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Overview of U.S. - China Trade in Advanced Technology Products

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Introduction

This volume presents a series of papers prepared by U.S. and Chinese researchers examining the development of trade between the United States and China in advanced technology products (ATPs) at the Joint Symposium on U.S.-China Advanced Technology Trade and Industrial Development, October 23-24, 2009, in Beijing, China. The symposium was organized by the United States International Trade Commission, the School of Public Policy and Management at Tsinghua University, the Institute for International Economic Research at the National Development and Reform Commission, and the Brookings-Tsinghua Center for Public Policy at Tsinghua University. The goal of the research efforts presented at the symposium was to better understand the factors affecting U.S.-China ATP trade and the rapid growth of China as a platform for ATP production and trade.

ATP trade has been a fast-growing segment of U.S.-China bilateral trade relations. This topic is of great interest, given that the United States, an advanced economy, likely has a comparative advantage in ATPs and is well

[1] The views expressed in this paper are those of the authors alone. They do not necessarily reflect the views of the U.S. International Trade Commission or any of its individual Commissioners. The authors would like to thank Dylan Carlson and Caitlyn Carrico for their excellent research assistance.

known for its high levels of innovation and advanced research, as illustrated through its leadership position in global patenting. China, on the other hand, is a fast-growing developing country that has used export-led growth as a major part of its development strategy. China has particularly encouraged large amounts of foreign direct investment (FDI) in export processing zones in an effort to encourage technological spillovers. Based on its export volumes China's strategy has led to an incongruous result: China exports extraordinary large levels of ATP products to the United States relative to its level of development. Research by Dani Rodrik and others has found that the technological sophistication of China's exports more closely resemble those of a developed country than those of a typical developing country, such as Brazil or India.[2] However, research on supply and value chain linkages by Koopman, Wang, and Wei (2008) and Dedrick, Kraemer, and Linden (2008), among others, clearly illustrates that much of the content and value of China's ATP exports originates in third countries such as the United States, Japan, several countries of the European Union (EU), and South Korea, and historically has been exported from foreign-invested enterprises in China's export processing zones.[3]

The papers in this volume cover a wide range of topics and perspectives related to U.S.-China ATP trade, from microfocused papers centered on industry- or product-specific case studies to a discussion of a broad international trade agreement and an assessment of macroeconomic financial flows. Despite this diversity of topics, consistent themes include the importance of the fragmentation of the value chain across Asia and the proactive role of Chinese government efforts supporting ATP-related investment and production. In this introduction, we will first survey these papers, then provide an overview of U.S.-China ATP trade in order to supply a fuller context for understanding the papers' findings.

In the first paper "A Tale of Two Cities: A Comparison of Patent-based Innovative Performance of Domestic and Multinational Companies in China," Zheng Liang and Lan Xue provide a brief history of the evolution of the Chinese patenting system, then compare domestic Chinese innovation with multinational innovation by examining patent behaviors and trends, firm-

[2] In addition to Rodrik (2006), Schott (2008), and Fontagne et al (2007).

[3] See Koopman, Wang, and Wei (2008), Dedrick, Kraemer, and Linden (2008), Ferrantino, Koopman, Wang, & Yinug (2008), Johnson and Noguera (2009), and Daudier et al. (2008).

level innovation, and behavior differences with respect to the U.S. Patent and Trademark Office. They find that Chinese firms innovate through three main pathways: (1) by developing processes in lower levels of global value chains, (2) by competing with low-cost research and development activities, and (3) by catering to the local market.

Huang Xianhai, Yang Gaoju, and Lu Jing, in "China's International Specialization Status in Advanced Technology Industry: A Case Study of Zhejiang Pinghu Opto-mechatronics Industry Cluster," assess the driving forces behind the rise of an opto-mechatronics industry cluster in Pinghu, Zhejiang province, as a case study for the development of China's ATP industry. They find that despite some progress most of Pinghu's enterprises continue to serve as processing and assembly bases for multinational companies; as a result, few incorporate high value-added production activities such as research and development and design.

Yansheng Zhang, Dawei Li, Changyong Yang, and Qiong Du, in "On the Value Chain and International Specialization of China's Pharmaceutical Industry," provide an overview of the pharmaceutical industry value chain and examine China's role in the international specialization of the pharmaceutical industry. The authors use a Trade Competitiveness Index and intra-industry trade analysis to compare China's and India's pharmaceutical industries. They conclude that while India's specialization is at the more technically sophisticated end of the supply chain, China's specialization is at the low end of the non-propriety chain. However, China's domestic value added in pharmaceuticals is relatively larger than other supply chains in which China is at the low end. This is largely due to the small, local nature of raw medicine producers in China compared to the highly vertical MNC-driven production other products.

Michael Anderson and Jacob Mohs, in "The Information Technology Agreement (ITA): An Assessment of World Trade in Information Technology Products," provide a historical perspective on ITA product trade, examining global trade flows and accession of new member countries during the 12 years of the ITA. They find that global IT trade grew by 10.1 percent annually between 1996 and 2008, from $1.2 trillion to $4.0 trillion. A prominent feature of expanding ITA related trade is the broadening participation of Asian countries, led by Singapore, South Korea, Thailand, and particularly China. This growth is the result of fragmentation-based specialization throughout the Asian region. China's growth in ITA exports has made it the largest exporter of technology goods in the world, supplying $463.7 billion worth (25 percent of global share) in 2008.

Wenkai Sun, Xiuke Yang, and Geng Xiao, in "Understanding China's High Investment Rate and FDI Levels: A Comparative Analysis of the Return to Capital in China, the United States, and Japan," show that FDI inflows to China have increased at an average rate of around 20 percent per year for nearly two decades, expanding from $3.5 billion in 1990 to $92.4 billion in 2008. Investigating the future sustainability of high investment rates and FDI inflow to China, the authors find that the relatively low return to labor and the capital-output ratios in China are the two major factors behind the sustained high returns to capital in China. They see little evidence that the returns have started to decline, though one would expect them to do so in the longer term.

Katherine Linton and Mihir Torsekar, in "Innovation in Biotechnology Seeds: Public and Private Initiatives in India and China," compare and contrast the introduction and development of the biotechnology seed sector in China and India. In a case study of *Bacillus thuringiensis* (Bt) cotton, China evidenced greater government involvement throughout the process, with the result that domestic Bt cotton varieties now hold 80 percent of the market. India showed less direct governmental involvement, allowing a 50-50 joint venture with a U.S. company to take the lead. In both countries the authors found serious problems in three areas vital to biotech seed innovation, including market access issues (with limited access for foreign firms in China, and significant price caps in India); limitations and gaps in IP protection and enforcement; and long delays in regulatory review.

Greg Linden, Jason Dedrick, and Kenneth L. Kraemer, in "Innovation and Job Creation in a Global Economy: The Case of Apple's iPod," analyze the iPod value chain, and in particular the foreign manufacturing process, to demonstrate that the employment and wage effects of this supply chain rely on foreign-made components but U.S. design. The authors conclude that this case shows that innovation can have a positive effect on U.S. employment and wages despite the outsourcing of production jobs, especially if the United States remains a critical base for a highly skilled labor force.

Overview of U.S.–China ATP Trade

U.S. Exports of ATPs to China

This section briefly surveys the magnitude and composition of recent U.S. exports of ATPs to China and examines how such exports differ from U.S. ATP exports to the rest of the world (ROW).[4] Figures 1 and 2[5] illustrate the evolution of U.S. ATP exports to China recent years. U.S. ATP exports to China have grown steadily since 2000, increasing by an estimated annual 13 percent year-over-year and becoming increasingly concentrated in electronic products (e.g., semiconductors).[6]

U.S. ATP exports to China have also outpaced U.S. ATP global exports (figure 1), reflecting the growing prominence of China's market and processing platform and Chinese manufacturers' efforts to integrate ATPs into their supply lines. Electronic products constitute a large and growing share of U.S. ATP exports to China (figure 2). Semiconductors dominate this category, representing about 90 percent of U.S. electronic ATP exports to China in 2009.[7] The information and communication goods category (which consists of machine parts, voice and data imaging machines and parts, and processing and phone parts) have also figured prominently in U.S. ATP exports to China. These products can be broadly considered intermediary goods that the United States ships to China as components for final assembly of other products. This trade phenomenon reflects the trend toward international fragmentation of production, wherein certain developed countries, such as the United States, specialize in producing various segments of global supply chains based on comparative advantage.[8]

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[4] In this discussion ATP simply denotes high-technology goods. For statistical purposes we use the U.S. Census Bureau definition for three reasons: it attempts to capture innovation broadly through a dynamic approach to data classification; it does not appear to be associated with policy objectives; and it lacks a competing international standard. See Ferrantino, Koopman, Wang, and Yinug (2010), for a more in-depth discussion of classification issues for ATP trade between the U.S. and China.

[5] Figures are located after the references.

[6] This is an estimate, since the regular modifications of ATP definitions impede more precise calculations.

[7] Although U.S. aerospace exports, primarily airplanes, accounted for more than a third of U.S. exports to China in 2009, exports of these products tend to be sporadic.

[8] See Dean, Ferrantino, and Wang, "Measuring the Vertical Specialization in Chinese Trade" (2007) for example.

A more detailed review of U.S. ATP exports to China underscores the prominence of several sectors, particularly electronics. As seen in figure 3, electronics accounted for approximately 40 percent of U.S. ATP exports to China in 2009, but less than 20 percent of U.S. exports to the ROW. U.S. electronic exports to China (chiefly semiconductors) have risen from $922 million in 2000 to $5.3 billion in 2009. Figure 4 presents the difference in export shares between U.S. ATP exports to China and to the ROW for three selected years since China's accession to the WTO. In the absence of export specialization, we would expect differences in export shares to be minimal and converge toward zero in time. Unlike any or the other aggregate sectors, the China-ROW difference in the electronics sector has exhibited a substantial change from a large negative (a relative concentration of U.S. exports to ROW) to a large positive (a relative concentration of U.S. exports to China). The export growth described above, combined with the large and rapidly shifting share in the electronics sector, reflects the global value chain fragmentation mentioned above and discussed in a number of articles in this volume.

The information and communication, biotechnology, and aerospace sectors also present unique stories as well.

Information and Communication: Over the past decade the United States has exported relatively more information and communication products to the ROW than to China. This is largely attributable to growing U.S. shipments of computers to the ROW, which have outpaced the growth of such shipments to China. However, more recent surges in U.S. exports of computer components, such as hard drives, to China have more than offset these trends, a development which explains the convergence in U.S. information and communication exports to China and the ROW since 2001.

Biotechnology: The United States also exports far more biotechnology products to the ROW than China, and the gap has been growing. This is primarily attributable to the steady growth in U.S. exports of blood fractions and human vaccines to the ROW, which have remained nominal in China. The diverging export specialization profiles suggest a possible trade opportunity for U.S. exporters. Weak Chinese demand for such products does not appear to explain such trends; German and other European companies are increasingly competitive in China against Chinese domestic producers, and there is growing Chinese demand for U.S. high-technology health care products in the related medical device sector (which is subsumed in the "life sciences" category above).

Aerospace: U.S. aerospace exports to China have also been proportionately smaller than such exports to the ROW. This is largely attributable to lower shares of U.S. airplane exports to China relative to the ROW in this period. Although this may possibly signal an export opportunity for U.S. companies, the irregular nature of airplane sales, along with the fact that the export profile of U.S. airplane sales to China is gradually converging with that of U.S. airplane sales to the ROW, inhibit broader conclusions.

