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The geography of innovation in China and India

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ABSTRACT

The BRICs, in general, and China and India, in particular, are now widely regarded as the areas of the world likely to challenge the economic leadership of the United States (US) and the European Union (EU). A large part of this challenge will come from a rapid technological catch up by China and India. Yet, despite a recent rise in interest, there is still limited knowledge about how and where innovation takes place in these two leading emerging countries and to what extent the Chinese and Indian territorial systems of innovation differ from those in the EU or the US. In this paper we explore the geography of innovation in China and India, concentrating on understanding key territorial-level innovation trends by country, region and technology field and using the US and the EU as benchmarks. We find significant contrasts between the geography of innovation in China and India and that of the US and the EU. First, the degree of concentration of innovative activities in both countries is extremely high. The agglomeration of innovation in the coastal provinces of China and in Delhi and the south of India significantly exceeds levels of agglomeration found in the USA and the EU. Second, China has witnessed a more rapid increase in the degree of concentration of innovation than India. We posit that the differences in the geography of innovation between, on the one hand, China and India and, on the other, between these countries and the developed world are rooted in different institutional settings, different systems of innovation and different national innovation strategies.

Keywords: *Innovation, patents, R&D, agglomeration, China, India, United States, European Union.*

1. Introduction

There has been considerable attention paid to the similarities and differences in the territorial dynamics of innovation between the European Union (EU) and the United States (US) (e.g. Freeman 2002, Crescenzi et al. 2007, Dosi et al. 2006, Navarro et al. 2008). The status as the leading innovation and technology hubs in the world warranted this attention. However, their position as the most innovative poles is being challenged by emerging countries, and specifically by the burst into the scene of the BRICS (or even the BRIICS – Brazil, Russia, India, Indonesia, China and South Africa) countries. The growing academic and policy interest in these countries – and especially in India and China – reflects their increasing economic importance as well as their demographic potential. BRICS countries have rapidly transformed themselves, gaining in the process significant economic and political clout. Spectacular urbanisation in India, and in particular, China has been the most visible symbol of this transmission. India's cities alone could generate 70 per cent of net new jobs to 2030 and by then represent more than 70 per cent of GDP, reflecting urban population growth from 290 million in 2001 to 340 million in 2008, and 590 million in 2030 (MGI 2010). Similarly, China's urban population is expected to increase from 636 million in 2010 to 905 million by 2030 (UN Population Division 2010). Rapid changes and sustained high levels of growth are likely to make some of the BRICS countries – and, fundamentally, China and India – some of the key economic players in the near future. China is already the second largest economy in the world and catching up quickly with the US. An influential Goldman Sachs report, 'Dreaming with BRICS', suggests that by 2040, China will be the largest economy in the world and India the third largest, surpassing those of Japan, Germany, France and Great Britain (Wilson and Purushothaman 2003; see also Jacques 2012).

In terms of innovation, the past two decades have seen the globalisation of production and the globalisation of R&D (Bruche 2009, Lundvall 2009, Yeung 2009, Fu and Soete 2010, Kuchiki and Tsuji 2010). China and India have been at the forefront of these shifts (Leadbeater and Wilsdon 2007, Popkin and Iyengar 2007, Parayil and D'Costa 2009) and their economic dynamism is increasingly based on endogenous innovative capacity, rather than on mass production and cheap labour (Friedman 2005). Yet, despite the growing economic importance of the BRICS countries and the phenomenal changes in innovation capacity in China and India, very little is known about the geography of innovation in these emerging countries. Little systematic comparative analysis exists and it has been fundamentally limited to describing the major 'inputs' for the generation of innovation, such as the quantity and quality of innovative efforts or the different levels of human capital accumulation, the structure of the educational system and the capacity to attract (diaspora) and generate and retain top-level scientists (Winters and Yusuf 2007). Alternatively, research has focused on the organisational and institutional settings which shape innovation, the innovation systems (e.g. Lundvall et al. 2006, Lundvall 2009), but the analysis of indigenous factors and their geography has been more limited, with literature generally based on case studies (e.g. Lewis 2007, Chaminade 2010) and, sometimes, on anecdotal evidence. By and large, there has been a tendency to assume, in a Rostovian way (Rostow 1959), that emerging countries are in an earlier stage of the innovative process than the EU or the US and that they will tend to follow a similar path towards innovation and development in the future (World Bank 2009). However, this assumption flies in the face of the facts that, first, the pace of change currently experienced by emerging countries has virtually no parallels in history (Henderson 2010) and that, second, the territorial dynamics of innovation have been rather different also in the EU with respect to the US (Crescenzi et al. 2007). Hence, the limited knowledge we have about the evolutionary trajectories of countries such as China or India, coupled with the diversity of development and innovation paths trod by countries now at the forefront of science and technology, raise numerous questions about the territorial dimension of the process of technological development in China and India. How have global changes in the production of ideas affected Chinese and Indian regions and cities? What role are regions and cities playing in the shifting geography of innovative activity? Are China and India going to follow the innovation path of the EU or are they more likely to go in the direction of the US? Or will they follow their own path and build their own unique systems of innovation?

This paper represents a first exploration the geography of innovation in China and India, using the USA and the EU as benchmarks and paying special attention to developments at subnational level. In order to do this, in section 2 we look at the spatial distribution of the innovative activity, proxied by patents, taking into account differences by country, region and technological sectors (ICT, biotech and nanotech).

In section 3 we revisit these stylised facts for China and India in light of the main theories of innovation and development in order to interpret existing evolutionary processes and identify emerging trends. Section 4 presents the main conclusions.

2. Innovation in China and India vs. Europe and the US: the broad picture in a territorial perspective

2.1. Country-level comparative perspective

The first stage of the analysis involves an overview of the comparative 'innovation performance' of China and India, using the US and the EU as benchmarks. We first focus on patents as the most commonly used, albeit highly imperfect, innovation 'output'.[1] An important caveat with the use of patent data in China and India is that it partly reflects patenting activity by multinational firms (MNEs). MNE patents may be filed in any office around the world, regardless of where the invention actually took place, making it hard to assign patents to a specific territory (Li and Pai 2010). There are close links between foreign firms, MNE clusters and patenting clusters in India and China. For example, Duan and Kong (2008), in a study of Chinese patents 1988-2007, observe that most 'Chinese' applications to the USPTO are owned by foreign applicants. Da Motta e Alburquerque (2003) suggests similar patterns for India. Patenting is also related to firm size. Patenting data over-represents innovations in large firms (often located in major agglomerations), while, at the same time, underestimating innovation in smaller firms, which also tend to be located outside the main centres of innovation. Finally, patenting is bound to significantly under-represent certain types of innovation, such as process innovation, and incremental innovation conducted by generally local firms. However, despite all the imperfections of patenting data for China and India – which reproduce the imperfections of patenting data elsewhere in the world – lack of alternative and comparable territorial data on innovation implies the need to resort to patents as the only suitable available

[1] Our data stem from OECD Reg-Pat PCT Patent Applications, thus avoiding problems that might arise from using domestic Chinese or Indian data (Li and Pai 2010, Wadhwa 2010).

indicator of innovation while relying on data based on patent applicants' location in order to capture the innovative performance of local firms to the maximum extent possible.

