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Breakthrough? China's and India's Transition from Production to Innovation

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Summary. — China and India have become major producers of products and services for global markets. This article explores to what extent they are also building up innovation capabilities. It draws on a combination of approaches—innovation systems, global value chains and professional networks—to analyze four of the most dynamic industries. We find that mounting innovation efforts only rarely materialized in cutting-edge innovations but suggest that if capital accumulation proceeds at the current pace, innovation capabilities will rapidly be built up in China and, with a time lag, India. We conclude by setting out the implications for both the developed and the developing world.

Key words — Asia, China, India, innovation, technology, catch-up

1. INTRODUCTION

China's and India's growth and transformation has attracted attention for two reasons: first, because it suggests that catching up with the OECD countries continues to be possible. Second, because it affects the whole world, resulting in new opportunities but also posing new threats. This has given rise to the notion of "Asian Drivers" of global change (see introduction to this Special Issue by Kaplinsky and Messner). The Asian Driver hypothesis is radical: it says that while the OECD countries continue to be important, the *change* comes primarily from Asia, in particular China but increasingly also India. This hypothesis has begun to define the agenda of global political economy—for both researchers and policy makers.

In the case of China, the external effects are much bigger than those of India because it started its export drive much earlier, its trade/GDP ratio is much higher and it forms part of an East Asian production network. This production network has brought about a major shift in *production* capability from Western Europe and North America to East Asia. In fact, one of the most striking facts about the global distribution of industrial activities is the massive dispersal of production capability away from the OECD countries to the developing world, in particular to East Asia. The magnitude and speed of change in the global distribution of production capability is historically unprecedented.

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In contrast, *innovation* capabilities have remained remarkably concentrated in the European Union, United States, and Japan. However, this is beginning to change. There are indications that China and India are developing significant innovation capabilities. Although OECD countries are still ahead in virtually all technological fields, the gap separating them from China and India has narrowed within a few years. If the catch-up process continues at the current pace, the Asian Drivers could have major effects on both the developed and developing world—albeit in different ways. The European Union, United States, and Japan compete above all on the basis of their innovative power. Will the bedrock of their prosperity crumble? Developing countries may benefit from imports of cheaper and more appropriate technology-based products, but may find it even more difficult to upgrade into the respective markets if China and India successfully combine cutting-edge technological capabilities and low-cost production.

Before investigating such repercussions, we need to understand *whether and how China and India are progressing from production to innovation*. This is the question which drives this paper. The problem is that this is an area of enormous uncertainty, marked by big knowledge gaps and controversy. While some authors predict a substantial shift in the global distribution of innovation activities, others stress that China's and India's innovative capabilities remain weak. Dissecting the claims and counterclaims and constructing a convincing account from the fragments of evidence are not easy. This paper therefore combines taking stock and framing questions for future research. Throughout, our search for answers is guided by both theory and attention to context specificity.

The paper is structured as follows: Section 2 provides the analytical groundwork, stressing that no single approach is sufficient to understand the catch-up process. The innovation systems approach provides the key elements and relationships at the local and national level but has no analytical grip on the trans-border relationships which are important to understand the buildup of innovation capabilities. We draw therefore on the global value chain and professional network approaches to bring in the global connections.

The need to focus on the mutual reinforcement of local and global linkages has been shown in the literature on the Asian Tigers (e.g., Hobday, 1995) but China and India are different in a way which is critical for the build-up of innovation capabilities. The combination of their large size and fast growth transforms the dynamics in a number of ways. At least this is what we hypothesize in Section 2. The large and growing internal market and the enormous capital accumulation resulting from long periods of fast growth give government and firms exceptional power to purchase, negotiate, and trade which needs to be taken into account if we want to understand China's and India's process of catching up.

Attempts to come to an overall judgement concerning the innovative power of Chinese or Indian industry have yielded poor results. This is shown in Section 3 which tries to assess the progress made on the basis of available *overall* indicators. Section 4 therefore analyzes four *specific* industrial sectors which, even though based on secondary sources, provide initial answers to our main question. The observed differences in trajectories underline the difficulty of generalization. We show, however, that in all four cases, China and India have managed to narrow the technological gap but their innovation capabilities do not yet suffice to seriously challenge global technological leaders. Furthermore, we highlight how in each sector the interaction of national and international forces is critical to understand the dynamics.

Section 5 summarizes the findings and dissects which trends favor technological catch-up and which ones might hamper it. All in all, we are optimistic about the prospects for catch-up, especially in China, provided the two countries succeed in handling certain overall economic and political risks.

Section 6 reflects on the implications for the OECD countries and the developing world. Given the unclear picture and remaining risks for catch-up in China and India it presents scenarios and questions for future research rather than wild speculation on the future. Overall, the article re-affirms that the global distribution of innovation activities is beginning to shift eastwards but that the speed and depth of this shift remain unclear.

A brief clarification on terminology: in order to make a judgement on whether and how China and India are catching up with the major OECD countries, we need to define what we mean by catching up. If one defines catching up in terms of the ability to compete on the basis of factor cost advantages, there is no question that China (and to a lesser extent India) have caught up. In many sectors, the share of China in global markets has risen rapidly, in particular at the expense of OECD countries. Catching up in this sense is about the accumulation of *production capabilities* [1]—which can be done by using and adapting existing knowledge. When we refer to catching up in this paper, we mean something more ambitious: the transition from production to *innovation capabilities*. We define the latter in terms of creating new knowledge and putting it to productive use.

This distinction between production and innovation capabilities draws on the work of Bell and Pavitt (1995), Bell and Albu (1999), Figeuiredo (2001), Ariffin and Figueiredo (2004). We recognize that the distinction is problematic. Using it specifically in this paper is problematic because the case material on China and India is rarely organized around this distinction. Using it more generally is problematic because innovation often involves knowledge adaptation. And this knowledge adaptation can be considered both part of the production and part of the innovation capability. Often there is a continuum between the two. However, as stressed by Bell (1984) a long time ago, there is *no automatic* continuum. On the contrary, over the recent decades, the two have decoupled. While products and services made in China and India (and other developing countries) conquered world markets, there was no corresponding accumulation of innovation capabilities in these countries. The question is whether this is now changing.

Our use of the term "catching up" is also related to the distinction between production and innovation capabilities. The buildup of production capabilities often entails adapting existing knowledge and thus minor innovations. For the purpose of this paper, technological catch-up has occurred when more than such minor adaptations have been made. "Technological" can be both in the hard sense, new knowledge embodied in machinery, and in the soft sense, new knowledge reflected in new ways of organizing the firm or the supply chain. This gives rise to the question of "new to whom"? The OECD (1997) guidelines for collecting and using innovation data (Oslo Manual) distinguish between different degrees of novelty: new to the firm, new to the country/region/relevant market, and new to the world. While taking into account this continuum, our ultimate question is to what extent China and India are developing processes, products or services new to the world (cutting-edge innovations).

2. ANALYTICAL FRAMEWORKS

While there is little hard evidence on the extent to which China and India have built up innovation capabilities, there is a flurry of analyses suggesting that the OECD monopoly in innovation is breaking up and that new innovation capabilities are emerging in China and India. A key feature of this debate is that the authors focus on a few specific factors which contribute to the buildup of innovation capabilities, deduced from a specific approach. The main argument in this section is that no single approach is sufficient, that we need to combine analytical frameworks to capture the buildup of innovation capabilities in China and India.

