JOURNAL OF ECONOMIC SURVEYS

doi: 10.1111/joes.12083

INNOVATION IN CHINA

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Abstract. Innovation has been increasingly recognized as a critical force in national economic growth not only in developed countries, but also in emerging countries such as China and India. This paper provides a critical review of the literature related to China's innovation capability. First, I evaluate the current status of China's innovation capability as measured not only by the level of human capital and output of academic research but also by patents, products, and services that directly benefit economic growth. I then review the development pathway of China's national innovation system since the economic reforms, including policies, the role of the government, and the engagement of different actors in the national innovation system. Following that, I examine theories and empirical evidence that help to explain the evolution of China's innovation capability. Finally, using China's experience, I analyze the relationship between innovation capability and economic development and highlight how the uneven spatial distribution of innovation capability may affect China's regional economic development.

Keywords. China; Innovation; Regions; Systems of innovation

1. Introduction

China has a long history of pursuing innovation and technological advancement. It is well known that the 'Middle Kingdom' produced the 'four great' inventions: the compass, gunpowder, papermaking, and printing. This ambition for technological supremacy has continued throughout the Maoist Era (1949–1978) and the reform period (1978–present). Though plagued by wars and poverty and under extreme difficulties due to an embargo by western nations, China conducted its first successful atomic bomb test in its northwestern desert in 1964. In recent decades, there have been significant achievements in biotechnology, astronautics and information technology, including: (1) together with four other countries at the forefront of genomic research (the USA, Japan, Germany, and France), China participated in the Human Genome working draft in 2001; (2) China became the third nation to launch a man into space in 2003, following Russia and the U.S.; and (3) China became the third country with supercomputing ability in 2004 and had the fastest supercomputers in the world in 2010 and 2013.

Nevertheless, there is a substantial difference between the pursuit of technological advancement from an historic perspective and the recent launch of an economic development strategy based on innovation. On November 8, 2012, in a report delivered by President Hu Jintao in the 18th National Congress Party, China announced that it would transition into an "innovation-driven economy." Thirty-five years of reform dramatically lifted China out of poverty and positioned the country as the second largest world economy in 2010. However, the growth model it used, which has converted the country into the world's largest factory, producing everything from clothing to electronics, has relied heavily on investments, exports, and a huge low-cost labor force. Currently, China is ready to shift to the next stage, through an economy mainly driven by technological advancement, to address the slow down of its past growth model. Improvements in innovation capability, especially in its industrial sectors, are considered essential to China's sustainable economic growth in the future. Similar to the rest of the world, the importance of innovation to economic growth in China means that innovation should not be treated as merely an element in an economic residual, but rather as a key issue that policy makers should consider as making a positive influence (McCann and Oxley, 2012; Yu *et al*., 2013).

Against the announcement of China's new economic development strategies driven by innovation are "believer's claims that China is out-innovating the West" and "doubter's claims that China is lagging on the innovation front" (Steinfeld, 2010, p. 34). The common perception is that China's rise in innovation capability poses a threat to U.S. leadership in science and technology.[1]

To unveil the myth of "innovation in China" and its impact on the rest of the world, it is essential to answer the following set of questions: What is the current status of innovation capability in China? How did China improve its innovation capability over the past 35 years? Has any theoretical proposition related to innovation found a resonance in the Chinese context? Further, what can we learn from China's experience, and what are the implications for other emerging countries? In this paper, I address some of the above questions by providing a critical review of innovation in China and related literature. First, I evaluate the current status of China's innovation capability through both the input and output indicators of China's innovation system, such as R&D personnel, R&D expenditure, patents, high-tech and service exports, and scientific and technical journal articles. Further, I underline the contribution of technological progress vis-à-vis labor and capital to China's economic development, indicated by annual GDP growth. I then review China's development of innovation since the economic reform and identify major factors that may explain its evolution, relying on theoretic frameworks of (1) systems of innovation (SI), (2) external linkages, such as global value chains, global production networks, overseas returnees, and R&D globalization, and (3) the dynamics of latecomers' catch-ups. Finally, I review the uneven spatial distribution of innovation capability and analyze possible causes for the inequality, as well as the emerging research in regional innovation systems.

2. Measuring Innovation in China

Innovation capability can be assessed using the input and output measures of the innovation system. The input measures are usually represented by indicators such as the amount of R&D investment and the number of researchers in R&D, whereas output measures are reflected by indicators such as patents, high-tech/service exports, and academic output like scientific and technical journal paper publication. This section will present the evaluation of innovation capability based on these commonly used indicators. It should be noted that one has to exercise caution when using the above-mentioned indicators or any other indicator as an accurate assessment of innovation capability, especially when comparing China's indicators with those of other countries. First, while there are useful guidelines that can make measurements of innovation indicators comparable between most developed countries, such as the OECD countries, China has not been a part of the collective process and thus it is difficult to compare China's indicators with others. Many countries in the OECD have adopted the principles of the Oslo Manual to collect innovation data. Currently, all member states of the European Union (EU) and some candidate countries for the EU[2] have used the community innovation survey (CIS) to standardize their models of innovation surveys (Lopez-Bassols, 2011). Other countries, such as China, Japan, Korea, and Russia, have adopted innovation surveys close to the CIS, but with some adaptations (Lopez-Bassols, 2011; Hong *et al*., 2012). Although CIS indicators are growing in use, they are still less widely used than the R&D statistics, due to concerns about quality, policy relevance, and international comparability outside of the EU (Lopez-Bassols, 2011). Second, innovation-related data are territory-based and national data does not actually reflect China's innovation due to foreign individuals' and organizations' activities in China, as well as the innovation of Chinese individuals and organizations outside of China (Altenburg *et al*., 2008).

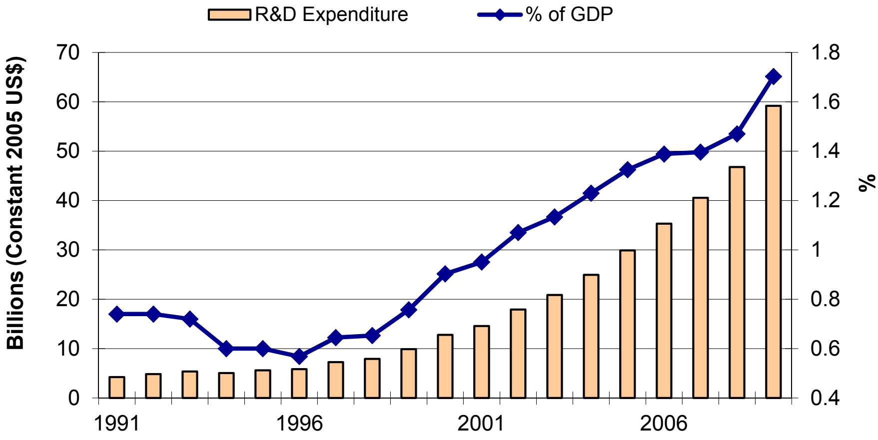

Figure 1. China's R&D Expenditure and Its Percentage of GDP, 1991–2009.

