large-scale technology foresight activities in China. Instead of pursuing the full coverage of academic departments or technical classification, key points are stressed in accordance with demands. Additionally, S&T planning for future technology development paths and development strategy selection can be performed by constructing a future social vision.

Second, more focus has been on future prospects to support transformations in manufacturing and industrial growth. In early 2010, the United Kingdom's Government Office for Science published a report, Technology and Innovation Futures: UK Growth Opportunities for the 2020s, in which one of the key messages is “there are strong opportunities for growth in the UK economy through the 2020s if businesses can harness scientific and industrial capabilities to take advantage of technology-enabled transformations in manufacturing, infrastructure and the Internet”. The same department published another report in 2013, The Future of Manufacturing: A New Era of Opportunity and Challenge for the UK. The analysis and advice in this report will help the

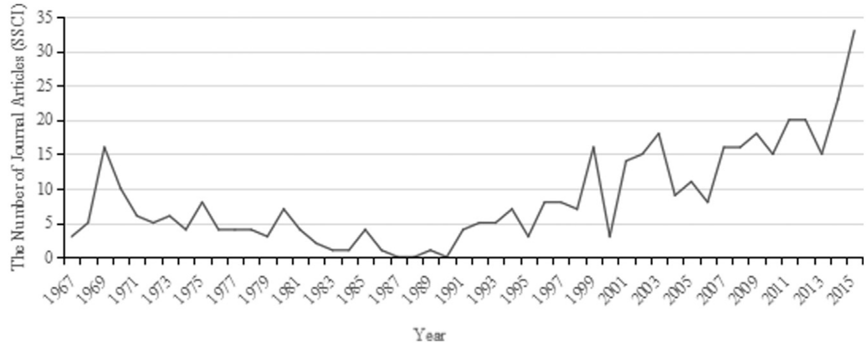

Fig. 1. The number of international TF journal articles in the SSCI database (1967–2015).

government amplify its support of the manufacturing industry. This tendency also emerged in China.

Third, surveyed experts come from more extensive fields. Recently, with the exception of technology experts, technology foresight activities have widely involved governments, enterprises, and the public, so future science and technology scenarios can be generated with a more comprehensive, broader view. Some countries have recently conducted technology foresight surveys by disclosing their Internet questionnaires to the public. Recent technology foresight activities conducted by China have also attached increasing importance to feedback from business circles and the public.

Fourth, increasing concern has been placed on emerging technology and disruptive innovation. The latter has significantly impacted industry structures, from travel to computer retailing to communications, and has often produced social change in the process, although social change caused by disruptive innovations is largely unintentional (Christensen et al., 2006, p. 1). Thus, many countries especially emphasize the scanning and analysis of disruptive technologies, using quantitative methods or such questions as which technology is the most disruptive.

Fifth, organizations in various countries that conduct technology foresight activities are rather stable, which is beneficial for the accumulation and inheritance of knowledge. With its fifth survey in 1992, Japan's National Institute of Science and Technology Policy became a major institution for the implementation of technology foresight activities; in Germany, both the Federal Ministry of Education and Research and the Fraunhofer Institute for Systems and Innovation Research play significant roles in technology foresight activities. China's national technology foresight activities are implemented and conducted by such institutions as the Chinese Academy of Science and Technology for Development (CASTED), under the Ministry of Science and Technology (MOST); and the Institute of Policy and Management (IPM) under the Chinese Academy of Sciences (CAS).

3. Trends in journal articles and governmental practices of technology foresight in China

The CSSCI (Chinese Social Sciences Citation Index) database is utilized to search Chinese journal articles related to technology foresight, and ultimately to comprehend trends in Chinese technology foresight studies. Some Chinese scholars and institutions (such as CASTED and MOST) capitalize on "technology forecasting" to express technology foresight. Therefore, this study's retrieval from the CSSCI database searches both subjects and the full text for "technology foresight" or "technology forecasting." This retrieval's starting time is the year 1998 because the CSSCI was founded in 1998. As a result, 268 and 1889 Chinese journal articles were obtained for "subject retrieval" and "full text retrieval," respectively, from 1998 to 2015.

Fig. 2 indicates that the number of Chinese journal articles gradually and more slowly increased from 1998 to 2001. Technology foresight practices were successively launched in China during this period. The Ministry of Science and Technology organized and implemented critical national technology selection in 1992 to 1995, and 24 critical technologies were chosen from the fields of information, biology, manufacturing, and material. Corresponding achievements were applied in the "Ninth Five-Year S&T Planning." Moreover, this also compelled some departments and regions to conduct critical technology selection activities to serve their S&T planning formulation. The MOST and other institutions conducted individualized foresight activities from 1997 to 1999, regarding the development of technology in three key fields: agriculture, information, and advanced manufacturing. The results were used in the formulation for the "Tenth Five-Year S&T planning." Meanwhile, abundant experience was accumulated, both theoretically and practically, and an expert network of specialized personnel engaged in technology foresight studies came into existence (Xue and Yang, 2005). Subsequently, China's technology foresight evolved into an exploratory period.

