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Introduction: China and India as Contrast Pair in Innovation and IP

Uday S. Racherla, Kenneth Guang-Lih Huang, and Kung-Chung Liu

1 Aims and Scope of the book

The goal of innovation is to create value through the implementation of viable commercial solutions to customer needs and business challenges, problems and opportunities that are open to exploitation. The innovation landscape of a nation is shaped by a variety of factors, such as its economic climate, government's vision, policies and commitment to growth and development, investment environment, academia that advances the frontiers of new knowledge and helps to build an innovative workforce, industry committed to innovation to improve the quality of life for everyone, intellectual property rights (IPR) laws and enforcement mechanisms, competition among industries for growth, academia-industry partnership, government-industry-academia policy alliance, climate for entrepreneurial startups, and trading conditions, to mention a few.

The current book takes the two most populous nations on earth, namely India and China, as focus to examine certain factors just mentioned, their interaction with

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and contribution to innovation and whether innovation and the impact from IPR on innovation can be measured and how. The comparison of and contrast between these two giants have great merits. Both countries are the two fastest-growing economies in the last two decades. Their population together takes up one-third of the world's total population and therefore exploring how to sustain their growth via innovation and IPR would have tremendous influence on the well-being of the globe. Second of all, such study is beneficial not only to Indian and Chinese people but also to countries around the world, as they all have to stay competitive in the endless innovation process. Last but not least, although both nations have long cultural history, shared socialist background and Buddhist-related religion, border disputes that sometimes erupted into military confrontation strain the bilateral relationship. Given that Singapore sits in the middle of these two giants and maintains friendly ties with either side, the Applied Research Center for Intellectual Assets and the Law in Asia (ARCIALA), Singapore Management University (SMU), has since its inception in May 2015 taken upon itself a role to facilitate mutual understanding and cooperation between India and China in the area of IP law and industries development.

On the one hand, China has in the last three decades successfully transformed itself from a closed and agricultural-centric economy to the world factory with astronomical foreign reserves, amazing urbanization and infrastructure achievement. In its strife to modernization China identifies IP law and industries as the key element, and therefore decided early on to embrace IP without reservation. As a result, China joins the Berne Convention in 1991, only 3 years later than the USA which took 102 years to join. Since the 1995 "Strategy of Sustainable Development," China embarks on a series of national strategy campaign: the "Education and Science Strategy to Revive the State (1996)," and the "Talent Strategy to Strengthen the State (2002)" and "National Intellectual Property Strategy (NIPS 2008)". For China, IP is ideology-neutral and the instrumental for national development and competitiveness. It therefore determined to become just what the Western power is good at, namely using strong IP portfolio as driver for sustainable growth in the knowledge economy era.

On the other, India's economic surge began in the 1990s when the late Prime Minister Narasimha Rao's government introduced economic liberalization policies. Prior to 1990, India's economic climate was predominantly one of protectionism, characterized by centralized planning, import substitution, regulated industrialization, stringent labor laws, controlled financial markets, and growing role of public sector undertakings. Indeed, innovation climate faced severe challenges in India due to the requirement of elaborate licensing procedures, heavy regulatory burden and inordinate red tape, often referred to as, the *License Raj*.[1] However, the dismantling of the *License Raj* was initiated by the Narasimha Rao government in

[1] Times of India. http://timesofindia.indiatimes.com/business/india-business/Street-hawking-promise-jobs-in-future/articleshow/1578908228.cms (2001); BBC News. http://news.bbc.co.uk/2/hi/south_asia/55427.stm (1998).

the 1990s, which led to an average gross domestic product (GDP) growth rate of 6.0 % during 1992–1998.[2]" A continuation of the economic reforms in India later by the Prime Minister Vajpayee government enabled GDP growth to continue to go up to 7.9 % in 2004. Finally, the Prime Minister Manmohan Singh government achieved an average GDP growth rate of 7.7 % during 2004–2012. Though GDP growth slowed down subsequently, it once gain started to gain momentum under Prime Minster Modi's Government, which won people's mandate on the election promise, "Minimum Government, Maximum Governance." The Modi government has vouched to international investors, "Red Carpet, and Not Red Tape," and has since been focusing on progressive economic reforms. The newly released government data shows that India achieved a GDP growth rate of 6.9 % in 2014 and is expected to increase to 7.4 % in 2017. Eric Bellman says, "India is on course to overtake China to claim the position as the world's fastest growing, big economy in the next 2 years.[3]"

Comparing countries of such diverse dimensions and magnitudes could never be comprehensive, let alone complete. However, a joint effort by scholars from across different disciplines, such as law, business management and economics with empirical approach would increase the chance of success. In October 2014, a workshop on the "Actual Role of IP in the Technological and Business Innovation" was convened in SMU, during which the possibility of producing a book on "Perspectives on Innovation and IPRs in China and India: Myths, Realities and Opportunities" had been discussed and agreed upon with the goal of breaking myths, revealing micro and macro realities and pointing out ways forwards.

The current book follows a three-part structure. In order to lay the groundwork for discussing China and India, the first part of the book contains three chapters and begins with in-depth doctrinal and empirical analysis of whether and how IPRs promote innovation. Chapter "Do IPRs Promote Innovation?" starts with the ultimate question: "Do IPRs promote innovation?" Rather than a clear "Yes" or "No," the right answer might be, "It depends." It further points out that not all inventions lead to innovations. In fact, inventions made without any commercial understanding are unlikely to be of business interest. IPRs protecting such inventions of little or no business interest do not promote innovation. Nevertheless, IPRs of this kind could still create an alternative stream of revenue via licensing or sale,

[2] According to Dr. Mashelkar, the former Director General of the Council of Scientific & Industrial Research (CSIR) in India, "India's first freedom came in 1947, as political freedom. India's second freedom, however, came only in 1991 when the Indian economy was liberated and opened up. Prior to that time, huge tariff barriers protected the Indian industry. There was no incentive for innovation since there was no competition in the marketplace. It was not a buyer's market; it was a seller's market. After 1991, however, the situation changed dramatically. Competition moved in and is now here to stay. Its influence is dramatic and can be illustrated by the breakthrough of India's leading industrial enterprise". See R. A. Mashelkar, Indian science, technology, and society: The changing landscape. Technology in Society, 30: 299–308 (2008).