Chinese Exports of ATPs to the United States

This section surveys the size and composition of Chinese exports of ATPs to the United States and illustrates how they differ from Chinese ATP exports to ROW. Chinese ATP exports to the United States have expanded rapidly in recent years, becoming increasingly concentrated in consumer electronics.[9] U.S. ATP imports have been growing steadily in recent years, amounting to $300 billion in 2009. China has been the source behind much of this growth, supplying as much as 30 percent of U.S. ATP imports in 2009, compared with 6 percent in 2000 (figure 5). In addition, these imports from China have been increasingly specialized in ATPs. For example ATPs represented 12 percent of U.S. imports from China in 2000, but 30 percent by 2009 (figure 6).[10] U.S. ATP imports from China consist mostly of informational and communication products, nearly 90 percent in 2009 (figure 7); this category includes mainly consumer electronics such as computers and their parts, telephones, TVs and monitors, printer parts, and cameras. The other large category of U.S. ATP imports from China is opto-electronics (7 percent in 2009), consisting of other consumer electronic products such as flat screen monitors and projectors, printers, and solar panels. The value of U.S. information and communication

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[9] For simplicity, assumptions were made to best approximate Chinese ATP trade category values, given the imposition of more precise U.S. ATP definitions on Chinese trade data. Likewise, we disregard well known differences in U.S. and Chinese trade statistics (much of which derives from how Hong Kong trade flows are classified), given anecdotal evidence that such discrepancies are relatively small for ATP products. U.S. ATPs are defined at the HS-10 digit level, which is not directly comparable to the Chinese HS-10 digit level. For simplicity, we have assumed that every Chinese HS-6 digit category (which is comparable to the United States' HS-6 digit category) that included a HS-10 digit product under the U.S. Census definition was an ATP category.

[10] Although annual revisions to the ATP product definitions might qualify some of this growth if ATP selection criteria became progressively restrictive, such revisions would nonetheless be minor compared to overall ATP trade values. Moreover, if such revisions broadened the scope of what was considered an ATP product throughout the considered period, they would not alone account for the clear and systematic trend towards ATP trade specialization in Chinese exports to the United States.

ATP imports from China has grown from $10 billion in 2000 to nearly $80 billion in 2009, while that of opto-electronics imports has grown from $1.5 billion to $6.5 billion over the same period.

Chinese ATP exports to the United States assume a different profile than Chinese ATP exports to the ROW, particularly in the information and communication, and electronics sectors. As seen in figure 8, information and communication exports accounted for approximately 82 percent of China's ATP exports to the United States in 2009, versus 73 percent of those to the ROW. This relatively larger specialization of Chinese ATP information and communication exports to the United States reflects a recent and dynamic change in the sector, as shown in the way the differences between the share of these goods in China's exports to the United States and to the ROW have varied in the past decade (figure 9). As recently as 2001 and 2005, China was more specialized in exports of these products to the ROW than the United States. However, China has since substantially increased the share of these products exported to the United States, such that the market specialization has reversed from ROW to the United States. On the other hand, Chinese exports of opto-electronic goods to the United States, which outpaced those to the ROW in 2001 and 2005, have been converging towards the profile of China's exports to the ROW in recent years. In contrast to both of these developments Chinese electronic ATP exports have been notably concentrated in the ROW relative to the United States, a trend that has become more pronounced since 2001.

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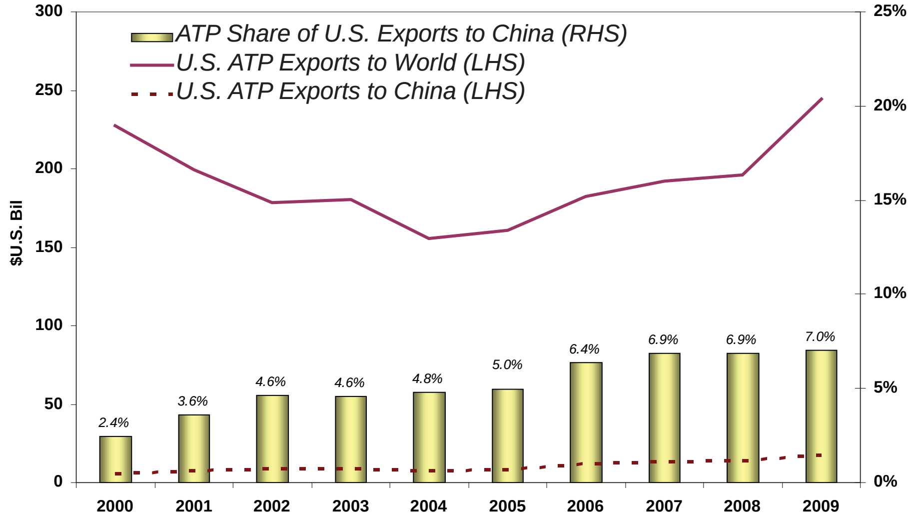
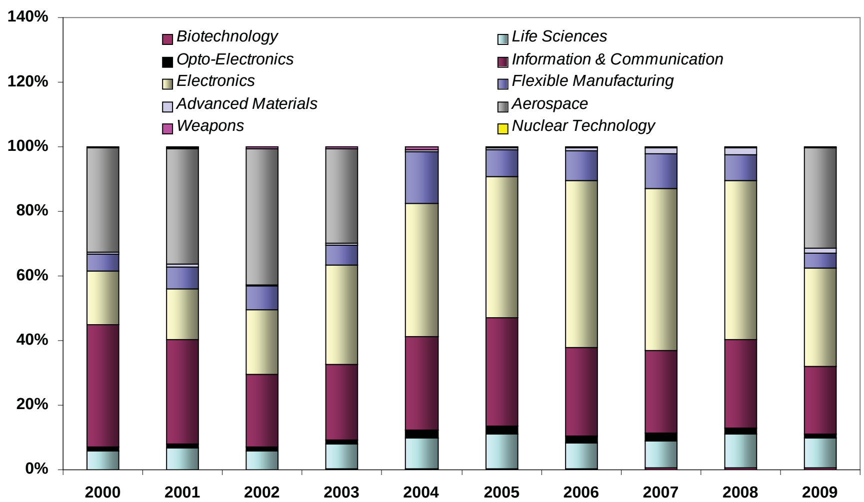
Figure 1: U.S. ATP EXPORTS TO CHINA
(In $U.S. Billions)



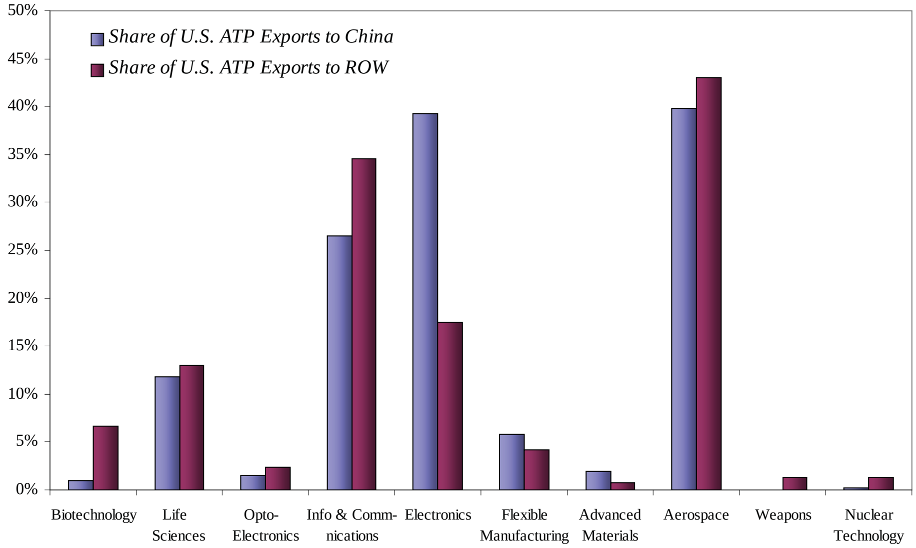
Source: World Trade Atlas

Figure 2: COMPOSITION OF U.S. ATP EXPORTS TO CHINA
(In percent)



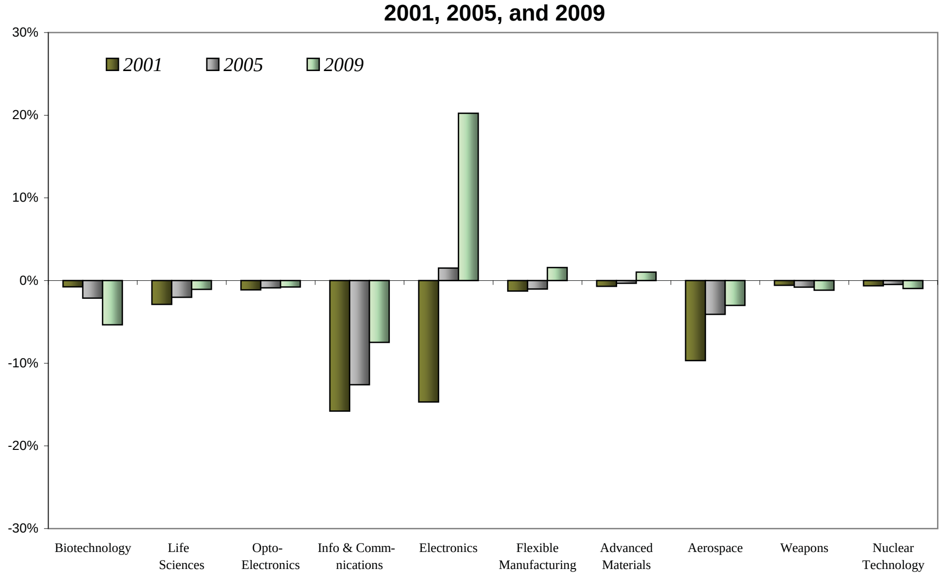
Source: World Trade Atlas

Figure 3: COMPOSITION OF U.S.ATP EXPORTS TO CHINA AND ROW BY SECTOR, 2009



Source: World Trade Atlas

Figure 4: DIFFERENCE BETWEEN U.S. ATP EXPORT SHARE TO CHINA AND ROW, 2001, 2005, and 2009



Source: World Trade Atlas

Figure 5: U.S. ATP IMPORTS
(In $US Billions)

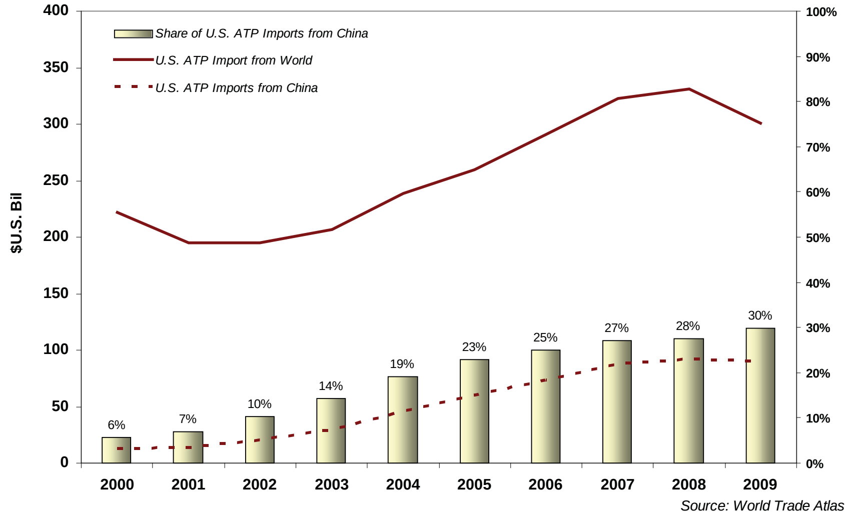


Figure 6: U.S. ATP IMPORTS FROM CHINA
(In $US Billions)

