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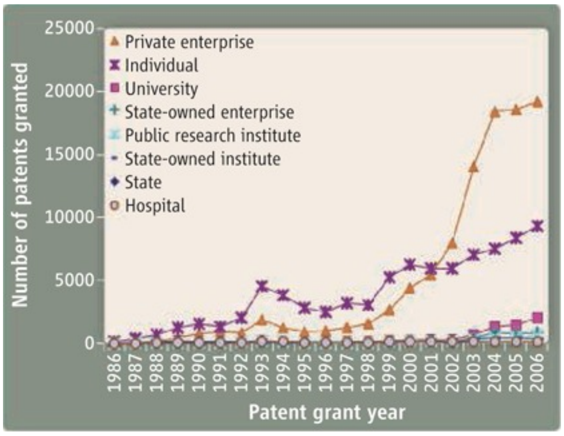
The People's Republic of China has experienced three decades of sustained, strong annual economic growth as it transitions from a centrally planned economy to a free market. Currently the world's second largest economy (1), China recognizes scientific and technological innovation as an increasingly important strategy to fuel the next phase of its productivity growth (2). However, the drivers and trajectories of China's scientific and technological growth remain under-investigated. To understand elements of China's innovative activities, particularly in science and technology, an analysis of comprehensive patent data provided by the State Intellectual Property Office (SIPO) of China is presented here.



SIPO patents granted in 12 major science and technology classes by assignee sector

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 (3). They identify the inventors, assignees (i.e., patent holders), location, date, and innovative characteristics of every filed invention over long periods of time (4, 5).

Although previous patent-based studies sought to examine determinants of national innovative capacity (6–9), economic growth and government policy (10, 11), and the impact of geographic localization of knowledge exchange and diffusion (12), 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 the U.S. Patent and Trademark Office (USPTO) to Chinese entities (9, 13). 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 present analysis provides an overview of China's overall innovative activities using more than 1.1 million SIPO-granted invention and utility model patents (14) from grant years 1986 to 2006. These patents are awarded from over 2 million SIPO patent applications (15), which include all 129 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 (16). The assignee sectors are private enterprise, individual, university, state-owned (or -run) enterprise, public research institute, state-owned (or -run) institute, state, and hospital (table S1).

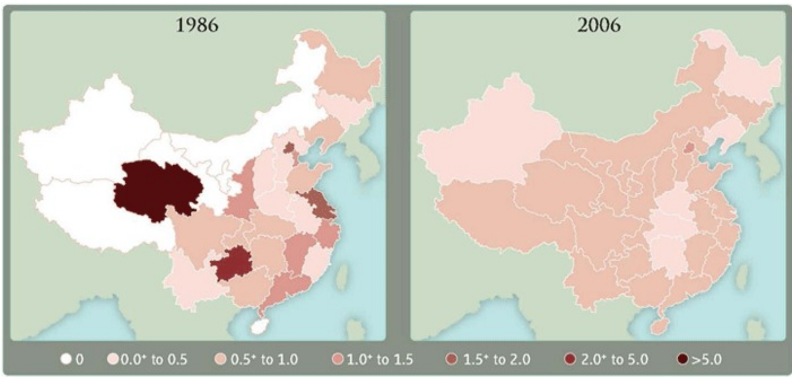


Table 1: Regional relative scientific and technological advantage by patent grant year.

The regions are 22 Chinese provinces, 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.

The analysis then focuses on over 200 thousand 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 (17–21), 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, microstructural technology, and nano technology (table S2).

Private, Domestic Growth

Patents granted across all patent classes and assignee sectors increased over 13% per year, on average, from 1986 to 2006 (fig. S1), despite China's relatively weak intellectual property (IP) environment, especially in terms of effectiveness in patent enforcement (22, 23). This may reflect the growth of direct foreign investment in China (24). 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 research and development (R&D) also may also have played roles (24).

In the 12 major science and technology classes, private enterprises—such as domestic firms and multinational corporations—steadily ascended to dominance after 2001 (see the first figure). 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 with individuals to develop such novel technologies. The SIPO patents granted in these 12 classes, led by medical sciences, semiconductors, communications, and computing (fig. S2), have grown from 12% of all patents in 1986 to over 20% of all patents in 2006 (table S3). 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 S4).

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%), U.S. (7%), Korea (3%), and Germany (2%) (fig. S3). The annual growth rate of SIPO patents assigned to Chinese entities averaged 33% during this period. U.S. assignees contribute about 55% of total USPTO patents in the 12 classes from 1986 to 2006; non-U.S. assignees from advanced economies like Japan's (24%), Germany's (5%), and Korea's (3%) largely make up the remaining (fig. S4). The annual growth rate of USPTO patents assigned to U.S. entities during this period averaged around 7%.

Geographic Diffusion

A relative scientific and technological advantage (RSTA) index (13, 25, 26) 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 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 the second figure. 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.

Conclusion and Future Research

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 patents granted to 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 evidence from the United States suggesting that diffusion of knowledge and innovation are geographically localized (12) and concentrated in major cities rather than outside (27), it could provide some validation to the goals of the Chinese government's policy to coordinate and develop the central and interior regions (16). 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.

Future research should untangle the complex relations linking spatial and temporal patterns of scientific and technological developments to investment environments and government policies. In addition, it will be important to investigate the strategic role of IP rights in shaping innovation and entrepreneurial ventures in China. Such valuable insights could stimulate sustainable R&D and entrepreneurship as China continues to transform from a manufacturing and industrial powerhouse into a knowledge-based economy.

Supplementary Online Material

http://www.sciencemag.org/cgi/content/full/329/5992/632/DC1

References and Notes

1. Based on gross domestic product (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).

2. Chinese president Hu Jintao called for greater emphasis on "technological advances and innovation to drive the good and fast development of the economy and society" at the opening ceremony of the member general assemblies of the Chinese Academy of Sciences and the Chinese Academy of Engineering on 5 June 2006.

3. 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 (28); analyses of their use entail assumptions, 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 (17–20), 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 (21). These patterns are more industry-specific than country-specific, although a weak IP environment can mitigate the propensity to apply for a patent (22, 23).

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14. 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., for the first radio communication device. An improvement patent modifies or builds on the technology of the basic patent, e.g., enhancements to the device.

15. 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.

16. Further notes on data, China's patent system, and government policy are available as supporting material on Science Online.

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