[3] Wall Street Journal. World Bank: India to Become Fastest-Growing Big Economy: http://blogs.wsj.com/indiarealtime/2015/01/14/world-bank-india-set-to-become-worlds-fastest-growing-big-economy/ (2015).

provided the firm knows how to effectively manage its intellectual assets. Only inventions with a strong business focus have a much higher probability of leading to successful innovations. IPRs protecting such inventions and innovations become part of the intellectual capital of firms, affording unique products/services, contributing to protected growth and competitive advantage, and attracting the attention of investors and shareholders. Consequently, this leads to higher market capitalization and raises the market expectations of shareholders and investors of even higher returns on their investments. This chapter presents evidence for the above hypothesis based on examples of individual firms.

Chapter "Technology and Business Innovation: Role and Value Measurement of IPRs" starts off defining innovation and then weighing on the interrelationship between IPR and innovation. It suggests that for poor countries, stronger IPRs appear to have no effect on innovation and have negative impact on international trade; to establish a conclusive causal link between IPR protection and increase in innovation needs some wider empirical research which is in scarce at international level; and it is surely not advisable to generalize any single principle concerning the relationship between IP and innovation. It continues to explore the measurement and valuation of assets in IP and contends that the valuation of IP depends upon the use of an interlocking series of estimates, assumptions and judgment. It is highly limited as regards the accuracy of its results.

A quantitative and large-scale research on the question: "whether patent strategy will negatively affect the long run supply of public knowledge and by how much?" was undertaken in the realm of human genetics by chapter "Does Patent Strategy Shape the Long-Run Supply of Public Knowledge?". By analyzing the population of 4270 human gene patents (covering almost 20 % of the 23,688 known human genes), from which 1279 human gene patent-paper pairs were identified. Its difference-in-differences estimates show that gene patents decrease public genetic knowledge, with broader patent scope, private sector ownership, patent thickets, fragmented patent ownership, and a gene's commercial relevance exacerbating this effect.

The second part of the book deals with India. Chapter "Innovation, IP and India: The Dichotomy Between Facts and Fiction" discusses the Indian attempt to innovation in the pharma, automotive, and semi-conductor industries after exploring the definition and types of innovation, the factors leading to or prohibiting innovation, and the IP-innovation relationship in general. It concludes that the "inference that innovation and IP are proportional cannot be drawn from the Indian experiences." Following India's accession to the TRIPS Agreement, its pharmaceutical patent laws were brought in line with those existing in the West. However, chapter "The Law and Politics of Pharmaceutical Patents in India" examines the choice between access to medicines and incentive to innovation in India's pharmaceutical patent debate by discussing two recent decisions, namely Novartis and Bayer. The study shows the tendency of the Indian state and judiciary to prioritize the former over the latter which has its roots in the social political and national interest consideration.

The last part of the book takes on China. Chapter "IPRs in China—Market-Oriented Innovation or Policy-Induced Rent-Seeking?", legal in nature, looks into

China's NIPS and the over-zealous pursuit of IPR quantity that has not only led to exponential increase in the number of applications for and granting and registration of IPRs but also to overflow of poor quality IPRs. Furthermore the insufficient innovation capacity, non-existence of IPR valuation mechanisms, lack of core competiveness in IPR industries, and the alienation of and rent-seeking through IPRs originating from the root cause of the misplaced government functions overshadow the future innovation in China. There are therefore rooms for recalibrating IPR and innovation policy in China.

Despite the concerns expressed in chapter "IPRs in China—Market-Oriented Innovation or Policy-Induced Rent-Seeking?" chapter "Estimates of the Value of Patent Rights in China" strives to evaluate Chinese invention patents and utility model patents applied for during 1987–1989 and 1986–1998, respectively. By undertaking a comprehensive study of annuity renewal information pertaining to Chinese patents under a nonlinear least square model, it finds out that patents applied for by foreign entities invariably have higher value (up to18 times) than those applied for by domestic entities, and the gap is significant. However, the value gap between invention patents applied for by domestic corporations and by foreign corporations was significantly narrower in the 2000s; the value of invention patents and utility model patents in the 1987 cohort applied for by domestic applicants represents 6.7 and 34.2 % of China's R&D expenditure in 1987, respectively, which indicates that patent system in China has offered substantial incentives to those willing to undertake inventive activity in the country.

From a similar patent-information based approach, chapter "Patent-Information Based Study on Patenting Behavior in China" studies and compares data indicative of patenting behavior, such as annuity, the country of origin, institutional identity, contents of patent documents, industrial sector, and technological area to uncover policy-driven patenting behavior in China: government "innovation indicators" with strong short-term benefits induce more direct response from patentees, which leaves room for speculation with innovation policy. On the whole, the efficiency or productiveness of the innovation and IPR policies in China may not be as rosy as it seems to be.

In the following, the overall innovation landscape of India and China will be provided to equip readers with prerequisite understanding of these two complex world players.

2 India's Innovation Landscape

India's performances on international indices that evaluate the innovativeness of nations defy consistency. While India shows a steady progress on some, it has been lagging on others. Thus, India fares very poorly on innovation inputs and innovation infrastructure such as R&D expenditures, physical infrastructure, transport, energy, government policy, and other innovation enablers. However, in spite of scarce innovation inputs and infrastructure, India continues to be innovative, demonstrating high innovation efficiency. In fact, India is one of the few nations in the world that possesses the knowledge, expertise, and capabilities in space science and technology, that includes satellite design and construction as well as launch vehicle technologies. India is also one of the few countries in the world that has expertise in supercomputers. Indeed, India developed its first supercomputer PARAM 8000 in 1991 based on parallel processing architecture, at a cost less than that of CRAY YMP system, in a span of less than 3 years. In 1998, India launched PARAM 10,000, proving India's ability to build 100-gigaflop machines, scalable to teraflops, which enabled India to join other advanced nations.[4] Thus, many observers acknowledge that India is perfectly capable of overcoming the constraints and risks to produce high quality innovation outputs.[5] In 2000, Jack Welsh, the former CEO of General Electric (GE), rationalized this apparent contradiction very well by noting, "The real treasure of India is its intellectual capital. The real opportunity of India is its incredibly skilled workforce. Raw talent here is like nowhere else in the world.[6]" Indeed, this is why GE made heavy R&D investments in Hyderabad, Mumbai, and Bangalore. Thus, India's innovation potential is yet to be fully realized and its best lies ahead.