Using patents as a measure of innovation tends to put the USA as world leader, followed, at some distance, in terms of patent intensity[2] by the EU (Crescenzi et al 2007). Figure 1 illustrates the evolution in patenting trends in China and India, relative to the US and the EU, between 1995 and 2007. The first feature that strikes when looking at patent intensity (Figure 1) is that of the gap that still exists between the two developed and two the emerging countries. The US and EU have seen their patenting activity rise more or less continuously during the period of analysis, from levels of around 61.1 patent applications per million people filed in 1994 in the USA (39.7 in the EU-15) to around 165 per million in 2007 (123 in the EU-15).

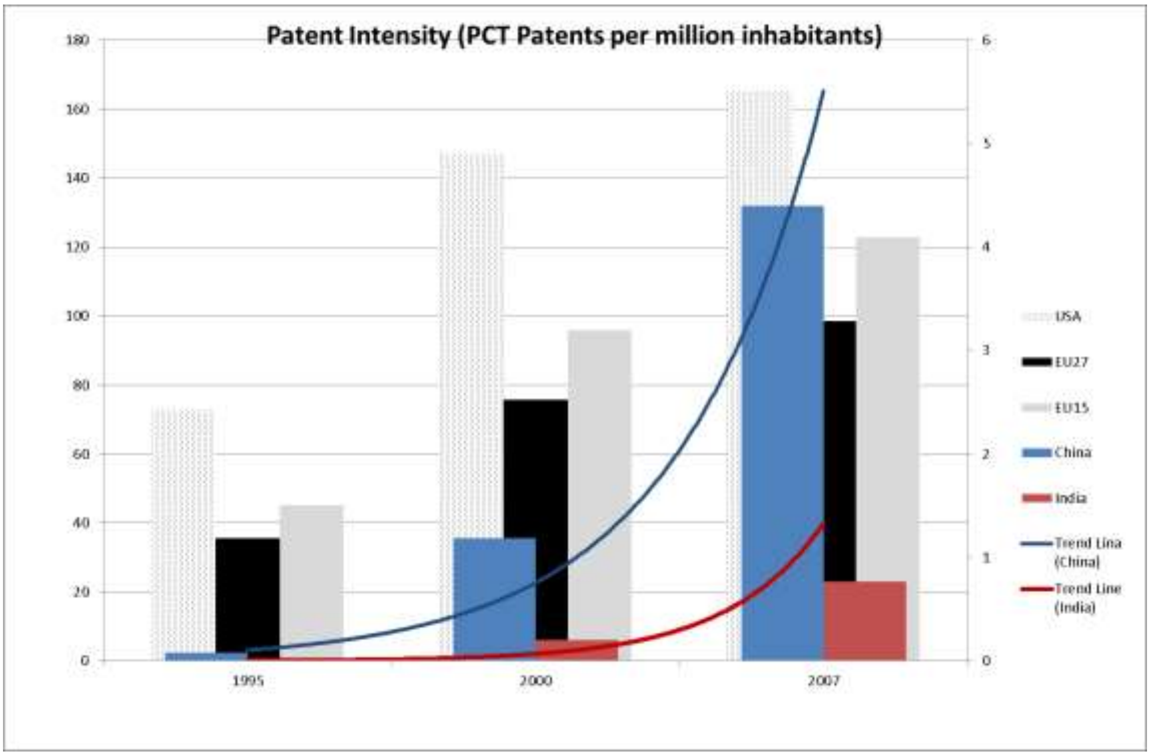
China and India during the 1990s invested heavily in innovation 'inputs', increasing literacy rates and higher education enrolment, raising production of engineering graduates and increasing expenditure on R&D. Both countries also began to 'globalise' their economies, facilitating FDI flows, licensing of foreign technology and moving students abroad (Dahlman 2010). These efforts translated into rapidly rising patenting rates (clearly visible in the corresponding trend lines in Figure 1). However, while matching each other during the 1990s, the 2000s witnessed a divergence between China and India. Indian patenting started to stall from 2003 onwards, precisely as China's patents took off. Between 2000 and 2007 patent intensity in China rose fourfold up to 4.4 patents per million inhabitants. By contrast, by 2007 patenting in India had not yet exceeded the 0.8 patents per million inhabitants threshold (Figure 1).

Despite this non-negligible catch up, in particular by China since 2000, the gap between the US and the EU, on the one hand, and China and India, on the other, is still considerable. In 2007, in absolute terms the EU filed almost 8 times more patent applications than China and almost 39 times more than India. Taking into account that this ratio was 156 to 1 with respect to China and more than 2000 to 1 with respect to

[2] The number of international patent applications per million inhabitants.

India in 1994, there has certainly been rapid convergence. But rapid convergence does not hide the sheer dimension of the innovation output gap between the leading developed countries and the leading emerging countries (Figure 1).

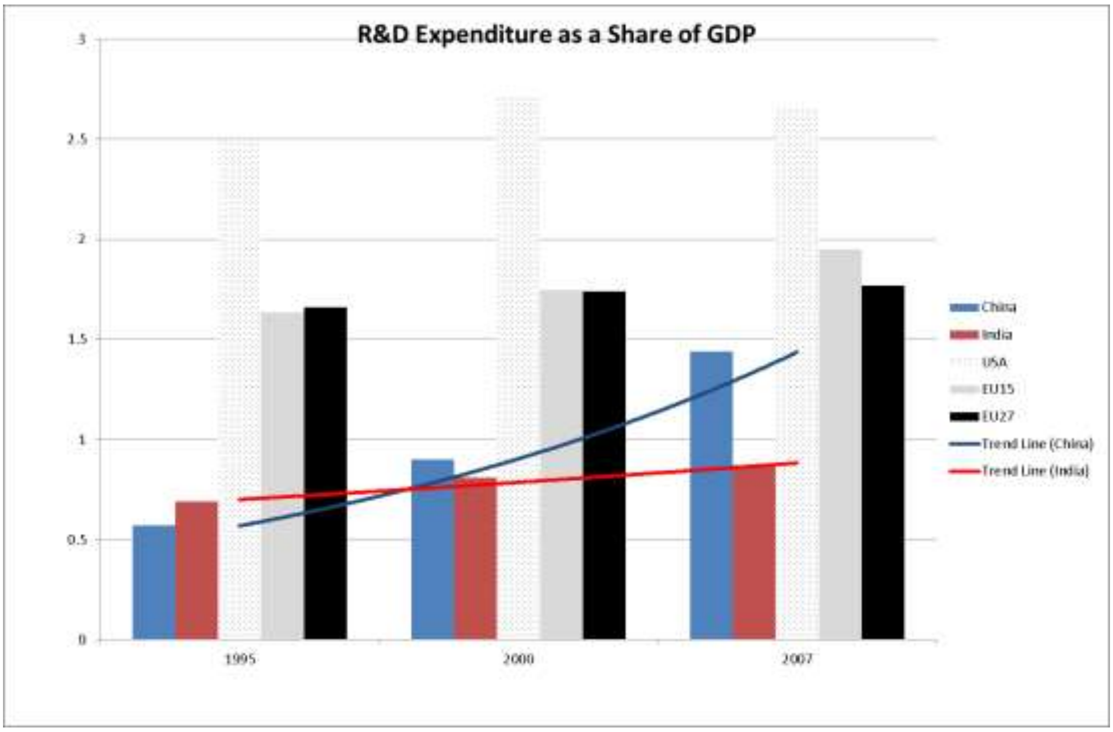
Figure 1. Patent Intensity, China, India, USA and EU. 1995-2007



