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Innovation capacity and economic development: China and India

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Abstract Decomposing the GDP growth from 1981 to 2004, this paper finds that innovation capacity has contributed significantly to the economic growth of China and India, especially in the 1990 s. Outputs of the national innovation system, measured by patents and high-tech/service exports, demonstrate the considerable progress China and India have made in innovation capacity. The enhanced innovation capacity of China and India is primarily due to their heavy investment in the inputs of innovation system, i.e., R&D expenditure and R&D personnel, in recent decades. This paper emphasizes the role that the governments have played in promoting innovation capacity and their contribution to economic development. Both governments have transformed their national innovation systems through linking the science sector with the business sector, providing incentives for innovation activities, and balancing import of technology and indigenous R&D effort. Using case studies of domestic biotech firms in China and India, this paper also offers micro-level insights on innovation capacity and economic development: (1) innovation capacity has become essential for domestic firms' market success and (2) global institutional factors and national government policies on innovation have considerable influence on the choice of innovation at the firm level, i.e., to conduct indigenous R&D or to import foreign technology.

Keywords China · India · Innovation capability · Domestic firms · ICT · Biotech

JEL Classification O31 · O3 · L65

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Abbreviations

IP	Intellectual property
IRIs	Industrial research institutes
MNCs	Multinational corporations
NDRC	National development and reform commission (of China)
NIEs	Newly industrialized economies
NIS	National innovation system
PE	Private equity
R&D	Research and development
S&T	Science and technology
SEZs	Special economic zones
TFP	Total factor productivity
TRIPS	Agreement on trade-related aspects of intellectual property rights
TVEs	Township and village enterprises
TPS	Technology policy state
USPTO	United States patent and trademark office
VC	Venture capital
WIPO	World intellectual property organization

1 Introduction

China and India have achieved impressive economic growth in recent years, enjoying a high annual GDP growth rate of 9.8 and 5.9%, respectively, from 1981 to 2004 (World Bank 2008). In 2006, China and India became the fourth and the twelfth largest economies in the world with nominal GDPs of US $2.68 trillion and US $0.92 trillion, respectively (China Daily 2007; The Economist 2007).

While innovation capacity has been widely acknowledged as a critical force to national economic growth for developed countries (Nelson 1993; Porter 1990), scholars have divergent views on the contribution of innovation capacity to economic development for latecomers such as China and India. For instance, some have argued that the growth of China and India is due to advantages in the abundance of low-cost production factors such as labour and land, in addition to foreign investments and technologies resulting from economic reforms that liberalized markets in China and India (Huang 2003; Naughton 2007). This is in line with the 'accumulation' theory of growth held by a camp of scholars who attribute high growth of the newly industrialized economies (NIEs), i.e., South Korea, Taiwan, Hong Kong, and Singapore, to high savings and investment as these factors enabled the NIEs to better utilize the technology inherited from the world's leaders (Collins and Bosworth 1996; Krugman 1994; Young 1995).

Nevertheless other scholars have emphasized the role of technological progress in economic development and documented how transformation of national innovation systems and certain government technology policies have promoted indigenous R&D in China and India (Fan 2006a; Fan and Watanabe 2006; Katrak 2002; Kumar and Jain 2002; Liu and White 2001; Motohashi and Yun 2007). They share the similar view with those who proposed the 'assimilation' theory, asserting that the productivity growth resulting from learning, entrepreneurship, and innovation has been the critical source of NIEs' growth (Dahlman 1994; Hobday 1995; Kim 1998).

In this paper, I evaluate the contribution of innovation capacity to economic development of China and India by decomposing GDP growth and assess the progress of national innovation systems by measuring their outputs and inputs (Sect. 2). Further, I reveal the role that the governments have played in enhancing innovation capacity (Sect. 3). It is worth noting that in addition to the macro-level data and policy analysis in Sects. 2 and 3, I offered case studies of innovative domestic biotech firms in China and India in Sect. 4. Although it is highly risky to generalize from experiences of these firms to large national economies such as China and India, the case studies can serve as a "heuristic exercise" to characterize the linkage between innovation capacity and economic development at a micro level. I further reveal the main challenges faced by domestic high-tech companies in developing innovation capacity.

This paper contributes to the current literature on innovation and economic development for latecomers on two accounts. First, by providing evidence on the contribution of innovation to economic development of China and India, this paper challenges the view that innovation thrives only in developed countries and suggests that innovation can be and should be used to facilitate catch-up for latecomers. Second, this paper highlights the role that the global institutional environment and the government played in innovation activities of domestic companies and organizations.

2 Economic development, innovation capacity, and national innovation systems

2.1 Economic development of China and India

From the independence in the 1940s, China and India utilized new ideologies to foster their growth: communism in China and Fabian socialism in India (Lal 1995). After long periods of state support and protection, both China and India have gone through the transition from planned economies to market economies and experienced rapid economic growth since the 1980s, despite differences in growth rate, growth pattern, and fast growing sectors.

Shortly after the establishment of the People's Republic of China in 1949, adopting a heavy-industry development strategy, the government took control of a large part of the economy and set up new industries. Though initially focusing on heavy industry, China started to promote light industry later (Naughton 2007). China's GDP per capita growth rate reached 2.9% per annum from 1960 to 1980 (Fig. 1), despite the disruption of the Great Culture Revolution. Nonetheless, China's explosive economic growth took off after the economic reform launched in

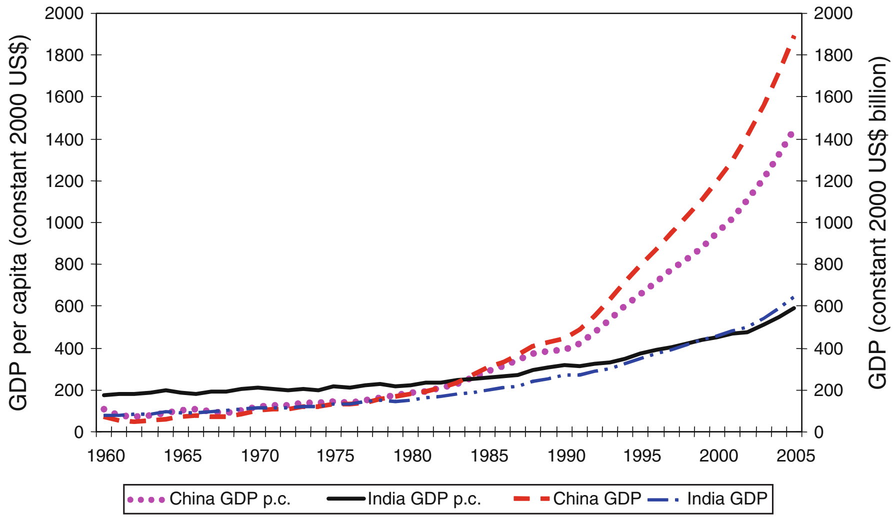

Fig. 1 Economic development in China and India, 1960–2005. *Source*: World Bank (2006)

1978 by Deng Xiaoping. Following the successful reform of the agriculture sector that dismantled the communes and introduced the household responsibility system at the end of the 1970s, township and village enterprises (TVEs) were set up, foreign direct investment were encouraged, and the country was linked to the world economy again through trade and import of foreign technologies (Naughton 2007). In the early 1990s, the economy experienced a second surge when foreign direct investment increased dramatically after the government formally announced in 1993 that the goal of the reform was to establish a socialist market economy and to set up special economic zones (SEZs). In 2001, China's membership in the WTO spurred another large inflow of foreign capital in subsequent years.

