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Exploring the impact of technology foresight studies on innovation: Case of BRIC countries

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ABSTRACT

This paper explores technology foresight activities in the BRIC countries. The article starts from recent trends in foresight research, including the generation models, methodologies, connections with innovation, and influence of globalization. The case analysis section will focus on the development of technology foresight activities in BRICs. Some common technology foresight issues and characteristics are identified and summarized for the BRICs and other emerging countries.

1. Introduction

Technology foresight has been widely applied as a policy instrument by governments around the world during the last few decades. National foresight studies are expanding from the industrialized economies to the developing countries. Standing in the middle of fully industrialized nations and underdeveloped counties, emerging economies such as Brazil, Russia, India, and China (BRIC) have been a new focus of the world. BRICs are unique that they share many attributes from both the developed and developing world. Due to their sheer size and populations, the BRIC countries are seen by Western scholars as golden bricks (BRICs) on the wall [1–4]. These countries may bring enormous business opportunities for the rest of the world: large potential market, fast growing economy, etc. However, foresight activities and related social impacts in these countries have not been studied much in literatures, especially as a group of countries with similar characteristics. A common feature in these countries is the proliferation of new institutions and innovation systems resulted by transitional economy. The research will focus on the characteristics of national technology foresight activities in the BRICs, exploring their common issues and challenges. The findings can provide insights for policy makers, foreign investors, local enterprises, and whoever wants to explore the market of the 'golden bricks'.

Following the trend of technology foresight worldwide, each of the BRIC countries has conducted its own foresight studies in recent years. Since the methods of national foresight are originally developed and applied in the advanced countries, there is no evidence these methods are also valid for latecomer countries. As applications in major emerging countries, technology foresight in the BRICs may provide some new insight for the world. How does technology foresight look like in the BRIC countries? It is well known that drastic social changes are undergoing in BRIC, are there any common issues and features exist in technology foresight studies in these emerging economic powers? What is the implication for other emerging countries? Through case analysis and comparisons, this paper will investigate technology foresight from the perspective of innovation, and identify major issues to be considered in future foresight studies.

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Following the introduction, the second section includes an overview of foresight studies, including practices in advanced countries, methodologies, and recent research trends. Such information provides a foundation for further discussion in the following sections. Here we take Japan and U.S. as typical examples of the developed countries. Since foresight of these two countries has been widely studied in literatures, we only briefly review their major characteristics. A highlight of Section 2 is the connection between technology foresight and innovation. This paper attempts to explore foresight from the perspective of innovation and globalization. In the third section, detailed discussions will be given to explore the foresight activities in the BRIC countries. Through careful examination of the common issues, we learn that technology foresights in the BRICs are largely influenced by their macro-level conditions. Technology development trends in the BRIC countries show some latecomer characteristics. Lastly, the article provides some suggestions for other emerging countries based on the findings from the BRIC cases.

2. Progress in foresight research

2.1. Foresight in developed countries

Nowadays, technology foresight has been adopted on a large scale across the world. However, most available foresight studies are shaped by the practices and methodologies from the developed countries, especially Japan and the United States. Nevertheless, the two countries have totally different attitude toward government-lead foresight activities. Japan is the most enthusiastic country in carrying out national technology foresight studies, but United States, surprisingly, are next to indifference to such large-scale foresight activities.

Major themes for technology foresight in the United States have been studied by literatures: strong contribution to foresight methodology development, important narrowly focused foresight efforts in some federal agencies, and no holistic national foresight studies [5]. Firstly, most of the widely applied foresight methodologies are developed by the United States. These tools include: the Delphi methods, scenario planning, Analytic Hierarchical Process (AHP), technology roadmapping, technology assessment, and impact assessment, etc. Secondly, some decentralized foresight studies have been undertaken at the sectoral levels. These foresight initiatives have been lead by agencies such as the US Environmental Protection Agency (EPA), the Department of Defense (DOD), and the Department of Energy (DOE). Thirdly, although there have been some foresight-like efforts in identifying critical technology during the 1990s [6], there is so far no comprehensive national level foresight studies, and it is unlikely to happen in the near future. There is no growing interest in national foresight, especially the Federal government. United states rely more on the market mechanism to establish priorities and allocate resources [5].

National technology foresight in Japan is based on large-scale Delphi surveys addressed to experts in a wide range of fields. The foresight activities have been repeated approximately for every five years since 1971. During this long time span, the scope of work and the range of methods applied have also expanded [7]. Except the first Delphi, which took three rounds, only two rounds were conducted since the second report. The fifth, sixth, and seventh surveys started to address socio-economic needs regarding to Japan's future. The eighth Delphi Survey was conducted in 2004. It addressed a 30-year period from 2006 to 2035. Although the study was still based on Delphi, some other methods were added for improvement. These new tools include: Bibliometrics, Scenario analysis, Socio-economic needs analysis, cluster analysis, and Analytical Hierarchy Process. The eighth survey consisted of 13 fields, 130 areas, 858 topics, and about 2300 participant experts, most of which are researchers, engineers, public and business executives [8]. Some key questions include: importance of technology, time of realization, leading countries, and necessity of government measures. As a country with extremely scarce resources, Japan continued its foresight activity for forty years and observed that it was an effective tool to make the future happen. Although the Delphi methodology was imported from the United States, it has been adapted and improved to suit Japan's circumstances. Technology foresight is proved to be useful in setting stable framework conditions for technology development and improving engagement with policy-making [7].