Note: USA, EU27 and EU15 Primary Axis (Left hand side scale) / China and India Secondary Axis (Right Hand side scale)
Source: Own elaboration with OECD PatStat data

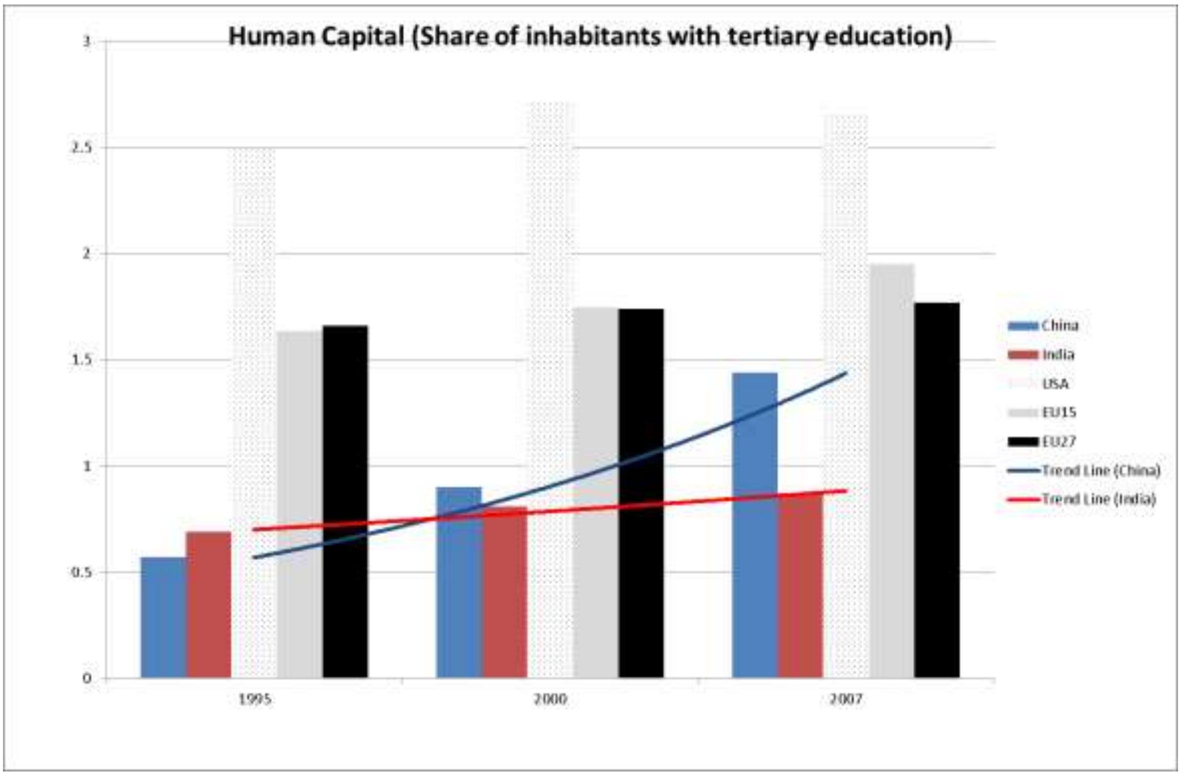
However, a quick look at the evolution of innovation 'inputs' indicates that the convergence rate of innovation outputs is not only likely to continue, but to accelerate in years to come. The gap in R&D expenditure as a percentage of GDP, often regarded as one of the key innovation inputs, has been narrowing very rapidly since the turn of the century. This is particularly the case between China and the EU. Whereas in 1995 R&D expenditure relative to GDP in the EU almost tripled that of China, the significant effort made by the Chinese government and firms to catch up in R&D expenditure meant that the gap in 2007 was a mere 20% higher in favour of the EU (Figure 2 – in this figure data for all countries uses the same axis/scale). The gaps in R&D expenditure between the US, the EU and India, by contrast, have remained more stable (Figure 2). The comparison of the trend lines between China and India confirms the higher R&D dynamism of the former.

Figure 2. Evolution of R&D expenditure as a percentage of GDP, China, India, USA and EU 1994-2007.



The recent evolution of the endowment of skilled human capital in both China and India also points towards a greatly enhanced potential to generate new knowledge and to assimilate externally generated innovation. The effort put in by both countries in order to increase their human capital is starting to pay off. The USA still has significantly more graduates than India or China, while the EU considerably trails the US, but still has a relevant margin in the endowment of human capital relative to China or India (Figure 3). There is evidence, however and especially since 2000, of a considerable catch up by the two emerging countries. In particular, in certain technological fields the gap is vanishing fast. The number of engineering graduates in China (352,000 graduates) and in India (184,000 graduates) already clearly exceeded that of the US (76,000 graduates) in the year 2000 (Mitra 2007). The quality of graduates has also improved. It is not only that Chinese and Indian universities have moved closer to the knowledge and technological frontier, since 2000 China has also been sending its best graduates to foreign institutions in droves. In this respect China has been more aggressive than India, although Indian returnees have been crucial for the development of specific high-tech and scientific sectors in the country, such as the ICT sector (Saxenian 2006). The internal effort has also been translated in a particular rise in the number of scientists. China only trails the US in overall number of researchers (Schaaper 2009), whereas India's R&D worker intensity, which rose significantly in the 1990s and early 2000s, has somewhat stalled since then.

Figure 3. Population shares with tertiary education. 1994-2007.



2.2. The territorial dimension of innovation in China and India

The country-level comparative perspective hides significant contrasts in how the innovative capacity is distributed both within China and India and in how the geography of innovation in these two countries differs from that of the US and Europe.

Research capacity and innovation are not spread evenly across China and India. Indeed, the geography of innovative activity in China and India is territorially very uneven. Patent counts at the sub-national level indicate that the five EU regions with the highest shares of patent applications together represent 35% of all EU patenting; for the US the corresponding figure is about 50%. By contrast, the five most innovative Indian regions cover 75% of Indian patents; in China, the five highest-patenting regions produce almost 80% of all patent applications.[3]

Both India and China have innovation systems which tend to be significantly more spatially concentrated than in the US and, of course, the EU, where the heritage of national innovation systems is still evident. China's innovative capacity is concentrated along coastal regions, especially in the larger cities and in the South (Sun 2003, Wang and Lin 2008). Our Chinese data find that Guangdong is the leading province counting for 46% of total average patent applications over the 1994-2007 period. The next two are the municipalities of Beijing (14%) and Shanghai (13%). The overall system is highly agglomerated, with the top three regions accounting for 73% of all patents.

In India, patent counts are highest in high-tech clusters such as Bangalore, Chennai, Delhi, Hyderabad, Mumbai and Pune (Mitra 2007). At the regional level, da Motta e Alburquerque (2003) finds that from 1981-2002, nearly half of all patents to Indian inventors are in two states, Maharashtra and Delhi. Our data find that Maharashtra (with Mumbai as its capital) and Delhi respectively count for 26% and 24% of total average patents. The third is Andhra Pradesh (13%, SE of Maharashtra, capital Hyderabad). The top three Indian states account for 64% of all patent counts during the period of analysis. One step below are the states around Delhi (Haryana – 7% of total patent counts – Punjab[4] or Himachal Pradesh) and some of the larger states of the South, such as Karnataka (8.7%, capital Bangalore), and Tamil Nadu (7%, South, capital Chennai).