After independence in 1947, Indian leaders introduced economic policies that were characterized by import substitution, industrialization, state intervention in labour and financial markets, a large public sector, business regulation, and central planning. Nevertheless, India's protectionism can be labelled as Fabian socialism, an evolutionary form of socialism rather than revolutionary, in which the state steadily increased its involvement in economic activity, and was less extreme than the Soviet style central-command system in China, because the regime involved both public and private sectors based on direct and indirect state intervention (Lal 1995). However, the leaders were not satisfied with the slow economic growth as the annual growth rate of GDP per capita was only 1.1% during 1960–1980 (Fig. 1). Rapid economic development for the period 1980–2005, with a high 3.7% annual growth rate of GDP per capita, can be attributed to two stages of reforms carried out by the leaders: the pro-business measures initiated by the seventh Prime Minister Rajiv Gandhi in the 1980 s and economic liberalization initiated in 1991 by the tenth Prime Minister P. V. Narasimha Rao and his finance minister, Manmohan Singh (Lal 1995).

2.2 The contribution of innovation capacity to economic growth

Through a decomposition analysis, this paper finds that the development of innovation capacity has contributed significantly to the expansion of GDP for both China and India (Fig. 2). GDP growth rate can be decomposed into the contributions of capital, labour, and technology, and the share of technology can be measured by total factor productivity (TFP) growth rate (Fan and Watanabe 2006). The decomposition reveals that technology has significantly influenced both countries' economic development in the 1990s.

At the beginning of China's reform era (1981–1985), capital was the leading factor for growth, contributing to GDP growth at 4.5% annually, while technology augmented GDP growth by 3.9% per annum. However, during 1986–2000, technological progress became the leading growth factor, contributing to half of the GDP growth. During 2001–2004, although a large injection of capital triggered a 9.8% growth in GDP, the share of technological progress in GDP nevertheless was 3.8% per annum. The share of capital was the lowest during 1996–2000, corresponding to the outbreak of the Asian financial crisis during the period, whereas labour's contribution to growth has decreased over time.

At the start of the reform era (1981–1985), capital, labour, and technology contributed to India's economic growth in descending order, as indicated by their contributions to GDP growth rate at 2.5, 1.5, and 1.4%, respectively. However, similar to China, from 1986 to 2000, technology became the leading contributor to GDP growth, except for the period of 1991–1995 when the contribution of technology was slightly behind that of capital. But from 2001 to 2004, the contribution from technological dropped to a marginal position, as its share in GDP growth was only 1.5% annually. This was in sharp contrast to the contribution of capital that caused the 3.5% GDP growth rate per annum. Unlike China, labour has

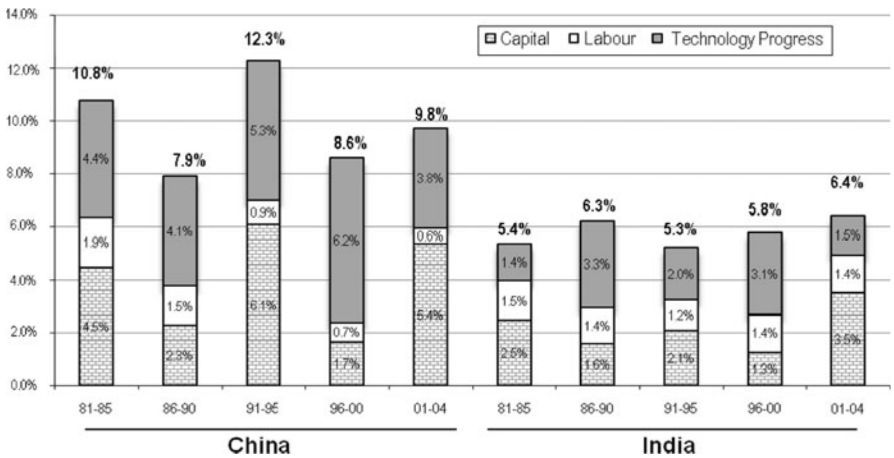

Fig. 2 Contribution of technological progress to economic growth in China and India, 1981–2004. *Source*: Computed by the author based on World Bank (2006) data

a quite important role to play in India's economic growth, as it consistently caused GDP to grow from 1.2% to 1.5%.

2.3 Indicators of innovation capacity: patents and high-tech/service exports

In addition to the evidence from the decomposition analysis, the considerable progress of China and India in innovation capacity can be reflected by rapidly growing patents and high-tech/service exports. First, patent activities, measured by patents granted by the US Patent office, have increased significantly for China and India (Table 1). Despite scepticism (Rassenfosse and Potterie 2009; Scherer 2003), the number of granted patents has been accepted as one of the most appropriate measures for innovation capacity (Barsberg 1987; Griliches 1990; Hagedoorn and Cooldt Hagedoorn and Cloodt 2003; Mansfield 1986). During 1970–1999, inventors based in China and India were granted 770 and 696 patents, respectively, by the US Patent Office. Though still being far behind those of Taiwan and South Korea, their numbers of approvals in the late 1990s were comparable to Hong Kong and Singapore. Innovation activities in domestic organizations seem to be more active in China than those in India as 44 of the top 50 patent winners in China are domestic firms or organizations, while about 30 out of top 50 patent winners in India are foreign multinationals or organizations (Mahmood and Singh 2003). Nevertheless, the situation seems to be changing; only 15% of patents during 1990–2001 went to foreign affiliates located in India (Mani 2004).