(a) *The innovation systems approach*

This approach has been used to analyze both the Chinese and Indian achievements (Krishnan, 2007; Li, 2005) and is probably the most influential approach worldwide. The starting point for innovation systems research is that innovation is an interactive process (Lundvall, 1988). This was a significant departure from the previously dominant approach which focused on what happened inside the firm. The interaction between producer and user became the focus of analysis—the relationships which producers and users have with specialized support institutions. The innovation system consists of the enterprises which produce and use innovation and the public and private organizations which carry out basic and applied research, train, advise, fund, coordinate, and regulate.

The central proposition of the innovation systems approach is that the innovative capability depends on the density and quality of relationships among enterprises and the relationships between enterprises and support institutions. Hence the approach goes much beyond traditional approaches which suggest that government should limit itself to providing a liberal business environment and investing in human capital, but regard supporting specific sectors, clusters or networks as frills which complicate the story and have at best marginal explanatory power.

Initially the focus was on the *national* innovation system (Freeman, 1995), but then it tended to shift to *regional or local* innovation systems (Iammarino, 2005). This occurred for two reasons: there are enormous variations within countries, especially big countries, and geographical and cultural proximity facilitate the interactive process which is at the heart of the innovation systems research. In other words, innovation is regarded as a socially and spatially embedded interactive learning process that cannot be understood independently of its region-specific institutional and cultural context. This perspective has led to a rich stream of research, mainly in OECD countries (Braczyk, Cooke, & Heidenreich, 1998; Edquist, 1997) but increasingly also in developing countries (Cassiolato, Lastres, & Maciel, 2003). It is further supported by the research on industrial clusters which does not always focus on innovation but underlines the importance of synergies and interaction for competitiveness (Porter, 2001; Schmitz & Nadvi, 1999). [2]

Taken together, these studies have transformed our understanding of why some countries or regions succeed and others fail. The problem is that they only depict part of the story and fail in two respects:

First, the innovation systems approach has no analytical grip on the relationships to key actors outside the region. Therefore we emphasize the need to integrate the analysis of territorially bounded innovation systems with approaches that focus on trans-border linkages (Humphrey & Schmitz, 2002).

Second, the understanding of the dynamics of innovation systems remains poor. [3] How do the structures of interaction develop and change over time? There is very little understanding about the emergence of knowledge-creating systems in contexts previously limited to knowledge using and little understanding of the timescales involved (Bell, 2006).

(b) *Conceptualizing external linkages*

The innovation systems approach is weak when it comes to understanding the role of external linkages. Yet these external linkages are very important in complementing or transforming the internal linkages. Innovation systems analysis is not blind to the operation of external players and relationships but it can only acknowledge their relevance in a descriptive way. It has no analytical apparatus to deal with the different kinds of relationships with external actors. Therein lies the case for combining it with two recent approaches that enable us to understand these external linkages: the global value chain and the global professional network approach. These latter approaches, however, are weak when it comes to understanding the local organizational and institutional context, hence our argument for combining them with the innovation system approach. [4]

The need to draw on the *global value chain approach* is particularly glaring in the Chinese case. As shown by Enright, Scott, and Chang (2005), the rapid growth of Chinese manufactured exports can only be understood if we grasp the insertion of Chinese enterprises into global value chains. What insights can we derive from the global value chain approach for our concern of trying to understand the transition from production to innovation capabilities?

To answer this question one needs to start with the acquisition of production capabilities. The *speed* with which these capabilities were acquired is due to the integration of developing country producers into chains co-ordinated by lead firms based in the United States, European Union, or Japan—or their intermediaries from Taiwan and Hong Kong. The rapid acquisition of production capabilities results from the dual role of these lead firms: they are extremely demanding but they also need to provide constructive monitoring so that these demands are met. This does not mean all producers joining such value chains can expect to learn fast from their customers. Lead firms only provide this support where they define the product and where they perceive a risk of supplier failure (Schmitz, 2006). This has been the typical situation in much sourcing from China and other low income countries. In this sense the global value chain approach helps to explain the massive and rapid dispersal of *production* capabilities away from the OECD countries.

As regards the spread of *innovation* capabilities, the approach is more ambiguous, revealing both forces that might block and constellations that accelerate the dispersion of innovation activities. To explain this, one needs to distinguish between different types of chains with different power constellations. In captive chains (Gereffi, Humphrey, & Sturgeon, 2005), the global buyer has co-ordinating power and can set the terms under which other firms in the chain operate. The acquisition of capabilities, which is in the buyers' interest, is likely to progress fast and might even be supported, notably the knowledge-using activities geared to strengthening the producers' existing position in the global value chains. The acquisition of capabilities, which is against the buyers' interests, is less likely to thrive and might even be discouraged, notably knowledge-creating activities in chain co-ordination, design and marketing. In a nutshell, the upgrading opportunities of local enterprises are often structured by the relationships in global value chains (Altenburg, 2006a; Schmitz, 2006). These opportunities vary with the way the chains are organized.

This approach of distinguishing between different types of chains proved very useful in understanding the successes and failures in innovation. The main insights provided by recent value chain research are

— The power of the lead firm is indeed critical but relationships change over time and new innovation opportunities emerge for suppliers willing to make the required investment (Altenburg, 2006b; Schmitz, 2006).

— Operating in several types of chains is particularly critical for acquiring innovation capabilities: producing to the specification of the lead firm in a global chain often provides access to new designs or processes (developed elsewhere) while national chains can be more conducive to developing innovation capabilities, because the power relationships with customers tend to be more symmetrical and there is more space for working with the national customers on design, marketing, and branding (Mitsuhashi, 2005; Navas-Aleman, 2006).

— Even in captive global chains, spaces for innovation open up for local suppliers. The outsourcing of lead firms includes not just routine activities but increasingly also knowledge-intensive activities, even including R&D and design services (Ernst, 2002; UNCTAD, 2005). The resulting buildup of innovation capability is, however, mostly limited to non-strategic areas.

— The lead firms' dispersion of knowledge-intensive activities is heavily concentrated in a few specialized clusters (Ernst, 2002; Sturgeon, 2002). Local synergies matter.

The global value chain approach thus provides insights which are highly relevant to understand innovation systems. Add to this that innovation systems are not only linked to the global economy via value chains, but also via two other mechanisms: via forward and backward linkages, but also cross-border mergers and acquisitions (UNCTAD, 2000); and the migration of scientists and entrepreneurs between leading and late-comer countries.

Saxenian's (2006) analysis of the Indian software cluster in Bangalore and the Chinese computer cluster of Zhongguancun/Beijing shows this clearly. She attributes the buildup of entrepreneurial and innovation capabilities above all to the strong *professional and personal networks* that have developed between these new innovative regions in China and India and the old innovative regions in the United States. The central figures in these networks are what she calls the "The New Argonauts"—highly mobile, technically skilled entrepreneurs, engineers, and scientists mostly of Indian/Chinese origin, with substantial research and work experience in the United States, applying their skills and capital in their country of origin. The feared "brain drain" has turned into "brain circulation," in those countries which—like China and India, and Korea and Taiwan at an earlier stage—experienced prolonged periods of high economic growth which created demand for highly skilled people. This is not just about return migration. The "New Argonauts" often operate in both the old and new regions, travel frequently between them, maintain close professional relationships on both sides and have strong professional associations on both sides. [5]

Clearly these highly talented, motivated and mobile people and their networks play a key role in the acquisition, transfer, adaptation, and creation of knowledge. The analysis of these global professional networks seems critical for understanding the accumulation of innovation capabilities in China and India but again, on its own this approach is not sufficient. As shown in later sections, combining the approaches presented here is essential for understanding the advances and limitations made in China's and India's quest to become major innovation powers.