2.1 Human Capital

Literacy rate is a leading indicator for socio-economic progress, and India has made good progress on it since its independence in 1947.[7] The literacy rate of India has grown from 12 % in 1947 to 74.04 % in 2011. However, India's literacy rate is well below the 2010 world average of 84 %,[8] and way behind the 95 % literacy rate achieved by China.[9]

However, India is the third largest scientific and technological manpower source of the world. A 2013 study on innovation landscape in India[10] noted the following facts: "By 2010, the gross enrollment in the Indian university system had reached almost 17 million (not including students enrolled in technical diploma institutes and other informal vocational institutes where overall annual intake has crossed one million).

[4] R. A. Mashelkar, Indian science, technology, and society: The changing landscape. Technology in Society. 30: 299–308 (2008).

[5] K. Bound, I. Thornton, Our Frugal Future. Lessons from India's Innovation System. https://www.nesta.org.uk/sites/default/files/our_frugal_future.pdf (2012).

[6] D. Kapur, R. Ramamurti. India's emerging competitive advantage in services. Academy of Management Executive. 15(2): 20–33 (2001).

[7] Census Report (Government of India). http://www.censusindia.gov.in/2011-prov-results/indiaatglance.html (2011).

[8] UNESCO Fact Sheet, http://www.uis.unesco.org/literacy/Documents/fs20-literacy-day-2012-en-v3.pdf (2012).

[9] UNESCO Institute for Statistics Stats.uis.unesco.org. Retrieved 2014-08-14.

[10] India Gate Report. http://www.apre.it/media/97864/indiagatedef1protetto.pdf (2013).

Engineering enrollment was roughly 2.8 million in 2010 although first year engineering enrollment touched a million in 2012. In 2012, the number of universities in India grew to 634, while affiliated colleges increased to over 33,000. There are nearly 200,000 people engaged in R&D activities in India. Of these roughly 63 % were working in the institutions, academia as well as publicly supported R&D organizations and 31 % in the private sector. Over 50 % of those working on R&D activities have post-graduate or higher degree and 30 % have graduate degree. Of the total R&D personnel the public institutions employ 76 % of the PhD and 50 % of post-graduates."

Today, India is the second most populous country in the world and is expected to surpass China in the next two decades. Some analysts consider this as "India's Demographic Dividend," as 50 % of India's population (about 600 million) is under 25 years of age. The youth literacy rate in India has been projected to be 90.1 % in 2015 and is expected to grow continually.[11] Accordingly, the Government of India had initiated several programs to cultivate human capital for advanced research. To cite an example, the Department of Science and Technology has launched the "Innovation in Science Pursuit for Inspired Research (INSPIRE)" program.[12] Under this program, India has awarded 2150 research fellowships for doctoral research and 270 faculty awards for post-doctoral researchers. In addition, it plans to set up innovation universities using public-private partnerships (PPP) to build new hubs for education, research, and innovation.

2.2 Science and Technology Infrastructure

The infrastructure of the science and technology establishment in India today has its origins in the strategic planning of the late Prime Minister Jawaharlal Nehru, who envisioned separating teaching from research. Thus, India developed universities and Indian Institutes of Technologies (IITs) for teaching and fundamental research and built advanced cluster research institutions – such as the Council of Scientific and Industrial Research (CSIR), Defense Research and Development Organization (DRDO), Indian Space Research Organization (ISRO), Indian Agricultural Research (IAR), Indian Council of Medical Research (ICMR), and Department of Atomic Energy (DAE), with multiple research laboratories and thousands of scientists/engineers – to conduct cutting-edge applied research. This kind of separation of teaching and research is not without its critics. According to Ramaswamy, Vice Chancellor of the University of Hyderabad, "The commitment to making

[11] See reference 9 for a detailed discussion.

[12] INSPIRE. http://www.inspire-dst.gov.in/facultyScheme_CallforAppl.pdf (2008).

independent India a scientific society was strong, but the manner of its implementation has had long-lasting repercussions."[13]

2.3 R&D Spending

The R&D spending of a country is indicative of its economic competitiveness. Countries like USA, UK, Australia, China, Japan, Germany, Korea, Singapore, and Taiwan typically allocate 1–4 % of their GDP on R&D.[14] According to India Gate Report,[15] India is a fringe player in the world in R&D spending. India spends only about 0.9 % of its GDP on R&D. Although India's R&D spending has increased from 0.6 % in 1990–1991 to 0.9 % in 2007–2008, it is still very small compared to China and other developed nations of the world. This report further notes the following: "The Government of India is the biggest contributor of research money with 75 % of share and all of it channeled through government agencies. . .The private sector contributes 20 % of expenditures on R&D. Most of the private R&D expenditure is incurred in the pharmaceutical industry, which saw a fivefold increase from 2000 to 2005. This is followed by automotive industry, which increased the R&D spends from under 500 million Rupees in 2001 to over a billion Rupees in 2006. In R&D output measures, India has been progressing well compared to its earlier performance, but well below other nations such as China. The number of research publications increased steadily over the last decade. Similarly, patents granted both abroad and in India to research and commercial organizations have also increased substantially. Interestingly, the patents granted to foreign nationals in India are three terms higher than the ones granted to Indian nationals."

Today, the R&D centers of multinational corporations in India play a critical role in research and innovation activities. It is estimated that India has about 851 such R&D centers as of 2010, and their R&D spending exceeds Rs. 28,830 million. These multinational R&D centers have been extremely active in patenting the work done in their Indian R&D centers. Thus, 1969 patents were granted by the U.S. Patent and Trademark Office (USPTO) to foreign companies with active R&D in India. Vast majority of these patents are in ICT and most of the companies who received patents are of US origin.[16]

[13] R. Ramaswamy, Science, Education and Research in India. Economic & Political Weekly, XLVIII (42): 20–23 (2013).