2.2. Foresight methodology

The selection of technology foresight methods involves a broader knowledge of foresight scope, objective, and criteria, all of which may vary with the actors participating in foresight activities. Since too many types of forecasting methods are available, classification of these methods becomes an important issue in the selection process. Generally, there are three ways to categorize foresight methodologies: 1. Exploratory or Normative methods; 2. Expert-based, Evidence-based, or Assumption-based methods; and 3. Quantitative or Qualitative methods [9]. Some scholars further divided the later into Quantitative, Semi-Quantitative, and Qualitative methods [10].

Quantitative techniques are used to monitor measurable variables and apply statistical techniques to process and analyze numerical data or indicators. Some frequently used quantitative methods include bibliometrics, modeling and simulation, and trend extrapolation. Qualitative methods are also frequently applied techniques in technology foresight activities. These techniques provide interpretations to development and observations. However, such analyses tend to be subjective and based on particular standpoints, perspectives, and perceptions. Some widely used foresight methods including literature review, expert panels and scenarios, all of which are qualitative. Semi-quantitative methods apply mathematical principles to quantify the opinions of experts. Such methods include cross-impact analysis; Delphi; critical technologies; multi-criteria analysis; quantitative scenarios, stake-holder mapping, and technology roadmapping [11].

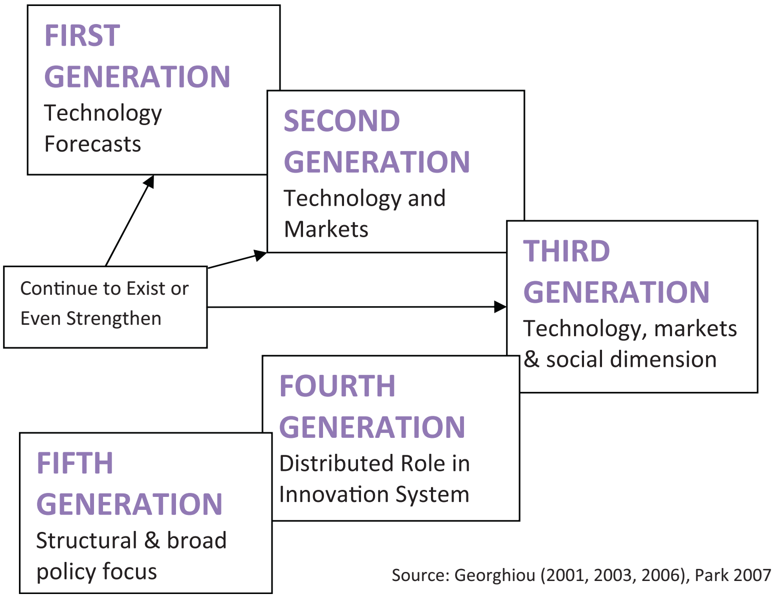

Fig. 1. Generations of technology foresight.

Due to the multifaceted environmental settings and requirements, combination of above methodologies is the trend in foresight and forecasting studies [12]. Methods can be combined in many different ways to create a more comprehensive methodology for the complex and lengthy foresight process. For example, the above mentioned various qualitative and quantitative methods can be selected to reach different goals in each host country. Since countries may have different developmental context and orientations, it is obvious that any methodological approach should be sensitive to the impacts sought from foresight. Ideally, methods should be selected and combined to achieve certain impacts in the target country [12].

2.3. Generations of technology foresight

The evolvement of foresight activities has been significant since the 1990s. It was applied to various environmental settings which included organizational, industrial, regional, national, or supranational level. Foresight scopes covered from limited technical experiments to major government initiatives. The timescale of foresight ranges from the immediate future to the far horizon. The range of actors involved, the process and methods used, and even the status of the activity varies considerably [13].

Scholars developed diversiform foresight models to reflect the increasing changes. Johnston proposed five stages in the chronology of foresight, with technology forecasting and futurism leading to technology foresight, from which emerged foresight, with its wider understanding of the economic and social processes that shape technology [14,15]. The author explored the strong progression within foresight studies towards being embedded within and directed towards planning and decision-making processes at various levels. Georghiou progressively posited a generational model of foresight in the last few years (Fig. 1) [16–18]. For the first generation foresight the key issues are accuracy of prediction and diffusion of technologies. In the second generation the take-up of priorities and connections of both industrial and academic participants become key issues, while the third generation implies the involvement of more stakeholders and looks for broader social concerns [13]. The fourth generation foresight moved into the distributed roles in innovation systems. To certain extent, the fifth generation further touched the complex policy issues of globalized innovation systems.

Scholar suggests that various generations of technology foresight can coexist in the future [19]. As illustrated in Fig. 1, Generations 1–3 will continue to exist or even strengthen respectively. This is similar to a contingency approach that depending on the context of the nation, organization or technology, one of the generations fits the best. Therefore, nowadays a first generation type of forecast may still be very well suited to apply.

2.4. Foresight wiring up innovation systems

Martin and Johnston first argued that technology foresight wires up and strengthens the connections within the national innovation system so that knowledge can flow more freely among the constituent actors, and the system as a whole can become more effective at learning and innovating [20]. Technology foresight exercise can be applied at organizational, industrial, regional, and national levels. From similar perspective, comparable research on innovation systems also has a multilevel structure. Four major types of innovation systems are studied in literatures, including National Innovation

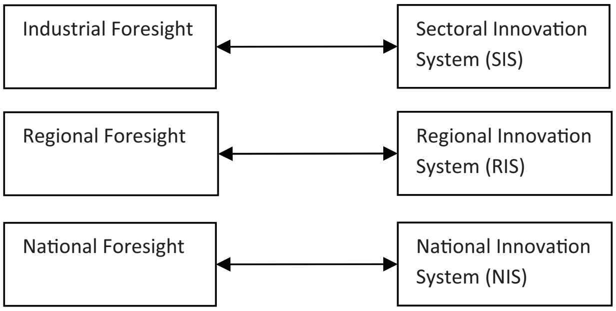

Fig. 2. Connections between technology foresight and innovation systems.