(c) *Understanding the dynamics*

What insights does the innovation literature provide on the dynamics of the catch-up process? The analysis most relevant for our concerns is provided by Hobday (1995). His main conclusion is that rather than leap frog, local, and foreign firms (in the East Asian Tiger economies) engaged in a painstaking and cumulative process of learning and moving forward in incremental ways: "a hard slog rather than a leap frog'' (p. 200). This process is analyzed in terms of interacting technology and market transition from OEM, to ODM and OBM. [6] The empirical analysis then shows why and how these transitions were managed in some industries more successfully than others. The key analytical messages are (using our terminology) understanding the dynamics requires a focus on the interaction of local and global linkages (confirming the point we made above) and a focus on the gradual movements from using to adapting to creating knowledge—rather than a search for the big leaps forward.

The question is whether Hobday's framework is too limiting for the Chinese and Indian case. His analysis concentrated on the Asian Tigers, all very successful but comparatively small economies. China and India have internal markets which are large and growing very rapidly. The combination of size and fast growth makes a difference—at least potentially—in two ways:

— Capital accumulation is possible on a much bigger scale. This enables both countries to invest heavily in R&D and skills development, to buy enormous quantities of embodied technology in different forms—licenses, machinery, brands, and even entire hi-tech firms—and to hire leading international scientists, managers, and consultants on an unprecedented scale.

— Both countries are highly attractive for FDI (although India lags behind), including a kind of FDI that makes ample use of local scientists and engineers. Especially China takes advantage of the fact that the world's major investors seek access to its large and growing market in order to oblige investors to share technologies. The government is trading market access for technology.

This extraordinary combination of economic purchasing and political bargaining power needs to be incorporated in the analysis: does it enable China and/or India *to join the league of innovating countries*?

This in turn gives rise to a question which is old but acquires new significance. How tradable is the knowledge required to innovate? The innovation systems literature draws attention to the limits of tradability, emphasizing that much knowledge is tacit and built up in a cumulative and path dependent way (Strambach, 2004). Knowledge is sticky and not easily transferable. Caution is also advised by those who have studied the wider institutional and social context of innovation. Pérez (1989) has long emphasized that technological and institutional change need to go hand in hand. More recently, Nelson (2004, p. 365) has stressed that the ''social technologies are more difficult to acquire than the physical.'' These social technologies are embodied in norms and values, organizational forms, incentive systems, laws and codes of conduct, public policies, administrative procedures, and the like (Nelson & Sampat, 2001). These insights from the innovation literature need to be taken into account in assessing the catch-up process of China and India.

However, we also need to ask whether the limits of tradability are changing. The organization of the innovation process has changed fundamentally in recent years. Many innovation activities that used to be carried out in-house are moved out to independent suppliers of knowledge-intensive business services or are transferred to key suppliers. This ''organizational decomposition of the innovation process'' (Schmitz & Strambach, 2007) makes it easier to target and purchase specific knowledge workers or their services.

This is particularly relevant for a country with extraordinary resources to invest in the necessary skills and hire the bearers of codified and tacit knowledge from abroad. Can strong government agencies and the companies which they support acquire the necessary system elements and integrate them in a short period of time? Do the ''New Argonauts'' (Saxenian, 2006) open up a fast track for developing the required ''social technologies'' (Nelson, 2004)? More generally, are the thresholds of codifiability and tradability shifting with the changing organization of the global knowledge economy, and if so, what does this imply for the catch-up opportunities of large and rapidly growing economies, like China and India? Sections 4 and 5 seek to address these important questions.

3. MEASURING CHINA'S AND INDIA'S ADVANCE

Where do China and India stand in the international pecking order? How much has their position changed in recent years? Are there indicators which enable us to make an overall judgement? This section shows why such an assessment is difficult and what existing indicators tell us about China's and India's progress.

(a) *The difficulty of measuring innovation*

Assessments of where China and India stand regarding their innovation capabilities, if and how rapidly they are catching up with OECD countries diverge considerably. There are four interrelated reasons that can explain this:

First, it is notoriously difficult to measure and compare innovation capabilities (see, e.g., Freeman & Soete, 2007; Tijssen & Hollanders, 2006). While within the OECD some comparability of relevant indicators has been achieved through the elaboration of a whole family of guidelines (e.g., the "Frascati-Manual" or the "Oslo-Manual"), [7] the same does not hold for comparisons between OECD and catching-up countries that have not been involved in this collective process.

Second, the most conspicuous indicators that seem to confirm the rapid advance of China and India are *input* factors, while *output* and *outcome* indicators show only modest progress. With the available information it is impossible to assess whether the gap between *effort* and *achievement* is due to the normal maturation time for innovations or whether it is due to inefficiencies in the emerging innovation system.

Third, innovation-related data generally describe the performance of the actors within a given territory. However, territorially bounded innovation systems are increasingly overlapping with cross-border networks and often global value chains through which knowledge is transmitted. This leads to the question of *whose* innovation capabilities are actually reflected in national data. For example, rapid increases of high-technology exports may be due to expansion in computer assembly. Or foreign lead firms may produce hi-tech products without being embedded in the national innovation systems.

Fourth, international comparison of Chinese and Indian innovation efforts and achievements is further complicated by huge internal disparities. This leads to the "hall of mirrors" effect (Leadbeater & Wilsdon, 2007, p. 11). Some indicators, while large in absolute terms, seem rather insignificant when population size is used as deflator. On the other hand, when the indicators are related to *per capita income*, they imply a much stronger performance of China and India.

(b) *Indicators of China's and India's innovation efforts and performance*

Keeping in mind these measurement problems, what does the available data tell us? *Input indicators* show enormous progress in the Chinese case. Since 1999, China's spending on R&D has increased by more than 20% each year. In 2005, it reached 1.3% of gross domestic product, up from 0.7% in 1998 (Wilsdon & Keeley, 2007, p. 4). In contrast, India's R&D expenditure as percentage of GDP has fluctuated around 0.8% since the 1990s. [8]

India's most important input factor into the innovation system is human capital. The annual enrolment at the level of graduate or above has risen from 6.6 million in 1995/96 to 9.8 million in 2004. Among those the percentage studying engineering has increased from 6.0% to 11.2%. Each year around 350,000 engineering graduates are released to the labor market. Estimates of annual science PhDs range from 5,000 to more than 6,700 (Bound, 2007, p. 9). In China, the investment in human resources is even more impressive. The number of researchers increased by 77% during 1995–2004 (OECD, 2006). In 2004 around half a million postgraduates were counted in science, medicine, and engineering, and 23,500 PhDs awarded, whereof 70% in science-related subjects (Wilsdon & Keeley, 2007, p. 17). However, the above authors also stress considerable quality problems in secondary, tertiary, and post-graduate education in both China and India.