Second, China and India have successfully promoted their high-tech and service exports in recent decades (China outperforms in high-tech export while India excels in service export), thus enjoying mounting economic benefit derived from technological progress in the global market (Fig. 3). While high-tech exports accounted for 5% of China's overall exports and less than 1% of GDP in 1992, they reached US$163 billion, accounting for over 25% and 8.4% of total exports and GDP, respectively, in 2004 (World Bank 2006). According to Wu Yi, China's Vice Premier, the country's policy of 'enhancing trade by relying on science and technology' had led to the rapid expansion of exports (Asia News 2004). Software service, a strong sector in India, was not considered as part of high-tech exports but rather as part of service exports. Although India increased its high-tech exports from

Table 1 US patents granted to Asian inventors, 1970–1999

Recipient countries	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	Total 1970–1999
Taiwan	1	176	397	1,772	5,271	12,366	19,983
South Korea	24	43	91	424	2,890	11,366	14,838
Hong Kong	59	75	113	177	279	570	1,273
Singapore	21	9	20	47	148	499	744
China	61	2	7	129	239	332	770
India	83	67	40	64	126	316	696

Source: Adapted from (Mahmood and Singh 2003: 1034)

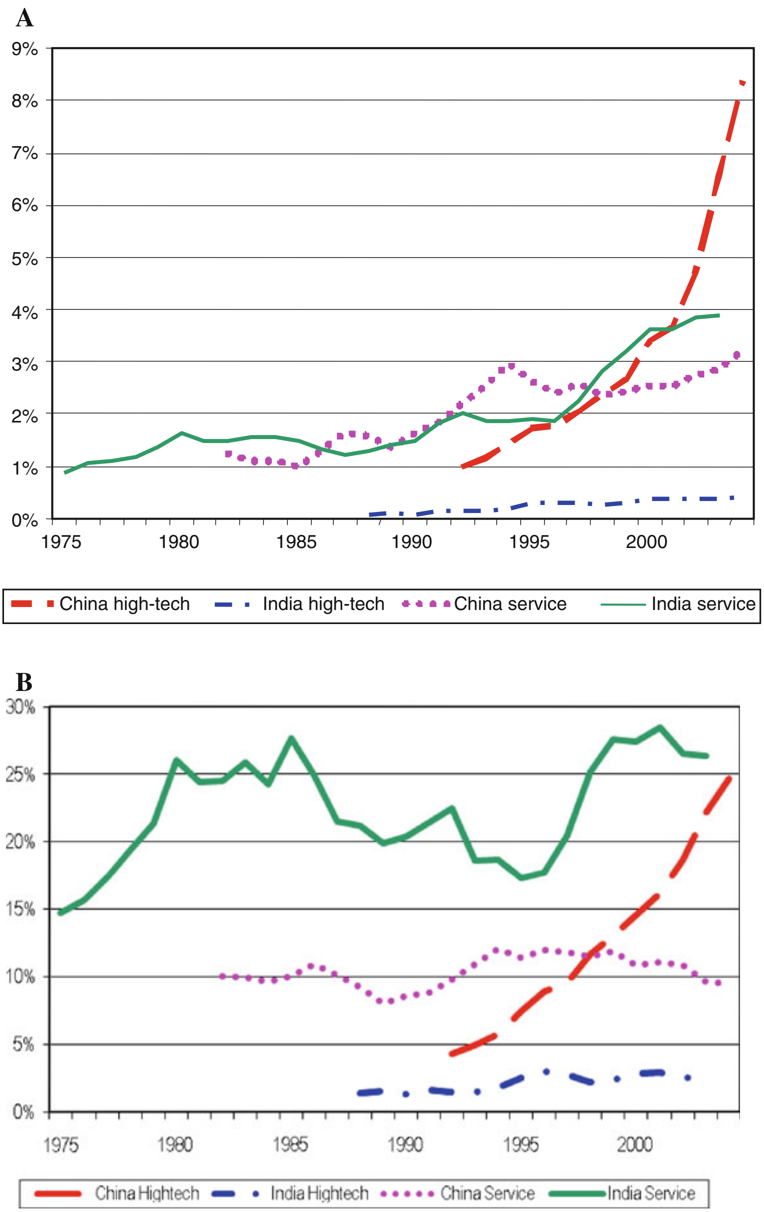

Fig. 3 **a** High tech and service exports as a percentage of GDP. *Source*: World Bank (2006). **b** High tech and service exports as a percentage of export. *Source*: World Bank (2006)

0.1% of GDP in 1988 to only 0.4% in 2005 (World Bank 2006), its service exports grew from 0.9% of GDP in 1975 to 3.9% of GDP in 2004, a pace much faster than China.

China and India have export profiles that are especially skewed towards high productivity goods and their exports have increased in sophistication, resembling to US, Japan and European countries (Rodrik 2006; Schott 2008). However, there is a growing literature enquiring to what extent China's growth in high-tech exports can truly reflect its improvement in innovation capacity (see, for instance, Amiti and Freund 2010; Blustein 1997; Feenstra and Wei 2010; Koopman et al. 2008). A large part of China's exports, including high-tech export such as PC, involves contract manufacturing in China for goods designed elsewhere, a phenomena dubbed as "processing trade" that firms in China import inputs into and assembled in China and then export again (Feenstra and Wei 2010). Some argue that most Chinese high-tech exports are just low technology products from high-tech industries (Blustein 1997). However, others found that the increased skill intensity of processing imports contributes to the increased skill content of exports (Amiti and Freund 2010) or rather, the improvement in human capital and government policies, especially those on tax-favoured high-tech zones, not "processing trade" or foreign firms, are vital to the increased sophistication of China's exports (Wang and Wei 2010). We need to be careful when linking this indicator with innovation capacity.

2.4 Inputs of national innovation system: R&D expenditure and personnel

The improvement of innovation capacity cannot be achieved without the appropriate inputs of national innovation systems, i.e., R&D expenditure and resources in R&D, two crucial elements for building up the innovation capacity of a nation (Audretsch and Feldman 2004). With some time lag, increasing R&D expenditure stimulates innovation and therefore enhances total factor productivity (Griliches 1979), as supported by empirical evidences from OECD countries including US, UK, Japan, France, Italy and Germany (Goto and Suzuki 1989; Griffith et al. 2004; Hall 1993; Hall et al. 2009; Hall and Mairesse 1995; Harhoff 1998; Lang 2009; Wakelin 2001). Many researchers have also provided evidences of effects of R&D expenditure on raising productivity and profits at the firm and industry level (Gonzalez and Gascon 2004; Griliches 1986; Hartmann 2003; Mansfield 1980, 1988; Meliciani 2000; Terleckyj 1982; Timmer 2003). A positive and significant relationship has been found between R&D expenditure of a firm and its productivity (Griliches and Mairesse 1984; Griliches 1986, 1998) and firm-level R&D is a driving force for technological innovation and economic growth (Romer 1986, 1990; Lucas 1988).