Systems (NIS), Regional Innovation Systems (RIS), Sectoral Innovation Systems (SIS), and Technological Innovation Systems (TIS). These innovation systems can be classified into three levels: macro perspective (NIS), meso perspective (RIS and SIS), and micro perspective (TIS). These innovation systems often link various national innovation resources (universities, R&D institutes, and enterprises) toward technological outputs (publications, patents, and new products). Fig. 2 shows the connections between technology foresight and innovation systems.

Technology foresight and innovation system research should be closely integrated so as to get a comprehensive understanding of emerging technologies and their social impacts. The development of the new generations of technology foresight models indicate the evolvement of foresight studies to match with the research in innovation, which include the structures or actors within the Science-Technology-Innovation system and broader social or economic concerns [18]. As illustrated in Fig. 2, the research in technology foresight and innovation systems can complement and mutually contribute to each other at various levels. From one direction, technology foresight explores future opportunities and set priorities for investment in science and innovation activities, which serves to reorient the Science and Innovation System. From the other direction, robust Innovation Systems provide better networks and linkages across scientific fields, industrial sectors and markets, which assist to guide technology development around problems. For example, the support may include synergies or systemic innovations such as the establishment of future technology standards, either between firms and research or among other innovators. Considering the high risks and uncertainties of technology development, it is necessary to create visions of the future through technology foresight, and at the same time, bringing the concerns of innovators into the strategic debate.

2.5. Influence of globalization

In the era of globalization and internationalization, the speed of technology development and innovation are vital for survival. By using national boundaries, actors sharing a common culture, history, language, social and political institutions are identified [21,22]. However, innovation systems are becoming more integrated across national boundaries, raising questions about how an individual country can best benefit from the changing situations [20]. The speed of globally synergic innovation has been accelerated by economic liberalization. The geographic locations of global innovation cradles are getting more dispersive than ever before. The question is that who can better utilize and benefit more from the globally distributed innovative resources.

Technology foresight activities should adapt to the changes brought by globalization of innovation systems. Environmental differences stem from country specific characteristics such as policy risk, financial instability, and market fluctuations. Technology characteristics among different countries may have impact on foresight exercises. Technology gaps exist because countries invest differently in education, R&D, and other inputs for technological change [23,24]. Their choices about how to invest, as well as the productivity of these investments will shape their path for future technology development [25,26]. Other influencing factors may include each country's technology level, technological proximity, and technological diversification [27,28]. Technology adaptability is also an important factor to consider in foresight studies. It decides the candidate technology's future market potential and feasibility in the host country.

3. Foresight in BRIC

3.1. Brazil

Brazil has a relatively long tradition of using and applying technology future studies in national development. The concepts and methodologies of technology foresight and innovation planning have been introduced into Brazil since the late 1970s. However, the history of national level foresight in science and technology the country is not very long. The first large scale foresight study is done by the Ministry of Science and Technology in 1998, which is named as Brazil 2020. This program is done through exploratory scenario analysis, where four scenarios were developed to depict future Brazilian society (Scenario A – GOOD – called ABATIAPÉ, Scenario B – FAIR – called BABORÉ, Scenario C – BAD – called CAEETÊ, and Scenario D – DESIRED – normative – called DIADORIM). The program did not touch too much on technology development, but focused

Table 1
Major foresight activities of Brazil in recent years.

Foresight programs	Year	Research fields	Research methods
The Prospectar Program	2000–2003	Aeronautics, Agriculture, Energy, Health, Hydro Resources, Materials, Space, Telecom and IT	Brainstorming, Delphi, and Prioritization
Brazilian Technology Foresight Program (to 2016)	2002	Civil Construction, Textiles and Garments, Plastics, Wood and Furniture	Critical Factor Analysis, Cross-impact analysis, Key Technology Analysis, Modeling, and Scenarios
Brazil 3 Moments (in 2007, 2015 and 2022)	2005	Trends in 7 dimensions: Institutional, Economic, Socio-cultural, Regional, Knowledge, Environment, and Global	Conjuncture analysis, Cross-impact analysis, Delphi, Retrospective analysis, Scenarios, and Simulations
CGEE Sectoral and Regional Technology Foresight	2002–2007	Advanced Materials, Bio-fuel, Biotechnology, Climate Change, Energy, Hydro Resources, Nanotechnology	Brainstorming, Delphi, Surveys, Workshops, etc.

on social and economic aspects. Major issued include: Political Paradigms, Globalization, International Trade, Economic Fluctuations, Foreign Investment, Government Expenditure, Resources, and Employment, etc. This program initiated and contributed to fostering the future-oriented thinking in the country. In the new decade, technology foresight activities have been widely applied at different levels, including regional, industrial/sectoral, and national foresight (Table 1).

The Prospectar Project was developed by the Ministry of S&T and National Council of S&T as the first national level technology foresight. The project was implemented between 2000 and 2003. It covered 8 major research fields and 1652 technology topics. The methodology used is online Delphi, where 10,939 experts responded to the study, among which 59% have Ph.D. degree [29]. The project had positive results given that it boosted an interest in long-term technological planning. However, there are some criticisms that the selection of technological topics was too specific, and a more systemic view would have been preferred [30]. Moreover, this Program was discontinued without apparent reasons and there is no evidence whether the results will be properly used or not [31].