Foreign companies both contribute to and draw on the pool of local talents. Corporations such as Microsoft, IBM, Motorola, Google, Siemens, Volkswagen, and Honda have established R&D centers in China and India, bringing in their own expertise and using the highly educated but cheap local workers to pursue their innovation strategies. By the end of 2006, about 750 foreign-funded R&D centers had been set up in China (China Daily, December 12, 2006). Simultaneously, China's and India's own corporations, such as Huawei Technologies (China) and Infosys (India), are increasingly "going global" and investing strategically in subsidiaries to tap local knowledge hubs and to strengthen linkages with international clients (UNCTAD, 2006, p. 130f).

Looking at *output indicators* there are signs that China and India might catch-up more rapidly in science than in technological innovation. Within 10 years—from 1995 to 2004 China's contribution to global production of scientific publications rose from 2.05% to 6.52% (Wilsdon & Keeley, 2007, p. 14). India's scientific performance is much weaker. The country "accounted for only 2.19% of the

Table 1. *Performance of India's and China's science system*

	GDP *per capita*	SCI publications (1997–2001)	SCI publications per GDP/capital per year	SCI citations (1997–2001)	SCI citations per GDP/capital per year
India	487	77,201	32	188,481	77
China	989	115,339	23	341,519	69
United States	36,006	1,265,808	7	10,850,549	60
United Kingdom	26,445	342,535	3	2,199,617	18
Germany	24,051	318,286	3	2,500,035	19

Source: Bound (2007, p. 15).

world's scientific publications in 1993–97 and this declined to 2.13% the period 1997–2001" (Krishnan, 2007, p. 1, see also Table 1).

Still weak is China's and India's patent records. Table 2 shows the number of patents granted by the US Patent and Trademark Office: Chinese and Indian patents have increased in absolute numbers as well as in relation to the totality of patents of foreign origin. However, the level of patenting is still low. China and India together represent just about 1% of all patents granted to foreigners, compared to more than 6% in the case of the much smaller South Korea.

Considering this mixed picture (strong commitment and technological efforts but still modest output) it does not come as a surprise that *composite indicators* such as the UNCTAD Innovation Capability Index and the Global Competitiveness Index rankings position neither China nor India as major innovation powers (see Table 3).

Obviously, such indicators are insufficient to assess the innovation capabilities of India and China. A combination of quantitative and qualitative methods is needed to judge the progress made in moving from production to innovation. The questions are clear but the answers are hard to find. Under what circumstances is the growth of industrial production capabilities transformed and extended into the growth of innovation capabilities? Are there common patterns in the evolution of these innovation capabilities? How does insertion into global

Table 2. *Patents granted by the US Patent and Trademark Office during 1963–2005, by geographic origin*

	Pre 1992	1995	2000	2001	2002	2003	2004	2005
Patents of foreign origin	721,716	45,680	72,426	78,436	80,360	81,130	80,020	69,169
China, PR	337	48	119	195	289	297	404	402
India	374	27	131	178	249	342	363	384
Germany	161,305	6,600	10,235	11,260	11,280	11,444	10,779	9,011
United Kingdom	76,452	2,481	3,669	3,967	3,843	3,631	3,450	3,148
South Korea	1,229	1,161	3,314	3,538	3,786	3,944	4,428	4,352
%								
China, PR	0.05%	0.14%	0.16%	0.25%	0.36%	0.37%	0.50%	0.58%
India	0.05%	0.08%	0.18%	0.23%	0.31%	0.42%	0.45%	0.56%
Germany	22.35%	14.45%	14.13%	14.36%	14.04%	14.11%	13.47%	13.03%
United Kingdom	10.59%	5.43%	5.07%	5.06%	4.78%	4.48%	4.31%	4.55%
South Korea	0.17%	2.54%	4.58%	4.51%	4.71%	4.86%	5.53%	6.29%

Source: US Patent and Trademark Office, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/reports.htm#by_geog.

Table 3. *China's and India's ranking in the Global Competitiveness Index (GCI) and three of its pillars*

Country	GCI	Pillar 5: Higher education and training	Pillar 7: Technological readiness	Pillar 9: Innovation
China	54	77	75	46
India	43	49	55	26

$N = 125$ countries.
Source: World Economic Forum (2006).

value chains influence these patterns? How do policy networks and support organizations of emerging innovation systems contribute? Unraveling the dynamics is particularly difficult. The next section provides some insights into these dynamics, drawing on sectoral accounts.

4. INSIGHTS FROM SELECT INDUSTRIES

Understanding the buildup of innovation capabilities requires combining different analytical approaches: this was the main message of Section 2 and this is the thread running through this empirical section. It focuses on two Chinese and two Indian industries and provides insights into the dynamics of the catch-up process. While necessarily brief, it shows to what extent the transition from production to innovation has been achieved, highlights how different elements of national innovation systems and global linkages have interacted, and indicates how the size of the economy and the power of accumulation have contributed. The chosen sectors are electronics and automobiles in China, and the software and space industries in India. [9] We opted for these sectors because they are among the largest in terms of production and/or R&D expenditure and because they show different trajectories arising from different combinations of change agents.

(a) *The electronics industry in China*

China's success in building the world's biggest production hub for global markets is strongly associated with FDI in the *electronics industry* (Ma, Nguyen, & Xu, 2006). The largest exporters are foreign, but within two decades several Chinese electronics firms have become global players, including Huawei Technologies, Lenovo, and the Haier Group:

— Huawei Technologies is a leading provider of telecommunications networks and increasingly challenges established competitors like Siemens, Cisco, and Alcatel, now serving 31 of the world's top 50 telecom operators. Its products encompass wireless products, network products, applications, and software, as well as computer terminals.

— Lenovo is a global leader in the PC market since it acquired the IBM Personal Computing Division (PCD) including its international research facilities.

— Haier is the fifth largest producer of electrical appliances worldwide, manufacturing large household appliances, air conditioners, LCDs and Plasma-TVs, DVD recorders and mobile phones.

All these multinationals are dedicating substantial resources to innovation. Huawei, for example, claims to invest more than US$1 bn. in R&D and to have almost 30,000 employees in this field (Handelsblatt, February 20, 2007).

Initially China's buildup of capabilities relied heavily on insertion in global value chains: export-oriented low-cost assembly in global value chains to the specifications of foreign customers. Chinese subcontractors rapidly gained expertise in high-volume manufacturing. Given the increasing concentration of global production facilities in China, the semiconductor industry (e.g., wafer fabs, integrated circuit design houses, semiconductor packaging, assembly, and testing) subsequently shifted production to China, thus locating increasing parts of the value chain in the country (PriceWaterhouseCoopers, 2005). Furthermore, the rapid growth of the domestic market for PCs and consumer electronics induced the leading Chinese companies to operate in both the home and export market. This allows them to achieve enormous economies of scale and to combine capabilities gained from operating in the global value chain with capabilities built in developing own products and brands. In the case of personal computers, for example, Chinese brands now have roughly two thirds of the domestic market (Zhou, 2005, p. 1121).

In parallel, the government made considerable sectorally targeted investments in innovation. "Electronics and communication equipment" and "electronic computers and office equipments" together account for 78% of total industrial R&D expenditure. [10] This was accompanied by targeting key capabilities in the electronics value chains, for example, an R&D fund for the development of IC (integrated circuit) design houses (PriceWaterhouseCoopers, 2005, p. 4). As shown by Zhou (2005), China has been able to transform its leading Science Park, Zhongguancun in Beijing, into an innovative cluster, specialized in computer hardware and software, by experimenting with new forms of collaboration between academic institutions and the private sector and between Chinese enterprises and multinational companies.