China and India have invested heavily in R&D since the mid 1990s. China increased R&D expenditure as a percentage of GDP increased from around 0.6% in 1996 to 1.44% in 2004 (Fig. 4). Although it is behind the R&D expenditures of the developed countries that spend on average 2–3% of GDP on R&D, China's progress is impressive, considering that its R&D expenditures increased even faster than its economy, which achieved an annual GDP growth rate of 9.8% during 1981–2004. According to OECD, China surpassed Japan in 2006 and became the second largest nation in R&D expenditure (Organization for Economic Co-operation and Development (OECD) 2006). While India spent around 0.65% of its GDP on R&D in 1996, the figure was 0.69% in 2004. This means that India's R&D expenditure has increased at the similar pace as its economy, which enjoyed a high

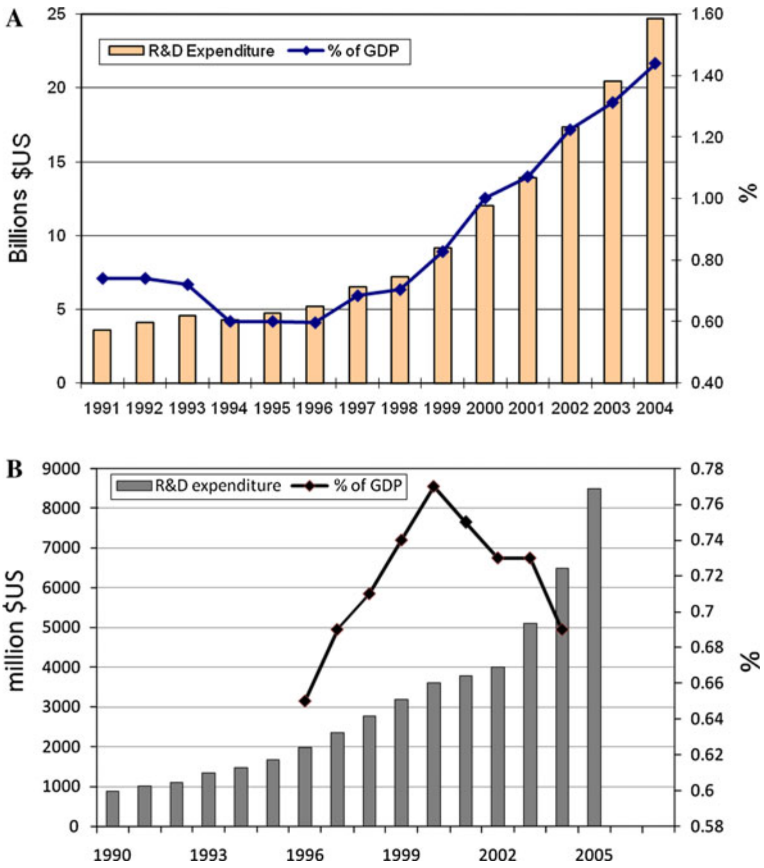

Fig. 4 **a** China's R&D expenditure and its percentage of GDP. *Source*: World Bank (2006). **b** India's R&D expenditure and its percentage of GDP. *Source*: Ministry of Science and Technology (2005) World Bank (2008)

annual GDP growth rate of 5.9% from 1981 to 2004. Nevertheless, the contributions of the business sector to R&D expenditure are different in China and India. In 2005, business enterprises accounted for over 60% of R&D expenditure in China (R&D Magazine 2005), they accounted for a mere 25% in India as central or state governments contributed to over 70% of the R&D expenditure (GoI, Government of India 2006).

In terms of R&D researchers per million people, China (926) and India (111) are in a lower category in comparison to OECD countries and other NIEs such as South Korea and Singapore or the emerging economies of Hungary, Ireland, and Russian Federation (Fig. 5).

However, China and India lead in R&D human resources with respect to absolute numbers due to large population bases. The rich reserves of R&D human resources have attracted multinational corporations to locate their corporate research centres in both countries. Multinational corporations have set up 750 foreign R&D centres

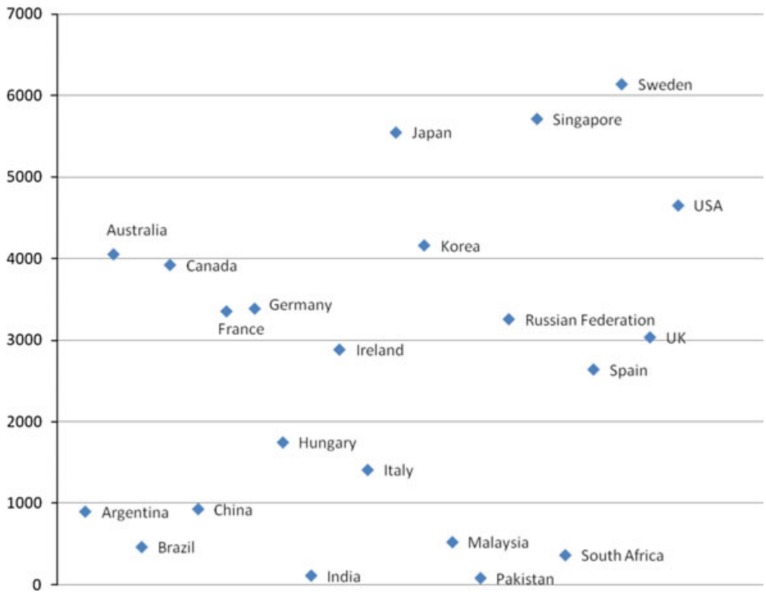

Fig. 5 Science and technology manpower in selected countries, 2004–2006 (Researchers in R&D per million population). *Source*: World Bank (2008). *Note*: India's data is 2000's figure

in China, growing five times since 2003 (Walsh 2007). Foreign R&D in China not only includes development to tailor products to the needs of the Chinese market (Sun et al. 2008), but also basic R&D, such as the Microsoft Research Centre set up in 1998. According to Richard F. Rashid, the senior vice president of Microsoft Research, 'China was really the No. 1 target from the beginning. We felt there was a tremendously deep pool of talent' (The New York Times 2004). Similarly, many multinationals have set up R&D laboratories in India, as for example, General Electric in the John. F. Welch Technology Centre in Bangalore, which in 2000 was their largest single R&D location outside the US. The ultimate reason for the relocation of multinationals to India and China is the high return on R&D investment, realized through the skilled R&D workers as Mr Welch, the then chief operating officer of General Electric, commented 'India is a developing country, but it is developed country as far as its intellectual infrastructure is concerned. We get the highest intellectual capital per dollar here' (Tripathi 2007).

Nevertheless, caution needs to be taken on the causality between R&D investments and innovation. Some researchers have questioned the efficacy of R&D expenditure to innovation and investigated significant factors contributing to R&D efficiency as other factors, such as private ownership, decentralized economies, and better R&D infrastructure are found to lead to more efficient R&D activities (Qian and Xu 1998; Huang and Xu 1998; Zhang et al. 2003). The issue deserves more attention as understanding the nature of R&D efficiency is important for designing policies to improve resource allocation (Wang and Huang 2007).