The Brazilian Technology Foresight Program (BTFP) was developed by the Ministry of Development, Industry and Commerce in 2002. The program received support from the UNIDO. BFTP aimed to develop competitive advantages in four major industries. In addition to conventional foresight methods, the application of production chain methodologies was a highlight in the foresight process. BTFP was a more practical approach in that it focused on industries where Brazil may achieve relative advantages globally. However, the program has also been criticized in certain aspects: (1) The approach by no means guarantees that the outcomes are easier to implement than those produced by traditional methods [32]. (2) There were no real evidences of the proper use of BTFP's results [31]. (3) It is difficult to translate findings into policy recommendations with a long-term vision [30].

The Project Brazil 3 Moments was lead by the Brazilian Presidential Strategic Affairs Unit in 2005. The study aimed to identify national strategic objectives through large-scale dialogs with different stakeholders of the Brazilian society. Scenario analyses have been applied to envision the country's future in 2007, 2015, and 2022 (representing short-, medium- and long-term goals). The results of Delphi survey indicate that education should be enhanced in Brazil's future development.

A series of sectoral and regional technology foresight studies have been carried out by the Center for Strategic Management and Studies (CGEE) between 2002 and 2007. Supervised by Brazil's Ministry of Science and Technology, CGEE is specialized in handling foresight activities and assisting national planning for S&T in the country. CGEE adopted and combined a variety of foresight methods that have been applied in European countries. Many of the CGEE's studies focus on emerging technologies that Brazil has the potential in catching-up with advanced countries, i.e. biotech and nanotech. In recent years, CGEE also works with the Ministry of Planning, Budget and Management to carry out regional foresights to evaluate local strengths and strategies.

3.1.1. Foresight characteristics in Brazil

Many Western techniques have been adopted in Brazil's foresight studies, and scenario analysis has been the most popular planning and administration tool for Brazil's practices. This is because heavy economic and political instability of the 1980s (energy shock and recession) led to seriously faulty (extrapolative) forecasts [33]. In the first decade of the new millennium, the use of scenarios has been combined with many new metrics. Some Brazilian scholars argued that the synergy between Competitive Intelligence, Knowledge Management and Technological Foresight should be regarded as a new mechanism to support decision-making for sustainable development and innovation [34]. As an instance, text mining techniques have been applied in recent Brazilian foresight research [35].

Globalization-related impacts impose the need for implementing new strategies in industrial and technological sector of emerging countries, like Brazil [36]. Foresight practices in Brazil not only need to emphasize issues catching up with advanced countries, but also need to consider issues competing against emerging economies of similar conditions. This pattern has been demonstrated in some recent CGEE foresight studies [35]. In an increasingly globalized context, the Brazilian market was opened to foreign competition, placing more emphasis on technological innovation, quality, and competition. However, many actions and issues with which Brazil needs to deal with are how to take advantage of its unique local assets that can provide competitive advantages in the global environment [37].

As the world's eighth largest economy, Brazil's innovative capability is still unsatisfactory. This hiatus between the generation of science and innovation is also typical of other emergent countries [38]. The country needs to construct a more effective national innovation system and integrate into the global innovation networks. Technology foresight can play a more important role in such process. However, as shown in the above reviews, some foresight studies experienced difficulties in implementing the foresight results or providing policy recommendations. This should be an area for future improvement.

3.2. Russia

The foresight activities in Russia experienced ups and downs due to drastic political and social changes in the last few decades. The first generation foresight can date back to the early 1970s, when a large-scale national project—the "multi-aspect program of technology progress" was carried out by the Soviet Union. Foresight during the 1980s assisted policy planning and stimulated academic interest in forecasting research, but the results were somewhat biased due to ideological influence. Although there were still foresight attempts to identify R&D priorities in the 1990s, degradation in scale and content are significant. The major reason is lack of interest from government, which have to emphasize on urgent current problems, rather than long-term technological issues [39]. As the political and social conditions improved and stabilized in the new century, foresight researches resuscitate in the Russian Federation.

Many national, sectoral, and regional foresight studies have been developed in the recent decade. The "Russian Critical Technologies 2015" program is a national foresight organized by the Ministry of Education and Science of the Russian Federation between 2004 and 2005. Setting S&T priorities has long been an important issue in Russia for the last four decades. It provides information and background for defining budgeting and forming the priorities of Federal S&T Programs [40]. Through surveys and expert panels, a list of eight priority areas was developed, including: ICT; Nanotech; Living systems; Nature utilization; Power and energy; Transport and aerospace; Safety and Security; and Defense technology. The sectoral foresight "Russian Nanotechnology 2020" was conducted in 2005 to outline the global and national trends. The project emphasized on Russia's catching-up through the analyses of foreign nanotech initiatives and local strengths. Methodologies used including scenarios, benchmarking, SWOT, Delphi and technology roadmaps. The main recommendations made to policy-makers were to develop measures to support spin-offs and start-ups, research teams and institutes, as well as training and education [41].

The "Concept for Long-Term Russian S&T Forecast till 2025" program was developed in association with key ministries, science and business representatives in 2007. The program has been regarded as a third generation foresight study, which covers technology, markets and global social dimensions [42]. The research was based on large scale Delphi, in which more than 2000 experts from 40 Russian regions participated in the surveys. Ten thematic research areas were developed based on the results of "Russian Critical Technologies 2015", adding areas of Medicine & Health and Manufacturing Systems, replacing Defense Technology with Technologies for Society. Each thematic area includes 5–8 technology areas and 80–110 technology topics [43]. In the survey questionnaire, each technology topic was evaluated using several criteria including importance, time of realization, leading countries (Fig. 3), domestic R&D level, feasibility of commercialization, and policy measures, etc.