Note: Expenditures for research and development are "current and capital expenditures (both public and private) on creative work undertaken systematically to increase knowledge, including knowledge of humanity, culture, and society, and the use of knowledge for new applications. R&D covers basic research, applied research, and experimental development" (World Bank, 2013, explanation of the definition of Research and development expenditure [% of GDP]).
Source: Figure created by the author based on data from World Development Indicator (World Bank, 2013).

2.1 *Input indicators*

2.1.1 *R&D Expenditure*

R&D expenditure is considered one of the most important elements in improving the innovation capacity of nations as well as firms (Audretsch and Feldman, 2004). Data analysis on OECD countries such as USA, UK, Japan, France, Italy and Germany, shows that R&D expenditure stimulates innovation and enhances total factor productivity (TFP) (Goto and Suzuki 1989; Hall, 1993; Hall and Mairesse, 1995; Harhoff, 1998; Wakelin, 2001; Griffith *et al.*, 2004; Lang, 2009). A positive and significant relationship has also been found between the R&D expenditure of a firm and its productivity (Griliches and Mairesse, 1984; Griliches, 1986, 1998; Romer 1986, 1990; Lucas, 1988).

Since the mid-1990s, China has invested heavily in R&D and has gradually increased R&D expenditure as a percentage of GDP from around 0.6% in 1996 to 1.7% in 2009 (Figure 1). It is worth noting that the "Decision on Accelerating S&T Development" announced by the state council in 1995 set the ambitious goal of increasing spending on R&D to 1.5% of GDP by 2000, resulting in China's R&D expenditure as a percentage of GDP after 1995 growing at a much faster pace than in previous years and reaching 1.7% in 2009 (Fan, 2011b). This percentage is still behind that of the OECD countries that, in general, spend on average 2–3% of GDP on R&D. However, considering that China's R&D expenditure increased even faster than its economy, which grew at a remarkable rate of around 10% in the 1990s and 2000s, its R&D expenditure was certainly impressive. The R&D figure expanded from US$4.2 billion in 1991 to US$59 billion in 2009, a 14-fold increase in the space of 18 years. In fact, before China overtook Japan as the second largest economy measured by GDP in 2010, China surpassed Japan to became the second largest nation in R&D expenditure in 2006 (OECD, 2006).

Table 1. Researchers in R&D in China, India, Japan, and the United States.

	Researchers in R&D (per million people)			Total researchers in R&D		
Country	*1996*	*2000*	*2007*	*1996*	*2000*	*2007*
China	447	548	1,077	544,163	691,518	1,419,507
India	152	110	136	147,897	114,656	153,075
Japan	4,946	5,151	5,409	622,044	653,494	691,101
United States	4,254	4,579	4,673	1,159,966	1,292,053	1,407,716

Note: U.S. 1996's figures are 1997's figures. India 2007's figures are 2005's figures.
According to the World Bank, Researchers in R&D are "professionals engaged in the conception or creation of new knowledge, products, processes, methods or systems and in the management of the projects concerned. Postgraduate PhD students (ISCED97 level 6) engaged in R&D are included" (World Bank, 2013, explanation on the definition of Researchers in R&D).

Source: Compiled by the author based on the data from World Development Indicator (World Bank, 2013).

2.1.2 *R&D Personnel*

The number of researchers in R&D reflects the level of human capital for innovation capability and is an important indicator. A comparison of China's data with that of the United States and Japan indicates that the country has improved in this dimension as well (Table 1). The number of researchers in R&D more than doubled, growing from 447 per million in 1996 to 1077 per million in 2007, making China's level around 20% of that of the USA and Japan. However, due to its large population size, when comparing the absolute numbers, China became the leader in terms of the number of total researchers in R&D, slightly surpassing the USA, and more than double that of Japan. In fact, the rich reserve of R&D human resources is one of the major reasons that multinational corporations (MNCs) have chosen to locate their corporate research centers in China. MNCs grew their R&D centers in China fivefold from 2003 to 2007, with 750 foreign R&D centers in China in 2007 (Walsh, 2007), including work to tailor products to the needs of the Chinese market as well as basic R&D (Sun *et al.*, 2008).

2.2 *Output Indicators*

2.2.1 *Patents*

Despite skepticism, the number of patents granted has been accepted as the most appropriate output measure for innovation capability (Mansfield, 1986; Basberg, 1987; Griliches, 1990; Hagedoorn and Cloodt, 2003). Different indices, such as those tracking R&D inputs, patent counts, paper citations and new product announcements, can all be used as an indicator for output measure of innovation capability. This paper follows Audretsch and Feldman (2004) and uses patent data as the main proxy of output measure of innovation capability. Hagedoorn and Cloodt (2003) found that statistical overlap between various innovativeness indicators is substantial and that any of these indicators, including patents, may be used to measure innovation capability.

Although China adopted modern patent law less than three decades ago in 1984, the number of patents granted to Chinese inventors, in China and worldwide, has been growing exponentially (Figure 2). In 2012, China's State Intellectual Property Office (SIPO) granted 1.26 million patents, a 31% increase over the number granted in 2011 and more than any other patent office in the world. Further, almost 80% of

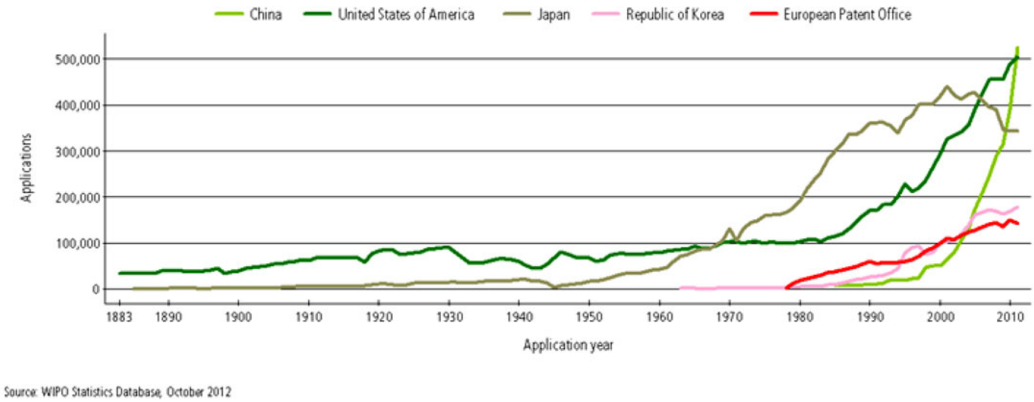

Figure 2. Trend in Invention Patent Application for Top Five Offices.