3 The role of the government

Improvement in innovation capacity in China and India, as indicated in Sect. 2, cannot be achieved without the involvement of national governments who set up environments to encourage innovation activities. Both governments have been very committed to promoting innovation capacity (Mani 2004; Motohashi and Yun 2007). In this section, I focus on reviewing two aspects of government involvement: (1) transforming national innovation systems to link the science sector with the business sector and (2) developing technology policies to provide incentives for innovation activities and balance import of technology and indigenous R&D effort.

3.1 China

3.1.1 Transforming national innovation system

In parallel with the economic reform, the Chinese government has been actively reforming the Soviet model for innovation system that China had applied from the 1950s. China's national innovation system (NIS) prior to the 1980s had been characterized by the complete separation of science and technology (S&T) activities in public research institutes from manufacturing activities at state-owned enterprises (Xue 1997). The NIS reform focused on connecting these two sectors by expanding the functions of each, i.e., introducing proper systems of innovation for both the science and industrial sectors (Liu and White 2001).

To push the R&D institutes to adapt to the market environment and to conduct R&D that had industrial implications, the Chinese government reduced institutional funding for public research institutes (PRIs) and universities (Motohashi and Yun 2007). It also undertook a three-step procedure: (1) advocating the merger of some R&D institutes with enterprises in 1987; (2) offering financial incentives to commercialize R&D results in 1988, especially through the Torch Programme; and (3) reforming the established R&D institutes into entities with economic functions, such as production and consultancy centres, from the 1990s (Fan 2006a; Fan and Watanabe 2006; Gu 1999). On the other hand, enterprises, not only state-owned ones, but also multinational corporations (MNCs) and new tech enterprises, became involved in the NIS and started to conduct more R&D. As a result, the business sector (large- and medium-sized enterprises) rose to become a major contributor of national R&D, 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 the R&D Magazine (2005), in 2004, R&D spending by the industry sector accounted for 61.2% of the national total.

Nevertheless, China's road to reform was not smooth. The initial NIS reform policy, merging R&D institutes with existing enterprises, was a failure because of the lack of financial resources from the enterprises to support the R&D institutes and the mismatch between the technology development needs of the enterprises and the research institutes (Fan and Watanabe 2006).

3.1.2 Development of technology policies

In conjunction with the transformation of the NIS, the government also put in place a series of technology policy initiatives, focusing on basic research for key areas and research for market need (Table 2). First, the principal components of the policies, Key Technologies Research and Development Programme, High-tech Research and Development Programme (Programme 863), and the National Programme for Priority Basic Research and Development (Programme 973), all focus on basic research of certain key areas to promote economic development of the nation.

The Key Technologies Research and Development Programme, initiated in 1982, is China's first and largest scientific and technological plan in the reform era. The programme targeted to find solutions to key technological issues related to national economic and social development, covering the fields of agriculture, electronic information, energy resources, transportation, materials, resource exploration, environmental protection, medical and health care, etc. Tens of thousands of individuals from more than a thousand scientific research institutes nationwide participated in the programme, making it the largest national S&T plan with respect to funds invested and personnel (China Net 2007).

High-tech Research and Development Plan or Programme 863 aimed to promote high-quality fundamental research in China with a specific focus on eight areas (biotechnology, aero-space, information, laser, automation, energy resources, new materials and oceanology) and 20 subjects that were critical to the country's technology and industrial development. Experienced scientists and researchers are selected for the project and the participation of domestic firms is also welcomed. The rationale of plan 863 is that this basic research is critical for China's national technological competitiveness, but too costly to conduct at individual research units or firms (GoC (Government of China) 2007a).

The National Programme for Priority Basic Research and Development (Programme 973), approved in June 1997, was to strengthen indigenous innovation and to target innovation related to sustainable development to such areas as agriculture, energy, information, resources and environment, population and health

Table 2 Major technology policy initiatives in China since the reform

Year	Policy initiative
1982	Key Technologies Research and Development Programme
1986	High-tech Research and Development Programme (Programme 863)
1988	Torch Programme
1991	The first high-tech park (Zhongguancun High-tech Park) was established
1990	First group of 27 high-tech parks was set up
1995	Decision on accelerating S&T development was announced by the State Council
1997	National Programme for Priority Basic Research and Development (Programme 973)

Source: Compiled by the author

and materials. The programme involved two development strategies: to 'rejuvenate the country through science and technology' and 'sustainable development' (GoC 2007c). The four main tasks of the programme include: (1) conducting multi-disciplinary integrated research and providing theoretic and scientific foundation for important scientific issues in the fields listed above; (2) deploying relevant, important and explorative forefront basic research; (3) nurturing highly qualified human resources in scientific fields; and (4) setting up a number of high-level national research bases and multi-disciplinary research centres (GoC 2007c).

Second, other policies have a special focus on high-tech industrialization. Complementary to the programmes which focus on fundamental research, the Torch Programme, initiated in 1988, was the most important high-tech industrial development plan in China to facilitate market-oriented technological development and commercialization of technology. The Torch Programme's objectives include (1) developing a favourable environment for high-tech industry; (2) setting up high-tech zones and start-up service centres for high-tech businesses; (3) executing industrial projects in areas identified by Plan 863; (4) facilitating international cooperation of Chinese high-tech firms; and (5) training high-quality human capital (GoC 2007b). One particular goal of the Torch Programme was to set up high-tech parks specializing in high-tech innovation, application, and diffusion to attract foreign high-tech multinational corporations and to encourage the development of domestic innovative firms. Since the establishment of Zhongguancun Science Park in May 1988, high-tech parks designated by the national government have developed into major locations for the country's high-tech industries. By 2003, China had about 33,392 high-tech enterprises, with 67% of these located in high-tech parks (Fan 2006b).

Similarly, the 'Decision on Accelerating S&T Development' announced by the state council in 1995 that outlined plans for China's scientific and technology development for the next several decades, also emphasized that S&T research should be closely linked to the market. One ambitious goal of the Decision was to increase spending on R&D to 1.5% of GDP by 2000 when at the time the corresponding figure was only 0.6% of GDP (State Council 1995). As a result, China's R&D expenditure as a percentage of GDP after 1995 has grown at a faster pace than in previous years and reached 1.44% in 2006 (World Bank 2008). It is not surprising to see the significant contribution of technological progress to economic growth in the second half of the 1990s.

Based on earlier reforms of the innovation system, China's tenth 5-year plan (2001–2005) further articulated its central theme in the new millennium—economic development driven by technological progress, once again, emphasizing that innovation activities are to be further promoted (People's Daily 2001).

3.2 India

The government of India has always emphasized promoting the development of indigenous technologies. It built up an extensive network of science and technology institutions, and granted tax incentives for the R&D efforts of enterprises. Recently, programmes have been organized on technology management to advise enterprises on technology forecasting and assessment as well as market evaluation (Katrak 2002).