[14] 2014 Global R&D Funding Forecast, http://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf (2013).

[15] See reference 10.

[16] See Indian National IPR Policy. This report details India strategy to change this situation, http://dipp.nic.in/English/Schemes/Intellectual_Property_Rights/IPR_Policy_24December2014.pdf (2014).

2.4 Scientific Publications and IPRs

India ranks ninth in the world in terms of the number of scientific publications.[17] During 2000–2010, India's share of global research publications increased from 2.2 to 3.5 %. In particular, during 2008–2010, India registered a 12 % annual growth rate of scientific publications against the global average of 4 %.[18] It must be pointed out that while scientific productivity can be easily quantified in numbers, it is difficult to measure either quality or impact.

Though IPRs are a source of huge revenues, India follows stringent rules to protect creativity or innovation.[19] Patent filings in India have gone up from 17,466 during 2004–2005 to 43,674 during 2012–2013, while the number of patents granted rose from 1911 to 4126. Consequently, while the total number of patents granted in India over the last 10 years was at 69,745, the average rejection rate of patent applications stood at 77.94 %, which is very high when compared to China, Japan, Korea, and Taiwan. This indicates that India has a stringent patenting system, policies, and enforcement to protect inventions. Trademark filings indicate the commercial activity in the country. Trademark filings in India increased from 130,172 in 2008–2009 to 194,216 in 2012–2013.

2.5 Government Policy

In India, the official usage of the term, "innovation" began only recently[20] though it was quickly embraced by everyone in the country. The Government of India announced 2010–2020 as the "Decade of Innovation," made it a major policy objective. Further, it constituted the National Innovation Council (NInC) to advance the cause under the leadership of Sam Pitroda and other luminaries from the corporate, social, and academic fields, as its council members. NInC serves as a forum and brings together various stakeholders to create a rapid and inclusive innovation movement in India. Towards this objective, NInC has undertaken the following major initiatives[21]:

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[17] India Brand Equity Foundation. http://www.ibef.org/industry/science-and-technology.aspx (2015).

[18] B. M. Gupta, Bala, A, Kshtij, A. S&T Publications Output of India: A Scientometric Analyses of Publications Output 1996–2011. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=2238&context=libphilprac (2013).

[19] Intellectual Property India Annual Report, http://ipindia.nic.in/cgpdtm/AnnualReport_English_2012_2013.pdf (2012–2013).

[20] National Knowledge Commission Report, Government of India. http://static1.squarespace.com/static/5356af05e4b095ff0fea9e11/t/539504b4e4b0d85a0d78c51e/1402274996341/NKCreport09+copy.pdf (2006-2009).

[21] See reference 10.

India Inclusive Innovation Fund: One billion Euro fund to invest in world-class enterprises engaged in developing products and solutions for the problems of poor.

Sectorial Innovation Councils: Aligned to central government ministries to enable the innovations within the sector.

State Innovation Councils: For each of the states and union territories to create an innovation ecosystem in the state.

Industry Innovation Clusters & Cluster Innovation Centers: To bring together different stakeholders for collaboration and promotion of innovation

Innovation in Education and University Clusters: To enable innovation in creativity in education system and create university clusters as hubs of innovation.

India is making a rapid progress in laying a firm foundation for the innovation infrastructure under NInC. It must be pointed out that though the concept of innovation is new for India, innovative solutions are not alien to this nation of billion people. While India can learn a great deal from the rest of the more advanced world, the world may also learn a bit from the "Frugal Innovations" that are taking place in India. Some such frugal innovations include Tata Nano (world's cheapest car), Mac 400 (a portable electrocardiograph from GE, priced at 610 Euros and delivers a report for less than one Euro), Tata SWATCH (a water filter that uses rice husk and other low-cost filtering materials and can provide a month of clean water for a family of five at 60 cents), Narayana Hrudayalaya (which charges patients flat 1144 Euros for heart surgeries compared to at least 3432 Euros at other heart hospitals), and Aravind Eye Care (that performs cataract operations for an extremely low cost).

Today, India finds itself in an amazing world of opportunities with all the right ingredients for achieving successful innovations that can transform the world. It is hoped that Prime Minister Narendra Modi's rapid economic reforms coupled with a vibrant climate for domestic and foreign direct investment will transform the Indian innovation landscape and unleash India's full innovation potential.

3 China's Innovation Landscape[22]

China has experienced three decades of sustained, strong annual economic growth as it transitions from a centrally planned economy to a stronger market-orientation. Currently the world's second largest economy,[23] China recognizes scientific and

[22] From Huang, K.G. (2010). China's Innovation Landscape. *Science*, 329(5992): 632–633. Reprinted with permission from AAAS.

[23] Based on GDP, purchasing power parity (PPP) calculations published by the International Monetary Fund (IMF), World Economic Outlook database (2009) and World Bank World Development Indicators database (2008).

technological innovation as an increasingly important strategy to fuel the next phase of its productivity growth. However, the drivers and trajectories of China's scientific and technological growth remain under-investigated. To understand the elements of China's innovative activities in science and technology, particularly to provide an overview of China's overall innovative activities, we use comprehensive patent data of more than 1.1 million SIPO-granted invention and utility model patents[24] from grant year 1986 to 2006 provided by the State Intellectual Property Office (SIPO) of China.

3.1 Patents and Innovation

Patents play a central role in empirical research on innovation, despite their limitations as measures of the introduction of new products, processes, and services.[25] They identify the inventors, assignees (i.e. patent holders), location, date, and innovative characteristics of every filed application over long periods of time.[26]

Although previous patent-based studies sought to examine determinants of national innovative capacity,[27] economic growth and government policy,[28] and the impact of geographic localization of knowledge exchange and diffusion,[29] they focused primarily on developed North American and European nations. The few studies that sought to understand the technological development of China and East Asian countries were constrained to the limited number of patents awarded by

[24] SIPO invention and utility model patents provide legal protection of 20 and 10 years, respectively, and are comparable with USPTO "basic" and "improvement" utility patents, respectively. A basic patent is usually a pioneering type of patent, e.g., the first radio communication device. An improvement patent modifies or builds on the technology of the basic patent, e.g., enhancements to the device.