Source: Neumeyer (2013, Figure 1).

Table 2. U.S. Patents Granted to Asian Inventors, 1970–2013.

	Total	1970–1979	1980–1989	1990–1999	2000–2009	2010–2013
Taiwan	141,431	57	2,613	22,507	72,365	43,889
S. Korea	127,786	10	646	15,306	58,024	53,800
Hong Kong	11,753	123	886	2,688	5,855	2,201
Singapore	9,967	11	102	957	5,166	3,731
China	37,688	2	178	900	13,219	23,389
India	15,068	81	166	679	5,529	8,613

Note: For 2013, the issue dates are from January 1 to October 30, 2013.

Source: Compiled by the author based on the USPTO Patent Collection Database, website: http://patft.uspto.gov/

China's patents were awarded to domestic applicants in 2012, while fewer than 50% of all U.S. patents went to U.S. citizens (Neumeyer, 2013).

Worldwide, China has been catching up rapidly in the intellectual property (IP) arena, as illustrated by the decadal data on patents granted by the United States Patent and Trademark Office (USPTO) (Table 2). Compared with other leading Asian inventors excluding Japan, China's progress is hard to dismiss. Although it was behind Hong Kong and Singapore in the 1990s, China's total number of granted patents from USPTO was more than the sum of those two economies in the 2000s. Further, in the past three years (2010–October 2013), China has substantially increased the number of granted patents, by almost doubling its figures from the 1990s, significantly improving its position vis-à-vis other emerging Asian innovation centers, namely Taiwan and Korea. In 2012, China was listed as No. 9 worldwide in terms of patent applications to the USPTO, trailing after the USA, Japan, Germany, Korea, Taiwan, Canada, the UK and France. However, applications from Chinese inventors increased by 41% over 2011, more than twice the rate of increase of any of those countries (Neumeyer, 2013). In 2012, with 782 U.S. patents granted, a Chinese company, Hong Fu Jin Precision Industry Corp., also become one of top 50 U.S. patent recipients for the first time.

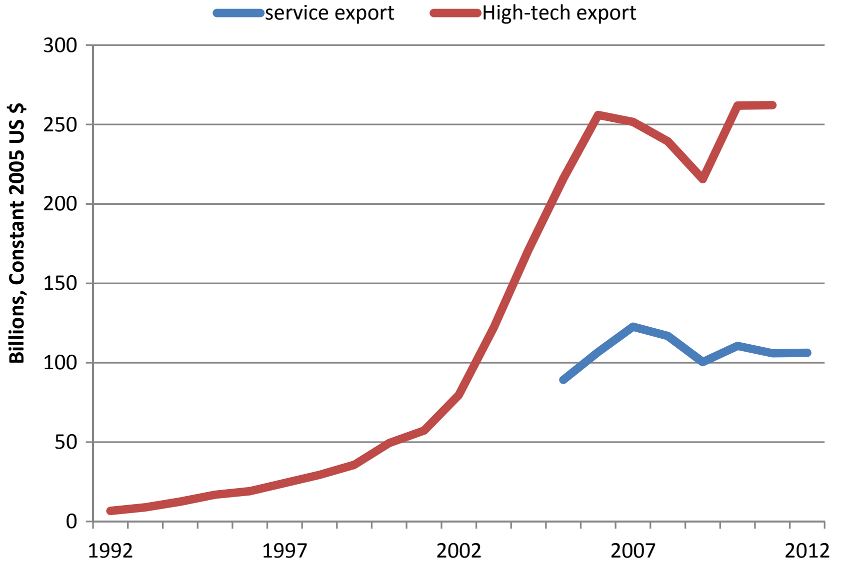

Figure 3. China's High-Tech Exports and Service Exports, 1992–2012.

Source: Figure created by the author based on data from World Development Indicator (World Bank, 2013).

2.2.2 *High-Tech and Service Export*

As its economy has grown, China has also increased the sophistication of its export files, growing particularly in the volume of high-tech and service exports (Figure 3). High-tech exports have gathered momentum and have experienced exponential growth since 2002, whereas the service export area has experienced steady growth since the early 2000s. This evolution pattern is similar to that of the OECD countries (Rodrik, 2006; Schott, 2008; Lai and Li, 2013). However, due to the debate on whether or not growth in high-tech exports can truly reflect improvements in innovation capacity, this paper suggests that readers use this indicator as a complementary reference for China's innovation system. Chinese high-tech exports have been considered as low technology products from high-tech industries (Blustein, 1997) or as the result of the "processing trade": contract manufacturing in China of goods designed elsewhere (Feenstra and Wei, 2010). In contrast to this negative view, some researchers have emphasized that China has gradually increased the skill content and sophistication of its exports in recent years due to ongoing improvement in human capital and government policies, especially those on tax-favored high-tech zones (Amiti and Freund, 2010; Wang and Wei, 2010; Berger and Martin, 2013).

2.2.3 *Scientific and Technical Journal Articles*

The number of scientific and engineering articles can be used as another output indicator to illustrate the efficiency of the innovation system, especially the more basic and fundamental aspects of innovation. This indicator refers to journal articles published in the following science and technology fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences, in journals classified by the Institute for Scientific Information's Science Citation Index (SCI) and the Social Sciences Citation Index (SSCI) (World Bank, 2013). Starting with

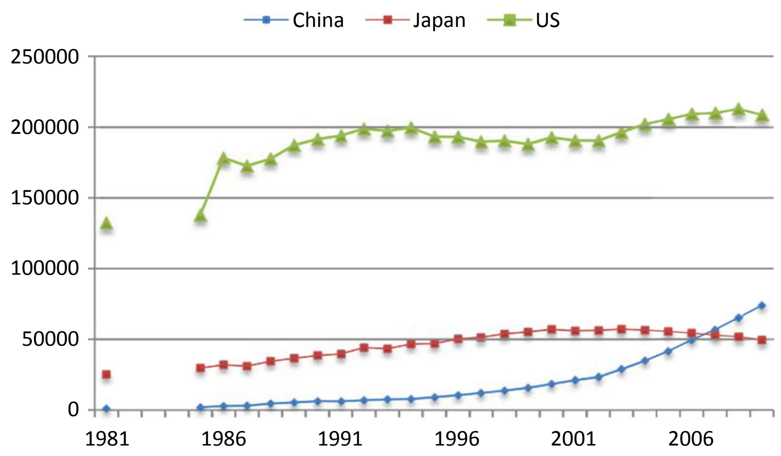

Figure 4. Scientific and Technical Journal Articles Published by China, Japan, and the USA, 1981–2009.