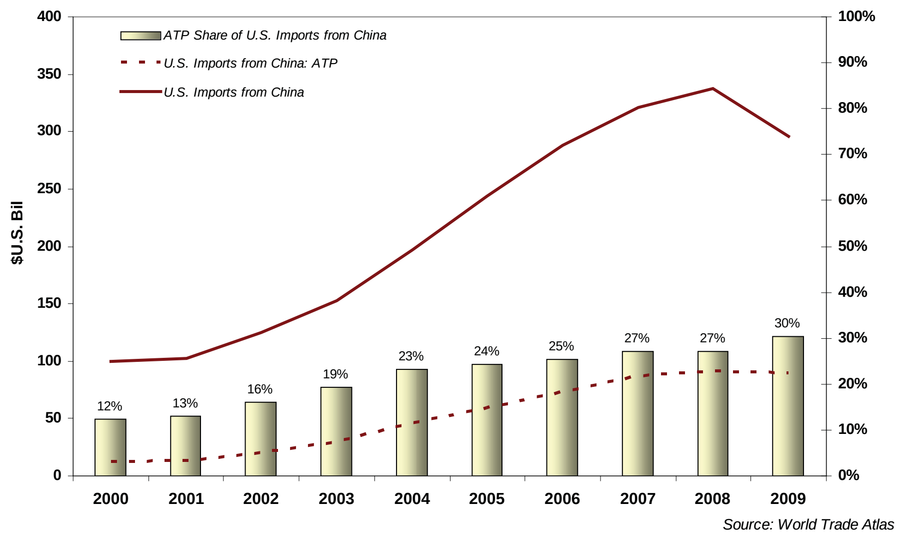


Figure 7: U.S. ATP IMPORTS FROM CHINA
(In percent)

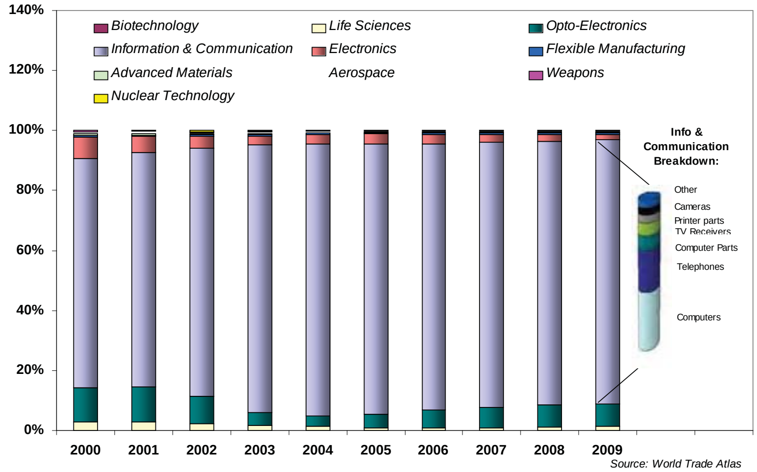


Figure 8: COMPOSITION OF CHINA'S ATP EXPORTS TO THE U.S. AND ROW
(2009)

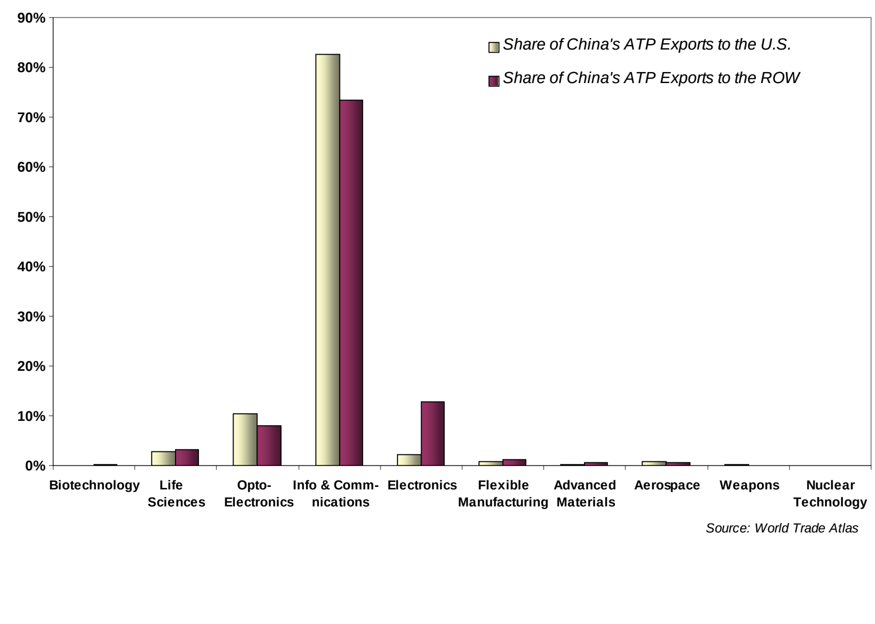
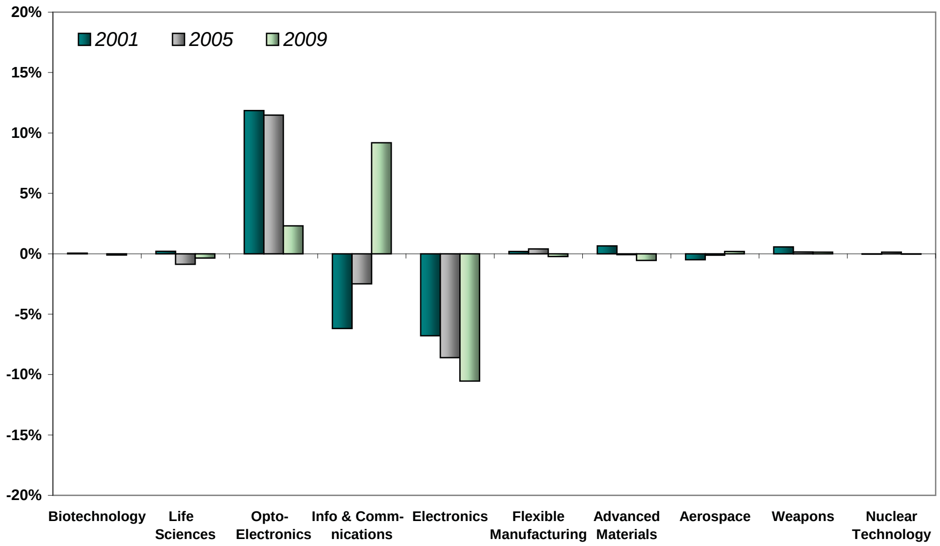


Figure 9: DIFFERENCE BETWEEN CHINA'S ATP EXPORT SHARE TO THE U.S. AND ROW, 2001, 2005, and 2009



Source: World Trade Atlas

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A Tale of Two Cities: A Comparison of Patent-based Innovative Performance of Domestic and Multinational Companies in China

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Abstract

The most remarkable economic phenomenon of the past 30 years may be China's "growth miracle." According to the World Bank (2003), the average growth rates for Chinese gross domestic product (GDP) during the 1980s and the 1990s were 10.1 percent and 11.2 percent, respectively, making China one of the fastest-growing economies in the world. The abandonment of centralized planning and the establishment of market institutions, as well as the market opening to foreign investment, have been credited as keys to the success of this growth. However, China's economic miracle is often attributed to relative abundance of inputs such as labor and natural resources, and not to Chinese innovation. Is this true? What

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about the innovative performance of China's domestic enterprises, in comparison with their competitors from abroad? In this paper, the question is explored using Chinese and U.S. patent data to estimate the innovative performance of firms.

Introduction

The conventional wisdom about intellectual property rights (IPR) is that strong IPR protection generates incentives for investment in research and development (R&D) and, hence, for technological progress in society (Arrow 1962; Nordhaus 1962; Scherer 1972). In addition, IPR protection helps disseminate technical information and reduce social cost (Malchup 1958)—the "information disclosure effect." All of these benefits make patents not only indicators of innovative performance and capabilities, but also the source of new innovations. At the same time, protecting IPR by assigning a monopolistic right to a piece of knowledge also entails economic costs. A monopoly position in a technology deters other firms from trying themselves to invent "in the neighborhood" (Scotchmer and Green 1990; Green and Scotchmer 1995). As a result, interactions between patent players have multidimensional effects on innovation.

Understanding the role of patents in China is further complicated by the fact that the Chinese economy in the reform era has been far more open than that of many other countries at a comparable stage of development. The patent system in China from the very start faced the double challenge of meeting the demands of multinational companies, which required strong IPR protection, while at the same time satisfying the appeals of domestic companies, which favored an IPR regime conducive to technology transfer and diffusion. This may have led to strategic use of the system, resulting in patenting behavior

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that does not necessarily reflect real innovative performance (Liang and Xue 2010).

In this paper, using empirical evidence from China, the patenting behavior of domestic and multinational firms in China is analyzed in comparison to their innovative performance based on patent data. The paper is organized as follows: part I describes the research methodology; part II briefly describes the evolution of China's patent system; part III investigates the patenting behavior of multinational firms and domestic players at the national level; parts IV and V evaluate the innovative performance of domestic and multinational firms in China at the firm level; part VI compares the patenting behavior of domestic and multinational firms based on the U.S. Patent and Trademark Office (USPTO) data; and part VII notes trends in innovation and patent use among both types of firms while touching briefly on future possibilities.

Methodology

Our analysis is carried out on two levels: at the national level, using patent data on applications, grants, validation, and other parameters, and at the enterprise level. We obtained data about individual and corporate players, both foreign and domestic, as well as different types of patents, including inventions, utility models, and designs, from the Statistical Annals of the State Intellectual Property Office of the People's Republic of China (SIPO) from 1985 to 2007. At the enterprise level, we chose the top 500 firms in China and the top 500 firms globally as the comparative samples.

For our domestic sample, from the list provided by SIPO, we selected 652 enterprises affiliated with China's 500 largest corporations in 2006, each of which had at least one invention patent application before the end of 2004.[2] We found 16,109 invention patent applications from these firms from April 1, 1985, to December 31, 2004, representing 4.62 percent of the total

[2] The list has been jointly issued by the Chinese Enterprise Alliance and the Chinese Entrepreneur Association annually since 2004 and ranked by total revenues. The 2006 ranking list (in Chinese) is available at *http://www.cec-ceda.org.cn/huodong/2006china500*. The 652 corporations selected were affiliated with the 500 largest corporations in 2006.

domestic invention patent applications in this period.3 For each application, we obtained the following information: the application date, grant date, prior right,4 assignees, inventors and their addresses, the International Patent Classification (IPC) section number, and the IPC class number.5 For comparison, we chose the Fortune Global 500 list (2006) as the foreign sample. From the list provided by SIPO of foreign firms that had at least one invention patent application before the end of 2004, we selected 775 affiliated corporations of the above firms. We then searched in SIPO's database and found 108,747 invention patent applications issued by these firms from April 1, 1985, to December 31, 2004, representing 30.47 percent of the total foreign invention patent applications in China in this period. Finally, we used USPTO patent data to compare the patent behavior of domestic and multinational firms operating in China.

[3] One firm might have several sub-firms applying for patents in China. Invention data were used instead of patent data because inventions involve more actual technology creation than do the other two forms of patents. Also, this is the only comparable patent field between multinational and domestic firms because most of the patent applications of multinational firms in China are for in-service inventions, and domestic firms are also the only dominant applicants in domestic in-service invention applications. (The in-service invention means the invention made by employee and assigned to the employer.)