The analysis of the geographical distribution of patent counts in the US puts the dimension of the geographical concentration of innovation activity in China and India into perspective. The US is acknowledged as the world leader on a range of innovation metrics and often considered as the epitome of geographically self-contained innovation systems (Crescenzi et al. 2007). Innovation in the US is indeed

[3] In each case the most appropriate, comparable spatial unit has been selected under the constraint of regionalised patent data availability from the OECD – Chinese provinces, Indian states, and, finally, American Bureau of Economic Analysis (BEA) Economic Areas, as benchmark

[4] Indira Gandhi's raid on the Golden Temple (1984) in Amritsar resulted in a large migration of skilled Sikh population which severely dented Punjab's innovation capacity.

geographically concentrated, displaying two important innovation cores along the North-East (New England and the eastern part of the Atlantic States) and the West Coast (from Seattle to San Diego). However, the rest of the country is far from being an innovation desert, as strong innovation hubs can be found throughout the country (e.g. Minneapolis, Milwaukee-Madison, Cincinnati, Austin).

This represents a smoother spatial distribution of patents applications in the US than in either China or India, as evidenced by Table 1, which lists the twenty most innovative regions in China, India and the US in terms of patent intensity. In the US, the three leading regions are San Jose-San Francisco-Oakland (Northern California), San Diego-Carlsbad-San Marcos (Southern California) and Appleton-Oshkosh-Neenah (Wisconsin). These three account for only 32% of all patenting, compared to 73% and 64% shares for, respectively, the leading Chinese and Indian regions. Generally, the more innovative regions in the US are located on the Western and Eastern seaboards, or the Great Lakes region (Michigan, Wisconsin). Less innovative areas are relatively less populated and tend to be confined to the Midwest – and, in particular, some of the Western Plain counties – and to the Deep South (Louisiana, Mississippi, Alabama and southern Georgia). But even in these areas there are major innovation hubs, such as, Austin (Texas), Houston-Baytown-Huntsville (Texas), and Denver-Aurora-Boulder (Colorado).

Table 1. Top 20 innovative regions, 1994-2007.

	China	***India***	***USA***		***China***	***India***	***USA***
1	Beijing	Delhi	San Jose-San Francisco-Oakland, CA	**11**	Chongqing	Himachal Pradesh	Reno-Sparks, NV
2	Shanghai	Haryana	San Diego-Carlsbad-San Marcos, CA	**12**	Heilongjiang	West Bengal	New York-Newark-Bridgeport, NY-NJ-CT-PA
3	Guangdong	Chandigarh	Appleton-Oshkosh-Neenah, WI	**13**	Sichuan	Kerala	Gainesville, FL
4	Tianjin	Maharashtra	Minneapolis-St. Paul-St. Cloud, MN-WI	**14**	Shaanxi	Punjab	Seattle-Tacoma-Olympia, WA
5	Zhejiang	Andhra	Boston-	**15**	Jilin	Uttar	Boise City-

		Pradesh	Worcester-Manchester, MA-NH			Pradesh	Nampa, ID
6	Fujian	Karnataka	Cincinnati-Middletown-Wilmington, OH-KY-IN	**16**	Hainan	Jharkhand	Chicago-Naperville-Michigan City, IL-IN-WI
7	Jiangsu	Goa	Rochester-Batavia-Seneca Falls, NY	**17**	Hubei	Rajasthan	Houston-Baytown-Huntsville, TX
8	Liaoning	Gujarat	Austin-Round Rock, TX	**18**	Shanxi	Madhya Pradesh	Hartford-West Hartford-Willimantic, CT
9	Shandong	Tamil Nadu	Philadelphia-Camden-Vineland, PA-NJ-DE-MD	**19**	Inner Mongolia	Jammu & Kashmir	Raleigh-Durham-Cary, NC
10	Hunan	Pondicherry	Albany-Schenectady-Amsterdam, NY	**20**	Xinjiang	Orissa	Santa Fe-Espanola, NM

Source: Own elaboration based on OECD data

In China, as we have seen, the leading regions for innovation tend to be in coastal areas. Outside these regions, very few provinces account for more than 1-3% of total patenting. These are fundamentally other coastal provinces (e.g. Fujian, Liaoning, Jiangsu, Zhejiang and, to a lesser extent, Shandong. Only Sichuan (SW) and Hunan (Centre) are not on the coast among those that file more than one percent of patents. The Centre and the West of China are less innovative, with western provinces, such as Tibet and Qinghai, and central provinces, such as Ningxia, barely generating patent applications.

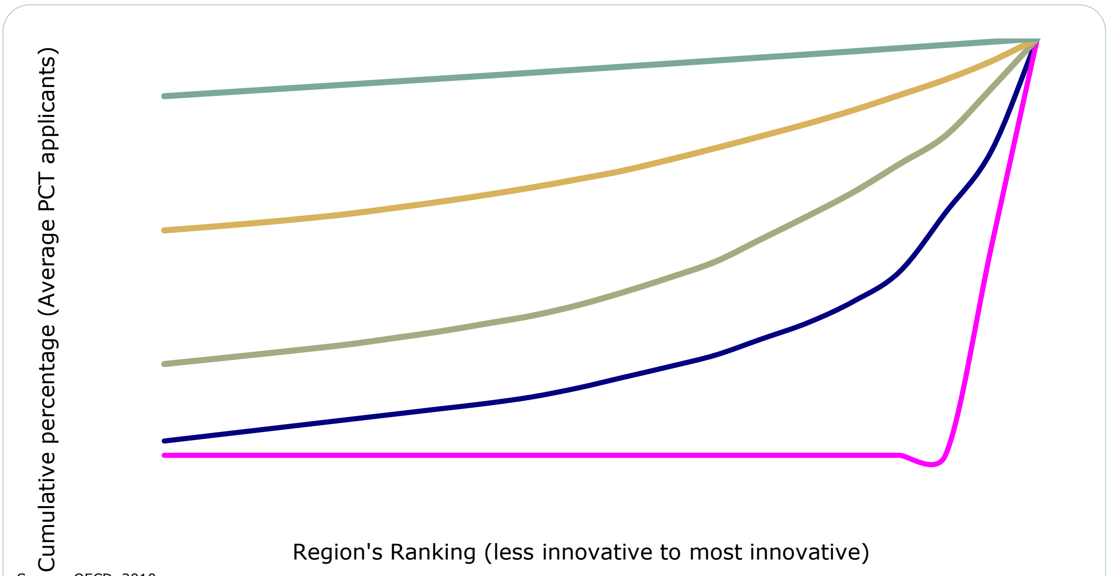
In India, there seems to be little innovation – at least, as measured by patents – conducted outside the already mentioned innovation hubs of Mumbai, Delhi, Bangalore, Chennai, Hyderabad, or Pune. Some of the largest and most populated states of the North – Bihar, Madhya Pradesh, Orissa, Rajasthan, or Uttar Pradesh - conduct little innovation, reflecting the presence of less dynamic or even dying sectors and industries and complex, when not outright problematic political environments and industrial relations. But even there the situation is better than in the ‘seven sister’ states of the extreme North East, which are virtually innovation deserts. Some of these had no patents applications until 2007, including some relatively big states such as Assam (located in North East India, bordering Bhutan and Bangladesh).