Source: Figure created by the author based on data from World Development Indicator (World Bank, 2013).

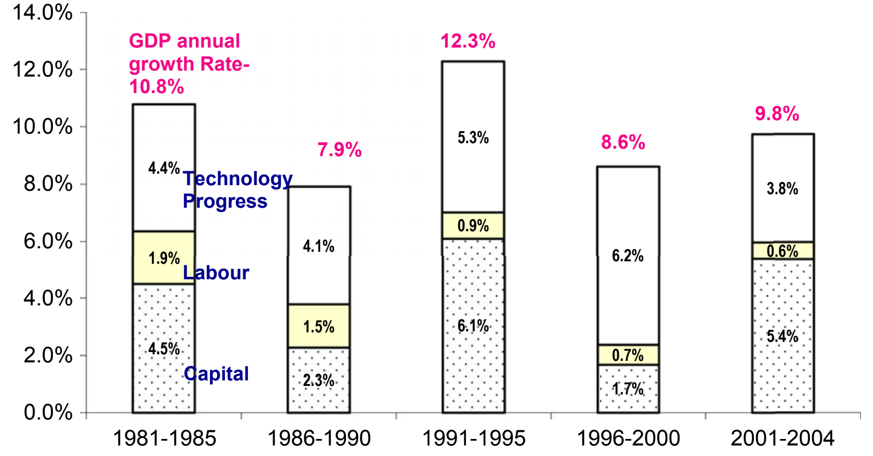

Figure 5. Contribution of Technological Progress to Economic Growth in China, 1981–2004.

Source: Adapted from Fan (2011a, p. 53).

only 1100 journal articles in 1981, China surpassed Japan and had around 74,000 scientific and technical journal articles, over a third of that of the USA (208,600), by 2009 (Figure 4).

Finally, through a decomposition analysis, one can assess how much innovation capability actually contributed to the economic development of China (Fan, 2011a) (Figure 5). As GDP growth can be decomposed into the contributions of capital, labor, and technology, the share of technology can be measured by TFP growth (Fan and Watanabe, 2006). The decomposition reveals that technology has significantly influenced China's economic development since the 1980s. It is interesting to note that while capital fluctuated in its contribution to GDP growth in different periods, technological progress made a relatively steady contribution. While at the beginning of the reform era (1981–1985), capital was the leading factor for growth, followed closely by technology, technological progress leaped forward and became the leading growth factor over the next five years (1986–1990) with capital some distance behind. In the 1990s and the early 2000s, technological progress consistently contributed to GDP growth at 4–6% annually, while capital displayed a very unstable pattern, fluctuating from 6.1% (1991–1995) to 1.7% (1996–2000), to 5.4% (2001–2004), reflecting the influences of large injections of capital and the outbreak of the Asian financial crisis.

3. Developing Innovation Capability: The Chinese way

3.1 *The System Approach*

Since Freeman first officially used the term "national system of innovation" (NSI) in his work to analyze technology policy and economic performance in Japan in 1987 (Freeman, 1987), the "SI" approach and its three perspectives, NSI, sectoral system of innovation (SSI), and regional system of innovation (RSI), have been developed and adopted by many researchers as conceptual frameworks to analyze innovation in different contexts (for example, NSI: Freeman, 1987, 1995; Lundvall, 1992; Nelson, 1993; SSI: Breschi and Malerba, 1997; Malerba, 2002, 2004, 2005; Geels, 2004; Malerba and Mani, 2009; RSI: Cooke *et al.*, 1997; Braczyk *et al.*, 1998; Cooke, 2001; Asheim and Isaksen, 2002). As it emphasizes that innovation is to "produce new knowledge or combine existing elements of knowledge in new ways" (Edquist, 2005, p. 184), the "SI" approach distinguishes itself from other approaches that consider technological change and innovation as exogenous (Edquist, 2005).

Due to its holistic and evolutionary perspectives, encompassing product and process innovation, an emphasis on interdependency and nonlinearity, and the role of institutions, the SI approach has also been used by a number of researchers to analyze innovation in China, particularly the evolution of its NSI (Xue, 1997; Gu, 1999; Liu and White, 2001; Fan and Watanabe, 2006; Motohashi and Yun, 2007; Altenburg *et al.*, 2008).[3] Prior to the 1980s, China had a NSI similar to other central planning economies such as the Soviet Union and India, characterized by the complete separation of research activities, education, and manufacturing activities in public research institutes (PRIs), universities, and state-owned enterprises (SOEs), respectively (Xue, 1997). Since the economic reform, the Chinese government has started to actively transform the Soviet model, especially by emphasizing colocating research and manufacturing. The government has used both carrots and sticks to pull and push the R&D institutes to adapt the market environment and to conduct R&D that has industrial implications. For instance, while it reduced institutional funding for PRIs in order to push the PRIs to conduct more market-oriented R&D through industries and universities (Liu and White, 2001), it also offered financial incentives to commercialize R&D results, especially through the Torch Program, a national science and technology program specifically targeting high-tech industrialization, launched in 1988. The government also performed an organizational transformation by advocating mergers of some R&D institutes with enterprises in 1987 and reforming established R&D institutes into entities with economic functions, such as production and consultancy centers, from the 1990s. (Gu, 1999; Fan and Watanabe, 2006; Fan, 2011a).