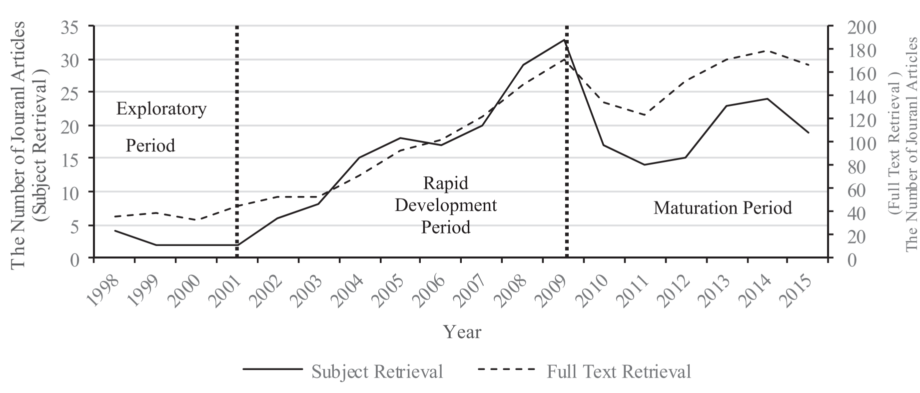

Fig. 2. The number of Chinese TF journal articles in the CSSCI database (1998–2015).

In entering the twenty-first century, the number of Chinese journal articles as of 2009 has dramatically increased. Regarding technology foresight practices, and especially since Beijing and Shanghai took the lead in launching regional-level technology foresight activities in 2001, technology foresight activities nationwide tended toward a much larger scale and wider scope, just as a single spark can start a prairie fire. The IPM/CAS conducted a program from 2003 to 2005 for "Technology Foresight Toward 2020 in China," based on an in-depth analysis and description of major science and technology demands for building a comprehensively prosperous society. This was accomplished by scenario analyses, a large-scale Delphi survey, and expert panels. Two rounds of Delphi surveys were directly performed for eight technology fields, including information, communication and electronic technology, advanced manufacturing technology, biotechnology and pharmaceutical technology, energy technology, chemistry and chemical technology, resource and environmental technology, space science and technology, as well as material science and technology. More than 70 famous Chinese technology experts and over 400 specialists were invited to form 8 field expert groups and 63 technology sub-field expert groups, respectively. Finally, 737 key technology topics were selected. Over 2000 experts nationwide completed the questionnaire, independently judged technology topics' significance, and estimated their time of completion, implementation possibility, China's current R&D level, international leading nations, and development obstacles. Ultimately, they selected the most important technology topics for the next 20 years in China; moreover, their research accomplishments were applied in part in the *National Medium and Long-Term Scientific and Technological Development Plan* and the *Eleventh Five-Year S&T Planning of CAS* to provide strong supports for S&T policy making (Mu et al., 2008).

Another technology foresight activity was conducted by MOST from 2003 to 2005, and alluded to 9 fields, including information, biology, new material, advanced manufacturing, resources and environment, energy, agriculture, population and health, and public security. More than 120 critical national technologies were selected by investigating 3981 experts, and evaluating more than 1000 optional technologies (Wang, 2015). This investigation is more scientific and systematic than previous technology foresight activities performed by MOST. Expert opinions from various fields were comprehensively integrated to analyze development trends and the S&T development direction for the next 10 years. Further, critical technology groups were chosen that should be preferentially developed to provide fundamental information for the formulation of S&T policy, development strategy, and planning in China.

The number of journal articles has been stable since 2009 (see Fig. 2). Governmental technology foresight activities have entered a new stage, called the maturation period. This does not mean that no development space exists for Chinese technology foresight; in contrast, this is an outstanding basis for future technology foresight development. From a regional perspective, the Science and Technology Commission of Shanghai Municipality (STCSM) has focused on technology foresight since 2001, and authorized the Shanghai Institute for Science of Science (SISS) to conduct regional technology foresight. Recently, SISS has been an emerging force in China's regional technology foresight. On the behalf of STCSM, SISS principally conducts technology foresight activities on a regional level, and simultaneously explores technology foresight theories. Additionally, technology foresight experts are employed to offer advice and suggestions for Shanghai's major scientific and technological projects, and to present a substantial number of annual medium- and long-term technology program proposals, as well as technology foresight reports, which are related to such fields as information, biology, new materials, advanced manufacturing, and social development. Further, most of these proposals powerfully support the formulation of Shanghai's medium- and long-term S&T planning. In addition to Beijing and Shanghai, where technology foresight is conducted rather early, such provinces and cities as Wuhan, Yunnan, and Shandong also launched technology foresight activities regarding the fields of biology, information technology, new materials, and medicine. Some of the provinces and cities have also issued regional technology foresight reports to support the formulation of local S&T policy.

4. Review and analysis of technology foresight methods in China

Qualitative methods are limited to some extent, and their applications combined with quantitative and semi-quantitative methods are able to appropriately improve the scientific nature of technology foresight. A Delphi survey has been most extensively used, both in practice and in journal articles. Cui et al. (2004) posited a "Market Delphi Method," applicable to technology foresight at a medium-micro level. Xu (2011) presented the concept of a joint technology roadmap and Delphi method, and proposed the establishment of a professional group, including a technology roadmap and a Delphi survey group that function simultaneously; in this process, dynamic information sharing is implemented between those groups to achieve a complementary purpose. Concerning the most distinguished differences between this and the classic Delphi, the former is more appropriate for enterprises' technology foresight, and places great emphasis on market demands.