2.3 An increasing tendency towards the concentration of innovation.

An important factor worth noting is that the geographical concentration of innovative activity in China and India shows no sign of abating. If anything, the agglomeration of innovation is increasing very rapidly, in particular in China. Patenting in India and China is far more spatially agglomerated than in the United States and, especially, Europe, where the distribution of patenting activity is more evenly spread across space. In addition, differential levels of investment in innovation inputs also appear to influence where innovative activity takes place. Top patenting regions in China account for a considerably larger share of innovative activity than those in India.

However, rather than ‘maturing’ and following the same path as the US or the EU towards a more even geographical distribution of innovative activity, the pace of concentration of innovation has accelerated during the period of analysis.

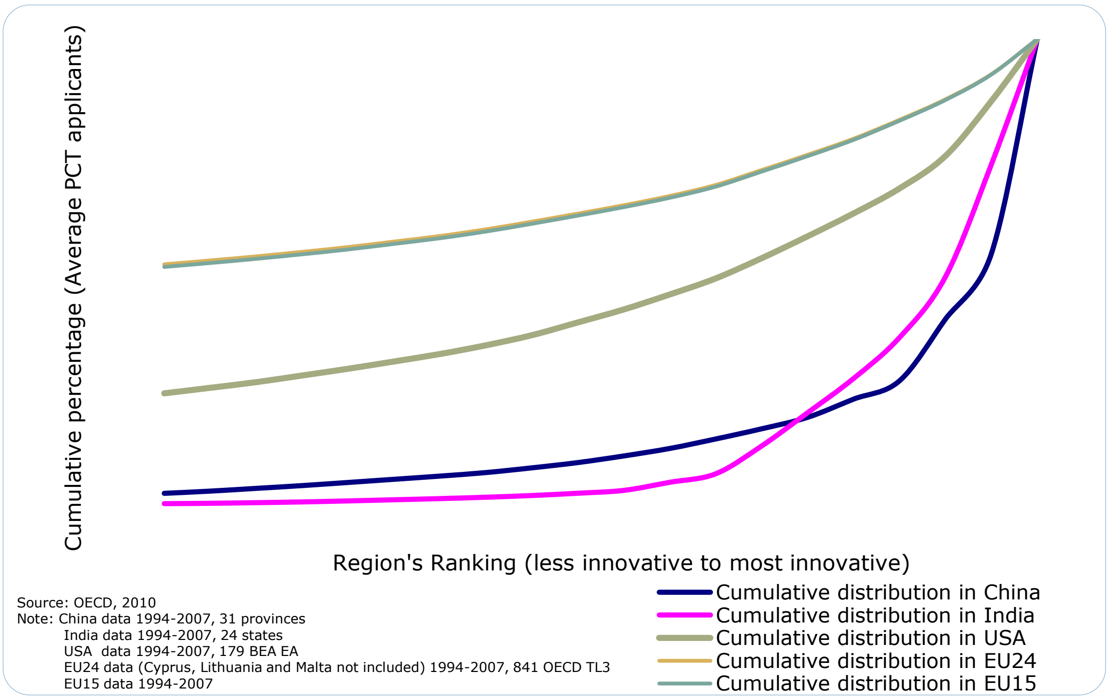
Figure 4. Cumulative Distribution of average PCT applications. Top 20 most innovative regions, 1994.



Source: OECD, 2010
Note: China data 31 provinces
India data 24 states
USA data 179 BEA EA
EU24 data (Cyprus, Lithuania and Malta not included) 841 OECD TL3
EU15 data 653 OECD TL3

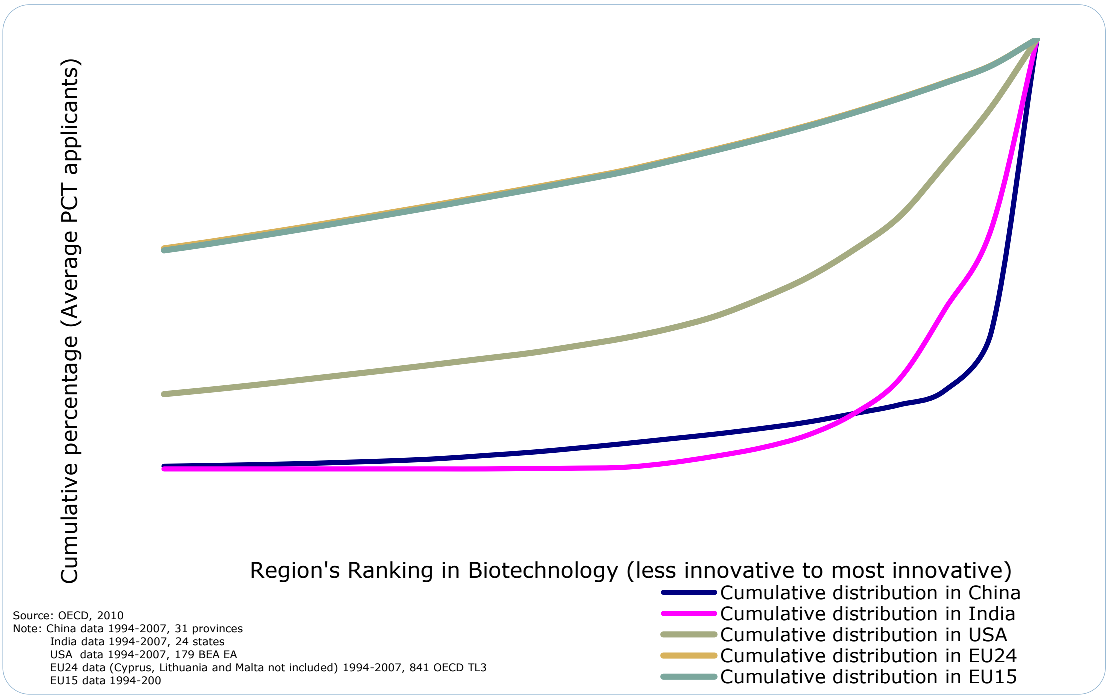
The comparison of figures 4 and 5 signals the evolution of the geographical dimension of innovation over the 1994-2007 period: Figure 4 refers to the situation in 1994, whereas Figure 5 covers that in 2007. As already highlighted by Sun (2003), we find evidence of increasing spatial agglomeration of innovative activity in China since the 1990s, as measured by patents, which since 2000 outstrips that of China. Between 1994 and 2000 innovative activity in India was far more concentrated than in China. The majority of Indian states did not generate any patents at the beginning of the period of analysis (only seven patent applications were filed in 1994 in India), meaning that all patenting activity was limited to two states (Figure 5). Innovation in China also exhibited at that time a high level of concentration in a limited number of provinces. This geographical agglomeration of innovation was far greater in China than in the US and, in turn, in the US than in the EU. By the late 1990s the pattern begins to change and by 2007 patenting is already more clustered in Chinese provinces than in Indian states (Figure 5).