[4] In patent law, a "priority right" (or right of priority) is a time-limited right, triggered by the first filing of an application for a patent. The priority right belongs to the applicant or his successor in title and allows him to then file a subsequent application for the same invention and use data from the date of filing of the first application. When filing the subsequent application, the applicant must "claim the priority" of the first application in order to make use of the right of priority. The period of priority is usually 12 months for patents.

[5] The Strasbourg Agreement (1971) concerning the IPC provides for a common classification of patents for invention, including published patent applications, utility models, and utility certificates. The IPC is a hierarchical system in which the whole area of technology is divided into a range of sections, classes, subclasses, and groups. This system is indispensable for the retrieval of patent documents when attempting to establish the novelty of an invention or determine the state of the art in a particular area of technology.

Background: The Evolution Of China's Patent System

China's first patent law was enacted in 1984 and came into force in April 1985. In general, the Chinese patent system has more in common with the Japanese system than with that of the United States. For example, the primary purpose of China's patent law is to facilitate the diffusion of new technologies, which is demonstrated by the three kinds of patents allowed (invention, utility model, and design),[6] their shorter period of validity the adoption of the principle of "first-to-file" instead of "first-to-invent," public disclosure of the invention after 18 months, and mixed requirement of single and multiple privilege claims. Typically, the adoption of "petty patents," such as utility models and designs, are mainly intended to encourage gradual innovation, which is often very important for domestic applicants. This ambition has been achieved in part, according to some empirical studies (Liu et al. 2003; Hu 2006).

China's patent system has evolved in three main stages. The first stage—the founding of China's IPR system—was from 1985 to 1992. Before 1985, China only had a Management System of Science and Technology Achievement, which belonged to the nation and could be freely used**.** While China's first patent law made it possible for individuals to file patents, it was difficult for inventors to extract monopoly rents except for occasional rewards for inventions (Alford, 1995). At the same time, without permission from the relevant administrative departments in the government, state-owned enterprises (SOEs) could not deal with their patents autonomously (e.g., licensing them out). These limitations dampened the enthusiasm of SOEs, as well as their technical staff, who were key players in industrial R&D. The first patent law also excluded chemical, pharmaceutical, and food or food processing inventions from patent coverage. This was regarded as creating an intentional tilt towards domestic industries, disadvantaging foreign applicants. These issues reflected the evolving balance between stimulating indigenous innovations and sharing in the worldwide knowledge pool by enforcing patent protection.

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[6] In China's patent law, "invention" means any new technical solution relating to a product, a process or improvement therefore. "Utility Model" means any new technical solution relating to the shape, the structure, or their combination, of a product, which is fit for practical use. "Design" means any new design of the shape, the pattern, or the combination, or the combination of the color with shape or pattern, of a product, which creates an aesthetic feeling and is fit for industrial application.

During the second stage, from 1992 to 2000, China's patent system made substantial progress. In the first revision of the patent law in 1992, the duration of patent protection for inventions was extended from 15 to 20 years, and the duration of utility model and design patents was extended from 5 to 10 years. Food, beverages, flavoring, pharmaceutical products, and substances obtained via chemical processes were also covered by patent protection. Another addition to the law was domestic priorities for filing applications. Individuals were allowed to own patents for inventions created during employment if an agreement was made between individuals and employers. All these amendments inspired rapid growth in patent applications.

The third stage is from 2001 to the present. China's patent law experienced a second major revision in 2000. In this revision, state-owned and privately owned enterprises were treated as equals for obtaining patent rights. Other amendments were mainly made to fit World Trade Organization (WTO) requirements, especially those in the Trade-Related Aspects of Intellectual Property Rights (TRIPS) Agreement; one example was the simplification of the examination process. Chinese authorities also increased efforts in IPR protection, with some success. One sign is that damages awarded for patent infringement by the courts have increased tremendously, from hundreds of thousands to tens of millions renminbi (RMB). All of these changes together led to another surge in patent applications.

A Comparison Of Patenting Behaviors Of Domestic And Multinational Companies In China

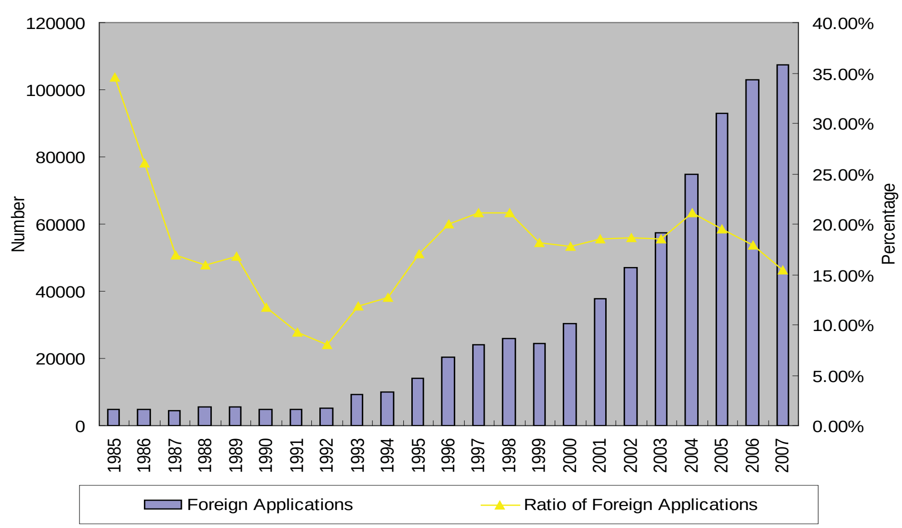
As discussed above, the evolution of China's patent system echoed the needs of different entities. Once it was founded, it would inevitably mold the behavior of these entities, even though they may have had completely different motivations. The observation of different behavior by multinational and domestic firms under the same patent system is one of the main concerns of this paper. In this section, we use the annual data issued by SIPO to examine firms' patent applications, grants, and validity in China, in order to discern their innovative performance.[7]

Sources of Patents

As figure 1 reveals, after a lukewarm start, foreign patent applications began to pick up following the first revision of China's patent law in 1992. This can be seen not only in the absolute numbers but also in the figures for foreign applications as a percentage of total applications. As discussed above, this revision brought patent standards in China closer to international standards. Furthermore, with the incentive of favorable policies, there also emerged the first surge of FDI inflows into China since the early 1990s. These two factors together led to a sharp increase of patent applications from foreigners, whose main ambition was to protect their sales and profits in China.

By contrast, the second revision of the patent law in 2000 induced a rapid increase of domestic and foreign applications simultaneously. The growth in domestic patent applications was also strongly stimulated by the central government's initiation of a new patent strategy in 2000, under which patents

Figure 1 Applications for the three kinds of foreign patent applications and their ratio to total applications (1985–2007)



[7] All the data used in this paper are cited from SIPO Statistical Annals, if not otherwise indicated.

became new evaluation indicators for industrial innovation, especially in public-funded projects. Considerable subsidies and bonuses were awarded to patent applicants by both the central government and local governments.

As shown in figure 2, the ratio of foreign to total invention patent applications reached its peak (62.24 percent) in 1997. After 1997, however, because of the increasing social recognition of patents and strong incentives from the government, domestic applications started growing at a faster rate, surpassing the figure for foreign applications in 2003 even as the latter were still increasing.

More interesting findings are revealed when we observe different kinds of patents as well as patents granted. Even until 2007, more invention patents are granted to foreigners than to locals, although the gap has quickly narrowed in the past five years. From figure 3 we can see distinct fluctuations in grants of invention patents over the past 20 years. Invention patent grants generally decreased for several years after the first revision of the patent law, with grants of patents to foreign applicants decreasing at a faster rate; this resulted in the first decrease in the ratio of foreign to total invention patent grants, from 1990 to 1996. However, as shown in table 1, after 1996 the granting ratio for domestic invention patent filers was distinctly lower than that of foreigners even as the number of domestic applications began to exceed foreign ones, which appears to indicate that the quality of patents filed by domestic entities is comparatively poor.

There are, however, major differences in the behavior of foreign and domestic applicants for utility model and design patents. As table 1 shows, from the patent system's founding in China to the present, domestic applicants have generated more than 99 percent of applications for utility models and more than 93 percent of applications for designs, with similar percentages for the numbers granted. Moreover, these petty patents, which require less progress on technological capabilities and technical breakthroughs and which incentivize incremental innovations and the diffusion of knowledge, are mainly used by domestic players. So, given the analysis above, it can be concluded that the increase in patent applications in China has been mainly due to domestic players' efforts to obtain petty patents which, in turn, is largely the result of the three-tiered system.

Figure 2 Distribution of annual domestic and foreign invention applications (1985–2007)

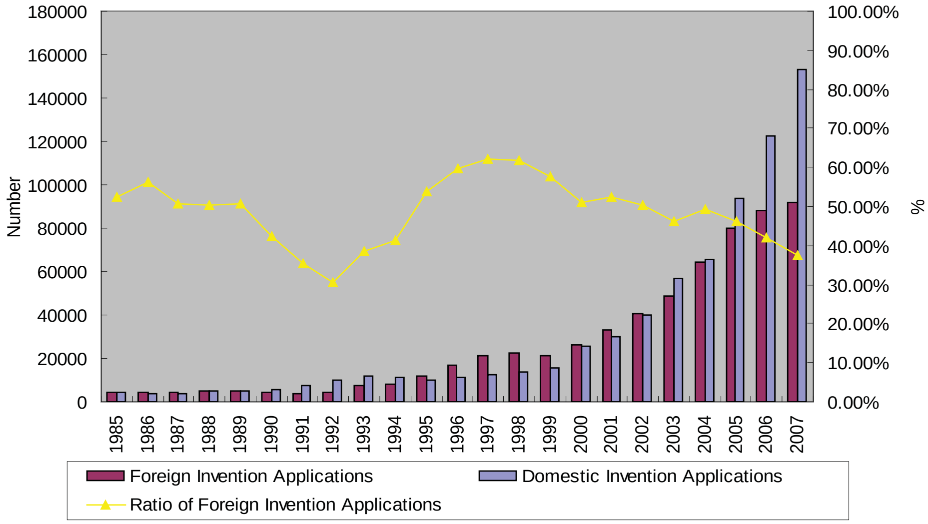


Figure 3 Annual distribution of grants of invention patents to domestic and foreign applicants (1985–2007)

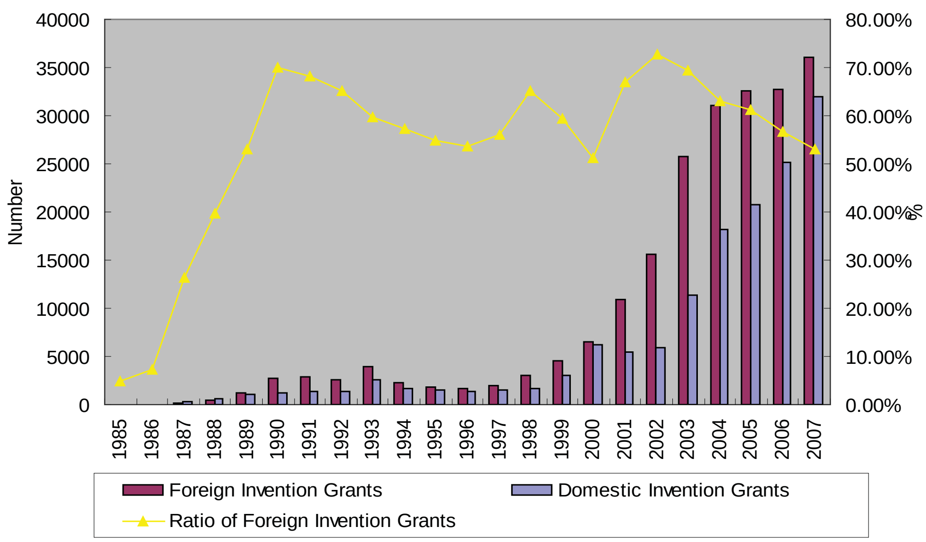


Table 1 Total domestic and foreign applications for the three kinds of patents (April 1985–September 2008)

		Total		Invention		Utility Model		Design	
		Number	Ratio	Number	Ratio	Number	Ratio	Number	Ratio
Total	Sum	4576636	100.00%	1534934	100.00%	1623279	100.00%	1418423	100.00%
	In-service	2310455	50.50%	1184568	77.20%	516158	31.80%	609729	43.00%
	Non-service	2266181	49.50%	350366	22.80%	1107121	68.20%	808694	57.00%
Domestic	Sum	3780652	100/82.6	848390	100/55.3	1611467	100/99.3	1320795	100/93.1
	In-service	1545971	40.90%	522632	61.60%	507198	31.50%	516141	39.10%
	Non-service	2234681	59.10%	325758	38.40%	1104269	68.50%	804654	60.90%
Foreign	Sum	795984	100/17.4	686544	100/44.7	11812	100/0.7	97628	100/6.9
	In-service	764484	96.00%	661936	96.40%	8960	75.90%	93588	95.90%
	Non-service	31500	4.00%	24608	3.60%	2852	24.10%	4040	4.10%

Source: SIPO 2008a.