Among all the leading countries, United States leads in more than 50% of all technology topics, followed by European Union and Japan each with more than 30%. Russia leads in only about 10% of the technology topics (total is above 100%

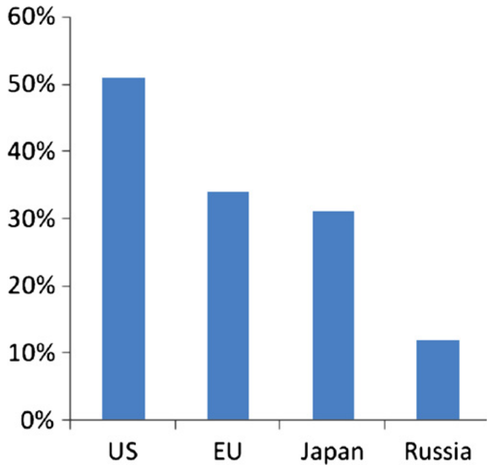

Fig. 3. Leading countries in technology.

Table 2
New technologies developed in Russia (Russia in 2007 statistical abstract).

Year	Total	Including		Ratio
		New for country	New in principle	
2000	688	569	72	12.7%
2001	637	543	44	8.1%
2002	727	606	70	11.6%
2003	821	582	56	9.6%
2004	676	569	52	9.1%
2005	637	538	60	11.2%
2006	735	642	52	8.1%
Average	703	578	58	10.0%

because countries can be on a par with others). The experts' judgment results are comparable with Russia's innovation statistics in the last few years. As shown in (Table 2), only about 10% of Russian innovations are really new worldwide (in principle). It also means that about 90% of Russian developed technologies are actually already exist in other countries. This shows a development pattern of catching-up economy.

3.2.1. Foresight characteristics in Russia

The foresight methods and formats being practiced in developed countries were the foundation for the Russian Foresight [44]. Formally almost all recognized foresight methods are used, but core of research is still large-scale Delphi survey [42]. The methodological approaches used for the Delphi exercise were based on the best available foreign practices, including Delphi surveys performed in Japan, Germany, the UK, and general methodological approaches from early RAND publications. Some methodological issues specific for Russia were taken into account, including a wide range of areas to be covered, a strong tradition of lobbying by leading research teams, concentration of R&D in big research institutes [43].

Although a leader in some technology fields, Russia still lags behind to major developed countries in many high-tech areas. Some Russian scholars raised the question whether Russia will develop catching-up with modernization or whether it will invent its own approach of exploring the future [44]. The selection of critical technologies in Russia meets several criteria: competitiveness, contribution to economic growth, and overcoming dependence on imports [40]. As Russia's development relies heavily on the exploitation of natural resources and raw materials, foresight studies have emphasis on traditional economic areas, including energy, agriculture, and natural mineral processing. Foresight reports state that the transition of the Russian economics to the innovation development is impossible without formation of a globally competitive national innovation system and set up of legal, financial and social institutions that would ensure interaction of the education, science, business enterprise and structures in all spheres of society [45]. Russia's available Innovation Systems are not effectively linked or optimized to foster innovation [42]. The Russian foresight agenda for the future should include the construction of an integrated national innovation system [39]. Globalization provides Russia new opportunities in technological collaborations with advanced countries. How to strengthen the global competitive advantages of Russia is an important aspect in Russia's foresight.

3.3. India

Technology foresight activities in India are carried out by the Technology Information, Forecasting & Assessment Council (TIFAC), which is an autonomous body under the Department of Science and Technology of India. The most important foresight program implemented by TIFAC is the *Technology Vision 2020* foresight study between 1993 and 1996. This is so far the most comprehensive foresight research in the country. It aimed to provide a long-term vision in important emerging technological areas for India up to 2020. Seventeen technology sectors and more than a hundred sub-sectors were identified as significant areas under four major categories (Table 3). The covered areas are those India may have comparative advantages, or where core strength should be built up.

The methodologies applied in *Technology Vision 2020* are based on combinations of scenarios, Delphi survey and interviews. Brainstorming sessions and the Nominal Groups have been employed to analyze various driving forces and barriers, including both global technology trends and local social, economic and market needs. The Delphi exercise involved more than 5000 experts including scientists, technologists, enterprise managers, and policy makers. 17 task forces and panels were formed, of which 10 were lead by industrial experts, 5 by experts from R&D Institutes, and 2 by experts from the government. More than 300 reports have been prepared in this mega project.

Although the *Technology Vision 2020* program was taken more than 15 years ago, no such national level foresight study with comparable scale has been conducted since then. There are some follow up projects taking place independently including some regional or sectoral practices, but only with limited scale. The Home Grown Technology (HGT) program is an approach of TIFAC for supporting the development of technologies by indigenous actors. The program supported 77 HGT projects, but was formally closed in the year 2005. Analysis of the programs reveals some shortcomings [46]: lack of funding for large projects, inadequate scale of operation, poor assessment of technology operations, lack of technically skilled manpower, and technology shifts which led to low market prospective.

Table 3
Technology vision for India up to 2020 (TIFAC 1998).

Category	Foresight sectors
Social-economic area	Agro-food & Processing; Food & Agriculture; Life Science & Biotechnology; Health Care
Infrastructure	Civil Aviation; Waterways; Road Transportation; Electric Power; Telecommunication; Services (including: Finance; Marketing; Logistics & Trading; Human Resource; Travel & Tourism; IPR; Technical Consultancy; Security; etc.)
Industry	Engineering Industries (including: Foundry & Forging; Transport & Vehicles; Electric machinery); Chemical Process Industries; Materials & Processing; Electronics & Communication
Strategic area	Advanced Sensors; Driving Forces & Impedances; Strategic Industries (including: Aircraft; Radar/Weather; Electronics; Space Communications, Remote Sensing; materials & Processing; Robotics & Artificial Intelligence; etc.)