Journal articles obtained from the CSSCI database note that the scientometrics method is widely discussed in papers published in China, except for the Delphi method. The former is a quantitative method that has been applied early, and is used extensively at present; moreover, considering that journal articles are good sources of scientific and technological information, and patents are the direct manifestations of scientific and technological activities, both journal articles and patents can be adopted to analyze history development, research fronts, and competitive science and technology situations, as well as to judge emerging technologies. Specifically, not only is the data source reliable and stable, but a scientometrics analysis can also visually display laws and trends in technology domains. Bibliometrics, patent analysis, and mapping knowledge domains all pertain to the scientometrics method, and have unique advantages in exploring S&T development laws and technology research hotspots, but are also disadvantageous in that they are not suitable for long-term foresight (Qiao, 2013; Wang and Wang, 2010). With the implementation of governmental technology foresight activities in China, the methodology has become much more diverse. In contrast, although other quantitative methods, such as system dynamics simulation, have been applied in regional and industrial technology foresight exercises, they still have not been involved in national technology foresight activities in China.

With technology foresight's scale and scope expansions, the requirements for such proposed exercises are increasingly strict; meanwhile, not only do technology foresight methods tend to be diversified and integrated; however, technology foresight methodology becomes a research hotspot regarding experts and scholars in related fields. Cameron et al. (1996) presented a "Triangle Structure" for foresight methodology, based on European and international technology foresight activities, to analyze ten methods from the creativity, expertise, and interaction dimensions. As technology foresight rapidly grows worldwide, the foresight method system is increasingly enriched; for example, many quantitative methods have emerged. Therefore, based on the "Triangle Structure" Popper (2008) added the "evidence" dimension and proposed a "Foresight Diamond," which contains 33 foresight methods (see Fig. 3) and employed three font styles to indicate the type of technique: qualitative (using a normal style), semi-quantitative (using a strong style) and quantitative (using an italic style).

The article examples listed in Table 2 are selected from the CSSCI database's subject retrieval results, in which most of the articles are regional- or industrial-level TF exercises. Most methods listed in

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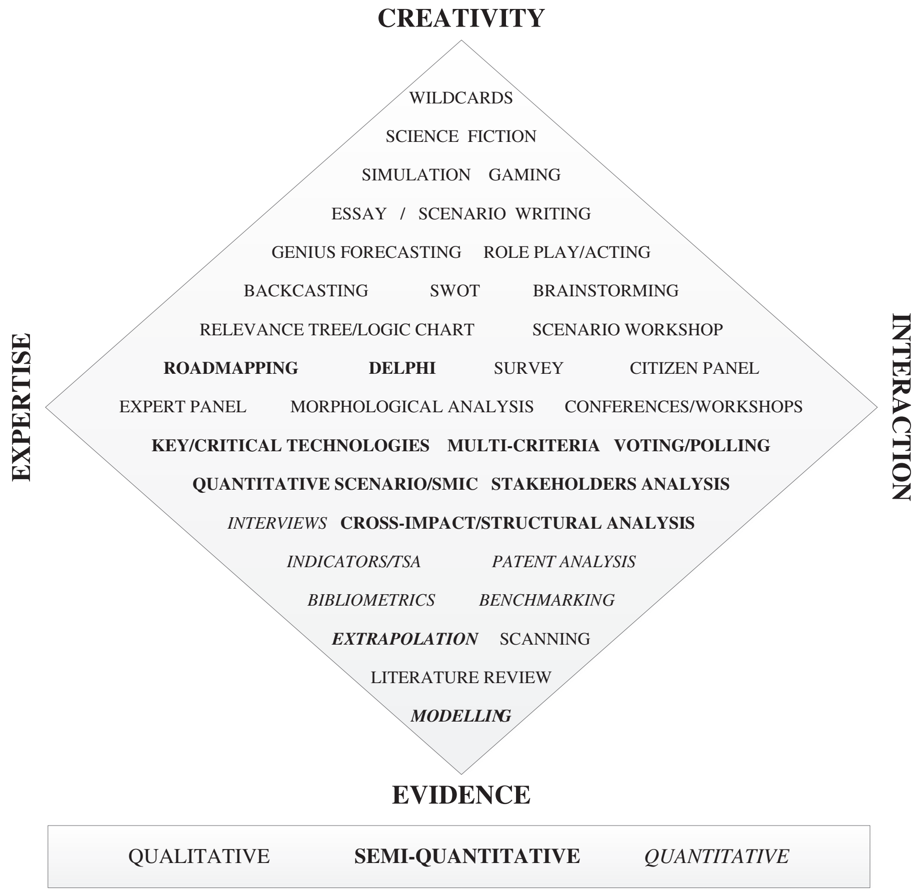

Fig. 3. The foresight diamond.
Source: Popper (2008).

Table 2 are basically located in the middle of the "Foresight Diamond," or close to the evidence dimension. Alternatively, the methods applied in the most national level TF exercises listed in Table 1, and especially the latest ones, are more approximate to the creativity, expertise, and interaction dimensions, which more closely parallels the "Triangle Structure."

Table 1
Technology foresight practices in China (national level).