[25] Patents, which represent only a fraction of all inventions, are constructed within complex institutional frameworks by strategic actors who use patents in different ways to strengthen competitive positions. Thus, not all patents are of equal importance and value; analyses of their use entail behavioral assumptions and heterogeneity, for example, in patent examination, granting, and follow-on citation behaviors. Patents are critical for investment and product development in chemical, biomedical, pharmaceutical, and life sciences, whereas in electronics and semiconductor industries, patents are important for strategic and defensive reasons, e.g., as cross-licensing bargaining chips or to fend off litigation. These patterns are more industry-specific than country-specific, although a weak IP environment can mitigate the propensity to apply for a patent.

[26] Z. Griliches, J. Econ. Lit. 27, 1661 (1990); M. Trajtenberg, Rand J. Econ. 21, 172 (1990).

[27] B. Lundvall, Ed., National Innovation Systems: To-wards a Theory of Innovation and Interactive Learning (Pinter Publishers, London, 1992); J. L. Furman, M. E. Porter, S. Stern, Res. Policy 31, 899 (2002); M.-C. Hu, J. A. Mathews, Res. Policy 34, 1322 (2005).;M.-C. Hu, J. A. Mathews, Res. Policy 37, 1465 (2008).

[28] A. B. Jaffe, M. Trajtenberg, Patents, Citations and Innovations: A Window on the Knowledge Economy (MIT Press, Cambridge, MA, 2002); K. G. Huang, F. E. Murray, Res. Policy 39, 567 (2010).

[29] A. B. Jaffe, M. Trajtenberg, R. Henderson, Q. J. Econ. 108, 577 (1993).

Table 1 Definition of the eight patent assignee sectors

Assignee Sector	Definition
Private enterprise	For-profit companies, firms or factories affiliated with an officially registered business or enterprise
Individual	Individual inventor(s)
University	Universities, colleges or educational institutions
State-owned (or -run) enterprise	For-profit companies, firms or factories (affiliated with an officially registered business or enterprise) owned or run by the central or state government, e.g., military products, some telecommunications, transportation, energy, heavy industries or regulated financial and securities firms
Public research institute	Non-profit research institutes, organizations, and laboratories
State-owned (or -run) institute	Non-profit research institutes, organizations and laboratories owned or run by the central or state government, e.g., Chinese Academy of Sciences or Chinese Textile Academy
State	Central or state government agencies, bureaus, ministries, armies, administrations, and councils
Hospital	Hospitals or clinics

Note: State-owned (or -run) enterprises are primarily documented under the State-owned Assets Supervision and Administration Commission of the State Council (http://www.sasac.gov.cn/n1180/n1226/n2425/index.html)

the USPTO to Chinese entities.[30] These studies were hindered by (i) selection bias, as the sample of Chinese firms willing and able to file a patent with the USPTO is severely restricted compared with the entire population of Chinese firms, particularly start-ups; and (ii) underrepresentation of government-related organizations, regulatory agencies, universities, or research institutes, because these organizations largely file patents within China.

The more than 1.1 million patents granted by SIPO from 1986 to 2006 are awarded from over two million patent applications,[31] which include all 129 three-digit classes of the international patent classification (IPC) of the World Intellectual Property Organization (WIPO) and all eight assignee sectors, from application year 1985, when the Chinese patent system started to process patent applications, to 2006. The assignee sectors are private enterprises; individual, universities, or state-owned (or run) enterprises; public research institutes; state-owned (or -run) institutes; the state; and hospitals (Table 1).

[30] I. P. Mahmood, J. Singh, Res. Policy 32, 1031 (2003).

[31] The patent applications include only patents that have been published by the SIPO, typically 18 months after the earliest priority date of the application. Before publication, the patent application is confidential to SIPO. Some applications received by SIPO may be pending publication or abandoned before publication. A subset of patents applied and published is eventually granted.

Table 2 International patent classification (IPC) codes and description of 12 major science and technology classes

A 61	Medical or veterinary science; hygiene
B 81	Microstructural technology
B 82	Nanotechnology
C 07	Organic chemistry (such compounds as the oxides, sulfides, or oxysulfides of carbon, cyanogen, phosgene, hydrocyanic acid or salts thereof C25B7/00)
C 08	Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon (manufacture or treatment of artificial threads, fibres, bristles, or ribbons D01)
C 12	Biochemistry; beer; spirits; wine; vinegar; microbiology; enzymology; mutation, or genetic engineering
G 02	Optics (making optical elements or apparatus C03C)
G 06	Computing; calculating; counting (score computers for games B43K29/08)
G 11	Information storage
H 01	Basic electric elements (includes semiconductor and devices)
H 03	Basic electronic circuitry
H 04	Electric communication technique

Source: Obtained from WIPO IPC codes http://www.wipo.int/classifications/ipc/en/

The analysis then focuses on over 200,000 granted patents in 12 major science and technology classes, also across all eight assignee sectors. These important classes are drawn from a large body of literature,[32] based on the IPC. They range from chemical and life sciences (i.e. organic chemistry, organic macromolecular compounds, biochemistry, microbiology, and genetics), and medical and pharmaceutical sciences to optics, computing, information and communication technology, electronics, semiconductors, and microstructural technology and nanotechnology (Table 2).

[32] E. Mansfield, Manage. Sci. 32, 173 (1986); R. Levin et al., Brookings Pap. Econ. Act. 1987(3), 783 (1987); W. M. Cohen, R. R. Nelson, J. P. Walsh, Natl. Bur. Econ. Res. Work. Pap. Ser., NBER Working Paper Series, no. 7552 (2000), available at: www.nber.org/papers/w7552; K. G. Huang, F. E. Murray, Acad. Manage. J. 52, 1193 (2009); B. H. Hall, R. H. Ziedonis, Rand J. Econ. 32, 101 (2001).