Figure 5. Cumulative Distribution of average PCT applications. Top 20 most innovative regions, 2007.



The above-mentioned concentration of innovation activity across Chinese provinces and Indian states is reproduced in every sector considered. When the overall patent counts is broken down into technology fields, the resulting figures mimic the pattern already unveiled in previous figures. Figure 6 shows the spatial distribution of biotechnology patenting across the countries included in the analysis, for the whole time period 1994-2007. Although biotechnology patenting is somewhat more spatially agglomerated in China and India than overall patenting, the general trends are very similar (Figure 6). In China, the top three 'biotech regions' account for over 80% of overall patenting in the field. As with overall counts both countries have more concentrated biotech patenting activity than the USA – where the top three regions account for just over 30% of all biotech patents – and Europe.

Figure 6. Cumulative Distribution of average PCT applications in Biotechnology. Top 20, 1994-2007.



The same territorial patterns of innovation are reproduced for other technology fields, such as information and communications technology (ICT) and nanotechnology. In terms of ICT patents sectoral activity is once again more agglomerated in China than in India, with both countries having long tails of trailing regions. Again, both countries' ICT patenting is much more spatially clustered than in the USA and in Europe. Only in innovation in Nanotechnology India is more territorially agglomerated than China. The top three Indian regions account for over 80% of nanotech patenting, against an approximate 60% share for the leading Chinese regions. As with the other two industries, nanotech patenting in both of these countries is significantly more agglomerated than in the USA or in the EU.

2.4 The spatial clustering of innovation inputs.

The spatial analysis of innovation inputs unveils some interesting dynamics in the geography of innovation in the different contexts. Table 2 reproduces the ranking analysis for R&D spending (India, USA) and science and technology spending (China). Expenditure is weighted by population in order to give comparable measures of intensity for these innovation inputs.

Patterns of agglomeration for R&D spending differ from those of patenting. For the USA, San Jose-San Francisco-Oakland is top of both league tables, but only three locations (San Jose-San Francisco-Oakland, Seattle-Tacoma-Olympia and Rochester-Batavia-Seneca Falls) remain in the top ten regions. Thirteen locations appear on both counts in the top 20. Noticeably, Detroit-Warren-Flint is the second highest patenting region, but does not feature in the top 20 areas for R&D.

Only three states appear in India’s top ten rankings in R&D and S&T technology intensity: Delhi, Haryana and Chandigarh, the top three locations for patenting, rank 17th, 7th and 4th for R&D spending respectively. Five of China’s top 10 regions for science and technology also feature in the top 10 for patenting applications, and Shanghai and Beijing remain in the top three regions (Guangdong is 3rd for patents but 17th for science and technology intensity).

Table 2. Top 5 regions in terms of R&D / science and technology intensity

	China, R&D, 2007		*India, R&D, 1994-2006*		*USA, BEA-EAs, Private R&D, 1994-2007*	
1	Beijing	5.40	Uttaranchal	0.47	San Jose-San Francisco-Oakland, CA (EA)	(Not comparable - Ranking only)

2	Shanghai	2.52	Himachal Pradesh	0.35	Detroit-Warren-Flint, MI (EA)	(Not comparable - Ranking only)
3	Tianjin	2.27	Jammu & Kashmir	0.21	New York-Newark-Bridgeport, NY-NJ-CT-PA (EA)	(Not comparable - Ranking only)
4	Shaanxi	2.23	Chandigarh	0.16	Davenport-Moline-Rock Island, IA-IL (EA)	(Not comparable - Ranking only)
5	Jiangsu	1.67	Punjab	0.15	Seattle-Tacoma-Olympia, WA (EA)	(Not comparable - Ranking only)

China: Intramural expenditure on R&D as percentage of regional GDP - China Statistical Yearbook on Science and Technology
India: Combines Central Government Extramural and State total expenditure in R&D as a percentage of regional GDP - R&D Statistics
USA: Regional Private R&D Expenditure as a percentage of Regional Total Personal Income - Proxy for Ranking purposes only calculated from Compustat firm-level data

Table 3, below, gives rankings for human capital inputs – as measured by country population shares with tertiary education or above. The spatial distribution of human capital is different again from patenting and R&D spending. China's territorial system is the most similar across inputs and outputs, with six of its top ten human capital regions also in the most innovative regions list. As with R&D spending, Beijing and Shanghai remain in the top three, in identical positions to their patents rankings.

Four of India's top human capital regions appear also in the ten most innovative regions lists, with Delhi and Chandigarh in the top three in both cases. There is substantial change in the rest of the top twenty. In the case of the USA, Washington-Baltimore-Northern Virginia is the economic area with the highest share of graduates, but does not even feature in the top twenty patenting regions. This is largely explained by DC's large community of graduates working in politics and public policy rather than sciences or high-tech manufacturing. Austin-Round Rock is a well-known US tech cluster with a large university, explaining its presence high up in the patents, R&D and human capital tables. Denver-Aurora-Boulder is the third highest region in terms of graduate population share, but again does not feature in the twenty highest-patenting regions. There is some movement in the rest of the table, but the set of regions remains largely the same.

Table 3. Top 5 regions in terms of Tertiary Education achievements, 1994-2007

	China,1995-2007		***India, 1995-2006***		***USA, BEA-EAs, 1990 & 2000***	
1	Beijing	0.20	Chandigarh	0.25	Washington-Baltimore-Northern Virginia, DC-MD-VA-WV (EA)	0.33
2	Shanghai	0.14	Delhi	0.21	Austin-Round Rock, TX (EA)	0.32
3	Tianjin	0.10	Himachal Pradesh	0.19	Denver-Aurora-Boulder, CO (EA)	0.31
4	Xinjiang	0.07	Goa	0.16	San Jose- San Francisco-Oakland, CA (EA)	0.30
5	Liaoning	0.07	Uttar Pradesh	0.15	Boston-Worcester-Manchester, MA-NH (EA)	0.29

China: People with college-level or higher degrees as a share of total provincial population (aged 6 and above) - China Statistical Yearbook, 1991-2008
India: People with college, diploma or higher degrees (in urban areas) as a share of total state population (aged 7 and above) - National Sample Survey
USA: People with Bachelor's degree and higher as a share of total BEA EA population (aged 25 and above) - USA Census Bureau Counties Data Files

3. The drivers of the geography of innovation in China and India

The analysis of the data has revealed a number of interesting trends and stylised facts. First that the traditional global hierarchy in terms of innovation capacity still persists. The USA remains the established world technology leader, comfortably outperforming the EU and still miles ahead of China and India, in R&D, R&D workforce, research quality and university-educated workforce population shares. But the gap between the innovative capacity of the developed world and these emerging countries, albeit still large, is closing fast. China and, to a lesser extent, India are setting the bases, in terms of innovation and human capital inputs, for the future generation of knowledge in a more competitive world. But the effort in R&D and human capital by these countries has been highly selective, favouring those centres and sectors with a greater potential and contributing to the emergence of highly unbalanced geographies of innovation. The territorial polarisation of innovation in these countries is unprecedented and exceeds anything seen in the US and in the EU, where we have witnessed in recent decades some consolidation of the most dynamic innovation poles (Crescenzi et al. 2007). And the drive towards a greater territorial polarisation of innovation potential shows no sign of fading.