	TF activity	Time span of implementation	Major sponsors	Research content	Time of foresight
Exploratory period	The national critical technology selection	1992–1995	National Science and Technology Commission[a]; Institute of Scientific and Technical Information of China	4 Fields	–
	The critical technology selection for social and economic development in the next 10 years	1993–1997	National Planning Commission[b]; National Science and Technology Commission; National Economic and Trade Commission	10 Fields	Next 10 years
	Technology forecast for national critical fields	1997–1999	Ministry of Science and Technology (MOST)	3 Fields	–
Rapid development period	The technology forecast and critical technology selection in high-tech fields of China	2003–2005	MOST	9 Fields	Next 10 years
	Technology foresight toward 2020 in China	2003–2005	Chinese Academy of Sciences (CAS), Institute of Policy and Management (IPM)	8 Fields	Toward 2020
	Strategic research on scientific and technological development roadmaps of major fields in China toward 2050	2007–2009	Chinese Academy of Sciences (CAS)	18 Fields	Toward 2050
Maturation period	National technology foresight	Launched in 2013	CASTED/MOST	13 Fields	Next 5–10 years
	Engineering S&T development strategy research toward 2035 in China	Launched in 2015	Chinese Academy of Engineering (CAE); National Natural Science Foundation of China (NSFC)	8 Fields of engineering technology	Toward 2035

[a] In 1998, the National Science and Technology Commission was renamed the Ministry of Science and Technology (MOST).
[b] In 2003, the National Planning Commission and other departments were integrated as the National Development and Reform Commission; the National Economic and Trade Commission and other departments were integrated as the Ministry of Commerce of the People's Republic of China.

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Table 2
Certain methods for Chinese TF exercises in the journal articles (regional/industrial level).

Methods	Article example	Type
Delphi + expert panel	Characteristics and implementation procedures of the "Market Delphi Method" are proposed (Cui et al., 2004).	Theoretical discussion
Delphi + technology roadmap	Considering technology foresight activity development in Shanghai as an example, analyzing the merits and demerits of the Delphi method and technology roadmap, and integrating the two methods provides a new visual angle for technology foresight development (Xu, 2011).	Regional
Delphi + scenario analysis	For example, the Chinese automobile industry first applies scenario techniques to identify technology requirements, then Delphi methods are used to complete green technology foresight, with a questionnaire and statistical model that are improved compared to the traditional ones (Liu et al., 2011).	Industrial
Patent content clustering	A patent content-clustering method is used to cluster different patent documents into homogenous groups, which are used to find a niche space for RFID (radio frequency identification devices) technology development in China (Trappey et al., 2011).	Industrial
Bibliometrics + patent analysis	A combination method of bibliometrics and patent analysis is applied to technology foresight, using the new material technology field as an example (Cheng and Chen, 2008).	Industrial
Mapping knowledge domains	The application of mapping knowledge domains in technology foresight are explored, and especially the aspects of selecting experts, determining technology fields and topics, enhancing foresight ability, supplying information support, and diffusing research results Wang and Wang (2010).	Theoretical discussion
Delphi + correlation analysis + clustering analysis	The Delphi Method and correlation and clustering analyses are adopted to discuss the development of future information technology in Shanghai, using information technology's technology foresight as an example (Li et al., 2005).	Regional& industrial
Delphi + System dynamics simulation	A two-stage technology foresight approach is proposed. During the first stage, critical technologies are identified and evaluated by nationwide experts through Delphi surveys. In the second stage, a system dynamics simulation model is used to estimate how critical parameter values are likely to impact the attainment of foresight goals (Chen et al., 2012).	Industrial
Semantic analysis + text mining + technology roadmap	Methods are presented including semantic analysis, text mining, and technology roadmap, and are applied into the demand analysis and technology selection of minimally invasive surgical procedures' clinical applications in Beijing (Li et al., 2009).	Regional & industrial

In conclusion, on the one hand, this analysis indicates that Chinese technology foresight methods comply with international correspondence rules; on the other hand, with the rapid development of science and technology, other methods must be further integrated to the technology foresight methodology formulation to improve the accuracy and scientific nature of the technology foresight results. Moreover, it is also critical to integrate these both organically and systematically. Additionally, the current methodology is not entirely and systematically incorporated into the overall technology foresight process, which is worth further exploration.

5. Latest development of national technology foresight practices in China

Almost all previous Chinese S&T planning has emphasized complete studies on tendencies in future science and technology. The most powerful motivator of technology foresight in China originated in the formulation of S&T planning. Academic research and practice regarding technology foresight in China cooled from 2009 to 2013. However, a new round of large-scale technology foresight activities, led by the government at a national level, has been conducted by the CASTED/MOST, the CAE, the NSFC, and the CAS since 2013. Moreover, this new round of technology foresight has become more concerned with an orientation toward solving grand societal challenges within the national innovation system. The methodology and process design of this new round of technology foresight are much more mature than in previous activities. Each activity has its own emphasis on an objective, and to some extent, technology foresight in China has transformed to "innovation foresight."

The latest comprehensive technology foresight activity was launched and organized by CASTED/MOST, and was implemented in 2013. This activity was implemented in three steps, technology evaluation, foresight survey, and key technology selection, and adopts a combined qualitative and quantitative method using large-scale Delphi surveys and bibliometrics (see Fig. 4). Currently, the investigation involves 13 fields, including information, biology, new materials, manufacturing, earth observation and navigation, energy, resources and environment, population and health, agriculture, ocean, transportation, public security, and urbanization. After the second round of surveys, the research group measured and chose 428 technologies, and selected 280 key technologies. Further research includes the key technology roadmap, future scenarios, and cross-impact and technology cluster analyses. The gap between China and the global advanced level has also been analyzed from aspects of the overall S&T development status and some typical S&T domains, striving to objectively evaluate the developing level of science and technology in China.