3.3.1. Foresight characteristics in India

The foresight methodologies of the Indian National foresight are based on Delphi, but have somewhat been modified according to India's unique social and economic contexts. The approach is a combination of scenario writing, Delphi questionnaire, and special response analysis using additional written inputs, fine tuning and short listing through seminars [47]. These extra steps aimed to critically analyze which low-cost mass technologies can be embedded in India's context, so as to exploit its competitive advantages. The process highlighted the fact that appropriateness of technology should be the guiding principle in India. It should be noted that what could be a critical technology for India may not be so for other developed countries such as the U.S. [48]. The technology needs of India ranged from strategic emerging technologies to rural development related technologies. All of which should be cost effective to match the domestic socio-economic needs [49].

The theme of Indian foresight has a strong emphasis in catching-up with the developed world through economic development. This conforms with government's goal which aims at increasing technical competence and self-reliance especially in strategic areas [50]. India has suffered from the technology-control regimes of advanced nations. Developing indigenous capabilities for self-reliance in critical technology areas where denials of technologies by advanced countries are India's strategic priorities [51]. However, developing indigenous technologies may encounter enormous difficulties if the domestic innovative capacities are not ready or cannot provide enough support. Therefore, the country's innovation infrastructure will need to be crafted with due foresight and careful planning. With a new context of globalization and inter-dependence, an integrated approach to strategic technology planning will be essential to developing the requisite capabilities for the future [51]. This calls for a new generation of technology foresight in India.

3.4. China

Technology foresight concept was introduced into China in the 1990s, but there was no formal foresight initiative in China until 2001, when two regional foresight studies were initiated in Beijing and Shanghai respectively. In recent years, there are two formal national foresight programs carried out by Ministry of Science and Technology (MOST) and Chinese Academy of Sciences (CAS) respectively. Since the time span of these two researches overlapped to each other, and both researches were split into different stages, noticeable confusion and misleading can be found in academic literatures. Here we compare the special features of the two foresight programs as a whole.

The Technology Foresight for National Critical Technology program was lead by MOST. The research was carried out between 2002 and 2005 in two stages, where each stage covered three different high-tech sectors [52,53]. The foresight program covered a total of 6 fields, with 42 sub-fields and 483 technology topics. In each stage, Delphi-based surveys were applied in three phases. The first phase is to identify technology topics and design the survey questionnaire based on China's socioeconomic needs and S&T trends. The second phase is to conduct the two-round survey and carry out statistical analysis of results. The third phase focus on the further validation and recommendation of national critical technologies through expert meetings and reports. During the first phase of stage one research, about 1000 experts participated in more than 40 consultation meetings. In the second phase, More than 600 experts (out of 1300) responded to the questionnaires [52,53]. The technology topics were evaluated under 17 criteria, including: importance, time of realization, impacts, domestic technological level, commercialization and industrialization, and IPR potential, etc.

An interesting investigation in the survey is about China's current technological level and leading countries. When comparing the 483 technology topics with advanced countries, China is leading in only one topic, which is the "Chinese character & information processing technology". Since Western developed countries do not use Chinese characters, it is obvious China can become the absolute leader in this field. For other high-tech areas, China has twenty technologies (less than 5%) on a par with international leading standards. Most technology fields (more than 90%) are lagging behind for 5 years or above (see Table 4).

The Technology Foresight Towards 2020 program is led by CAS from 2003 to 2006. There is a time overlap with MOST's foresight program (2002–2005), but CAS's foresight program covered more topics and recruited more experts. The research of the CAS also consists of two stages, and each stage covered 4 different high-tech fields [54]. A total of 8 fields, 62 sub-fields, and 737 technology topics were studied (Table 5). The foresight methodology was based on expert panels, scenario analysis, and the Delphi method. Scenarios were designed for achieving a broad-based medium-level wealth society. Expert panel

Table 4
China's technological level compared with other countries (MOST 2005).

Technology fields	China leading	China on a par with leader	China lagging 5 years	China lagging 6–10 years
Information and communications	1	5	66	3
Biotechnology and life science	0	7	76	0
New materials	0	6	49	9
Energy	0	2	81	0
Resources and environment	0	0	99	1
Advanced manufacturing	0	0	52	26
Total	1	20	423	39

meetings played important role in the selection of technology topics. During the Delphi survey, more than 1500 experts from selected areas responded to the questionnaires [55]. Technology topics are evaluated under several criteria including: importance of technology, feasibility of technology, difficulties for realization of technology, domestic research capability, leading countries of technology, and the expected time of realization.

3.4.1. Foresight characteristics in China

The methodologies of technology foresight in China are based on adapting the best practices from developed countries, including Japan, Germany, UK, and Korea. The foresight results showed that resource allocation is an important issue to be faced by the government. The findings highlight some potential improvement areas for policy-makers. For instance, under the criteria "Difficulty of Realization", the results reveal some constraints on the technology development: (1) regulation, policy, and standards, (2) human resources, (3) research funding, and (4) basic research infrastructure, etc.

The foresight revealed that China's technology level is lagging behind advanced Western countries. Table 6 shows the results of technology leading countries. The USA leads in all technology fields, followed by Japan and Europe Union. Russia ranked in the fourth place, and other countries are barely perceived as technology leaders. One exception is South Africa, which leads in the energy sector for a type of coal and petroleum processing technology.

4. Discussions

This section explores the common issues or features of the foresight activities in the BRIC countries. These areas include timing of technology realization, appropriate technologies, and some strategic concerns. Based on the analysis of such issues, some possible recommendations are provided for future foresight studies in the BRIC countries, as well as similar studies in other emerging economies.

4.1. Technology realization

A common issue of foresight in the BRIC countries is how to forecast the time of technology realization. Since the technology level of the host country is generally lagging behind of world leading standard, the question become shall the foresight study focus on local realization time or global realization time. If the foresight study focuses on the local realization time in the host country, the technology may be realized first in some more advanced countries. For this situation in the

Table 5
Technology fields and sub-fields (CAS 2006).