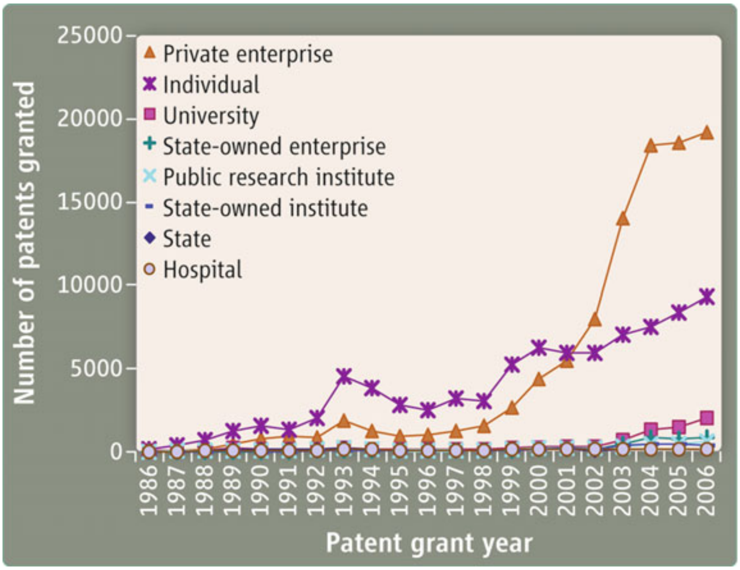

Fig. 1 SIPO Patents granted in 12 major science and technology classes by assignee sector

3.2 Private, Domestic Growth

Patents granted across all patent classes and assignee sectors increased over 13 % per year, on average, from 1986 to 2006, despite China's relatively weak IP environment, especially in terms of effective patent enforcement.[33] This may reflect the growth of direct foreign investment in China.[34] Foreign firms with expanding activities in China demonstrated the strategic importance of patent rights against competitors, providing opportunities for domestic firms to learn and innovate. This may have prompted Chinese firms to apply for and subsequently receive more patents. Clarification of IP laws favoring patent protection and better alignment with international standards, as well as increased domestic investment in R&D, may also have played a role.[35]

In the 12 major science and technology classes, private enterprises – such as domestic firms and multinational corporations – steadily ascended to dominance after 2001 (Fig. 1).

This trend and the diminishing relative share of patents granted to individual inventors could be due to an increase in sophistication and cost of the R&D and technologies being patented, with firms likely to have more resources compared

[33] M. Zhao, Manage. Sci. 52, 1185 (2006); K. G. Huang, Acad. Manage. Best Pap. Proceed. (Acad. Manage. Annual Meeting, Chicago, August 7 to 11, 2009), pp. 1–6. (2009).

[34] A. G. Hu, G. H. Jefferson, J. Dev. Econ. 90, 57 (2009).

[35] Ibid.

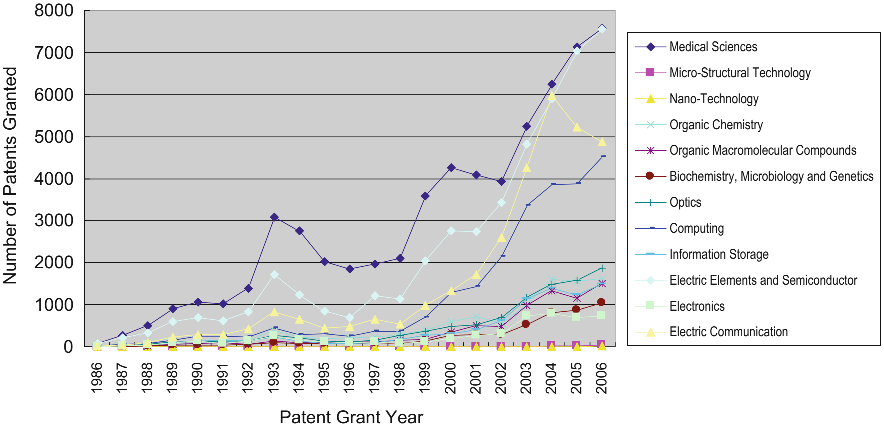

Fig. 2 SIPO patents granted in 12 major science and technology classes for grant years 1986–2006 (Number of patents, $N = 209{,}471$)

with individuals to develop such novel technologies. SIPO patents granted in these 12 classes led by medical sciences, semiconductors, communications, and computing (Fig. 2) have grown from 12 % of all patents in 1986 to over 20 % of all patents in 2006 (Table 3). They equal nearly one-fifth the number of USPTO patents granted in the same classes and time period; over 53 % of all USPTO patents were in these 12 classes in 2006 (Table 4).

Patents assigned to Chinese entities from 1986 to 2006 account for over 58 % of the total patents in the 12 classes, followed by Japan (12 %), Taiwan (11 %), USA (7 %), Korea (3 %), and Germany (2 %) (Fig. 3). The annual growth rate of SIPO patents assigned to Chinese entities averaged 33 % during this period. US assignees contribute about 55 % of total USPTO patents in the 12 classes from 1986 to 2006; non-US assignees from advanced economies like Japan (24 %), Germany (5 %), and Korea (3 %) largely make up the remaining (Fig. 4). The annual growth rate of USPTO patents assigned to US entities during this period averaged around 7 %.

3.3 Geographic Diffusion

A relative scientific and technological advantage (RSTA) index[36] can reflect how scientific and technological capabilities in these 12 classes evolve over time across geographic regions. This index is defined here as a region's share of SIPO patents across the 12 major science or technology classes, divided by that region's share of SIPO patents across all classes. For example, a region responsible for 20 % of

[36] I. P. Mahmood, J. Singh, Res. Policy 32, 1031 (2003); L. Soete, Res. Policy 16, 101 (1987); D. Archibugi, M. Pianta, The Technological Specialization of Advanced Countries (Kluwer Academic Publishers, Dordrecht, 1992).