The CAE and NSFC jointly launched the "Engineering S&T Development Strategy Research Toward 2035 in China" program in 2015 (see Fig. 5). Such methods as bibliometrics, patent analysis, and Delphi and technology roadmaps were applied in practice, and the interval between the two rounds of Delphi surveys was lengthened. The list of the first round of optional technologies consists of 11 fields, and includes 93 sub-fields and 833 technologies. In October 2015, the first round of Delphi surveys has been completed. More than 8400 experts were invited from various fields and sectors, nearly 3000 people completed the questionnaire with a total participation ratio of 35%, and approximately 30,000 questionnaires were submitted from various fields. A demand investigation was conducted at the same time as technology foresight; the demand investigation questionnaire was based on six visions of the year 2035, and 102 questions were proposed. After the first-round Delphi survey, a research group from each field performed an in-depth study on critical technologies and technological paths, and especially disputed the technologies arising from the first-round survey according to the demand investigation's results. When the trends in technology were more thoroughly grasped, the second-round Delphi survey was conducted, and some targeted survey questions were added for the convenience of better serving the research. Developmental targets, critical development fields, key technologies requiring breakthroughs, major projects needing constructing, and fundamental research directions of priority development for China's engineering S&T toward 2035 were proposed. Such a TF activity would ultimately support systematic S&T planning and forward deployment for national engineering science and technology, as well as fundamental research in related fields.

6. Impacts of technology foresight on S&T planning

China's S&T planning can be divided into different grades, in which the preliminary grade involves listing fundamental factors, including targets, missions, and development priorities. The medium grade explicitly illustrates tacit relations among different factors. The higher

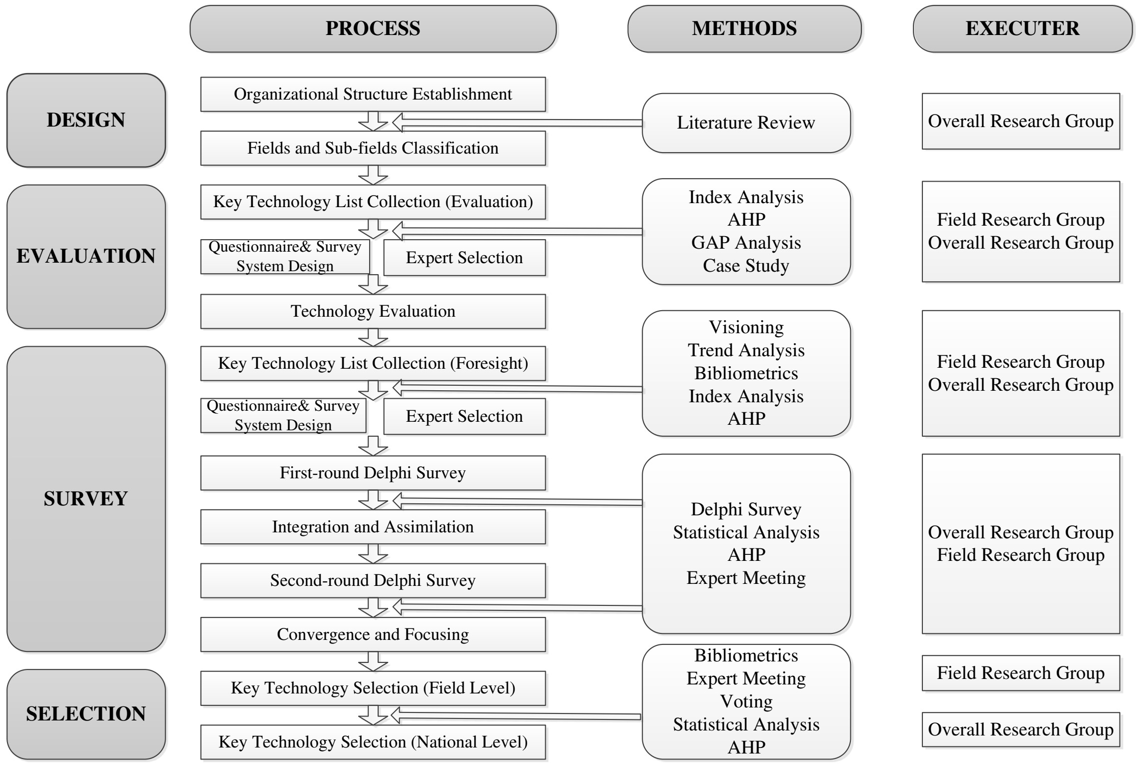

Fig. 4. The framework for "national technology foresight" (launched in 2013).
Source: modified from Yuan (2015).