Finally, China's industry has tapped additional international knowledge pools.

Acquisition of foreign firms—as in the case of IBM PCD—has helped not only to acquire brand reputation but also to access international R&D networks. The new Lenovo now has R&D centers in China, Japan, and the United States. Similarly, Huawei has created a network of global R&D centers in China, India, United States, Sweden, and Russia. Another important international connection was the return migration of Chinese scientists and entrepreneurs from the United States, essential in particular for the semiconductor industry in Shanghai (Sternberg & Müller, 2005). China's government supports this process providing incentives for returnees with technological skills (Yusuf, Nabeshima, & Perkins, 2006, p. 32). In the case of the electronics industry, the Chinese government thus comes close to what Fromhold-Eisebith (2007) calls the "master of the scales": global, national, and local.

(b) *The auto industry in China*

Regarding the *Chinese automotive industry*, industry analysts agree that domestic innovation capabilities still lag far behind leading nations, although production capabilities have grown rapidly. While two decades ago China did not have any relevant automobile industry, it is now the fourth-largest producer in the world (Noble, 2006). The industry is fueled by the rapid expansion of domestic demand. According to projections by Goldman Sachs, the Chinese market for automobiles will increase from 19 million units in 2005 to 199 million in 2025, overtaking even the US market (Wilson, Puroshothaman, & Fiotakis, 2004, p. 23).

Increasing competitiveness is reflected in the fact that China's automobile and autoparts exports are rapidly increasing, although from a low level; in 2004 its share in the global market was still as low as 0.7% (WTO, 2005). Its strength is mainly in labor-intensive auto component exports which are based on cost advantages, although China's companies have recently developed their own car brands and started exporting these to low-end markets. All this, however, shows improved and expanded production capabilities rather than innovation capabilities. Auto production is almost fully carried out under licence from foreign manufacturers. Most product development is based on reverse engineering, and no significant indigenous technological development has yet occurred. At first sight it therefore seems quite unlikely that China may join the league of countries with domestic innovation capabilities in the automotive industry, especially given the fact that the industry is characterized by mergers and acquisitions that will leave only a few globally integrated auto firms and first-tier suppliers in the market (Noble, 2006).

However, public and private efforts to catch-up technologically are underway. It is estimated that in 2004, 1.4% of revenues in the Chinese automotive industry have been used for R&D. Local manufacturer Geely even claims to invest 10% of revenues in R&D (Noble, 2006). Some national programs are targeting cutting-edge innovations in fields like the development of hybrid cars and hydrogen fuel cells. Increasingly demanding government standards for fuel efficiency and pollution control increase pressure to innovate from the demand side. Complementing national R&D efforts, the global leaders increasingly shift automotive engineering and R&D offshore, with China being the main destination. In 2005, 130 auto and parts companies, including industry leaders like General Motors and Volkswagen, had built up R&D facilities in China. There are two reasons for this. One is that these companies want to make use of a growing pool of skilled engineers and technicians to cut their research expenditure. The other one is government pressure. To get approbation, foreign investors need to undergo a screening process and have to make concessions, for example, committing themselves to invest in R&D and to share technologies. Similarly, foreign manufacturers have a greater chance to be considered in public tenders if they set up R&D centers in China. Chinese authorities "swap market for technology" (Long, 2005, p. 334).

As in the case of electronics, some national manufacturers try to buy know-how and property rights in the global market. China's largest auto parts manufacturer Wanxiang acquired, merged with, or established 30 companies in eight countries, including United States, England, and Germany (Gao, 2004). Shanghai Automotive Industries Corporation (SAIC) intends to develop its own car based on Chinese technologies. For this purpose SAIC acquired a majority stake in Korean Ssangyong for US$500 million (Frankfurter Allgemeine Zeitung, June 22, 2005). It remains to be seen whether such acquisitions really give the expected boost to innovation capabilities.

(c) *The software industry in India*

In India, *software* is the most outstanding sector in terms of rapidly building indigenous innovation capabilities. After 1984 and especially from the mid-nineties onwards the industry has grown in a spectacular way, achieving average annual growth rates of more than 30% over the past decade. The National Association of Software and Service Companies (Nasscom) estimates that the software and services sector employed nearly 1.3 million persons in 2006. Revenues from these sectors reached US$30.3 billion in the same year (Nasscom, 2007). The industry is dominated by major domestic champions, Tata Consultancy Services (TCS), Infosys, Wipro Technologies, and Satyam, each with revenues above US$1 billion. But in recent years subsidiaries of major IT multinationals, such as IBM and Accenture, have expanded their Indian operations aggressively, some of them with revenues in excess of US$500 million. IBM currently employs more than 60,000 people in India (Dossani & Kenney, 2007).

The seeds for these achievements were laid by the Indian government in the 1950s onwards by investing heavily in engineering education and research institutions in the national innovation system (Kumar, 2001). These included universities, technical colleges, and other training and research centers. India graduated an estimated 500,000 engineers in 2006. But besides its focus on skills development the government did not support the industry throughout the 1970s and early 1980s. Trade and FDI policies were rather disadvantageous for the globalizing industry. To offset deficiencies in the business environment in the early 1990s, the central government established a network of national software technology parks which provide broadband connectivity based on satellite and fiber technology, single-window clearance system to software exporters, and incubation services. Today, over 6,000 companies nationwide benefit from this national Software Technology Parks of India programme.

For a long time, Indian IT-software production was associated with low-cost programming services, high in demand from Western companies seeking operational cost advantages. Functioning as "virtual extensions" of these western customers, Indian IT firms followed strict design guidelines established by contracting companies (Lema, 2006). While this type of engagement model is still dominant, the industry has taken on more complex work in recent years. While at the end of the 1980s, around 90% of the overall export work was done onsite, subsequently this share has declined rapidly to 30% in 2005, reflecting a rapid growth of offshore development. This implies that the countries' capabilities in independently managing projects with a larger degree of autonomy from customers have considerably increased.

The industry continues to be dominated by more routine-based tasks (such as application development and maintenance). However, recent indications suggest that a highly dynamic segment of firms is stretching beyond low value-added service by complementing routine activities with innovative niche services (Lema, 2007). Moreover, the knowledge-intensive business lines—engineering services, R&D, and software products—are growing fast. These accounted for US$2.9 billion in sales in 2004 and in 2007 this figure is projected to rise to US$6.5 billion, amounting to a share of 17% of total services (Nasscom, 2007). Intel, Cisco, Siemens, SAP, and many other TNCs have opened centers for chip design or software research in Bangalore and other emerging Indian clusters. All this indicates that India is currently increasing its innovation capabilities and the ability to compete globally for knowledge-intensive service tasks.

The insertion in global value chains was the key for India's success. High growth was and continues to be based on a highly successful penetration of global software markets. Exports accounted for nearly 80% of industry sales in 2006 (Nasscom, 2007). The presence of a large number of highly educated Indians in the West, particularly United States, has also been important. In 1986, for instance, about 59% of Indian Institute of Technology graduates in computer science and engineering emigrated (Siwek & Furchgott-Roth, 1993, p. 140). Moreover, from the 1980s large service providers such as TCS started to offer onsite programming services ("body shopping"), sending teams of programmers to clients in the United States and other OECD countries. Indian IT-specialists working in the US computer and software industry were important inter-cultural mediators, establishing contacts to the emerging IT-sector in India and facilitating contracts for onsite and offshore projects. Indian nationals are the main beneficiaries of the H1-B Visa which the United States issues to attract foreign professionals. Adding to the "brain circulation" many of the emigrated professionals have returned to India once the overall conditions for the IT-industry improved. They brought back technological expertise, inter-cultural knowledge, and contacts (Saxenian, 2006).