3.2.1 Transforming NIS

Similar to China, the Indian government has taken a series of steps to modernize its NIS, starting from the 1980s when economic reform took place to change the highly restrictive old regime characterized by protection of its domestic firms from both international and internal competitions (Aggarwal 2000; Katrak 1998, 2002; Mani 2004). The competition between domestic and international firms was increased through the abolishment of industrial licensing and exchange rate adjustment by allowing the depreciation of rupee and liberalizing foreign capital and imported technologies. The restrictions on technology imports were relaxed substantially through measures such as reduction of sectoral restrictions on technology imports, substantial tax cuts on royalties and technical fees, simplification of tax structure, and deregulation of imports of drawings and designs (Aggarwal 2000; Katrak 2002).

In tandem with the change to a more liberalized regime, India also reformed its industrial research institutes (IRIs), which had been set up by the government to promote indigenous technological know-how and to help enterprises introduce new products and procedures, with subsidies and grants for R&D as the principal public support mechanism (Katrak 1998; Sikka 1998). Even though the economic rational had been to bridge the gap caused by 'market failure', India's IRIs performed poorly due to financial problems, uncertainty, and other issues and user enterprises lacked the capability to assimilate technologies of the IRIs (Katrak 1998). The weak performance of the IRIs could also be attributed to the inefficient use of resources and ineffective institutional arrangement, affected by an 'ivory tower' attitude of scientists, engineers and technologists, who concentrated on technological projects which would bring them peer recognition but have only limited commercial use (Katrak 1998).

To encourage the IRIs to make more commercially relevant technological efforts, the government gradually reduced its funding to IRIs and since 1990, requiring IRIs to cover at least 30% of their expenditures from their earned revenues (Katrak 1998). For instance, national laboratories of the Council of Scientific and Industrial Research (CSIR) and other prestigious technical institutes were instructed to earn at least 30–50% of their R&D expenditures through the commercialization of indigenously developed technologies and the generation and utilization of patents (Sikka 1998). It was proposed that R&D institutions recognized by the Department of Science and Technology should be allowed to retain equity holdings in the private enterprises that used their technology (Katrak 1998).

3.2.2 Development of technology policies

With a long history of encouraging technology development, the Indian government focused on creating a strong technological infrastructure and providing human resources to research communities and industries before the reform (Mani 2004). By 1998, India had about 3,000 scientific institutions, with 2,000 devoted to R&D (including in-house research and development units of industrial sector, academic institutions, test laboratories and technology centres) (Kumar and Jain 2003). Key initiatives in the pre-reform era include the Scientific Policy Resolution enacted in

1958 to support early and critical stages of industrialization and the Indian Patents Act of 1970, which granted patents for the specific processes of products rather than the products themselves, creating opportunities for Indian firms to adapt reverse engineering for optimal processes and thus boosted their R&D capability (Mani 2004).

After the reform, policies have been geared to provide more funding resources for innovation activities and to encourage indigenous technology development. To provide risk-sharing funds and managerial expertise for technology development and commercialization, the Technology Policy Statement (1983), Research and Development Cess Act (1986), and Technology Development Board Act (1995) were enacted for the provision of venture capital funds (Mani 2004). In addition, some other resources are also provided through venture capital funds and a few other schemes, such as the Technology Information and Forecasting Assessment Council (TIFAC) established in 1988 under the Home Grown Technology scheme (Kumar and Jain 2002).

To increase technological competence and self-reliance in strategic areas, the Technology Policy Statement (TPS) of 1983 encouraged indigenous technology development and advocated a mix of indigenous and imported technology (Kumar and Jain 2002). Further, the Research and Development Cess Act of 1986 established a fund not only to import technologies, but also to finance development of indigenous technologies, and to make imported technologies indigenous.

Other related schemes to facilitate and promote technology testing, up-scaling, and commercialization include the Programme Aimed at Technological Self-Reliance, The Sponsored Research and Developments Scheme, and the Programme for Acceleration of Commercial Energy Research, etc. (Kumar and Jain 2003).

The government announced a new S&T policy in 2003 which ambitiously set the goal of R&D spending at 2% of GDP by March 2007 and articulated eleven strategies for achieving the objectives. While it acknowledged that patenting activities have increased both at home and abroad, the government realized that it has to address some additional issues, such as the low density of R&D human resources, the need to manage brain-drain, and the need to monitor implementation of the policies (Table 3; Mani 2004).

4 Innovation capacity development of domestic biotech firms

To complement the macro level data analysis and policy review in Sects. 2, 3, in this section, I provide the development experience of innovative domestic biotech firms in China and India as a micro level evidence to illustrate the crucial role played by innovation capacity to economic growth.

Biotechnology constitutes one of the essential technologies of the knowledge economy, with its industrial revenue growing rapidly in recent years, reaching US $60 billion in 2006, or ten times of its 1996 level (Nature Biotechnology 2006). It is one of the most R&D intensive industries as global leaders of the biotech industry spent an average of more than 20% of their revenue on R&D, whereas other high-tech sectors, such as computer hardware and software fields spent, on average, less

Table 3 Major technology policy initiatives in India

Year	Policy initiative
1958	Scientific Policy Resolution
1970	Indian Patent Act
1983	Technology Policy Statement (new draft announced in 1993, but not adopted)
1986	Research and Development Cess Act
1988	Announcement of the Venture Capital Guidelines
1995	Technology Development Board Act
1996	Announcement of CSIR 2001: Vision and Strategy
	Securities and Exchange Board of India (Venture Capital Funds) Regulations 1996 (replacing the 1988 Venture Capital Guidelines)
1999	Amendment of the Indian Patents Act 1970
2000	Announcement of New Millennium Indian Technology Leadership
2003	New S&T Policy

Source: Mani (2004)

than 10 and 20%, respectively (MIT Technology Review 2003). Similar to their success in the ICT industry (China focusing on ICT hardware and India on ICT software), these two giants have made significant progress as world players in the biotech industry within a short time span. For instance, since 2001 China's biopharmaceutical industry has witnessed 20–30% revenue growth annually (Zhou 2007), while India achieved a growth rate of 36% during 2005–2006 (Biospectrum 2006a). In 2006, China and India ranked as the ninth and the eleventh, respectively, in biotech revenue (Buckley et al. 2006). Although India has currently outperformed China in terms of quantity, scale of manufacturing, and globalization (Buckley et al. 2006; Frew et al. 2007; Jia 2007; Kumar et al. 2004; Li et al. 2004), innovative domestic firms are essential for the expansion of the biotech industry in both countries (Fan and Watanabe 2008; Frew et al. 2007; Jia 2006a). For instance, 14 of India's top 20 biotech firms were 'home grown' and all top 6 firms are domestic (Biospectrum 2006a).