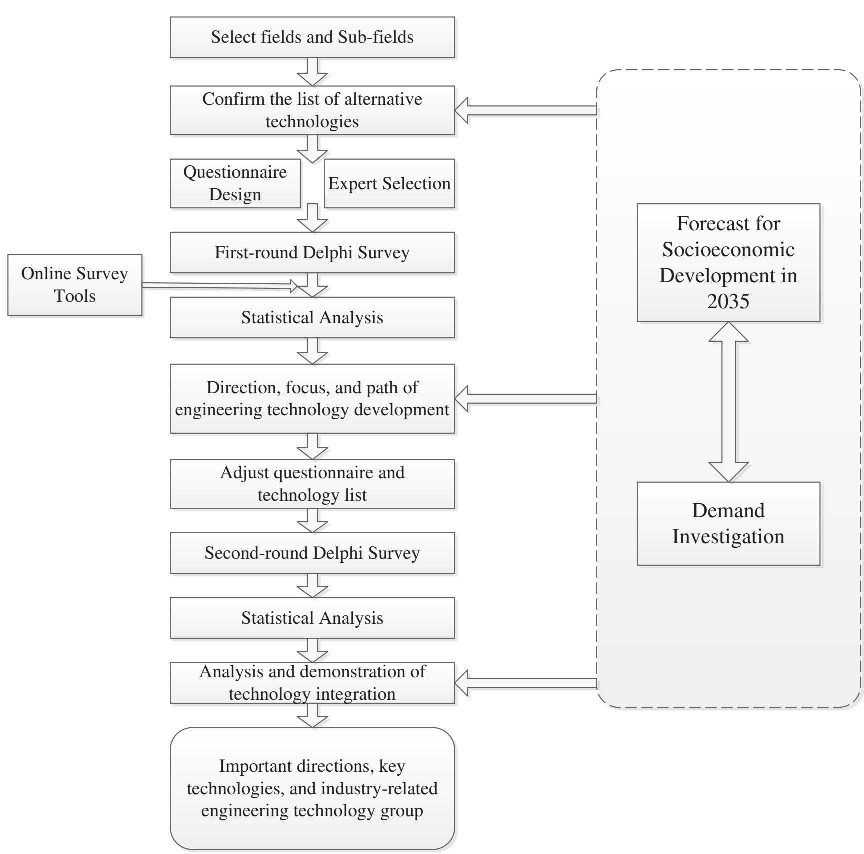

Fig. 5. The schematic diagram of procedure for "Engineering S&T Development Strategy Research Toward 2035 in China" (launched in 2015) Source: modified from Zheng (2015).

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grade prioritizes development strategies based on the nation's targets and values. Complete S&T planning clearly states the relationships among targets and resource allocations, as well as explicit evaluation standards for target fulfillment and the impact of implementation. Technology foresight studies have strengthened, adjusting the government's function in S&T (Yang, 2015). This governmental S&T function in market-economy countries experienced comprehensive adjustment after the mid-1990s, when technology foresight began rapidly developing. This can be observed in Japan, the United Kingdom, and South Korea. The S&T management research in these countries is separate from governmental functions, and is designated to professional institutions.

The instruments to realizing top-level S&T planning can be deciphered when studies on national S&T strategies are integrated into technology foresight exercises as a result of national critical technology selection. Fig. 6 demonstrates the basic technology foresight process in China, which includes studies on demand, forecast, and selection. A set of methods are formed during each technology foresight implementation stage, including the structural design method, selection procedure of alternative technologies, scientific index design, and expert group and data analysis systems to meet decision-making demands. These methods can guarantee reasonable results from technology foresight.

The continuation of technology foresight activities shapes a foresight culture, which provides a stable, favorable, and soft environment for S&T planning. The Delphi survey method is key for China's national technology foresight, as a resource corpus (including corpora for foresight methods, technology fields and sub-fields, technology topics, and experts) will be built during the survey. This is important for the continuous development of technology foresight. The objective of technology foresight is not only to posit a list of critical technologies that must be prioritized for development, but also to create a network platform for the government, industrial sectors, research institutions, and the public to communicate with each other and gain insight as to the supply and demand relations between technology and social development. Through the technology foresight process, they can garner new understandings to face future challenges together, and form a more closely connected social network. Martin and Johnston (1999) once summarized this kind of connection as “technology foresight for wiring up the national innovation system.”

The development of technology foresight in different countries demonstrates that its results play an important supporting role for S&T planning. Technology foresight activities based on communication, negotiation, and cooperation are very valuable by themselves. However, if the results cannot meet the decision-makers' requirements, technology foresight cannot be fully applied. Therefore, we should comprehensively and effectively analyze the Delphi survey's results, and introduce a mature policy analysis method into the analysis. Generally, mature technology foresight includes four parts: scenario analysis, studies on important and emerging scientific and technological areas, special studies on popular topics, and a large-scale Delphi survey (see Fig. 7). While a scenario analysis can assist in grasping China's economic and social trends, studies on important, emerging scientific and technological fields and special studies on popular topics can illuminate the technological solutions to major economic and social issues that China may face in the future. Meanwhile, a comprehensive Delphi survey can help researchers to grasp current situations, developmental trends, limited factors, and the possible social and economic benefits of critical technology studies, both domestically and abroad. All of these methods can provide important evidence for the formulation of national S&T planning. Therefore, technology foresight achievements can make national S&T planning more precise and accurate, which is beneficial for decision-makers to understand future trends in S&T and optional policy responses.