(d) *The space industry of India*

The Indian *space industry* represents yet another very different trajectory. Industry development here is largely research-driven and relies to a great extent on a network of public institutions strongly supported by government R&D funds. 13% of India's research budget goes into space research (Thomas, 2006, p. 6). Despite being a national "pet project," relationships with foreign knowledge hubs—in this case mainly public space agencies like NASA—were crucial for technological learning.

Starting to develop capabilities immediately after independence, India has built one of the world's leading national space programs covering three major complementary areas: satellites, missiles, and ground systems. The country has the ability to design, produce, and launch its own satellites, to control and track them from the ground, and to receive and process complex remote sensing data gathered by the satellites.

In the area of satellites, India's space program comprises communications satellites (for telecommunication, television broadcasting, and meteorological services) and remote sensing satellites (for resource survey and management, environmental monitoring, and meteorological services). Its technological capabilities evolved from TV-camera-based systems in the late 1970s to state-of-the art high resolution imaging systems (Kasturirangan, 2004, p. 841). India has developed and launched its own remote sensing satellite, intermediate-range ballistic missiles for civilian and military purposes and powerful rockets based on Russian technology. Ground system technologies comprise rocket launching facilities, spacecraft control, and tracking facilities as well as facilities for receiving, processing, and utilizing satellite data. India has made significant advances in all these technologies (Baskaran, 2005).

India is now one of the main providers of satellites in the civilian domain, and revenues from commercial applications help to recover some of the costs of the annual space budget. The global satellite manufacturing industry, however, is plagued by significant over-capacity, and it is not sure whether India's industry will survive without continued subsidies. Its innovative capability is impressive but its economic viability is shaky.

Space programs require an extraordinarily broad array of technologies including optics design, electronics and telecommunications systems, software development, new materials, advanced combustion technologies, testing, and evaluation. The development of the related capabilities has generated spillovers into different manufacturing industries. In addition, the great number of technologies required for the space programme calls for enhanced capacities to manage very complex systems of closely intertwined technologies. National-level projects, which involved a great number of research institutions as well as public and private enterprises, helped to develop these capabilities which are crucial for systems integration in other industries. Hence India's space programme is the result of a deliberate effort to build an Indian-owned sectoral innovation system.

However, international linkages were fundamental in all phases of development. Unlike in most other industrial sectors, the main sources of foreign technology were institutional partners rather than private foreign investment. In early phases, NASA, as well as ITU, UNDP, and other international organizations, supported the program through donations, training, and increasingly joint research programs. Later on, French, Russian, and German space research organizations as well as ESA were important partners. Furthermore India sent a great number of scientists and engineers to be trained in industrialized countries and the Indian Space Research Organisation generously sponsors participation of Indian scientists in collaborative space research programs with foreign space agencies (Baskaran, 2005).

(e) *The alignment of global and national forces*

In sum, the case studies have shown impressive progress in Chinese and Indian industries. Both countries are increasingly mastering sophisticated production processes, meeting international quality standards as well as productivity levels. Enhanced competitiveness is reflected in rapidly increasing global market shares in a number of industries. This reflects growing capabilities for technology absorption and reverse engineering as well as minor incremental innovations. Comparing both countries, China has a broader industrial basis, is more integrated globally than India, attracts more R&D outsourcing and is on the whole scientifically more advanced. India on the other hand ranks higher on the Global Competitiveness Index, reflecting a perceived superiority of its private businesses.

However, a focus on results suggests both countries lag far behind that of leading OECD countries. None of the successful industries has brought about major cutting-edge innovations. Comparative advantages remain primarily based on lower factor costs. These advantages, however, are no longer confined to simple labor-intensive activities. Furthermore, both countries have stepped up their innovation efforts, and there are good reasons to assume that the technological gap will be further narrowed in a number of industries (see Section 5).

What explains this partial success? More specifically, to what extent was it due to investments in territorially bounded innovation systems, and what has been the role of global linkages? Although there is a marked variation among the trajectories of different industries, all industries in our sample show a combination of successfully *tapping into international pools of knowledge* on the one hand, and *strong investments in national skills development and innovation capabilities* on the other. [11] Integration in GVC helped to link up with the most innovative lead users of technology, to train scientists and engineers in advanced countries, and to master up-to-date production technologies. Furthermore it helped to achieve economies of scale and accumulate the capital necessary for substantial investments in innovation systems back home. These in turn helped to strengthen absorptive capacities, to make good use of external knowledge for national projects, and to raise the attractiveness of the two countries for new types of knowledge-intensive collaboration.

Activities that kept national innovation systems open for inflows from *international pools of knowledge* were a crucial success factor, although the type of linkages with the global economy varied strongly. China's electronics industry started by attracting export-oriented FDI on the basis of cost advantages in semi-skilled labor. Thus multinational lead firms in global value chains triggered this development. At later stages, highly skilled scientists and engineers returned from the United States, and finally the acquisition of foreign companies enabled emerging Chinese enterprises to access foreign technology and link up with global R&D. India's software industry is a similar case of engaging in global value chains. The "New Argonauts" (Saxenian, 2006) were critical in the formation of such value chains. China's automotive industry emerged as a typical import-substitution industry based on multinational corporations. In contrast to other countries, however, Chinese government partners are in a rather strong bargaining position to trade access to foreign technology for access to the national market. In addition, capital accumulation in Chinese firms is sufficiently strong to acquire foreign firms and brand names and to offer long-term contracts to foreign project developers. Finally, India's space project, although considered a strategic national project, strongly built on research cooperation with international space agencies.

In all these industries, global linkages were flanked by considerable *investments in domestic innovation systems*, especially in R&D and the development of advanced skills. Both governments have shown a clear commitment to science and innovation, define sector-specific technological targets and allocate resources accordingly. As exemplified by the space industry, some industries are science-driven and relied on national research funding. But also in the other sectors, effective research institutions, technology parks, and other dedicated institutions were set up to indigenize foreign and develop own technologies. Even in the case of the Indian software cluster, which is sometimes heralded as an example of development with "benign neglect" (Pack & Saggi, 2006) of the government, a number of case studies show that the government played an active role in developing the necessary skills and institutional support (Krishnan, 2007).

National efforts to increase innovation capabilities in turn made the two countries attractive for multinational corporations willing to shift R&D and other knowledge-intensive services to their subsidiaries in China and India or contract domestic service providers for this purpose. Although this is in most cases still relatively simple adaptive R&D, there is a clear trend to move into more sophisticated R&D services (UNCTAD, 2005). This way, the development of the national innovation system and strategic integration in global value chains and international research communities may well create a virtuous circle of technological catch-up.

5. HOW LIKELY ARE CHINA AND INDIA TO CATCH-UP?

The case studies have shed some light on China's and India's achievements and their remaining challenges. In this section we ask whether it is realistic to extrapolate recent trends and assume a process of increasing technological mastery which will eventually result in path-breaking innovations, in leaps in productivity and higher economic returns. We argue that it would be premature to give a definite answer to this question. Both countries are still at a crossroads and several developments may derail their catch-up process; there are doubts to the extent to which common assumptions about technological catch-up processes apply to these very large and fast growing economies. But we can identify some of the key issues that will determine (relative) success or failure and put forward questions for further research.