Table 3 Number of patents granted by SIPO in 12 major science and technology classes for grant years 1986–2006

Patent grant Year	Medical sciences (A61)	Micro-structural Tech (B81)	Nano-tech (B82)	Organic chemistry (C07)	Organic compounds (C08)	Biochemistry, microbiology or genetics (C12)	Optics (G02)	Computing (G06)	Information storage (G11)	Electric elements (H01)	Electronics (H03)	Electric communi-cation (H04)	Total for 12 classes	Percent of SIPO Patents across all classes
1986	75	0	0	2	2	1	16	21	3	83	6	10	219	12.03
1987	262	0	0	5	14	4	22	58	29	212	24	46	676	13.09
1988	505	0	0	17	18	23	61	71	41	324	34	88	1182	12.97
1989	900	0	0	53	53	37	123	152	103	588	92	225	2326	14.74
1990	1063	0	0	77	76	41	123	254	141	697	135	285	2892	13.88
1991	1015	0	0	109	98	46	126	243	159	612	86	280	2774	14.30
1992	1389	0	0	160	62	48	143	225	125	830	136	420	3538	14.03
1993	3079	0	0	376	132	100	262	440	233	1714	256	837	7429	14.29
1994	2759	0	0	238	88	74	211	293	130	1236	148	648	5825	14.86
1995	2027	0	0	193	90	80	139	311	78	846	110	451	4325	13.27
1996	1851	0	0	220	120	77	124	253	72	687	93	477	3974	13.22
1997	1963	0	0	236	124	87	151	359	90	1210	114	653	4987	15.90
1998	2092	0	0	291	153	75	272	373	172	1142	75	543	5188	14.64
1999	3587	0	0	387	171	130	367	692	265	2051	111	984	8745	14.52
2000	4265	0	0	598	350	274	481	1298	301	2749	200	1323	11,839	17.41
2001	4089	1	0	723	493	298	519	1417	408	2735	263	1719	12,665	17.39
2002	3932	1	1	561	474	292	685	2140	618	3425	308	2606	15,043	18.71
2003	5234	2	1	1000	986	526	1171	3363	1129	4829	732	4255	23,228	22.24
2004	6239	11	7	1609	1329	803	1494	3864	1379	5896	782	5975	29,388	24.38
2005	7128	27	8	1562	1164	865	1576	3876	1232	7027	697	5230	30,392	22.87

2006	7577	39	25	1628	1512	1033	1867	4515	1486	7552	724	4878	32,836	20.30
Total	**61,031**	**81**	**42**	**10,045**	**7509**	**4914**	**9933**	**24,218**	**8194**	**46,445**	**5126**	**31,933**	**209,471**	**18.72**

Note: If a patent falls under more than one IPC class, the fraction of each science or technology class to which this patent had been classified under was calculated. For example, if a patent is classified under classes A61, B81, B82, and C07, each of these four classes is weighted as 0.25. The numbers presented in the table above have been rounded up to the nearest whole number

Table 4 Number of patents granted by USPTO in 12 major science and technology classes for grant years 1986–2006

Patent grant Year	Medical sciences (A61)	Micro-structural tech (B81)	Nano-tech (B82)	Organic chemistry (C07)	Organic compounds (C08)	Biochemistry, microbiology or genetics (C12)	Optics (G02)	Computing (G06)	Information storage (G11)	Electric elements (H01)	Electronics (H03)	Electric communi-cation (H04n	Total for 12 classes	Percent of USPTO patents across all classes
1986	4112	3	1	3304	2355	405	967	1224	1451	4700	1383	2334	22,240	31.37
1987	4962	13	10	3498	2603	572	1445	1622	1967	5884	1478	3001	27,054	32.59
1988	4691	3	0	3394	2602	565	1598	1700	1890	5564	1308	2705	26,021	33.38
1989	6313	6	0	4218	3073	714	1786	2406	2424	6630	1557	3451	32,577	34.10
1990	6171	2	0	4275	3035	786	1708	2203	1881	6459	1425	3175	31,121	34.43
1991	6709	6	1	4329	3549	823	1911	2376	2236	7107	1645	3397	34,089	35.31
1992	6835	4	1	4537	3688	1014	2019	2791	2271	7235	1696	3657	35,749	36.67
1993	6993	10	1	4986	3771	1156	1985	3322	2581	7454	1508	4010	37,776	38.40
1994	7622	13	2	4216	3528	1078	1897	3960	2963	8199	1778	4839	40,097	39.41
1995	7800	21	3	4472	3035	1129	1871	4559	3042	8297	1976	5279	41,483	40.91
1996	8608	28	4	4592	2993	1507	2228	5846	3401	8707	2009	6383	46,307	42.26
1997	10,026	34	4	5414	2907	1967	2371	6105	3540	9130	1926	5977	49,401	44.11
1998	12,939	43	4	6048	3282	2915	3324	9853	5028	12,234	2680	9443	67,793	45.96
1999	13,143	51	6	5802	3273	3026	3148	9968	5063	14,379	2772	9892	70,523	45.94
2000	12,865	70	6	5388	3308	2676	3380	9552	5249	16,421	3010	10,244	72,170	45.83
2001	13,492	99	12	5669	3612	3073	3794	10,240	5419	18,634	3312	10,520	77,874	46.89
2002	13,499	136	9	5961	3706	2787	4076	10,217	5584	19,473	3483	11,125	80,056	47.84
2003	14,034	204	14	5200	3484	2532	4700	11,100	5745	19,958	3574	11,930	82,473	48.79
2004	11,057	258	16	4451	3146	2158	5208	12,140	6013	20,274	3679	13,592	81,993	49.91
2005	9259	210	16	3963	2230	1879	4881	11,527	5229	17,629	3356	12,314	72,494	50.44

2006	10,452	18	7	4757	2520	2839	5268	21,630	5732	19,069	4400	16,556	93,248	53.70
Total	**191,582**	**1232**	**120**	**98,475**	**65,700**	**35,602**	**59,561**	**144,341**	**78,710**	**243,437**	**49,956**	**153,823**	**1,122,538**	**43.55**

Note: If a patent falls under more than one IPC class, the fraction of each science or technology class to which this patent had been classified under was calculated. For example, if a patent is classified under classes A61, B81, B82, and C07, each of these four classes is weighted as 0.25. The numbers presented in the table above have been rounded up to the nearest whole number

Source: Extracted from OECD Statistics on Science, Technology and Patents: Patents Statistics http://stats.oecd.org/index.aspx