Up to now, Liu and White's (2001) analysis of China's NIS remains the most comprehensive of its kind. They identified five fundamental activities in an innovation system, which extend beyond the R&D system and include inputs to research activity and the use of research outputs. The activities are: "(1) research (basic, developmental, engineering), (2) implementation (manufacturing), (3) end-use (customers of the product or process outputs), (4) linkage (bringing together complementary knowledge), and (5) education" (Liu and White, 2001, p. 1,094). They also coined the term "primary actors," referring to organizations that perform one of the five above-mentioned fundamental activities. Applying this updated framework, they concluded that China's NIS in the transition era had two distinguishing characteristics: the inclusion of new actors for each of the fundamental activities and diversification of the activities of the primary actors. Here, I update their summary of the five fundamental activities in the NSI with some new developments that have occurred in the 2000s.

In the transition era, the most fundamental activity, R&D, has had a significant transformation in both nature and distribution. While the original primary actors, i.e., PRIs, are still among the main actors performing R&D, they were given strong financial incentives to conduct applied research. However, a large amount of direct funding for basic research, particularly in "strategic" high-tech industries such as information technology and biotechnology, is available through national programs such as 863 and 973 (explained in more detail later in this section). The distribution of R&D activities has been extended through colocating R&D and implementation (manufacturing), by either adding in-house R&D to enterprises or inserting the commercial component into research institutes (Liu and White, 2001). Further, new players such as R&D centers for MNCs (Sun *et al.*, 2008), new technology enterprises (Zhou, 2008), and high-tech firms started by overseas returnees (Saxenian, 2002, 2006; Zweig *et al.*, 2006), have entered the scene, while domestic companies started to tap global R&D resources by setting up their R&D units in global hot spots of high-tech development (Fan, 2011b). The business sector quickly rose to become a major contributor to national R&D, with large- and medium-sized enterprises spending RMB 44 billion in 2001, an increase of RMB 14 billion from the 1995 level and accounting for 42% of the national total (Fan and Watanabe, 2006). According to R&D Magazine, in 2004, R&D spending by the industry sector accounted for 61.2% of the national total.

In implementation (manufacturing) activities, many new actors have joined SOEs to become primary actors, including MNCs, joint ventures, township and village enterprises (TVEs), and private companies. In responding to the incentives and freedom to pursue more revenue-generating activities, primary actors in other activities, especially universities and PRIs, have diversified into manufacturing (Gu, 1999), usually in the form of spin-off ventures. For end-use activities, there is a significant increase in individual and industrial consumers as actors, providing incentives for companies to conduct market-oriented innovation. It is worth mentioning that China's end users, either individuals or organizations, have become more sophisticated as the country's economy has expanded. By understanding, the needs of the end users better and being willing to customize R&D for those end users, some Chinese companies, such as Huawei and ZTE in the telecommunication sector (Fan, 2006a, 2011b), have established competitive advantages compared to the MNCs.

In educational activities, while universities are still the main primary actors, they have extended their activities into R&D and manufacturing. China has rapidly scaled up its higher education sector by expanding existing universities through increased admission and establishing more higher educational institutions, and this has led to a natural increase in graduates with science and technology degrees. Further, the universities have been increasingly pushing for research productivity from their faculties. One such example is the required numbers of publications for not only promotion of faculty, but also to be allowed to have graduate students to supervise. It is therefore not surprising to see China's gigantic leap in numbers of published journal articles (Figure 4).

Finally, the relationships between the actors have been transformed. While the government was previously in direct control of resource transfer/distribution and coordination of organizations in the innovation system, it is now involved in linking R&D with implementation through a number of measures, including setting up productivity promotion centers to assist firms to implement technologies originating from state R&D institutes and creating incubator centers (Liu and White, 2001). For instance, for basic research, funding from national programs such as Program 973 (explained further below) usually requires the involvement of several research institutes or universities. However, government can directly facilitate the linkage between end users and the implementation sector to promote the R&D results, illustrated by the experience of domestic telecommunication equipment producers (Fan, 2006b).

In addition to reforming its Soviet-style NSI, China has implemented a variety of technology policy initiatives, with a focus on basic research for key areas and research for market needs (Fan, 2011a).

Programs for enhancing its basic research include the Key Technologies Research and Development Program in 1982, the High-tech Research and Development Program (Program 863) in 1986, and the National Program for Priority Basic Research and Development (Program 973) in 1997. Policies focusing on high-tech industrialization include the well-known Torch Program, initiated in 1988, which advocated setting up high-tech parks specializing in high-tech innovation, application, and diffusion. The parks are set up to attract foreign high-tech MNCs and to encourage the development of innovative domestic firms. In 2003, about 67% of China's 33,392 high-tech enterprises were located in high-tech parks (Fan, 2011) where they enjoy various benefits for innovation-related activities. For instance, in Zhongguancun Science Park, China's Silicon Valley, benefits for innovation include: (1) a tax cut of up to 15% for key companies in the creative industries, (2) reduction of personal income tax for investors in high-tech R&D to further boost the venture capital sector to aid more tech startups, (3) tax benefits for company income generated by patent transfers, and (4) waiver of the enterprise tax on patents sold at less than 5 million yuan ($820,000) or half the rate of the enterprise tax for higher values.[4]

Although the system approach is very helpful in understanding the internal structure and the evolution of innovation for a specific country/region, it has been criticized for lacking consideration of relationships with key actors outside of the system and for poor understanding of the dynamics of the innovation system, i.e., how structures of interaction develop and change over time (Humphrey and Schmitz, 2002; Bell, 2006). To address these weaknesses, researchers have proposed integrating transborder linkages into the territorially bounded innovation system and analyzing the catch-up in innovation capability, taking into account the changes in technological regimes and the global economic environment (Altenburg *et al.*, 2008; Fan, 2011b). In the following sections, I will focus on analyzing China's innovation along these two dimensions.

3.2 *Global Linkages*

3.2.1 *Interfirm Linkages*

Global linkages, especially those describing relationships between firms, are mostly derived from the literature of interfirm networks, which are considered crucial to fostering innovation inside firms as well as at the regional level. Firms can increase the efficiency of their R&D as interfirm networks allow businesses to leverage their capacity and gain access to external resources, thus reducing the risk and cost of R&D (Hagedoorn and Schakenraad, 1994; Mowery *et al.*, 1996; Ahuja, 2000; Stuart, 2000). Global linkages forged by firms from developing countries are considered particularly helpful for technological upgrading because of the limited resources of local companies in developing countries. The global value chain (GVC) (Humphrey and Schmitz, 2002, 2004; Schmitz, 2004; Gereffi *et al.*, 2005; Sturgeon *et al.*, 2008) and global production network (GPN) (Dicken *et al.*, 2001; Ernst and Kim, 2002; Henderson *et al.*, 2002; Coe *et al.*, 2004; Coe *et al.*, 2008; Yeung, 2009) are two approaches that have emphasized how firms from foreign countries have been instrumental in transferring technology, particularly tacit knowledge, to local companies (Sun and Zhou, 2011). However, several studies have indicated that interfirm networks have limited impact on innovation capability, reflected either by the number of patents (Stuart, 2000), or the novelty or impact of the products (Kotabe and Swan, 1995).