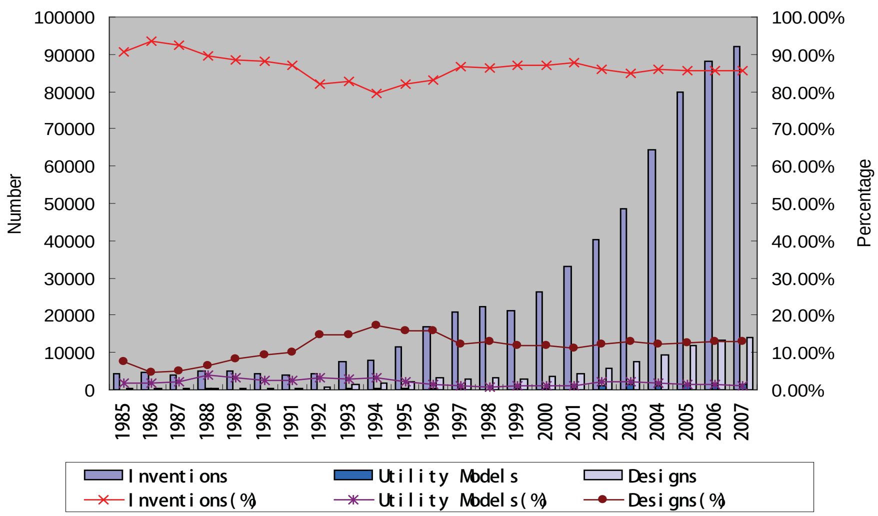
Structure of Patents

Figures 4 and 5 give us a clearer idea of the differing behavior of foreign and domestic patent applicants. As figure 4 shows, the distribution of the three kinds of foreign patent was very stable during 1985–2007; invention patent applications were dominant, which means that foreign players (mainly firms) concentrated mostly on high-quality patents. In most years, invention patent applications accounted for more than 85 percent of the total applications.

Another interesting phenomenon is that although foreign applicants seldom applied for utility model patents (even though these were regarded as "part of inventions" by China's patent law), they did apply for quite a few design patents. Nonetheless, the ratio of foreign design applications to total applications never exceeded the peak of 17 percent in 1994. Even in 2007, foreigners submitted 1,325 utility patent applications, less than 14 times the number submitted in 1985 (97). But during the same period, foreign invention patent applications in China expanded 20-fold (4,493 to 92,101), and foreign design patent applications expanded nearly 38-fold (371 to 13,993). As some commentators have noted, given that the protection of trademarks in China is weaker than that of patents and given also that they are similar to some extent, some companies may combine trademark registrations with design patent applications (Yang et al. 2004).

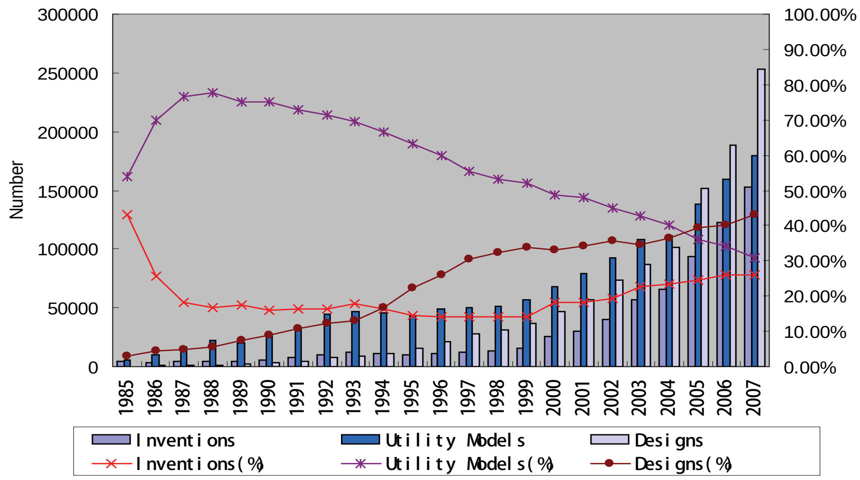
In comparison, as figure 5 shows, the distribution of domestic patent applications is very different from that of foreign applications. Although applications for utility model patents have been dominant in the long term, the ratio of these applications to total applications began to decrease continuously after reaching a peak (77.64 percent) in 1988; this was because of the rapid rise in the number of applications for invention and design patents, especially the latter.

Figure 4 Distribution of annual foreign applications for the three kinds of patents, 1985–2007



As figure 5 depicts, there was a surge of invention patent applications after 2000, but design patent applications expanded even more quickly. As a result, among all patent applications received from domestic applicants in 2007, applications for design patents predominated (43.21 percent), while those for utility model patents ranked second (30.69 percent), followed by those for invention patents (only 26.1 percent). In China, utility models and designs, unlike inventions, need not undergo substantial examination before a patent is granted. Also, because utility model patents have stricter requirements in terms of technological creativity, domestic applicants may have an incentive to select design patents as their first choice of application type, especially small enterprises in traditional areas such as food and beverages.

Figure 5 Distribution of annual domestic applications for the three kinds of patents, 1985–2007



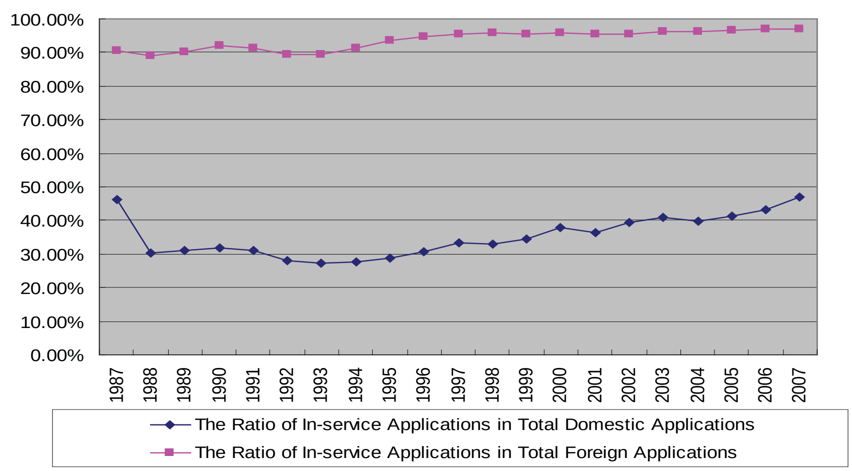
Characteristics of Applicants

More detailed information on the characteristics of foreign and domestic applicants can reveal major differences between them. As figure 6 and table 1 show, in-service applications occupied dominant positions in total applications received from abroad; most of these applications was submitted by multinational companies.[8] Moreover, the ratio of in-service applications to total foreign applications from 1987 to 2007 was very stable and seldom fell under 90 percent, as figure 5 shows. On the other hand, in-service applications did not exceed 50 percent of annual domestic applications until 2007. What factors account for this difference? If all of the applications are divided into the three kinds of patents, the answer may become clearer. As table 1 shows, there are no distinct differences among in-service application ratios for the three kinds of patents sought by foreigners, except for the relatively low ratios for utility models (75.90 percent). As noted before, the annual number of foreign applications for utility model patents was much lower than that for the other two kinds of patents. It seems that multinational firms seldom apply for utility model patents.

[8] An in-service application refers to an invention by an employee of a company that is made as part of that employment. Once the application is granted, an in-service patent belongs to the employer. For an application that is not in-service, the individual inventor is the patent holder.

At the same time, domestic applications for the three kinds of patents showed nearly diametrically opposite trends. Among total domestic applications for invention patents, more than 60 percent were in-service. But for utility models, this ratio just exceeds 30 percent, and for designs, the ratio is nearly 40 percent. So it can be concluded that most petty patents in China are sought by Chinese individuals, not by firms and other organizations. The high ratio of individual patent applications in China may be attributed to two factors. First, quite a few petty patents in China are generated by small businesses indeed. But in order to save costs and avoid disputes on property rights, the entrepreneurs themselves may file for many of the patents originated by these firms. Second, because of the ambiguity of the identification of in-service and non-service patents, along with the incomplete IPR protection and incentive systems inside many organizations, some patent applications submitted by corporations are actually filed by individuals.

Figure 6 Comparisons of the ratios of domestic and foreign in-service patent applications



Patent Validity

Once a patent is granted, the patentee must pay annual fees to maintain the validity of the patent. Generally, the patentee will pay this fee only when he or she estimates that the return on this patent will exceed the cost of maintaining it. So we can partially estimate the quality and value of a patent from its validity. As table 2 shows, through 2007, of all the patents granted by SIPO in the past 23 years, only 40 percent were still valid (in force). The validity ratios for each the three kinds of patents granted to foreigners are higher than those for domestic patents, which implies that foreign patents are more valuable than domestic ones. At the same time, the gap between domestic and foreign invention patents is not very large (66 to 80 percent) compared to the huge gaps for utility models and designs. These gaps suggest that although domestic applications and grants of petty patents grew very quickly in China during 1987–2007 and contributed to the total increase in patents, their quality was still poor compared to the same kind of patents held by foreigners. In fact, many petty patents were given up by the patentees themselves after a short term. From table 2 we can also see that, whether foreign or domestic, the invention patents had the highest validity ratios, which means that invention patents are more valuable than petty patents in China, just as in other countries. According to our interviews with some local firms, the lower validity ratio of patents is also due to the Chinese firms' poor management of IPR, especially the lack of strategic planning and commercializing capabilities in the management and use of patents.

Innovative Performance Of Domestic Firms: Evaluation By Patent Data

As mentioned earlier, China's 500 largest corporations in 2006 were chosen as the population for investigation. During the period 1985–2004, sampled domestic firms applied for a total of 16,109 invention patents in China. Figure 7 presents the annual number of domestic sample firms' invention patent applications. Before 1999, such applications were rare. The first round of patent law amendment boosted domestic firms' invention patent application activities to some degree, but this was not very evident. After 2000, with the second round of patent law revisions, domestic firms' innovation levels increased noticeably, especially in 2002, when invention patent applications increased by 92 percent from the previous year, reaching a total of 3,625.