As indicated in Section 2, research on innovation systems has not yet shed much light on the relationships between those elements that can be bought in global technology markets (patents, licenses, equipment) and labor markets (scientists, engineers) and those that require careful adaptation to national conditions, mutual acculturation, and local learning processes. The literature (e.g., Nelson, 2004) emphasizes the extraordinary relevance of social institutions that are deemed indispensable to lubricate the interactive processes of technology development, thus implicitly assuming a necessarily slow process of institutional maturing. There are indications, however, that due to their sheer size and growth dynamic China and India may leapfrog certain developments. As shown in the case studies, fast growth and high savings rates enable China, and increasingly also India, to invest not only in huge infrastructure projects but also in major R&D programs, to set up first-class research and training institutions and technology parks, to acquire foreign licenses and even entire firms, to provide competitive salaries and well-equipped research facilities to lure top researchers away from the United States and other industrialized countries, and so on. In a nutshell, capital accumulation allows these big Asian economies to simultaneously purchase substantial amounts of embodied knowledge *and* make substantial investments in R&D and a highly skilled and globally integrated workforce.

In addition, some formerly "tacit" elements of innovation systems can today largely be codified and are thus more "tradable." For example, quality management systems (such as ISO 9000f) and practices of supply chain management have since the late 1980s been laid down in a series of standardized procedures that are today applied on a global scale. Hence it becomes relatively easier to hire experienced service providers who have the expertise to put whole subsystems into operation—provided the customers can pay for it, which is definitely the case in key sectors of the Chinese and Indian economies. Nanjing Automobile in China, for example, transferred whole MG Rover teams, including the director of quality, to China; likewise, Chinese automobile manufacturers hired large design companies from the United Kingdom for long-term development projects (The Economist Intelligence Unit, 2006).

Another specific feature of large and fast growing countries is their government's bargaining power *vis-à-vis* foreign technology owners—which is obviously related to the exceptional market potential. Especially the Chinese government deliberately trades market access for technologies, obliging investors to share technologies if they want to sell to the domestic market. Likewise there is competition among universities and research centers worldwide to form alliances with counterpart institutions in India and China to market their courses and tap into the growing local talent pools.

Moreover, Chinese and Indian researchers and engineers are increasingly integrating in transnational scientific and technical communities (Saxenian, 2006). This applies both to global research networks, such as the Human Genome project, and to global intra-firm communities in TNCs, where Chinese and Indians occupy leading positions in management and research. Truly globalized company networks and scientific networks, rather than nation states or regions, may become the relevant loci of innovation. Participation of research centers or individual researchers in such networks opens additional pipelines for cross-border knowledge flows.

The combination of market size and expansion, bargaining power, enormous capital accumulation, heavy investment in human resources, FDI, and strong presence in global professional networks make China's and India's catch-up process unique. Future research will need to show whether this combination of factors enables China and India to leapfrog certain processes and develop innovation *systems* and *dynamics* specific to large fast growing economies. In this context, it will be particularly interesting to examine whether the return migrants, attracted by the prospects of fast upward mobility and capable of straddling very different cultures, help to develop new blends of "social technologies."

Other elements that are crucial to assess both countries' prospects for catch-up, but fraught with uncertainties, include the following:

— *The sustainability of the growth process*: As stressed above, the buildup of innovation capabilities can only proceed at the current pace if the two economies continue to grow at high rates. This cannot be taken for granted. To assess the likelihood of an economic crisis that would slow capital accumulation down, however, is beyond the scope of this paper and probably beyond the grip of scientifically based projections in general.

— The *availability of appropriate human capital* in quantitative and qualitative terms: China's and India's investment in human resources has created an advantage for local firms and R&D institutions as well as incentives for TNCs to shift knowledge-based operations to China and India. China is the first and India the third global destination for R&D outsourcing (UNCTAD, 2005). Even if most of this is adaptive R&D, many centers are winning increasingly demanding contracts as scientific expertise and local business linkages develop. This opens up another important avenue for technological catch-up. At the same time, the modernization process requires huge amounts of managers, engineers, scientists, and other highly skilled workers in a wide range of private and public activities, both innovation-related and for "mundane" administrative tasks (Yusuf *et al.*, 2006, p. 50). There are indications that the rapidly increasing innovation efforts in both countries are not matched by equally evolving capabilities in the management of the innovation system and its elements. Krishnan (2007) identifies seven quite severe weaknesses in India's innovation system which are to a large extent related to a shortage of critical skills. The potential for catch-up thus depends on the ability of education systems to supply the necessary highly skilled workforce in times of rapidly increasing demand.

— *Economies of scale and the level of internationalization*: Although Chinese and Indian firms are rapidly globalizing, most of them are still minor players in the global market, and in some activities their global entry may come too late for the ongoing global round of mergers and acquisitions. In the global market for large passenger aircraft, for example, only two global producers remain. Similar concentration processes are on their way in other (e.g., automotive and satellite) industries and might force latecomers like China and India to abandon their efforts to catch-up. At the same time, global technological leaders are increasingly operating—and carrying out research—in all major markets to register new market trends at an early stage and be able to tap into new developments. As newcomers, most Chinese and Indian multinationals are not yet fully embedded in foreign markets and networks. This is a critical constraint, for example, for Indian software providers who have not yet built up networks comparable to those of their United States and European competitors. [12] As shown in the cases of Lenovo and Huawei, however, other emerging multinationals succeeded in building up such international R&D networks.

— *The importance of domestic user-producer linkages*: Innovation systems research emphasizes feedback loops between producers and demanding users with a high quality consciousness and willingness to pay for high-end brand products as important drivers of innovation (Lundvall, 1988). Such interactive loops seem underdeveloped in China and India. Further research will have to show to what extent integration in global value chains can compensate for weak local user-producer linkages. In addition it remains to be seen at what pace the number of demanding consumers increases in each of the two countries and to what extent this will foster the emergence of a quality culture that drives innovation.

— *The role of industrial policy*: The usefulness of industrial policies is hotly debated, mainly because there are doubts about the ability of policymakers to identify the right intervention mechanisms and to withstand political capture. [13] Some of the promising industries in both China and India, however, emerged on the basis of targeted policies, trade-related investment measures, and even discretionary deals with foreign investors. Today both countries are increasingly forced to play by the rules of the WTO. Stricter enforcement of agreements on trade and intellectual property will make it more difficult to copy designs and processes, thus limiting the scope for reverse engineering. This problem may prove to be especially severe in China, where many industries are heavily dominated by foreign investors. However it is also likely to limit the dynamism of India's drug industry (Thomas, 2006, p. 14ff). Although it is hard to judge to what extent past industrial policies really helped to catch-up technologically, it is obvious that the rules of the game are now changing.

In sum, China especially seems to have a solid foundation for catching up in a number of industries. Its unique combination of market size and growth, emphasis on skills development and innovation, and the government's bargaining power strongly favor technological upgrading. We have shown that a country that accumulates capital at China's pace can buy in enterprises, talents, and even complex technological solutions, and set strong incentives for technology transfer. Put differently, many elements of national innovation systems seem to have become more "tradable." Some—especially politically embedded—institutions though may take more time to develop, and it is difficult to assess the time horizons necessary to overcome the respective institutional barriers. Conditions in India are somewhat different. Market institutions are generally better developed than in China, but India lags behind in terms of capital accumulation, R&D expenditure, attractiveness for FDI, and other drivers of innovation, thus leading us to assume a slower catch-up process.