Currently, China still faces technical problems in the formulation of S&T planning, as the relationships among targets, missions, and priorities in S&T planning are implicit. These relationships must be explicitly illustrated through graphics. Yang (2015) proposed an approach to connect a strategic demand analysis to critical technologies selected through technology foresight exercises (see Fig. 8). Some important factors, such as the importance of technology, technological foundation, technological gap, time for realization, and development paths, which might affect critical technologies, should be identified and analyzed. The development path, potential products, and prospects' application in the market can then be highlighted. Thus, the technology roadmap can be formed, based on the above process.

7. Summary and future direction for research

Technology foresight has attracted much attention from the government, academia, and the industrial sector. Developed countries actively conduct technology foresight in multiple dimensions, and some developing countries also launch initiatives for national technology foresight and studies on the selection of critical technologies. China plays an active role in the development of technology foresight practices and studies. This paper tracks and analyzes the development trend by a bibliometric analysis, and reviews governmental technology foresight practices and policy applications in China. Some interesting findings are found.

Technology foresight has obtained rapid development in China, which is receiving more and more attention of academic researchers and government policy makers and going through a maturation period. Specifically speaking, Chinese technology foresight studies experience three periods: exploratory, rapid development, and maturation. Technology foresight promotes communication and negotiations between the government, industrial sector, academia, and other sectors

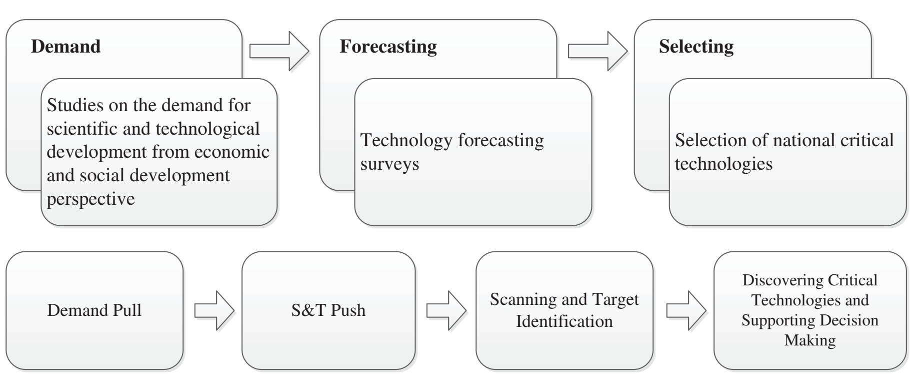

Fig. 6. A basic technology foresight process.
Source: Yang (2015).