Technology fields	Sub-fields
Information, Communication and Electronics	Broadcast and TV, Bio-Informatics, Computer, Communications, Display and storage, human-machine interface, Micro-electronics, photoelectron and MEMS, Info retrieval and sensors, Info security, IT Applications, Network, Software.
Energy	Coal, petroleum and natural gas, Electric power, Heat and mechanical energy, Hydrogen energy, Nuclear, Renewable Energy.
Materials	Functional materials, Inorganic and Ceramic materials, Macromolecule materials, Metals, Nano-materials, Photo-electronics.
Bio-tech & Medicine	Agriculture & environment, Biological catalyst & transformer, Cognition & human behavior, Discovery of novel medicines, Measurements, Platforms, Prevention & therapy of disease, Stem-cell & regenerative medicine.
Advanced Manufacturing	Advanced processing & equipment, autoimmunization, Bio-tech Manufacturing, Digitalized design and manufacture, Integrated manufacturing system, Lean manufacture, Micro-Nanofabrication, Robot & intelligent control, Sensor & detection.
Resources & Environment	Disaster Prevention and Mitigation, Ecology, Environment, Marine resources, Solid Mineral Resources, Soil and water resources, Weather and Climate.
Chemistry & Chemical Technology	Biomedicines, Chemical materials, Environment and security, Resources Exploitation, System design of info & process, Transformation and control.
Space Technology	Astronomy observation, Manned-space flight, Communications, Global navigation & position, Launchers, Platforms of spacecrafts, Space exploration, Space Remote Control.

Table 6
Technology leading countries (CAS 2006).

Field	No. of topics	USA		Japan		EU		Russia		Others	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Information, Communications and Electronics	150	150	0	1	97	0	56	0	0	0	0
Energy Technology	72	50	17	5	17	15	38	2	1	1	0
Materials S&T	86	73	11	12	68	2	6	0	1	0	0
Bio-tech & Medicine	101	94	7	6	23	1	74	0	0	0	0
Advanced Manufacturing	90	79	10	8	48	4	34	0	0	0	0
Resources & Environment	82	64	13	7	17	14	52	1	2	0	0
Chemistry & Chemical Tech	78	72	4	4	24	3	51	0	0	0	0
Space Technology	78	76	2	0	0	0	50	2	26	0	0
Total	737	658	64	43	294	39	361	5	30	1	0

future, the target technology will be readily available in a foreign advanced country. If the host country is lagging 5 or 10 years behind in development, does this worth it to keep the original investment or R&D effort in that technology area? Or if the foresight study focuses on the global/foreign realization time, what are the impacts on local technology development?

The real situation today is that the BRIC countries are still striving to develop many technologies that are already available in the developed countries. This can be seen in the above analysis of foresight in Russia and China. One thing in common of the BRIC countries is they face technology export control from the Western developed countries. Many technology leading countries, especially the US, have strict limit over high-tech transactions with foreign countries to prevent technology leakage which may potentially damage national interest. These countries have issued numerous law terms and regulations regarding cross-border technical transactions. The technology export control also exists at the enterprise level, where multinationals are reluctant to deliver high technologies to raise potential competitors in the emerging markets. These factors significantly influenced technology development and realization in the BRIC countries. In their foresight study of many high technology fields, the realization time or paths are variables that depend on foreign factors.

Moreover, available technology foresight methodologies are originally developed and applied in the industrialized countries. These techniques may not be fully appropriate to the BRIC's context in many aspects. Restrictions apply on the BRIC countries concerning their transitional social, economic, and technological conditions. With relatively weaker innovative capacity and fewer available technological resources and foreign technology control, emphasis on technology and innovation planning, including technology realization, would be extremely necessary [56].

4.2. Appropriate technologies

The critical areas of priorities for technological development in the BRIC countries may not be the same as those of the United States, Japan, and other developed countries of EU. For example, Indian scholar argued that critical technologies in India may not be that critical for the United States [48]. From another perspective, the similarity to technological priorities of developed countries is determined by certain similarities in their initial economic and technological positions [39]. Due to the BRIC countries' unique context and social circumstances, they may have different needs and expectations in technology development. To cater such needs, the foresight studies of BRICs are to identify candidate technologies suitable for the host country's development in the future. Technology foresight or forecasting studies give the direction of technological development. The focus of interest is appropriate technologies that can serve as possible window of opportunity for innovation and leapfrogging. The direction of technology advancement can be integrated into the overall national planning process at the higher level. This includes selecting the appropriate technology areas for current needs, as well as choosing the right direction for future investment.

From the perspective of the BRIC countries, appropriate technology can offer an opportunity window to catch-up with technology leaders. Whilst the enterprises tend to follow market drivers and focus on short-term interest of monetary profits, the government will plan for overall social needs and emphasize on long-term benefits of social welfare [57]. National foresight projects can link the countries' unique context, and serve as a tool to exploit technological opportunities. Prospective technologies can be selected based on the host country's limited resources and serve to help the country to further develop innovation capabilities. Russian scholars argued that when selecting critical technologies for the civil sector, they should restrict the number to a minimum level due to the need for concentrating resources [40]. This is to provide sufficient budget funding for each of the critical technologies through federal S&T programs. The critical technologies should provide innovation products for potential markets within a relatively short time period and at comparatively low investment.

Since no country, however rich, can afford to pursue all the possible opportunities in science and technology, there need better mechanisms for choosing between competing alternatives and resources [20]. In order to compete in the globalized market, it is better for latecomers to focus on technology areas where comparative advantage can be achieved in the shortest amount of time. Technology foresight offers such possibilities to identify and take advantage of opportunities, and to underpin prospective research areas likely to yield the greatest economic and social benefits.