It is widely acknowledged that China's economic development has closely been associated with its incorporation into the GVC or global production network (Enright *et al.*, 2005; Zhou 2008; Lin *et al.*, 2013). But what are the exact impacts of these linkages on firms' innovation capabilities? Altenburg *et al.* (2008) suggested that the opportunity to improve the innovation capabilities of local firms depends on the types of linkages forged and the power constellations within their global partners. For instance, in a captive chain, capability (knowledge-using) that goes with the lead firms' interests will be facilitated and encouraged, whereas capability directed against the interests of the lead firms (knowledge-creating) will have less chance to thrive and may even be discouraged. It is also suggested that while working with lead firms provides access to advanced technology, new design, and process, domestic linkages can be more conducive to the development of innovation capability as there is more opportunity to work with domestic consumers on design, marketing, and branding (Mitsuhashi, 2006; Navas-Alemán, 2006). Based on a large-scale survey of more than 1000 ICT companies in China, Sun and Zhou (2011) made interesting findings in terms of the impacts of global linkages on innovation in domestic companies compared to the impacts of domestic linkages. First, many Chinese firms (more than half of the surveyed firms) did not have any interfirm linkages, with either domestic or foreign companies. Second, while positive impacts of interfirm linkages on firms' innovation were found, global linkages offered more benefit than domestic linkages, and firms that had both global and domestic linkages benefitted the most. Third, while more intense global linkages led to higher impacts on innovation in local firms, more intense domestic linkages caused overembeddedness and had a negative impact on firms' innovation. Finally, Chinese firms' internal characteristics and local/regional settings also affected linkages, such as: (1) internal R&D did not seem to enhance the positive impact of interfirm technological linkage on firms' innovation; (2) ownership of firms did not seem to have any impact on innovativeness or the use of interfirm linkages for innovation; and (3) the positive impact of technological linkages on innovation in firms remained the same regardless of the types of industrial hubs involved (Sun and Zhou, 2011).

3.2.2 *Global Networks of Professionals and Returnees*

In addition to global linkages in the interfirm network sphere, other linkages, such as global networks of professionals, have increasingly gained attention in explaining the improvement in China's innovation capability, especially after the publication of Saxenian's (2006) work on the development of Bangalore's software and China's computer industry through entrepreneurs, engineers, and scientists who originally came from China but gained substantial work experience in the USA.

In fact, China has a significant advantage in tapping into the global networks of Chinese professionals in the high-tech sector, due to the large number of Chinese students being sent to study in western countries since the economic reforms (Zweig *et al*., 2004, 2006; Zweig, 2006; Simon and Cao, 2009). Between 1978 and 2013, more than one million Chinese went abroad for study and research (Cao, 2004; MOE, 2013) and the number has been exploding in recent years. The annual number of students who went overseas has risen nearly twenty times, from 20,000 in the late 1990s to nearly 400,000 in recent years (Wang *et al*., 2009; MOE, 2013). The Chinese government has realized the value of this talent pool and has attempted to entice overseas talent to return to China, in the hope of repeating Taiwan's success story in the electronics industry (Li *et al*., 2004; Fan and Watanabe, 2006). The government has initiated quite a few programs, from central government level such as the "1000 Talents Programs" and the "1000 Young Talents Program," to local governments, such as Nanjing's "321 Program," Wuxi's "530 Program," and Shenzhen's "Peacock Program." Attracting talent has become a critical task for China and other countries to develop innovative economies (Simon and Cao, 2009; Florida, 2010; Beaverstock and Hall, 2012).

Despite a plethora of literature on returnees, there are some gaps that need to be addressed to improve our understanding of how global professional networks and overseas returnees have contributed to the improvement of the innovation capability of the home countries, such as the strategies and performances of returnee companies vis-à-vis home-grown companies, the specific global linkages that can have significant impact on innovation in returnee companies, and regional (subnational) variations in terms of locating and growing returnee companies. More studies on returnee entrepreneurs and companies that are founded or managed by returnees (returnee companies) are expected to fulfill this need in the near future (Altenburg *et al.*, 2008; Solimano, 2008).

3.2.3 *R&D Globalization*

Along with forging interfirm linkages with global partners, domestic Chinese firms have also started to use R&D globalization as a proactive approach to tap into the resources that global hotspots of innovation have to offer. Examining the locations, purposes, and patterns of R&D globalization has offered important insights concerning innovation by latecomers.

R&D globalization has increasingly been used to improve firms' innovation capability, boost foreign market share, attract talent, and reduce R&D cost (Niosi, 1999; Reddy, 2000; UNCTAD, 2005; Fan, 2011b). Two types of foreign R&D units should be differentiated: home-base-augmenting (HBA) and home-base-exploiting (HBE) units (Kuemmerle, 1997, 1999a, 1999b). While HBA is established "to augment firm-specific capabilities if this mode of augmenting firms' knowledge base offers higher payoffs than licensing in" (Kuemmerle, 1999a, p. 184), HBE units are set up to "exploit firm-specific capabilities if this mode of exploitation offers higher pay-off than licensing out" (Kuemmerle, 1999a, p. 184). The eclectic "ownership-location-internalization" (OLI) theory (Dunning, 1981, 1988) and the internationalization process (IP) theory (Johanson and Vahlue, 1977) are also useful to explain the locations and motivations of R&D by foreign MNCs in China and the R&D globalization of Chinese MNCs as latecomers.

The findings on Chinese firms in the telecom equipment sector indicate that although Chinese firms do not differ from established firms in terms of locations of HBA and HBE R&D units, they differ in the order and pace of development. In contrast to the IP theory, their R&D globalization has progressed simultaneously with, and even ahead of, their globalization of markets and manufacturing. These differences confirm that the R&D globalization of latecomers is not so much about exploiting the existing "ownership" advantages, like the established multinationals, but, rather, to tap into resources and markets that would otherwise be unavailable (Buckley *et al.*, 2007; Li, 2007; Luo and Tung, 2007; Niosi and Tschang, 2009). Further, as these units are particularly attractive to local skilled personnel who originally came from China, the global R&D units represent another way to tap into the global network of Chinese professionals (Fan, 2011b).