Table 2 Total numbers of patents applied for, granted, and in force for the three kinds of patents, by domestic and foreign applicants (April 1985 through December 2007)

		Total		Invention		Utility Model		Design	
		Number	%	Number	%	Number	%	Number	%
Total	Application	4028284	100.00	1334676	33.10	1471191	36.50	1222417	30.30
	Grant	2089286	100.00	364451	17.40	988264	47.30	736571	35.30
	In Force	850043	100.00	271917	32.00	299242	35.20	278884	32.80
	Grant/Application		51.87		27.31		67.17		60.26
	In Force/Grant		40.69		74.61		30.28		37.86
Domestic	Application	3314355	82.30	718207	21.70	1460557	44.10	1135591	34.30
	Grant	1790379	85.70	144387	8.10	980029	54.70	665963	37.20
	In Force	622409	73.20	95678	15.40	294463	47.30	232268	37.30
	Grant/Application		54.02		20.10		67.10		58.64
	In Force/Grant		34.76		66.26		30.05		34.88
Foreign	Application	713929	17.70	616469	86.30	10634	1.50	86826	12.20
	Grant	298907	14.30	220064	73.60	8235	2.80	70608	23.60
	In Force	227634	26.80	176239	77.40	4779	2.10	46616	20.50
	Grant/Application		41.87		35.70		77.44		81.32
	In Force/Grant		76.16		80.09		58.03		66.02

Source: SIPO 2008b.

Figure 7 Invention patent applications of domestic sample firms (1985–2004)

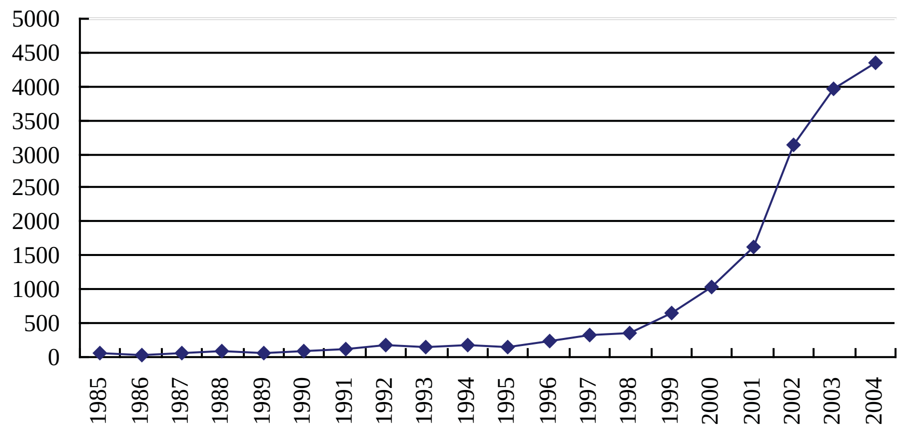


Table 3 presents the provincial distribution of domestic sample firms' invention patent applications. Beijing, Guangdong, and Shanghai are the three provinces with the most such applications, accounting for over four-fifths of the total.

Table 4 lists domestic firms with over 200 invention patent applications during the two decades. Huawei Technology Ltd. applied for 5,365 such patents and ranked first, accounting for as much as 33.3 percent of all invention patent applications filed by sample firms. SINOPEC,[9] Lenovo Ltd., and ZTE Corporations followed Huawei Technology. These five corporations submitted more than 60 percent of the total invention patent applications filed by all companies in the sample. SINOPEC and Huawei together accounted for 54 percent of applications from the top 500 firms, showing that the top domestic invention patent filers are highly concentrated and that the main players are just several large corporations. However, as stated before, all of the sample companies accounted for only 4.62 percent of the total domestic invention patent applications, which means that more than 95 percent of these applications were submitted by firms outside the top 500. In other words, except for several unique firms, invention patent applications are highly dispersed in China.

[9] Includes China Petroleum and Chemical Ltd., China Petroleum and Chemical Group, and China Petroleum and Chemical Corporation.

Table 3 Top 10 provinces accounting for domestic sample firms' invention patent applications (1985-2004)

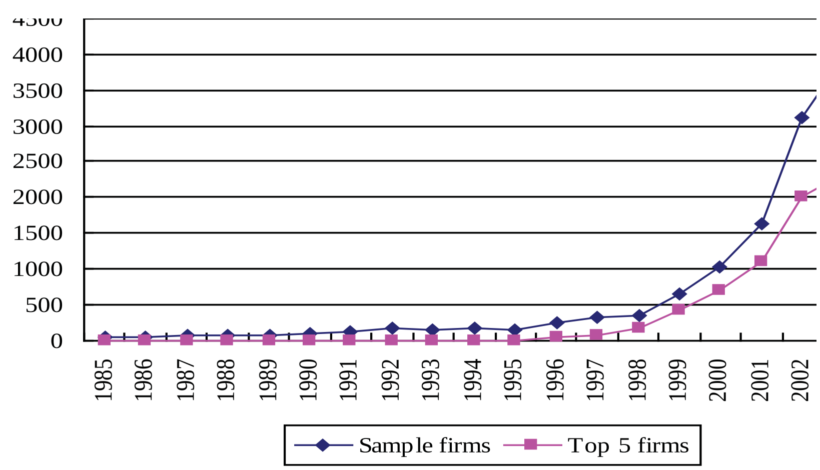
Province	**Invention patent applications**	**Percentage**
Beijing	6,586	39.08
Guangdong	6,544	38.83
Shanghai	917	5.44
Shandong	552	3.28
Liaoning	341	2.02
Jiangsu	277	1.64
Hubei	240	1.42
Sichuan	226	1.34
Hunan	166	0.98
Hebei	160	0.95
Total	16,009	94.98

Table 4 Domestic sample firms with over 200 invention patent applications (1985–2004)

Patentee	Industry	Invention application	Percentage
Huawei Technology Ltd.	IT	5,365	33.30
SINOPEC (China Petroleum and Chemical Ltd.)	Chemicals	2,093	12.99
SINOPEC (China Petroleum and Chemical Group)	Chemicals	782	4.85
Lenovo Ltd.	IT	745	4.62
ZTE Corporation	IT	739	4.59
SINOPEC (China Petroleum and Chemical Corporation)	Chemicals	458	2.84
PetroChina Company Limited	Chemicals	346	2.15
Baosteel Ltd.	Steel	325	2.02
Haier Ltd.	Household Durables	256	1.59
Total		11,109	68.95

Figure 8 illustrates invention patent applications of the top five firms listed above, in comparison with the total applications by firms in the sample. Before 1998, these firms submitted very few patent applications. From 1999 to 2002, the share of invention patent applications by the top five firms kept rising, representing 80 percent of overall annual applications by firms in the sample. After 2002, however, the top five firms' rate of applications slowed and they were outpaced by other firms, reflecting a greater recognition of the importance of patents and improved innovation capabilities of other domestic firms.[10] As mentioned above, government incentives since 2000 relating to patent applications (inventions were given more emphasis and stronger incentives) helped spur this increase.

Figure 8 Number of invention patent applications submitted by top five domestic firms and by sample firms (1985–2004)



[10] According to statistics, the average R&D intensity (R&D expenditure to total revenue) of China's large and medium-sized companies increased from 0.46 percent to 0.83 percent during 1995 and 2002.

Table 5 IPC subclass distribution of domestic sample firms' invention patent applications (1985-2004) (those with more than 200 applications)

IPC subclass number	IPC subclass	Invention patent applications	Percentage
H04L	Transmission of digital information, e.g., telegraphic communication	2,675	16.61
H04Q	Selecting	1,595	9.90
G06F	Electric digital data processing	1,120	6.95
C10G	Cracking hydrocarbon oils; production of liquid hydrocarbon mixtures, e.g., by destructive hydrogenation, oligomerisation, polymerization	1,067	6.62
B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	826	5.13
H04J	Multiplex communication	726	4.51
H04B	Transmission	598	3.71
C07C	Acyclic or carbocyclic compounds	570	3.54
H04M	Telephonic communication	539	3.35
C08F	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds	396	2.46
H04N	Pictorial communication, e.g., television	368	2.28
C01B	Non-metallic elements; compounds thereof	274	1.70
G01N	Investigating or analyzing materials by determining their chemical or physical properties	251	1.56
C22C	Alloys	226	1.40
Total		11,231	69.72

Table 6 lists the top five IPC subclass classifications for each of the top five corporations listed in table 4. It can be seen that the top corporations' inventions are highly concentrated in a limited number of IPC subclasses. Generally, the top five categories of IPC subclasses make up 70 to 80 percent of the overall invention patent applications of a given corporation. Some companies focus on a single very specific area. For example, as table 6 shows, more than 60 percent of Lenovo's applications fell into one category—G06F. At the same time, some companies, such as Huawei and ZTE, overlap significantly in the areas in which they file patent applications, which may reflect the convergence of their technology and patent strategies. Additionally, in certain categories, some companies have overwhelming advantages. For example, in the H04L category, Huawei submitted nearly 12 times as many applications as its biggest domestic competitor, ZTE, and 16 times as many as another potential competitor, Lenovo. The same relationship can also be found between SINOPEC and PetroChina. In the C10G category, for example, SINOPEC submitted more than 22 times as many applications as PetroChina.

Comparing table 6 with table 5, it can be seen that the IPC subclass distributions of the top firms' applications are very similar to the distributions of all sample companies. This reflects the fact that among the top companies in China, invention patent applications are highly concentrated among several firms whose patent strategies and filing areas have great influence over the total sampled population. For example, Huawei applied for 2,107 inventions in the H04L subclass, which accounted for nearly 40 percent of its total applications and 78.8 percent of the overall invention patent applications in that subclass submitted by all sample firms; this reflects Huawei's dominant advantages in this area.

Table 6 IPC subclasses distribution of the top 5 domestic sample firms (1985-2004)

IPC Subclass Number	IPC subclass	Invention Application	Percentage
Huawei			
H04L	Transmission of digital information, e.g., telegraphic communication	2107	39.27
H04Q	Selecting	1134	21.14
H04J	Multiplex communication	496	9.25
G06F	Electric digital data processing	390	7.27
H04B	Transmission	385	7.18
SINOPEC			
C10G	Cracking hydrocarbon oils; production of liquid hydrocarbon mixtures, e.g., by destructive hydrogenation, oligomerisation, polymerization	921	27.63

B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	669	20.07
C07C	Acyclic or carbocyclic compounds	421	12.63
C08F	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds	279	8.37
C01B	Nonmetallic elements; compounds thereof	184	5.52
Lenovo			
G06F	Electric digital data processing	454	60.94
H04L	Transmission of digital information, e.g., telegraphic communication	129	17.32
H04M	Telephonic communication	30	4.03
H04Q	Selecting	26	3.49
H04N	Pictorial communication, e.g., television	19	2.55
ZTE			
H04L	Transmission of digital information, e.g., telegraphic communication	179	24.22
H04Q	Selecting	152	20.57
H04J	Multiplex communication	128	17.32
G06F	Electric digital data processing	63	8.53
H04B	Transmission	63	8.53
PetroChina			
C10G	Cracking hydrocarbon oils; production of liquid hydrocarbon mixtures, e.g., by destructive hydrogenation, oligomerisation, polymerization	41	11.85
C08F	Macromolecular compounds obtained by reactions only involving carbon-to-carbon unsaturated bonds	35	10.12
C10M	Lubricating compositions; use of chemical substances either alone or as lubricating ingredients in a lubricating composition	31	8.96
C07C	Acyclic or carbocyclic compounds	29	8.38
B01J	Chemical or physical processes, e.g., catalysis, colloid chemistry; their relevant apparatus	24	6.94

Innovative Performance Of Multinational Companies: Evaluation By Patent Data

As mentioned earlier, Fortune Global 500 firms (2006) were used as the population of foreign companies. During 1985 to 2004, foreign sample companies filed a total of 108,747 invention patent applications in China, about 10 times the number filed by domestic sample firms. Figure 9 presents the annual number of foreign sample firms' invention patent applications. As the figure shows, multinational companies' invention patent applications in China peaked twice, with the first peak around 1993 and the second around 2001, similar to the earlier findings in this paper. From 1993 to 1997, foreign applications increased by over 50 percent annually. From 1997 to 2000, they rose more moderately and actually decreased in 1999. During the second upsurge, from 2002 to 2004, a total of 56,432 invention patents were applied for, accounting for over 50 percent of the overall applications for the 1985–2004 period.