6. IMPLICATIONS FOR THE REST OF THE WORLD

China's and India's advances in building up innovation capabilities have implications for advanced and developing countries. This final section sets out possible scenarios and identifies questions for future research.

(a) *Implications for advanced countries*

Is China's and India's innovation drive a threat to the OECD countries? This is a central question in the current debate on the costs and benefits of offshoring. Some consider it as an opportunity to drastically lower costs in a wide range of industries; others stress the threat not only to simple routine jobs but increasingly also to knowledge-intensive employment in OECD countries. [14] India and China are by far the most important hotspots for global offshoring of IT related jobs, at this stage mainly in the production of services, but increasingly also in R&D. However, the potential for job relocation is probably more limited than initially thought, at least in the *short run* (Stamm, 2005).

The blurry picture of the current catch-up process in both countries makes it difficult to predict its *long-term* effects on OECD countries. Three scenarios can be distinguished:

— *High impact scenario*: China and India manage to catch-up technologically in the short term, challenging industrialized countries in their core competencies and markets. Innovation rents of European firms, and the associated welfare gains, shrink substantially or even disappear. Offshoring of knowledge-intensive activities to China and India strongly increases and becomes common practice even in cutting-edge products and services.

— *Low impact scenario*: Catching up is hampered or gets stuck due to a loss of economic dynamism, mainly for reasons external to the innovation system, for example, political or environmental reasons. The unique capability to invest in innovation systems gets lost. The OECD countries gain time to consolidate their position as technological leaders, and their loss of jobs remains largely limited to low to medium skilled positions (call centers, standard engineering).

— *Mixed blessing scenario*: China and India maintain a strong upward trend in science, technology, and innovation, but this is largely compensated by increased technological efforts in OECD countries. The latter lose some innovation activities (e.g., industrial design) to China and India, but maintain the lead in strategic innovation fields. Losses are balanced by increased markets in Asia.

(b) *Implications for developing countries*

The effects, which China's and India's build-up of innovation capabilities might have on the developing world, are also hard to judge but the questions that arise are clear.

— *Do China's and India's advances in innovation open up new production opportunities for other low wage countries?* In the case of the smaller "Asian Tigers," growth and transformation led to rising labor costs and the location of labor-intensive stages of the value chain in countries with lower wages. Will the same happen in China and India? Their labor reserves seem nearly inexhaustible but the limits in their labor supply are also apparent. In the case of China this is due to demographic trends and in the case of India there is the question of whether its education system will provide "employable workers" in sufficient numbers.

— *Will China and India provide access to technology at lower cost?* Capital goods and knowledge-intensive business services are likely to be cheaper—compared with those bought from OECD countries. But what about proprietary technology? Will access be easier? Will licensing fees be lower? Does it matter—in terms of access and cost—whether the innovating company is domestic or foreign owned? Access to and price of technology have been fought over for decades—in multilateral fora and bilateral negotiations between OECD and the developing world. A shift seems now on its way but how substantial is it? What will be the scope and depth of "South–South" technology alliances? Will the alliances be primarily between the likes of China, India, Brazil, Mexico, and South Africa, or will smaller/weaker countries benefit?

— *Are the product or process innovations coming out of China and India more suited to the needs of the developing world?* Innovating companies in China and India are likely to be influenced by the requirements, factor endowments, and demand conditions of their home market that may turn out to be much closer to those of other developing countries. Examples include the development of low-cost generic drugs, new vaccines for tropical diseases, new HIV/AIDS treatment derived from traditional Chinese medicine (Chaturvedi & Chataway, 2006; Grace, 2005). Companies in both countries, with government support, are investing in the development of cars which are small, cheap, and energy efficient, using biofuel and fuel cells (Noble, 2006). The desirability of investing in "appropriate products" is clear, but it is not yet clear which configuration of factors leads to such investments being made.

— *Are China and India providing the most effective centers of learning for the talents of the developing world?* Universities in India and China have long received students from other parts of the developing world. But for decades, the greatest talents were sent to universities in North America and Western Europe. Families, governments, foundations, and other donors assumed that this was the best investment in the future. To what extent does this assumption remain valid? Given the massive investment in higher education—in particular in science and engineering—and given the closer relationships between the academic and corporate circles, China and India can now offer some excellent centers of learning. How do they compare with the best in United States and United Kingdom? There are likely to be enormous variations by specialization and location. But once costs are taken into account, do China and India provide more effective options for developing countries?

To conclude, in the past three decades the global division of labor has undergone far-reaching changes. Production capabilities have shifted eastward at an unprecedented pace, while innovation capabilities have remained remarkably concentrated in OECD countries. Our analysis suggests that, although China's and India's technological efforts have rarely materialized in cutting-edge innovations at this stage, they have created conditions to attract the key elements of first-class innovation systems. The prospects for making the transition from production to innovation capabilities seem good, provided growth and capital accumulation continue at a high pace. This creates challenges for the rest of the world. The main question for the leading OECD countries is whether they can retain their jobs and prosperity based on innovation rents and the main question for the developing world is whether innovations coming from China and India improve their possibilities of generating sustainable income growth.

NOTES

1. Forbes and Wield (2002, p. 3) go one step further and suggest that "catching up is about increasing value-added through production of goods and services per employee."

2. Some scholars argue that sectoral dynamics are more important than territorial dynamics and have therefore focused on the Sectoral Innovation System (Malerba, 2002). In substance, this approach is, however, closer to the value chain approach discussed below.

3. The dynamics of innovation systems are rarely the focus of analysis. For an exception, see Lee and Tunzelmann (2005).

4. The importance of combining different approaches and scales is also emphasized by Kim and Tunzelmann (1998) and Fromhold-Eisebith (2007).

5. This is supported by research on return migration to India and China (Commander, Kangasniemi, & Winters, 2003; Sternberg & Müller, 2005).

6. Original equipment manufacture, own design manufacture, and own brand manufacture.

7. For an historical overview on 40 years of developing science, technology, and innovation indicators, see Freeman and Soete (2007).

8. Here again methodological considerations call for a cautious interpretation. The most dynamic technology sectors in India are software and IT-enabled services, where innovative activities are often not considered R&D in the strict sense and the related expenditures not counted in the national statistics.

9. Other industries in which China has built up innovation capabilities include missile and spacecraft, biotechnology, telecommunications, and permanent magnetic levitation rail transport. In the case of Indian industries, significant advances have been made in—among others—pharmaceuticals, the media industry, missile and satellite technology, nuclear and solar energy, and telecommunications.

10. National Bureau of Statistics of China (2005, Table 21ff).

11. This is confirmed by Hennemann and Liefner (2006) who show that firms in China's most innovative regions rely on a combination of national and international knowledge flows.

12. Balaji Parthasarathy, Indian Institute of Information Technology, personal communication.

13. See, for example, Pack and Saggi (2006) for a critical, and Cimoli *et al.* (2006) for an affirmative perspective.

14. A "Google-Search" of the word Offshoring on Websites hosted on German servers, in February 2007 resulted in more than 1 million hits.

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