3.3 *Dynamics of Catching Up of Latecomers*

Latecomers, in comparison with first movers, are challenged with many disadvantages in developing their innovation capability, such as technological leadership of incumbent firms, preemption of assets, and high buyer switching costs (Lieberman and Montgomery, 1988, 1998; Kardes and Kalyanaram, 1992), but are also blessed with advantages because enhanced information and free-rider effects can save them money and time due to information spillover and learning from the experiences of first movers. Meanwhile, changes in market or consumer tastes and technological regimes, in combination with the resources, people and organization committed by first movers to meet earlier market and technology requirements, can disadvantage first movers and offer opportunities for latecomers to catch up (Richardson, 1996; Cho *et al.*, 1998; Lieberman and Montgomery, 1998). Among the literature on catching-up and technological upgrading strategies of latecomers (e.g., Hobday, 1995; Leonard-Barton, 1995), one can apply Kim's technology learning framework (Kim, 1997) to understand how China catches up in different sectors as a latecomer (Fan, 2011b) and highlight the differences between China and the earlier latecomers such as Japan and the newly industrialized economies (NIEs).

Kim (1997) observed that the technological trajectory of catch-up countries, such as Korea, is in the reverse direction to that of advanced countries. While technology development in advanced countries goes through stages of emergence, consolidation, and maturity, firms in catching-up countries move from imitation, i.e., acquiring, assimilating, and improving mature technologies from advanced countries, to innovation, i.e., eventually accumulating indigenous innovative capability and generating emerging technologies (Kim, 1997). Firms in catching-up countries can rely on three main groups of resources for technological learning: the international community, the domestic community, and in-house efforts.

However, compared to the NIEs, Chinese companies, such as those in the telecom-equipment industry, demonstrated marked differences from their peers in NIEs when they started to catch up (Fan, 2011b; Yu and Li-Hua, 2011; Gao, 2014), mainly due to the changing tradability of knowledge or technological regimes (Altenburg *et al.*, 2008) and the global economic environment.

For instance, while Korean firms initially relied heavily on foreign sources for their catching-up in the automotive, electronics, and semiconductor industries, Chinese firms chose to conduct in-house R&D on switch technology, due to the high cost and unavailability of the existing technology, their lack of understanding of foreign markets and technology, and MNEs' interest in China's market. Further, situated in a dynamic technological regime and a much more integrated global economic environment, in order to compensate for their limited access to global resources, Chinese telecom firms were able to adopt some global technology strategies such as joint collaboration, participation in industrial standards (Gao, 2014), and R&D globalization at a much earlier stage of their catch-up than the Korean firms (Gao *et al.*, 2007; Fan, 2011b).

4. Regional Inequality in Innovation and Regional Innovation System

In stark contrast with the well-researched economic inequality literature, only a few studies, such as those of Li (2009), Liu and White (2001), Sun (2000, 2003), and Fan *et al.* (2012), have assessed regional inequality in innovation capability and its drivers in China.

Using a primary index, a top-five index, a top-10 index and coefficients of variation to indicate spatial patterns of innovation, Sun (2000) found that patents in China were highly clustered in the east–coastal region and the inland provinces, although the degree of spatial concentration declined from 1985 to 1995. When other indicators of innovation, such as new product sales and R&D spending were used, the spatial concentration was found to be on the rise in the 1990s (Sun, 2003).

Using patent numbers from 1985 to 1995, Liu and White (2001) found that economic activity and innovation inputs (i.e., R&D funding and personnel) led to differences in the innovation performance of regions. Also using patent data from 1998 to 2003, Li (2009) illustrated that government support, share of R&D performed by universities and research institutes, and the regional industry-specific innovation environment were significant determinants of innovation efficiency. Li emphasized that the innovation efficiency between regions becomes more disparate when innovation modes are transformed from being university and research institute dominant to being firm dominant.

Fan *et al.* (2012) found that east–central–west interregional inequality increased over time from 1995 to 2006, whereas interprovincial inequality showed a V-pattern until 2003. Using a recently developed decomposition framework, they identified the major factors driving innovation inequality as population, economic development, R&D, location, and openness. The aggravated innovation inequality reflects the growth of China's innovation centers in the eastern region and their admission into the global innovation networks. For instance, 60% of the foreign R&D laboratories in China are located in Beijing, 18% in Shanghai, and 6% in Shenzhen (Yuan, 2005). The fact that R&D is a major factor driving inequality suggests that the efficiency of R&D investment improved in certain regions during the period 1995–2006. Finally, geographic location and openness affect innovation inequality primarily through the coupled evolution of innovation capability and economic development, resulting in first-mover advantages in provinces of the eastern region (Fan *et al.*, 2012).

Worldwide, cities have become the focused locations for economic development and policy intervention (Petrella, 1995; Scott, 2000), facilitated by neoliberal globalization (Harvey, 2005) and the revolution in information and communication technology (ICT) (Castells, 2000–2003). Innovation in the emerging innovative city-regions in China is an exciting field, deserving of more research. For instance, although possessing only 3.2% of the nation's population, Beijing, Shanghai, Shenzhen, and Xian together generated 11% of GDP, 30% of exports, and 24% of the foreign direct investment (FDI) in China. Further, these four city-regions occupy leading positions in the development of high-tech industries, such as ICT and biomedical industries, and they differ in their paths for developing innovation capabilities in these industries. **Beijing** leads in R&D capacity and is the largest base of China's high-tech industries, as it topped other cities in revenue and number of employees in high-tech parks in 2009. Depending little on foreign capital or markets, Beijing's ICT industry features a large number of small- and medium-sized domestic companies focused on software and computer services (Zhou, 2008). **Shanghai** possesses strong manufacturing capacity in the ICT and biotech industries, especially in the integrated circuit (IC) and biomedical sectors, with the largest, most complete, and technologically advanced IC industrial cluster in China. Most of Shanghai's high-tech manufacturing capacity comes from large SOEs and MNCs, with little contribution from nongovernmental firms due to an unsupportive institutional environment for them (Breznitz and Murphree, 2011). **Shenzhen** developed itself from a small fishing village in 1978 to the third largest high-tech industrialization base in China within three decades, featuring mostly domestic firms actively involved in indigenous innovation (Zhou *et al.*, 2011). Accessible venture capital from Hong Kong, the completeness of the ICT industrial value chain, and active private entrepreneurship have been cited as the basis of the prosperity of domestic high-tech firms in Shenzhen (Breznitz and Murphree, 2011). **Xi'an** is the fourth leading city-region in high-tech industrialization in China. While it has mainly relied on SOEs and MNCs (Segal, 2003), in recent years, the government has begun to give more support to the innovation activities of nongovernmental domestic companies.