What are the reasons behind, first, such a marked catch-up in innovation by China and India and, second, the highly unbalanced geographical nature of the innovation efforts in these two countries? The reasons for these developments can be found in the different innovation policies adopted by China and India and can be interpreted through the analytical lenses of the different theories which have dominated how we think about innovation in recent decades: the linear model of innovation, geographical analyses of knowledge spillovers, and the theories about institutions and (regional) systems of innovation.

First, both India and China have adopted innovation strategies which can be directly extracted from the book of linear innovation and endogenous growth theories. The linear model of innovation (Bush 1945, Maclaurin 1953) posits a relatively simple path towards innovation: innovation is the direct outcome of putting greater resources in science and technology and human capital. The greater the investment in R&D, the greater the capacity of a country to innovate. Although starting from a different perspective, endogenous growth theories also highlight the importance of human capital, technology and knowledge in advancing the technological frontier. Subsequent productivity gains drive long-term growth rates (Romer 1990). In practice, national governments have tended to operationalise linear model innovation and endogenous growth ideas by seeking to raise overall levels of human capital and ideas production. As such, policy frameworks are effectively 'national innovation system' models promoting key innovative actors such as businesses, central government, universities and public research institutes (Liu and White 2001) – closely resembling the 'national science systems' explored by David Mowery and others (Mowery 1992, Mowery and Oxley 1995). Analyses focus on countries' performance on key inputs – R&D spending, human capital stock, university investment – and their links to key outputs such as patenting rates and 'gazelle' firms, which approximate ideas generation and diffusion.

The trajectories of China and India in this respect have by no means been completely similar. China not only has a more globalised economy. Its science and technology and innovation systems have also developed greater linkages to the rest of the world. China's economic opening started timidly in 1978, with the creation of special enterprise zones and, by the time India was starting to think about the liberalisation of its economy in 1991, the networks between its economy and the rest of the world where on the verge of taking-off (Jian et al 1996, Liu and Buck 2007, Dahlman 2010). Consequently, China has benefited from greater intakes of FDI and inflows of foreign technology than the South Asian giant (Dahlman 2010). By contrast, until the 1991 currency crisis forced an acceleration of economic liberalization, India's development strategy had been largely autarkic, based on import substitution (Dahlman 2010). Since then the country has shifted from 'highly regulated, autarkic' development to more market-led models, with a further acceleration in the early 2000s (Gajwani et al. 2006, Fleischer et al. 2010). More than China, India has since been able to make a virtue of cultural and historical specificities in developing innovative capacity – most obviously the English language and democratic political institutions (Bound 2007, Bruche 2009).

But, in terms of innovation, the similarities possibly outweigh the differences. China and India have not been shy of adopting national-level perspectives of innovation. Both countries have had a historic emphasis on technology-led national growth (Leadbeater and Wilsdon 2007). Historically, both India and China have used innovation and technology-led development to pursue national prestige / international positioning, for example via space flight and atomic weapons programmes (Leadbeater and Wilsdon 2007). The shift from heavily statist models of public policy, towards market-led reforms (Jian et al. 1996, Fan 2008, Fleischer et al. 2010) since the mid-1980s (China) to early 1990s (India) has not implied an abandonment of national frameworks for innovation. China and India continue to invest heavily in 'innovation inputs', such as R&D and HE investment, while developing their domestic innovation capacities China (Lundin and Schwaag Serger 2007), which both feeds into and feeds from rapid macroeconomic growth.

The policy paths are similar but not necessarily the same. In 2006 China announced a ‘Medium to Long Term Science and Technology Development Programme’. The main aim of this programme is to increase R&D spending from levels of 1.3% of GDP (in 2006) to 2.5% by 2020. This implies a sustained effort and growth rates in R&D in the range of 10 to 15% per year. India, in contrast, has been less vocal on the R&D front and concentrated more on the development of human capital and the clustering of scientific and technological activity in science parks (Mitra 2007). It has also sought to encourage the improvement of science and technology generation and innovative capacity by means of specific instruments, such as the increase of research grants for researchers and tax incentives and concessional loans for firms (Mani 2004). The Indian government has also encouraged the emergence of venture capital in order to address some of the funding problems affecting innovative firms. Furthermore, India has also promoted the adoption of foreign technology in specific sectors, such as ICT (Dahlman 2010), while China has been keener on enhancing the capacity of domestic S&T sectors.

The main drawback of linear models of innovation activity is that they pay minimal attention to space – and so do not explain why innovative activity is so spatially concentrated in China and India.

The phenomenal level of concentration of innovative activities in China and India can therefore be explained by resorting to research on knowledge spillovers and the spatial dynamics of innovation. Different streams of literature bring space into the picture, by showing how agglomeration supports innovative activity, via localised knowledge spillovers (e.g. Jaffe et al. 1993, Audretsch and Feldman 1996, Malmberg et al. 1996, Acs et al. 2002, Carlino et al. 2007). As neither agglomeration nor innovation can be measured directly, density and patenting are typically used as proxies (as in the data presented in the previous section of the paper). Research on knowledge spillovers has put the emphasis on the fact that innovation does not diffuse costlessly in space. Indeed, analyses of innovation diffusion have tended to highlight the presence of relatively strong distance decay-effects. This has been found to be true in Europe (Moreno et al. 2005, Rodríguez-Pose and Crescenzi 2008), as well as in the US (Anselin et al. 1997, Varga 2000, Sonn and Storper 2008). Hence the combination of economies of agglomeration, often linked to urbanisation, with high costs for the diffusion of innovation, point towards the fact that countries wanting to make a significant leap in the innovation capacity may be better off by geographically concentrating their innovation inputs.

A number of studies suggest that proximity-spillover-innovation links also operate in developing country contexts, with strong evidence that urbanisation boosts productive efficiency (Scott and Garofoli 2007, Duranton 2008, Xu 2009). And China and India are no exceptions. Sustained national inputs into innovation, coupled with agglomeration and economic externalities have been key for the rapid emergence of cities such as Delhi, Mumbai, Bangalore or Hyderabad as innovation hubs in India, and to the prevalence of Beijing, Shanghai, Guangzhou or Shenzhen as the centres of innovation activity in China. Most indicators point towards the fact that these dynamic innovation poles suck large resources from neighbouring areas, while so far providing limited evidence of a large-scale diffusion of the knowledge being generated there. Both in China and India backwash innovation effects seem to still clearly prevail over spread effects. However, the dimension and evolution of backwash innovation effects may be constrained by the very pace of urbanisation which is driving them. Specifically, rapid or chaotic urbanisation can outstrip governments' ability to provide adequate infrastructure and public services (Venables 2005, Cohen 2006). As such, agglomerations are also strongly correlated with poverty and informal development and may undermine future innovative capacity.

Path dependency is another factor explaining the uneven geography of innovation. This is particularly evident in the case of India, which has tended to suffer less of the historical upheavals – at least in terms of the location of innovation and industrial activity – than China. Maharashtra's success has been partially built on an old concentration of pharmaceutical industries and on the industrial hubs in Mumbai-Pune-Nasik. Mumbai has also benefited from the presence of prestigious research institutes, such as the Tata Institute of Fundamental Research (TIFR) or the Indian Institute of Technology (IIT). The states in the south also enjoyed historical comparative advantages, such as the presence of an old hub of auto components in Tamil Nadu or some of the top Indian engineering schools in Karnataka. Gujarat in the west has built its innovation capacity on the back of a dynamic entrepreneurial class.