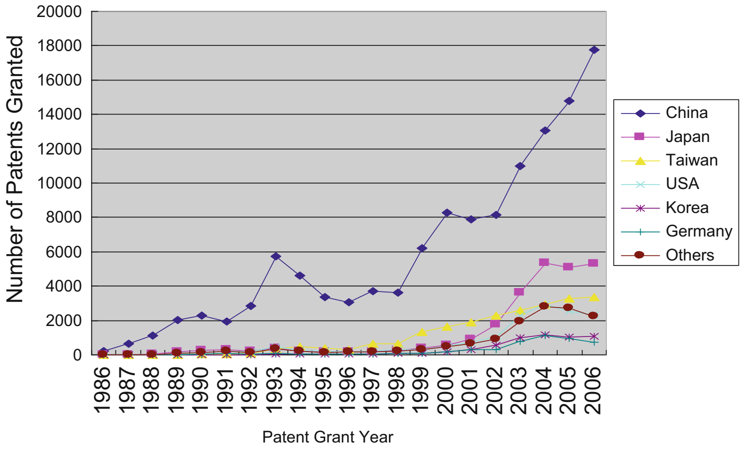

Fig. 3 SIPO patents granted in 12 major science and technology classes by assignee country for grant years 1986–2006 (Number of patents, $N = 209{,}471$)

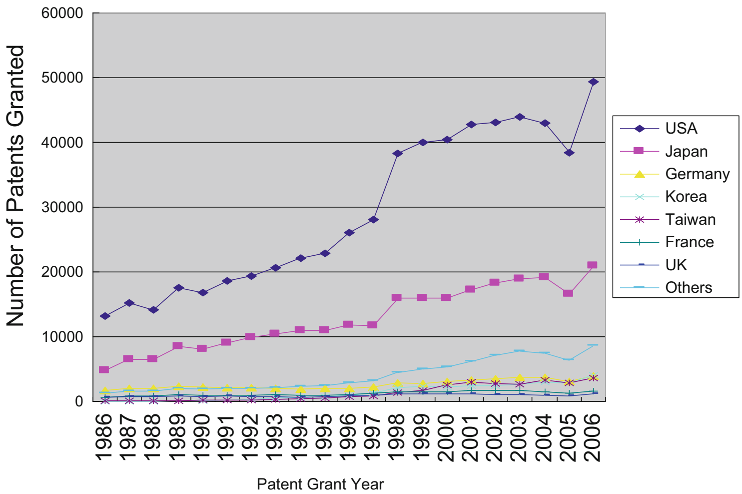

Fig. 4 USPTO patents granted in 12 major science and technology classes by assignee country for grant years 1986–2006 (Number of patents, $N = 1{,}122{,}538$) (Source: OECD Statistics on Science, Technology and Patents: Patents Statistics http://stats.oecd.org/index.aspx)

patents in the 12 classes, but only 10 % of all patents, has a RSTA of 2, suggesting relative strength in the 12 key classes.

The RSTA at the province level in 1986 and 2006 is shown in Fig. 5. The scientific and technological advantages of key regions such as Shaanxi, Guangdong, Shanghai, Tianjin, Beijing, Jiangsu, Shandong, and other coastal provinces have diminished over time relative to the central and interior regions.

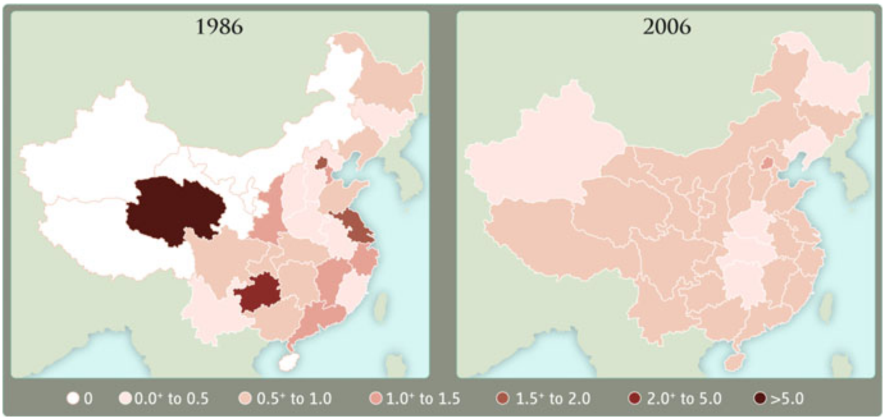

Fig. 5 Regional RSTA by patent grant year. The regions are 22 Chinese provinces and five autonomous regions [Tibet (Xizang), Guangxi, Xinjiang, Inner Mongolia, and Ningxia], and four municipalities (Beijing, Tianjin, Chongqing, and Shanghai). The two special administrative regions (Hong Kong and Macau) are not considered part of domestic China because of differences in their historical and technological developments, patent filing, and reporting systems

4 Key Trends

Three key trends stand out. First, the increasing dominance of private firms over individuals, universities, and state-affiliated institutes suggests a fundamental shift in contribution to China's innovation landscape toward the private sector as China liberalizes its markets. Second, the surge in patenting by domestic Chinese entities versus foreign entities across the 12 major science and technology classes suggests a rise in China's indigenous innovative capabilities, which have been well established in regions of major economic and social developments, such as Beijing, Shanghai, Tianjin, Guangdong, and Jiangsu. Third, the evening out of regional RSTA suggests that scientific and technological capabilities have systematically diffused inward across the provinces to enhance China's overall innovative capacity. Although this pattern contrasts with previous empirical evidences from the United States suggesting that the diffusion of knowledge and innovation are geographically localized and concentrated in major cities rather than outside, it could provide some validation to the goals of the Chinese government's policy to coordinate and develop the central and interior regions. Such a centrally enforced strategy has the potential to promote innovation diffusion.

Evaluation of patterns of the evolution of innovative capabilities across geographic regions, technological classes, and ownership sectors could enable effective and targeted public policies to address specific regional and sectoral needs. For firms, identifying and matching their core scientific and technological competencies and trajectories to appropriate location choices is crucial for optimal exchange and application of knowledge, skills, and other resources. These assessments are particularly important for policymakers and firm managers to devise effective innovation policy and strategies in the emerging economy of China which is and will be experiencing major institutional and technological changes for many years to come.