4.1 Selected domestic firms

Based on my research of biopharmaceutical industries in China and India, I have selected three firms from each country. They are innovative domestic firms recognized by other players in the industry and the media (BioSpectrum 2006a; Frew et al. 2007; Jia 2006a).

Located on the east coast and established in the late 1990s, the three Chinese biotech firms were the first group of firms gaining approval from China's State Food and Drug Administration (SFDA) for their innovative experimental biologic drugs (Table 4), such as the first commercialized gene therapy worldwide, Gendicine, by SiBiono, the first commercialized oncolytic virus, H101, by Sunway, and angiogenic inhibitor, Endostar, by MedGenn (China Daily 2004; Jia 2006a).

Table 4 Innovative domestic medical biotech firms in China and India

Firm	Established	Location	Main innovations
China			
Shenzhen SiBiono GeneTech Co. Ltd (SiBiono)	1998	Shenzhen	Gendicine (recombinant adenovirus type 5 gene therapy carry human p53 gene) for head and neck cancer squamous—cell carcinoma: first gene therapy in the world
Yantai MedGenn Co. Ltd (MedGenn)	1999	Yantai, Shandong	Endostar (recombinant human endostatin) for non-small cell lung cancer
			Originally developed by Entremed until 2003, endostar has an additional 9-amino acid sequence at N terminus
Shanghai Sunway Biotech Co. Ltd (Sunway)	1995	Shanghai	H 100 Series
			H101: (recombinant oncolytic adenovirus type 5) for head and neck cancer squamous–cell carcinoma
			H101: a modified version of Onyx-015
			Note: originally developed by Onyx Pharm. and later abandoned
India			
Shantha Biotechnics	1993	Hyderabad	r-DNA hepatitis B vaccine (first in India), erythropoietin, streptokinase, oncology segment
			More than half of revenue from exports
Bharat Biotech International	1996	Hyderabad	r-DNA hepatitis B vaccine, streptokinase (first in India), typhoid vaccine, vaccines for malaria and rotavirus infection
			More than half of revenue from exports
Jupiter Bioscience Limited	1985	Hyderabad	Leading player in drug intermediates, especially peptide, one of the top 5 global players (only one in Asia)
			Most revenue come from exports

Source: Jia (2006a) for China; compiled by author for India

Located in Hyderabad, the bio-valley of India, two of the three firms, Shantha Biotechnics and Bharat Biotech International, are acknowledged as dedicated and innovative biopharmaceutical firms that have managed to gain significant success and recognition (Frew et al. 2007). The three Indian firms demonstrate their innovation capability by a large number of their own brands of recombinant products (Table 4). For instance, Shantha was the first in India to develop the r-DNA hepatitis B vaccine, followed by Bharat and others. Both Shantha and Bharat have a range of recombinant products based on their own innovations. Jupiter, on the other hand, is the leading world producer in drug intermediates (Fan and Watanabe 2008).

4.2 Innovation capacity

The comparison of innovative biotech firms in China and India reveal that they have distinct different development paths. Started with products that were already produced by multinational corporations, India firms began by building manufacturing parallels, thus improving their R&D capability (Fan and Watanabe 2008). Chinese firms, on the other hand, collected ideas dropped by the US start-up firms and leapfrogged to first position in the sector (Jia 2006a). Nevertheless, they share the following main attributes relating to the development of innovation capacity.

First, innovation capability has become increasingly vital to the success of the Chinese and Indian biotech firms as well as the survival of traditional pharmaceutical companies who are struggling with declining profits. The six firms are highly successful in the market due to the branded products they introduced to the market through their innovation (Table 4). Moreover, other Indian biotech firms also invest heavily in R&D for biotech products; as a result, 7 of 14 recombinant biotech products approved by the Indian government were developed and are currently manufactured by Indian firms (DBT 2006b). Further, faced with declining profits due to price wars, traditional pharmaceutical firms are looking into innovation in the biotech area as an alternative. For instance, India's pharmaceutical firms, such as Biocon and Dr Reddy's, have entered the bio-drug field (Frew et al. 2007). Traditional pharmaceutical firms in China are looking for options to overcome their present predicament, for example, through the purchase of small innovative biotech firms (Jia 2007).

Second, institutional factors, especially the involvement of the government, have significantly affected innovation decisions at the firm level, i.e., to conduct indigenous R&D or to import foreign technology. The change in the intellectual property (IP) regime and memberships in WTO and TRIPS has provided a push for domestic firms in China and India to move towards indigenous R&D. Although Indian firms' conventional manufacturing procedures based on reverse engineering are deeply challenged as they are effectively barred from replicating innovations patented in the western world due to the implementation of WTO-GATT Agreement in 2005 (Mani 2004), it is easier for Indian firms to file patents to protect IP rights as India has become a signatory to the Patent Cooperation Treaty administered by the WIPO. Similarly, China's membership in the WTO and signing of the TRIPS imply that rather than duplicating or reverse-engineering western patents, the country needs more indigenous R&D. Further, both governments have provided crucial stimulus to starting-up these innovative firms and encouraged domestic firms to innovate through direct funding, creating new biotech governance, or establishing innovation policies particularly for biotech (Fan and Watanabe 2008; Jia 2006a; Kumar et al. 2004; Li et al. 2004), in addition to technology policies mentioned in Sect. 3. India established Department of Biotechnology in 1986 to provide a better environment for biotech development, particularly technology transfer between research institutes and private firms (Fan and Watanabe 2008; Li et al. 2004). Likewise, China's National Development and Reform Commission (NDRC) has provided financial guidelines promoting innovation activities. For instance, the Guideline on Pharmaceutical Industry Development for the 11th Five-Year Period (2006–2010) released in 2006 proposed that both public and private money earmarked for pharmaceutical R&D should be increased from the current 1–3% of revenue from pharmaceutical sales by the end of 2010 (Jia 2006b). The guideline also outlined greater pricing leeway to producers of innovative drugs to encourage investment in biotech research, whereas the NDRC had earlier forced pharmaceutical firms to slash their prices (Jia 2006b).