A number of recent studies have examined industrial and technological development in China's city-regions and how regional systems have interacted with the national system (Segal, 2003; Walcott, 2003; Huang, 2008; Zhou, 2008; Breznitz and Murphree, 2011; Zhou *et al.*, 2011). By studying nongovernmental firms in Beijing, Shanghai, Guangzhou, and Xi'an, Segal (2003) noted regional variations in technological dynamism and argued that different local states accounted for these differences. He further identified the local government of Beijing as the most effective state for the development of nongovernmental firms among the four city-regions. However, his research did not touch upon interactions between MNCs and local firms (Zhou *et al.*, 2011), or the globalization of firms in these city-regions. Walcott (2003) explored the role of policies in developing science and technology parks in Beijing, Shanghai-Suzhou, Shenzhen-Dongwan, and Xi'an. She emphasized that the main differences in policies lay in those promoting MNCs versus those encouraging ties to local research entities. Her work focused on administrative policies and did not examine the technological catching-up of domestic firms through external linkages. Breznitz and Murphree (2011) also investigated the divergent regional systems in Beijing, Shanghai, and Peal-river Delta and how the inherent "structured uncertainty" in China's national and local political systems has contributed to the variations. They argued that these different systems combine to form a unique national system that uses the logic of value creation—focusing on second-generation product and process innovation through specialization in certain production and service stages, enabled by fragmentation of global production and services. Nevertheless, they gave little attention to how successful local firms have actively sought global resources, for instance, through R&D globalization, to improve their innovation capabilities to go beyond second-generation innovation.

More academic research is necessary to address these critical gaps related to the innovation capability of China's emerging city-regions. In this respect, several approaches mentioned by McCann and Oxley (2012) can be considered as appropriate methods to further decode the mystery of innovation and regional development, such as developing conceptual frameworks to analyze the differences between regional and local innovation systems (Crescenzi and Rodríguez-Pose, 2012), computing a composite index to measure the regional degree of exposure to external knowledge sources, thus indicating a region's potential capacity to access nonlocal items of knowledge (Moreno and Miguélez, 2012), and hierarchical or multilevel modeling of under-used firm-level datasets (van Oort *et al.*, 2012).

5. Conclusion

This paper offers a comprehensive and critical review of innovation in China in the postreform era. China's recent progress in innovation capability after the launch of its economic reforms is certainly impressive, illustrated by the dramatic improvement in input and output indicators of innovation systems such as R&D personnel, R&D expenditure, patents, high-tech and service export, and scientific and technical journal articles. Nevertheless, although improvement in quantity is always the first step in any catch-up scheme, the quality of many indicators has been questioned.

The analysis of China's development of innovation can have implications for others when applying three major theoretic frameworks: (1) system of innovation, (2) global linkages, such as GVCs, global production networks, overseas returnees, and R&D globalization, and (3) the dynamics of latecomers' catch-up processes. While China's evolution of its national innovation system has been the fundamental approach to unleashing the creativity of the "middle kingdom" in postreform years, various global linkages, enabled by the transformation of technological regimes and the global economic environment, have considerably affected China's progress towards becoming a technological superpower. However, we are in need of a better assessment of the impact of these global linkages, i.e., whether these linkages augment or undermine indigenous innovation capability and how. One interesting area that deserves further analysis is how global networks of Chinese professionals and returnees have affected this process. Moreover, being a latecomer, China's catch-up exhibits differences from its predecessors from the NIEs, such as choosing to conduct in-house R&D at an early stage but opting for a much more globally integrated approach later on, as illustrated by the telecom equipment manufacturers. More research would be welcomed in this area to provide policy recommendations for other latecomer countries or regions.

With the rise of emerging nations and the improved innovation capabilities of China and India in particular, one thing is certain: "the long-held monopoly of the west with respect to innovation will be over."[5] After decades of reform, China, along with India, is close to competing on an equal footing with leading OECD countries, such as the USA, Japan, and Germany. In addition to issues at the national level, the uneven spatial distribution of innovation capability of China needs to be taken seriously by the Chinese government, as the increased disparity in innovation capability may significantly affect China's regional economic development in today's knowledge economy. Just like its economic reform, transitioning from "made in China" to "innovated in China" can be a tough national journey with numerous opportunities and challenges unfolding along the way. China may also discover a proper model for its "innovation-driven economy" by learning from the experiences of its various city-regions in experimenting with distinct development pathways for technological upgrading.

Acknowledgment

I thank the editor of the journal, Iris Claus, and two anonymous reviewers for their constructive and helpful comments on an earlier draft of this paper. I also thank friends and colleagues who have been helpful to me during my research on innovation in China. Particularly, I appreciate Guanghua Wan at the Asian Development Bank, Yifei Sun at California State University at Northridge, Denis Simon at Arizona State University, Yu Zhou at Vassar College, and William Lazonick at University of Massachusetts Lowell who provided helpful conversations on China's innovation and economic development on various occasions. Any opinions, findings, conclusions, and recommendations expressed in this paper are solely my own. I am also fully responsible for any errors.

Notes

1. East-West Center. 2011. China not an immediate threat to U.S. technology leadership, expert tells the review commission. Available at http://www.eastwestcenter.org/news-center/east-west-wire/

china-not-an-immediate-threat-to-us-tech-leadership-expert-tells-review-commission, accessed on Oct. 30, 2013.

2. As of May 2014, there are five candidate countries for the EU: The former Yugoslav Republic of Macedonia, Iceland, Montenegro, Serbia, and Turkey.
3. In this section, I will focus on NSI and address RSI in Part 4.
4. China Watch. 2013. Tax benefits to fuel innovation, growth. Available at http://chinawatch.washingtonpost.com/2013/11/tax-benefits-to-fuel-innovation-growth.php accessed on Mar. 5, 2014.
5. Kumar, Nirmalya. 2012. India Inside. The emerging innovation threat to the West. Presentation at the London School of Business. Available at http://www.slideshare.net/londonbusinessschool/india-inside-the-emerging-innovation-threat-to-the-west-lbs-professor-nirmalya-kumar accessed on Oct. 30, 2013.

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