Inadequate institutional capacity may also become another important barrier in the drive towards innovation in these countries. Country- and locality-specific factors – history, institutions, networks and norms – have an important influence over innovation outcomes and have played an important role in the development of the literatures on institutions and systems of innovation (Freeman 1987; Lundvall et al. 2009). 'Regional innovation systems' (RIS) localise and spatialise these frameworks to specific regions and clusters (Piore and Sabel 1984, Saxenian 1994, Cooke et al 1997, Storper 1997 Cooke 2002, Asheim and Gertler 2005). The central insight is that proximity facilitates innovation, or as Asheim and Gertler (2005: 309-310) suggest, 'the geographic configuration of economic agents … is fundamentally important in shaping the innovative capabilities of firms and industries'. RIS analysis heavily focuses on firms and firms' capabilities. Specific regional factors such as the presence of universities and public agencies, networks and institutions determine, in conjunction with the national level factors and institutions, the economic performance of individual firms and local actors. The interactions within RIS between the private sector, the public sector and universities conform a 'triple helix' of relationships (Cooke 2002) at the heart of the success (or lack of it) of individual innovation systems.

RIS may not work in exactly the same way in emerging countries (e.g. Scott and Garofoli 2007, Lundvall et al. 2009 and Padilla-Pérez et al. 2009). First, large sections of local innovative systems in China and India rely, to a much greater extent than in developed countries, on informal activities and even the informal sector. The institutional framework and social capital on which these systems rely are therefore shaped in a different way from what has been described in the developed world (Lundvall et al. 2009). Second, China and India's systems have evolved much more rapidly as a consequence – especially in China – of the rapid emergence of the country and of the insertion of innovative actors into global production chains (Mitra 2007, Bruche 2009, Yeung 2009). Third, such international ascent has happened in the absence of robust, stable and high quality institutions which are generally deemed to be essential in order to generate greater innovation, productivity and economic growth, generating the 'puzzle' of trying to explain the rapid development of innovation in weak institutional conditions (Saxenian and Sabel, 2008).

Unlike innovation systems in developed countries, formal institutions are weak in countries such as China and India, especially at regional level. Intellectual property regimes provide only partial coverage and public agencies that may not always be welfare-maximising (Altenburg 2009, Joseph 2009). Capital and finance is often limited, and university-industry collaborations more limited, with universities simply acting as suppliers of human capital (of varying quality), rather than of direct innovation-generating knowledge (Padilla-Pérez et al. 2009).

All of these factors place constraints on the ability of firms and economic organisations in China and India to develop new products and services – and limit managers' incentives to collaborate with other firms (Altenburg 2009). In this context, multinational enterprises (MNEs) become crucial providers of both capital flows (via FDI) and new technologies (via alliances / collaborations and spillovers) (Cantwell 2005). More than half of global R&D is currently done within multinational enterprises; in 2007 Toyota ($8.4bn) and GM ($8.1bn) each spent more on R&D than India (Dahlman 2010). And in China and India multinational firms' location patterns closely follow those of patents, and vice versa. Between 60-80% of all MNEs in India and China are concentrated in Beijing and Shanghai and in the Bangalore, Pune, Delhi axis, respectively (Bruche 2009).

Scarce or inadequate innovation agents, limited capacity to collaborate among firms, and a limited presence of multinational firms in inland China and in north eastern India thus represent insurmountable barriers for the development of innovative capacity in these areas. If we add inadequate institutions on top, it is not surprising that agglomeration and regional systems of innovation reinforce one another in order to create a very uneven and territorially unbalanced geography of innovation in China and in India.

In these conditions, export markets and trade entry points become an important source of knowledge exchange and innovation; and the Chinese and Indian nation-states (and national policy frameworks) are, by the implementation of all sorts of different policies, contributing to the reinforcement of existing innovation hubs to possibly a greater extent than local efforts (Padilla-Pérez et al. 2009). 'Discretionary public policies' in national development strategies are critical (Cimoli et al. 2009). Moreover, large cities and trade entry points in China and India have become the gateways for diaspora migrants and trans-national communities in facilitating innovation, by spreading ideas, developing globalised production systems and influencing institutional reform in 'home' countries (Saxenian 2006, Saxenian and Sabel 2008) further aggravating the internal gap between innovative and non-innovative territories.

These developments combine themes from research on how the changes in global innovation networks have affected emerging countries (e.g. Mowery 2001). According to Archibugi and Iammarino (2002), the innovative success of emerging countries has tended to rely not only on how well individual countries managed to internationalise and exploit local innovations, but also on how much knowledge and technology was transferred by multinational corporations and on the extent to which local firms have been able and capable of branching into global scientific and technology networks. In all these areas both China and India, albeit following very different paths, have been successful on all three counts. They both have managed to absorb knowledge and know-how from MNEs and to create a number of 'lead firms' capable of not only engaging and competing with leading firms elsewhere in the world, but also of developing the all-important local networks through which knowledge and innovation are distributed within clusters and then diffused across different parts of the country (Yeung 2009). All these processes are at the origin of the very uneven geography of innovation observed in both China and India and shown by the data discussed in the previous section of this paper.

4. Conclusion

This paper has presented a first view into the geography of innovation in China and India, comparing it with that of developed spaces in the world, namely the US and the EU.

The picture which emerges from the analysis is one of countries still significantly lagging in terms of innovation capacity, but which are also setting the bases for sustained and rapid catch-up in the endogenous generation of innovation. The impressive rate of convergence in recent years – albeit from very low initial levels – are possibly just a sign of what is likely to happen in years to come: two countries rapidly rising up the ranks of the world science and technology and innovation hierarchy which are developing innovation systems which are different from what is the norm in the developed world. In this respect, Jacques' (2012) prophecy that Chinese – and Indian – modernity will be very different from Western modernity is being reproduced in terms of the spatial organisation of the innovation systems of these two countries.

The innovation effort in both China and India is, however, far from uniform and sustained in by what all standards are very uneven geographies of innovation. National innovation strategies and policies, galloping urbanisation, and uneven institutional capacities across regions in China and India are combining in order to create innovation 'mountains' in large urban areas next to 'deserts' where innovation capacity is virtually absent. The location of FDI and multinationals in these 'mountains' further contributes to the emergence of self-reinforcing virtuous cycles of innovation in selected metropolises and trade entry hubs such as Beijing, Shanghai, Guangzhou and Shenzhen in China, or Delhi, Mumbai, Hyderabad and Bangalore in India. Picking winners is further contributing to this mounting territorial imbalance. The innovation 'mountains' are complemented by 'deserts' where not only virtually no innovation takes place – i.e. the 'seven sister' states of North Eastern India or numerous provinces in the West of China – but where existing conditions are unlikely to trigger any sort of innovative surge in the near future. In fact, the lack of a critical mass of innovative actors, coupled with national policies of picking winners and with the advantages of economics of agglomeration and trade access for the generation and diffusion of knowledge are likely to perpetuate what is already a very uneven, and perhaps unsustainable, geography of innovation in the two main emerging countries of the world.

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