4.3. Strategic concerns

Another major issue is how to address strategic concerns of technology development in foresight studies. For the BRIC countries, they faced the problem of how to strategically implement the technology topics identified in their foresight studies. Longer-term perspectives and strategies resulted from the foresight studies call for better use of limited resources. The implication is that successful foresight must include understanding of the interaction of foresight studies with the strategic behavior of policy and economic actors [58]. Globalization of innovation systems has increasingly changed the culture of technology foresight as well as the strategic behavior of the implementing bodies. The foresight programs have to cover both the technology status in the world and in host country. Brazilian scholars have used the term "gloCalization" to describe the strategy of "think globally, act locally" [34]. This idea perfectly matches the goal of technology foresight studies today. Latecomer countries can avoid "reinventing the wheel" or "remaking the mistakes" of advanced countries. This may be achieved by learning through foreign experience, and adapting to its own situation but not by just following. Therefore, incorporating adequate innovation strategies in foresight studies is an extremely important topic in an increasingly globalized innovation environment.

For the BRIC countries, the target technologies in foresight studies may be already available in developed countries. The host country may face a dilemma of "make or buy", which means shall we develop the technology indigenously or acquire it from abroad? This is a dilemma because both strategies may encounter problems. When developing indigenously, the country may lack innovative capacity and time span is long; when acquiring from abroad, the country may face foreign technology control or high acquisition cost. As a result, in a globalized innovation network, it is necessary to balance the innovation strategies for technology development to achieve best economic return and social interests. Scholars argue that the innovation strategies may vary from sector to sector and across time. To reveal sector/time-specific characteristics, comparative evaluations of innovation strategies and their impact on organizational performance across various sectors and in multiple time frames may produce findings of greater relevance to policy makers [59].

There are several routes toward innovation and technology development. Chinese scholars defined three types of innovation activities in China: independent innovation, imitative innovation, and cooperative innovation [60]. The idea of independent innovation stresses focus on a country's predominant core technology base and capabilities to improve its competitive ability [61,62]. Imitative innovation refers to the introduction and the adaptation of the advanced innovators' technology, driven by the influences of the leading innovators' demonstration and interest mechanism. Other scholars defined similar concept of re-innovation as "It is the part of new product development which studies the extension of existing innovations, which can only happen after the first generation of a new product is launched." [63] Cooperative innovation is a strategy to implement innovative activities with alliances, and is dependent on the mutual or multi-facet cooperation among stakeholders. The premise of cooperative innovation is that each side shares the common achievements and develops all together. Accordingly, countries or enterprises with competitive relations and conflicting interest can work hand in hand to gain profits and development momentum [60]. Active cooperation between countries can enable them to achieve outcomes that they could not achieve on their own, while allowing each individual partner to realize its own strategic goals [64]. Moreover, international technology transfer is still an important way for less developed countries to realize the latecomer advantage and achieve technology leapfrogging [65]. Achieving proper balance of these development strategies helps to enhance host country's potential in creating competitive advantage with reduced cost and time implications.

4.4. Reflections for other emerging countries

After a deeper analysis of above identified issues faced by the BRIC countries, we discovered that these issues also exist among other emerging countries. Catching-up is the main theme of technology development in most emerging countries. Their technology levels are generally lagging behind against world leading standards. These countries differ in terms of historic evolution, economic development, technology capacity, and other social factors. Technology foresight activities have to consider local needs, capabilities, and social differences. Therefore, identifying critical technology areas that is appropriate for domestic development is a primary concern. These countries also need to consider how to transfer foresight results into effective policy measures and implementation strategies.

In many aspects, the emerging countries, due to their stage of development, have transitional and weaker innovation systems when compared with the advanced countries. Governments need to decide on how to increase domestic innovative capacity and leverage their limited R&D resources. There is little evidence that current frameworks of foresight approach in developed nations are also workable for the latecomers. This is because emerging countries have different environmental contexts and changing agents. The majority of available studies ignore the fact that the characteristics of technological change of industrializing economies are largely shaped from the outside realms of foreign institutions in industrialized countries [66]. No evidence shows that available theoretical and conceptual framework is appropriate for dealing with the processes of technology future studies in emerging countries.

Russian scholar argued that technology foresight activity should be aimed at the creation of new productive networks and the construction of an integrated national innovation system [39]. Institutional requirements should be met in order for technology foresight to become a useful instrument in elaborating economic and technological strategy, and contributing to the improvement of the NIS. This conforms to the trend that technology foresight is evolving towards new stages in the fourth and fifth generations to include considerations of innovation systems and globalization. Therefore, emerging economies need to improve their innovative capability and capacity.

5. Concluding remarks

Through learning from foreign experience, each of the BRIC countries has carried out its own foresight studies. Although with many differences in practice, there are some common issues and characteristics. This paper identified and discussed several major issues in these countries. Firstly, technology realization issue in latecomer countries; secondly, the selection of appropriate technology from a local perspective; and thirdly, the support of more elaborated innovation strategies. These issues are also something to be considered in other emerging countries. This is due to the differences in their aspirations concerning their future role in the global economy, political will, availability of economic resources, technological positions, and social conditions [39].

Social conditions in BRIC are rapidly evolving, so a dynamic thinking is very necessary. Technology foresight studies should be adjusted in a timely manner to deal with economic and social changes. Overall, the research of foresight studies are moving to new generations of stage four and five, which emphasize on the distributed roles in innovation systems, structural improvement and broader policy concerns. The foresight research in the BRICs provides new perspectives and insights for emerging countries.

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