However, domestic biotech firms in China and India are confronted with two major challenges in developing innovation capacity: financial and human resource constraints. First, as limited financial resources have become the bottleneck for high-tech firms, including biotech firms, of China and India (Buckley et al. 2006), it is critical to reform current regulations on funding mechanisms and to attract international resources. As mentioned in Sect. 3, both countries set up technology policies to facilitate funding for R&D activities due to the underdeveloped mechanism to fund high-tech ventures. As a result, currently government support has been the main avenue for financing domestic biotech firms, especially for start up firms, in China and India, although Indian firms are able to channel a quite significant portion of the revenue back to R&D due to their outstanding performance in manufacturing (Jia 2006a; Fan and Watanabe 2008). The three Chinese firms introduced in this paper relied heavily on financial support from the government; Medgenn and Sibiono received US $12.4 million and US $9.6 million, most of their research funding, respectively, from various levels of governments (Jia 2006a). Other financing mechanisms, such as venture capital (VC) or private equity (PE), have increasingly become options. However, their contributions remain insignificant in both countries (Li et al. 2004; Fan and Watanabe 2008). In China, biotech VCs are mainly created by governments and strict regulations discourage international VCs to enter the market (Li et al. 2004). To deal with limited domestic resource, Indian firms started actively seeking international funding sources, ranging from venture capital, international organizations such as the World Bank and the IMF, to philanthropic organizations such as the Bill and Melinda Gates Foundation (Biospectrum 2006b, c).

The second major hindrance relates to the mediocre qualification of human resources. Although both countries have a good education infrastructure and a large pool of low-cost scientists, it seems that their university education cannot meet the standards of the industry (Buckley et al. 2006; Fan and Watanabe 2008; Frew et al. 2007; Jia 2007). To rectify the situation, the human resource plan of DBT has proposed various approaches for a quick fix of qualified biotech graduates, postgraduate doctors, and scientists in India (DBT (Department of Biotechnology) 2006a). Compared to India, China particularly needs manufacturing technicians (Buckley et al. 2006; Jia 2007). However, China's technology policies have not correspondingly addressed the quality of human resources needed by high-tech ventures. Further, both countries are looking to attracting expatriates from overseas into high-level elite positions in the hope of repeating Taiwan's success story in the electronics industry (Fan and Watanabe 2008; Li et al. 2004).

5 Conclusion

In this paper, I first evaluated the contribution of innovation capacity to economic development in China and India. Decomposing China and India's GDP growth from 1981 to 2004 into the contribution of three factors reveals that technology progress has contributed significantly to both countries' GDP's growth, especially in the 1990s. Rapid growth of high-tech exports, service exports, and certified patents from United States Patent and Trademark Office (USPTO) further attested the enhanced innovation capacity of both countries, realized through heavy investment in inputs of innovation systems such as R&D expenditures and R&D human resources. While the business sector has become the main actor in R&D in China as it increased its share in R&D expenditures, India's R&D is still dominated by public research institutes.

I stressed that the increasingly important role of innovation capacity to economic development has been closely associated with both governments' effort in transforming their rigid national innovation systems and setting up technology policies to adapt to economic development needs. They connected the science and business sectors, provided incentives for innovation activities, and advocated a balanced mix of the import of technology and indigenous R&D effort. To provide a micro-level prospective, I further reviewed the development of several innovative biotech firms in both countries. The cases revealed that (1) innovation capacity has become essential for domestic biotech firms to achieve market success and (2) institutional factors have significantly affected innovation decision at the firm level, i.e., to conduct indigenous R&D or to import foreign technology. Limited financial resources and mediocre human resource qualification remain two major challenges for domestic firms in China and India.

Although this paper offers some insights into how innovation contributes to the economic development of China and India, it raises a number of questions requiring further research. First, to what extent the gains in innovation capability in the market reform era necessarily build on previous regimes of protection and support from the state in China and India? Several researchers point out the disadvantages of the old national innovation systems implemented in China and India before the reform era, especially in terms of the suffocation of the growth of creativity and commercialization of research results from public research institutes and universities (Gu 1999; Katrak 1998, 2002; Liu and White 2001; Motohashi and Yun; Sikka 1998). Nevertheless, the old NIS may have contributed to the building of solid national technological base, protected the development of indigenous technology, and ensured technology development addressing urgent needs of the countries in a coordinate and collective way, in addition to preparing a large stock of human capital which is essential for the catch-up. We need a better understanding of how current technological achievements of both countries are linked to efforts of the states in the past.

Second, will the growing presence of transnational corporations (TNCs), especially foreign R&D, augment or undermine innovation capability of China and India? Both countries have become two of the world's largest recipients of foreign direct investment, with China received US $52.7 billion and India received US $2.3 billion in 2002 (Das 2005). Recently, they also become favourite locations of foreign R&D, listed as two of the top ten locations for global R&D (Economist Intelligence Unit (EIU) 2004; United Nations Conference on Trade, Development (UNCTAD) 2005). As host countries China and India may benefit from their growing presence through sponsorship and subcontract from foreign R&D to local firms and

R&D units and technology transfer to local personnel. They will also enjoy the spin-off effects such as firms set up by former employees of foreign R&D, the upgrade of suppliers' skill through meeting higher standards set up by MNCs, and the spill-over effect such as formation of innovation culture and pressure for local firms to innovate (Reddy 2000, 2005). However, negative impacts of foreign R&D may occur such as competition of local R&D resources, little diffusion to the regions, and the adverse effect due to merger and acquisition (UNCTAD 2005). Whether or not growing foreign R&D augment or undermine innovation capability of host countries depend on how host countries can effectively utilize the advantage while mitigating or avoiding the negative impacts. Further investigation on this issue has significant policy implications.

Third, how will R&D globalization of domestic firms affect innovation capability of China and India? Few researches have been conducted on the globalization of Chinese firms (Yeung and Liu 2008). Little attention has been paid to the R&D globalization of Chinese and Indian firms, despite noted examples such as Infosys, a leading IT service provider from India and Huawei, a global telecom firm from China (Reddy 2005). How did China and India utilize resource provided by globalization of R&D and enhance their own innovation capability? How can they effectively use global innovation networks (GIN, see Ernst 2006) to overcome latecomer disadvantages in technology development?

Fourth, does TFP arise from activities which are not reflected in formal input and output indicators such as R&D and patents? Will market reforms and competition reinforce or undermine TFP growth in future? TFP may arise from other factors such as the acceleration of the IT revolution and the increased market efficiency. The revolutionary development in information and communication industry, especially in the drop of prices yet increased performance of hardware (processors and storage devices), not only leads to substantial TFP growth in this sector but also pushes up TFP at macro level (Shibata 2009). For instance, in Japan, IT investment, mostly from hardware, explains about 80% of the overall TFP growth rate in the late 1990s (Jorgenson and Motohashi 2005). Similarly, China's IT investment, accounted for only 6% of TFP growth from 1980 to 1995 but over 50% from 1995 to 2003 (Hu 2008). Further, market reforms may significantly affect the growth of TFP in future for both countries. Studies on telecom sector have shown that regulatory reform such as deregulation, competition, and privatization have improve TFP growth considerably in US, UK, Canada, and Japan (Kwoka 1993; Oum and Zhang 1995; Shin and Ying 1992; Oniki et al. 1994). We need a more comprehensive assessment of other contributing factors to TFP growth.

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