Figure 9 Invention Patent Applications of Foreign Sample Firms (1985–2004)

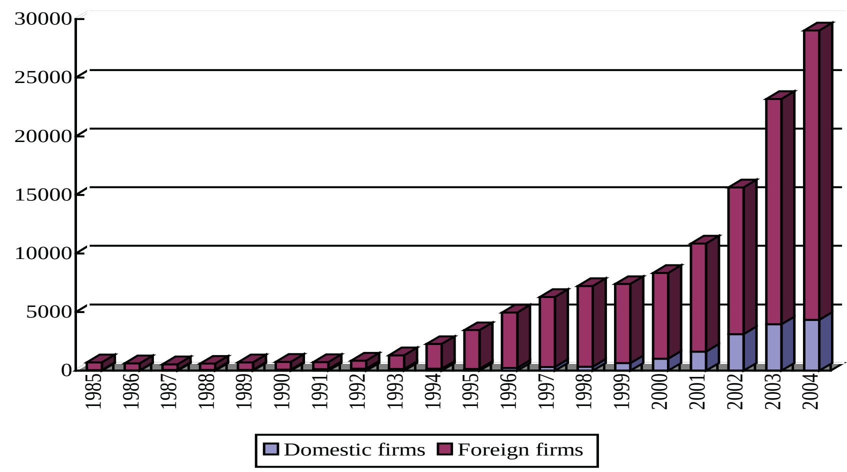


Figure 10 compares the invention patent applications of domestic firms and foreign firms in China from 1985 to 2004. It is clear that before 2000, there was a huge gap between the two groups, with the number of applications from domestic firms less than one-fifteenth those from foreign firms. This mainly reflects the huge gap in innovation capabilities. After 2000, however, applications from domestic firms increased dramatically and reached one-fifth of those from foreign firms, which partly indicates the rapid improvement of domestic innovation capabilities.

With regard to parent country distribution, during 1985–2004 Japanese companies ranked first, with a total of 50,779 filings, or 46.7 percent of total invention patent applications; U.S. companies ranked second with 24,001 filings, or 22.1 percent; Korean companies ranked third with 13,115 filings, or 12.1 percent; and Dutch and German companies ranked fourth and fifth respectively. The companies from these five countries together accounted for over 95 percent of the total foreign invention patent applications.

Figure 10 Invention patent applications of domestic sample firms and foreign sample firms (1985–2004)

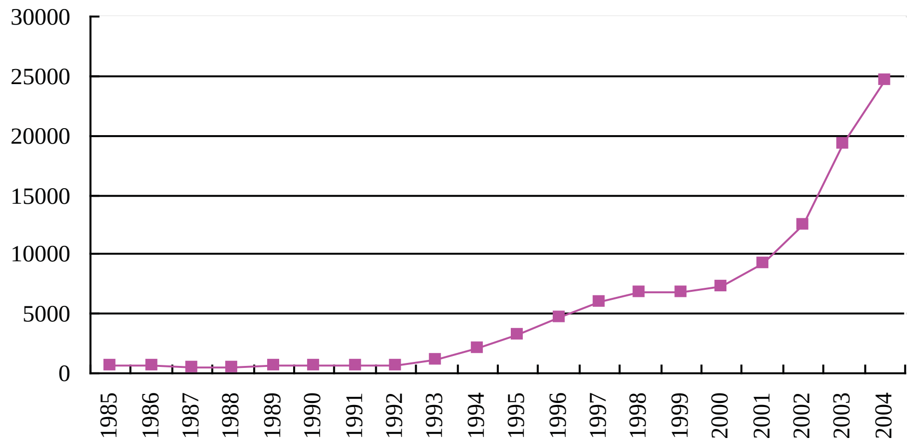
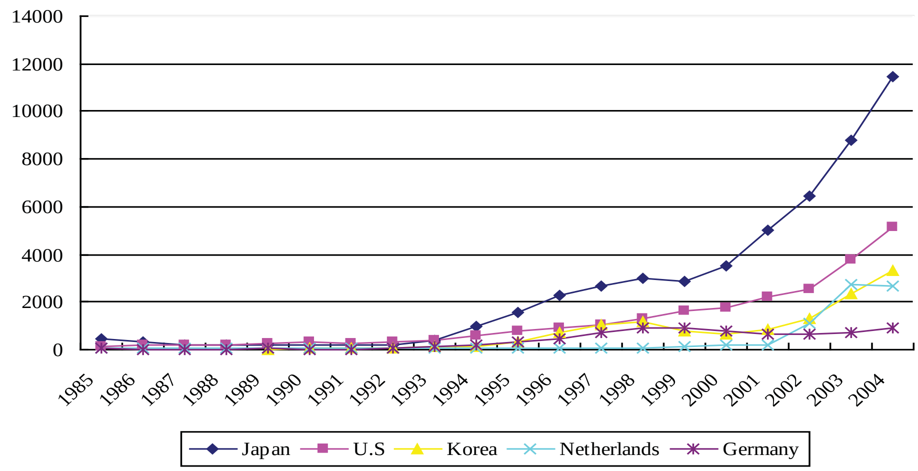


Figure 11 depicts the annual invention patent applications of the above five countries from 1985 to 2004. As the figure shows, there were very few such applications before 1993. Korean firms, which were relatively late entering the Chinese market, applied for their first invention patent in 1989. After 1993, Japanese firms' annual filing pace accelerated rapidly, whereas that of U.S. firms accelerated rather moderately. Japanese and Korean firms were the largest foreign filers in the USPTO in the 1990s and 2000s. It is likely that the same phenomenon will also occur in China, partly reflecting Japan's and Korea's participation in the Chinese market. It is also interesting to note that German firms' invention patent applications decreased after 1998; the reason needs further investigation.

Table 7 lists foreign firms with over 1,000 invention patent applications from 1985 to 2004. Panasonic (Japan) applied for 12,644 invention patents, ranking first and comprising 11.63 percent of all applications. Samsung ranks second with 9,998 filings, or 9.19 percent. Philips ranks third with 5,586 filings, or 5.14 percent. Out of the top 10 multinational companies, five are from Japan, two from the U.S., and one each from Korea, the Netherlands, and Germany. Generally, applications from Japan are more concentrated among just a few firms, compared to those from the United States. Applications by Samsung, Philips, and Siemens all comprised a large proportion of the total applications from their parent countries.

Figure 11 Annual invention patent applications of the sample companies from top five countries (1985–2004)



Source: Caculated by the authors based on sample companies' data.

Table 8 lists the top 20 PCT[11] applicants globally for 2008. All were multinational companies; if we put Tables 7 and 8 together, we find that 11 were also among the top foreign applicants for patents in China. This indicates that the patent strategies of multinational firms in China and globally are not very different. Geographical proximity also apparently plays a role. Some of the companies from Korea and Japan that fall into the second or third rank in terms of applications submitted, such as Samsung, Mitsubishi, Canon, and Sony, play large roles in the Chinese market.

[11] Patent Cooperation Treaty (PCT) is an international treaty, administered by the World Intellectual Property Organization, which makes it possible to seek patent protection for an invention simultaneously in each of a large number of countries (that are Contracting States to the PCT) by first filing a single "international" patent application. The authority to grant patents remains entirely with the national or regional patent Offices in what is called the PCT "national phase" or "regional phase."

Table 7 Foreign firms with over 1,000 invention patent applications in China (1985-2004)

Patentee	Parent country	Invention patent applications	Percentage
Panasonic	Japan	12,644	11.63
Samsung	Korea	9,998	9.19
Philips	Netherlands	5,586	5.14
Siemens	Germany	4,713	4.33
Mitsubishi	Japan	4,454	4.10
IBM	U.S.	4,119	3.79
Canon	Japan	4,117	3.79
Sony Electronics	Japan	3,832	3.52
Sanyo Electronics	Japan	3,122	2.87
Motorola	U.S.	2,769	2.55
Sony	Japan	2,762	2.54
Honda	Japan	2,559	2.35
Intel	U.S.	2,199	2.02
DuPont	U.S.	2,183	2.01
GE	U.S.	2,135	1.96
Fujitsu	Japan	2,060	1.89
P&G	U.S.	1,817	1.67
3M	U.S.	1,557	1.43
Shell	Holland	1,458	1.34
Sharp	Japan	1,424	1.31
Microsoft	U.S.	1,011	0.93
Sumitomo Chemical	Japan	1,009	0.93
Total		77528	71.29

Source: Ibid.

Table 8 Top 20 PCT applicants based on the number of PCT international applications published in 2008

Applicant's Name	Country of Origin	PCT International Applications Published in 2008
HUAWEI TECHNOLOGIES CO., LTD.	China	1,737
PANASONIC CORPORATION	Japan	1,729
KONINKLIJKE PHILIPS ELECTRONICS N.V.	Netherlands	1,551
TOYOTA JIDOSHA KABUSHIKI KAISHA	Japan	1,364
ROBERT BOSCH GMBH	Germany	1,273
SIEMENS AKTIENGESELLSCHAFT	Germany	1,089
NOKIA CORPORATION	Finland	1,005
LG ELECTRONICS INC.	Republic of Korea	992
TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)	Sweden	984
FUJITSU LIMITED	Japan	983
QUALCOMM INCORPORATED	United States of America	907
NEC CORPORATION	Japan	825
SHARP KABUSHIKI KAISHA	Japan	814
MICROSOFT CORPORATION	United States of America	805
MOTOROLA, INC.	United States of America	778
BASF SE	Germany	721
INTERNATIONAL BUSINESS MACHINES CORPORATION	United States of America	664
3M INNOVATIVE PROPERTIES COMPANY	United States of America	663
SAMSUNG ELECTRONICS CO., LTD.	Republic of Korea	639
E.I. DUPONT DE NEMOURS AND COMPANY	United States of America	517

Source: WIPO 2009.

Comparing the distribution of applicants among foreign sample firms with that of domestic sample firms, it is clear that there is much more concentration among the domestic firms. For example, whereas the top five foreign firms accounted for one-third of foreign applications, a single company, Huawei Technology, accounted for one-third of domestic applications. But the concentration is relative; as stated before, the top 500 firms in China accounted for only 4.62 percent of the total domestic invention patent applications. By contrast, the Fortune Global 500 firms accounted for 30.47 percent of total foreign invention patent applications. This indicates that even the top domestic patent filers are still weak in innovation capabilities and in their use of patent strategy, although some unique players, such as Huawei, have emerged.

Table 9 shows the IPC subclass distribution of foreign sample firms' invention patent applications (those with above 2,000 filings). It can be seen that the main subclasses are digital signal transmission and processing, information storage, and certain semiconductor devices. These five subclasses account for as much as 29.11 percent of foreign sample firms' total invention patent applications. Compared to domestic firms, foreign companies' patent applications are more diversified because many of the firms are conglomerates and operate different businesses simultaneously. It can also be seen from the tables that, except for the chemical sector, the IPC distribution of foreign sample firms is quite similar to that of domestic firms; this means that there is competition between multinational firms and China's leading domestic companies, especially in certain areas such as telecommunication.