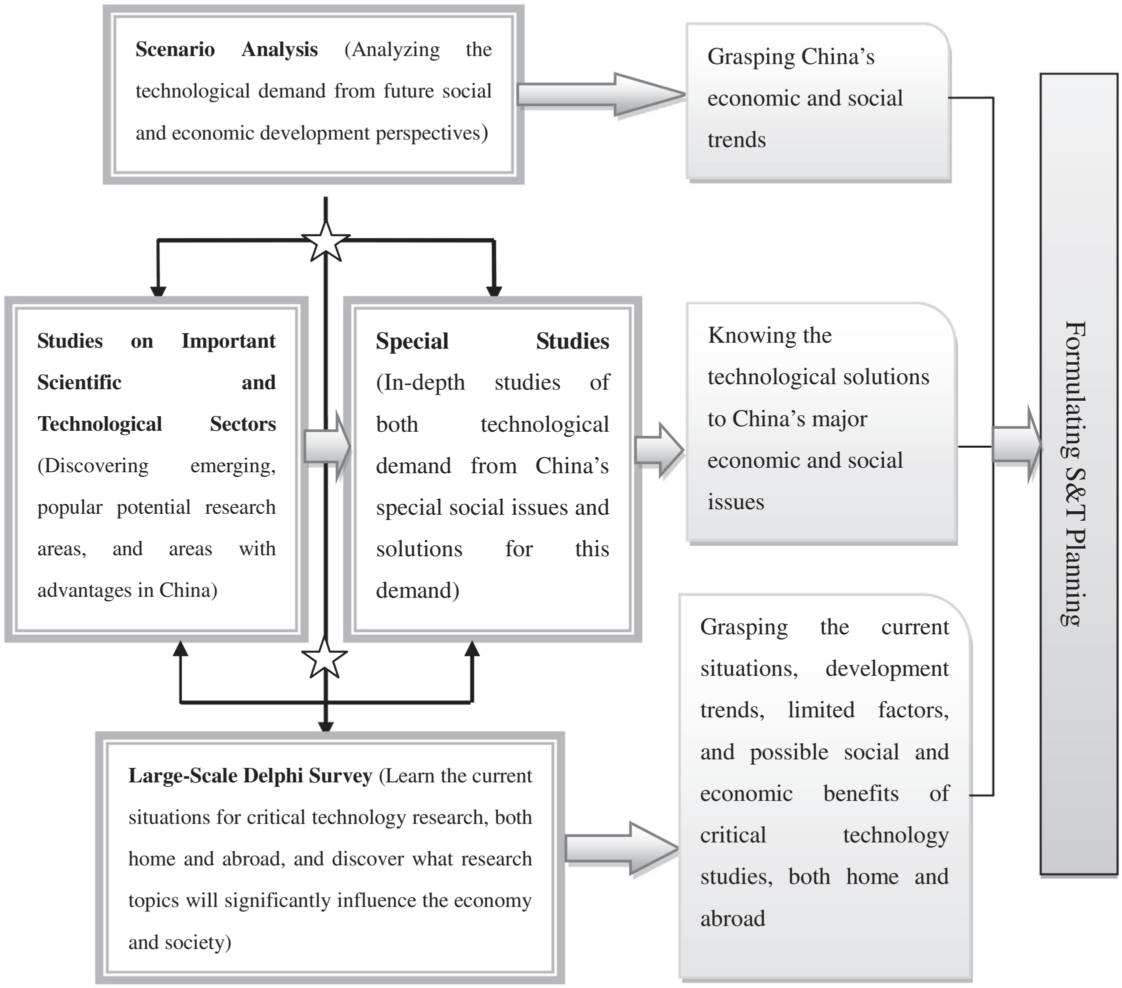

Fig. 7. Technology foresight and S&T planning in China.
Source: Research Group of Technology Foresight towards 2020 in China (2006).

in society. It holds significance as it improves policy-making and accelerates policy implementation, broadcasts foresight culture, and establishes a favorable, soft environment. A policy-making process based on technology foresight studies can help relevant stakeholders reach a common understanding regarding some major issues, and reduce obstructions to policy implementation. The results of technology exercises can address difficult issues we could possibly face in the future.

In the practical implementation of technology foresight in China, some quantitative and semi-quantitative methods were used to

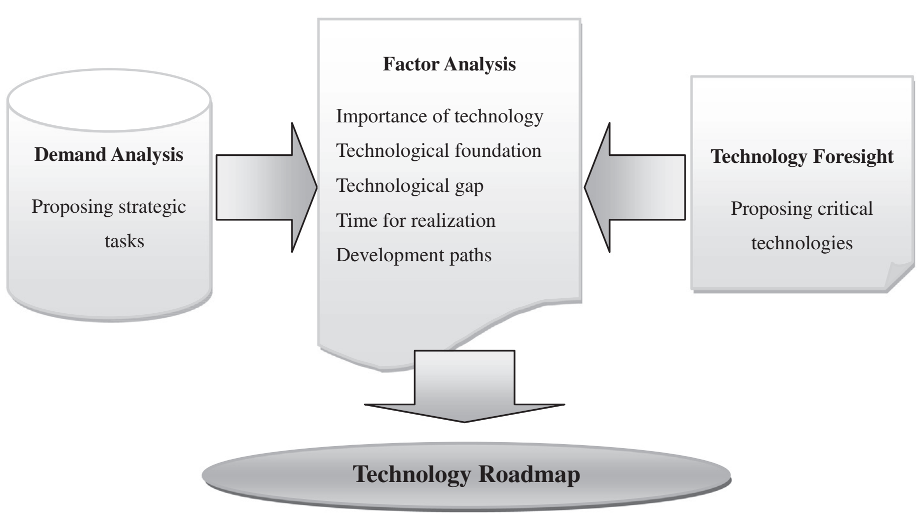

Fig. 8. Illustration of a technology roadmap approach.
Source: modified from Yang (2015).

Please cite this article as: Li, N., et al., Technology foresight in China: Academic studies, governmental practices and policy applications, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.010

appropriately improve the scientific nature of technology foresight. Besides, more qualitative approaches are incorporated into technology foresight activities in China. It is found based on China's practices that many problems in developing and planning science, technology, and innovation activities can be solved when comprehensive approaches are adopted to conduct technology foresight activities, including large-scale Delphi survey, scenario analysis, technology roadmap, and bibliometrics, among others. Foresight studies can employ various methodologies, depending on their goals (Meissner, 2013, p.47). For example, a technology roadmap can explicitly illustrate mutually implicit relationships among targets, missions, and priorities in long-term S&T planning, as well as those between long- and short-term plans. The scenario method is more appropriate to detect disruptive innovation and emerging technologies, and the scenario planning method aims to construct representations of possible futures, as well as the routes that lead there. This reveals the technological demands for economic and social development. From an S&T planning formulation perspective, some technology foresight methods can improve the quality of national innovative policy-making.

After two decades' localization in China, technology foresight methods are becoming increasingly mature, which are beneficial to ensure scientific results. However, current technology foresight in China must still explore more ways to establish its own methodology, as some issues remain unsolved. For example, while providing a full disclosure of the positive effectiveness of science and technology, some negative effects should be avoided: specifically, environmental and moral issues. Moreover, technology foresight's application to S&T planning also requires a scientific method. Therefore, technology foresight and S&T planning methodologies still have vast room for improvement. This is the only way this field can maintain increasingly complicated scientific and technological development, and evolve its results as more scientific and applicable. Science, technology, and innovation policies tend to be overwhelmingly scientific and democratic. Technology foresight provides a comprehensive platform to collect ideas and suggestions, to help formulate these scientific and democratic policies.

Acknowledgments

The work in this study was funded by the National Natural Science Foundation of China (Project number 71471170; 71103173), the China Youth Innovation Promotion Association (Project number 2015131), the Major Research Task of the Institute of Policy and Management in the Chinese Academy of Sciences (Project number Y201121Z01), and the Major Research Task of the Institutes of Science and Development in the Chinese Academy of Sciences (Project number Y501131S01).

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Please cite this article as: Li, N., et al., Technology foresight in China: Academic studies, governmental practices and policy applications, Technol. Forecast. Soc. Change (2016), http://dx.doi.org/10.1016/j.techfore.2016.08.010