Table 9 IPC subclass distribution of foreign sample firms' invention patent applications (1985-2004) (those with over 2,000 applications filed)

IPC subclass number	IPC subclass	Invention patent applications	Percentage
G06F	Electric digital data processing	8,320	7.65
G11B	Information storage based on relative movement between record carrier and transducer	7,064	6.50
H04N	Pictorial communication, e.g., television	5,971	5.49
H01L	Semiconductor devices; electric solid-state devices not otherwise provided for	5,450	5.01
H04L	Transmission of digital information, e.g., telegraphic communication	4,856	4.47
H04Q	Selecting	3,801	3.50
H04B	Transmission	3,204	2.95
H01M	Processes or means, e.g., batteries, for the direct conversion of chemical energy into electrical energy	2,182	2.01
H01J	Electric discharge tubes or discharge lamps	2,137	1.97
G03G	Electrography; electrophotography; magnetography	2,055	1.89
Total		45,040	41.44

Source: Calculated by the authors based on sample companies' data.

The patent data analysis also reveals that during the past 20 years, about 96 percent (or 104,091) of the total 108,747 invention patent applications filed by foreign companies have "priorities" (i.e., they have been applied for before abroad, most likely in their home countries). These filings are mainly based on earlier research and accomplished creations. This confirms Hu's speculation (2006) that foreign companies bring invention patent applications to SIPO when the market is ready, without necessarily waiting to perfect the technologies. Additional research performed by the authors has also proved this point (Zhu and Liang 2006).

Different Patent Behaviors Of Domestic And Multinational Companies In China: Evaluation By Uspto Patent Data

Some may claim that SIPO patent data are not suitable for comparing the innovative performances of domestic and foreign firms, so we decided to examine USPTO patent data as well for comparison. USPTO patent data are used widely in the innovation research field because of the data's high standards. The sample we chose includes all of the patents granted by the USPTO to inventors with Chinese addresses from 1969 to 2008, as well as corresponding information, such as grant date and assignees. As table 10 shows, the top holders of USPTO patents in China were individuals, roughly similar to the SIPO patent distribution. There were other kinds of patent players in China besides individuals. For example, among the top five patent holders (not including individuals), three were Taiwanese joint ventures in mainland China.[12] They are focused on ICT product manufacturing (assembling), and their patent behaviors are strictly correlated with their products and main export market. This was the reason why they filed so many patents in the United States. Microsoft ranks second among the top five holders; most of the corresponding patents had been generated by Microsoft's R&D staff in China but assigned to parent company in US, and were successively implemented into its global product portfolio. The same strategy was also applied by Intel and IBM (Liang and Xue, 2010). Furthermore, although Huawei is the

[12] Hon Hai Precision Industry Co., Ltd., Hong Fu Jin Precision Industry (Shenzhen) Co., Ltd., and Fu Zhun Precision Industrial (Shenzhen) Co., Ltd., are all affiliated with Foxconn Group.

champion in both SIPO and PCT patent (2008) applications in China, it ranks only fifth on this list, behind those joint ventures. This is likely partially due to the non-trade barriers that Huawei has faced in entering the U.S. market.

Besides Chinese foreign-invested companies (including wholly owned firms and joint ventures) and local private enterprises, state owned enterprises such as SINOPEC, are also among the top USPTO patent holders. The reason for this is the strong R&D capabilities they inherited from the planning system age. Top universities, such as Tsinghua, also play very important roles in industrial R&D and patent creation, based on their industrial service tradition and incentives from the government on R&D collaborations with enterprises. Patents, especially foreign patents of SOEs, universities, and public research institutes in China, are occasionally regarded as a symbol of technological strength or reputation rather than a source of commercial benefit. For example, patents were an important indicator in academic promotions in China in recent years, inspiring the surge of applications from universities, both domestically and abroad.

Table 10 Patents granted by the USPTO to Chinese inventors (1969–2008)

First-named assignee	Grants
INDIVIDUALLY OWNED PATENT	1,033
HON HAI PRECISION IND. CO., LTD.	641
MICROSOFT CORPORATION	295
HONG FU JIN PRECISION INDUSTRY (SHENZHEN) CO., LTD.	205
FU ZHUN PRECISION INDUSTRIAL (SHENZHEN) CO., LTD.	109
HUAWEI TECHNOLOGIES CO., LTD.	103
TSINGHUA UNIVERSITY	101
CHINA PETROCHEMICAL DEVELOPMENT CORP.	79
INTEL CORPORATION	74
CHINA PETROLEUM AND CHEMICAL CORPORATION	65
SEMICONDUCTOR MANUFACTURING INTERNATIONAL (SHANGHAI) CORPORATION	62
SAE MAGNETICS (H.K.) LTD.	61
INTERNATIONAL BUSINESS MACHINES CORPORATION	49
SHENZHEN FUTAIHONG PRECISION INDUSTRIAL CO., LTD.	42
WINBOND ELECTRONICS CORP.	37
UNITED MICROELECTRONICS CORPORATION	27
ASIA OPTICAL CO., INC.	24
CHANGCHUN INSTITUTE OF APPLIED CHEMISTRY, CHINESE ACADEMY OF SCIENCES OF CHINA	23

Source: Calculated by author based on the USPTO database.

As the USPTO data discloses, there are different kinds of domestic firms in China; their patent behaviors abroad are diversified and different from those of multinational firms operating in China. This also reflects one face of their different innovative performances. The main holders of patents may not be the most innovative firms.

Conclusions

As the SIPO patent data reflect, the innovative performance of multinational companies during 1985 to 2004 far surpassed that of China's domestic firms, in both quantity and quality. Most foreign patent applications were for inventions and in-service applications, and have higher granting and validity ratios than domestic applications. However, multinational firms' patent applications in China are mainly regarded as competition tools oriented toward market benefits, either actually or potentially. They use China's patent system to provide them with a strategic competitive advantage rather than to gain monopoly rent from their technological advantage. At the same time, however, their patent applications in China not only inspire the "patent competition" in corresponding areas, but also give a chance for domestic firms to imitate and "invent around." Some empirical studies reveal correlations between foreign invention patent applications and domestic utility/design applications, which partly proves this point (Liu et al. 2003; Hu 2006).

Local firms also adapted to China's patent system through gradual innovation, taking advantage of the two kinds of patents for minor innovation. However, most Chinese firms have not been able to become true innovators in their corresponding industries, as evidenced by the lower granting ratio for their invention patent applications, with a few exceptions such as Huawei. Despite a domestic patent surge in recent years, local firms' understanding of patent and patent strategies is still at an early stage. The small quantities and low concentration of leading firms in domestic invention patent applications partially reveals this. In particular, the weak orientation toward innovation and pervasively imitative behaviors among domestic firms may also harm the cultivation of their long-term and core competences.

As the USPTO patent data disclosed, there have been three different pathways to innovation in China. The first is for a firm to orient its innovations toward the lower levels of the international industrial value chain, drawing on China's unchallenged advantages in large-scale and low-cost production (processing/assembling) capabilities and successively growing into a company that can deliver integrated manufacturing services, including product design; a good example of such a company is Foxconn. The second is to compete in an advanced market based on low-cost R&D talent and quick response to customer needs. Examples in the telecommunication sector include Huawei and ZTE, whose innovative capabilities experienced an exceptional boost due to the severe competition in the global market. The third is to exploit the unique needs of the domestic market while cultivating autonomous R&D capabilities, finally developing new technology, products, or business models that can also compete in the global market. Some SOEs, such as SINOPEC and China Mobile, have this potential but need to overcome the disadvantages on corporate governance so as to fully develop their capabilities.

However, accompanied with the improvement of capabilities, the innovative performance and pathway of different kinds of firms may also converge. Huawei's story is a typical case. Huawei has 83,000 employees, of whom 43 percent are dedicated to R&D. Huawei spends more than 10 percent of its total revenue on R&D every year. Today, Huawei has became one of the leading suppliers of next-generation telecommunications networks and serves 35 of the world's top 50 operators, including Vodafone, British Telecom, Telefonica, France Telecom/Orange, and China Mobile. Huawei has over 1 billion users worldwide, and more than 70 percent of its revenues come from abroad. In fact, it was Cisco's lawsuit against Huawei for patent infringement (settled in 2004 after 20 months) that directly stimulated the formulation of Huawei's IPR Strategy. Huawei founded a pre-research department which includes more than 1,000 people and emphasizes cutting-edge technological research. At the same time, Huawei strengthened patent analysis and concentrated on the breakthrough technologies, such as Wideband Code Division Multiple Access (WCDMA), that would build on Huawei's comparative advantages. It improved collaboration with multinational firms and founded strategic partnerships with most of its industry peers, such as 3Com and Siemens. Huawei made every effort to obtain technologies through licensing and through mergers and acquisitions. It also actively participated in the process of establishing international standards and became a member of 83 standardization organizations. As a result, Huawei filed 6,770 new patents in 2009, bringing its total number of patents filed to 42,543 (Huawei n.d.). It also became the world largest patent applicant under the WIPO PCT, with 1,737 applications published in 2008; Huawei's patenting sustains its worldwide business expansion. Huawei has followed a competitive strategy of not only relying heavily on IPR protection of its core technologies but also using its own technological advantage to integrate global innovation resources. During this process, Huawei developed new collaborative relationships with multinational firms, whose roles also changed towards Huawei: first they acted as "teachers," then as competitors, and finally as collaborators. This has become the typical road for China's domestic leading companies, such as Lenovo, Chery, Geely, and others.

On the other hand, multinational firms, such as Microsoft, IBM, Intel, and Nokia, are searching for new knowledge in China and aim to allocate this knowledge worldwide. Multinational firms' innovation models in China may also converge with those in advanced markets in the future, to some extent. Chinese domestic firms may also integrate their knowledge acquired worldwide and use it to serve domestic market needs.

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Study of China's International Specialization Status in Advanced Technology Industry: A Case Study of Zhejiang Pinghu Opto-mechatronics Industry Cluster

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Abstract

Using the opto-mechatronics industry cluster of Pinghu, China, as a case study, this paper analyzes the international specialization status of China's advanced-technology industry. Our research indicates that Pinghu's industry cluster follows an exogenous industry cluster development model, which is typical of China's advanced-technology industries. In this model, government-guided foreign investment comes to a region first and generates learning spillovers for local enterprises, enabling the government to create a public platform for technology innovation. Foreign-owned and local private companies then work together to promote the further development of industry clusters. True to this model, the initial driving force behind the opto-mechatronics industry was the Chinese government, with foreign investment as its engine; then followed the

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public technology platform and supporting industries. Our study, based on interviews with industry personnel, also indicates that the performance of Pinghu's opto-mechatronics industry exceeds the national average and that Pinghu is becoming more like an endogenous cluster over time—more market-oriented and increasingly reliant on domestic factors. However, its average value-added ratio was relatively low; imported intermediate inputs still constitute a large share of the value of manufactured output. Thus, although Pinghu's opto-mechatronics industry enjoys a leading position in China, it remains largely concentrated on processing and assembly, which is at the low-skill-intensive end of the production chain.

Key words: Advanced-technology, international specialization, opto-mechatronics industry, industry cluster

1. Introduction

According to the theory of comparative advantage, China should not be strong in exporting advanced-technology products, because it is a large developing country with a huge pool of low-skilled labor. But since the 1990s, China's advanced technology exports have actually been increasing rapidly (figure 1). In 2007, the total volume and value of China's advanced-technology manufacturing exports ranked the second in the world. Some scholars attribute this to the advent of global production fragmentation and intraproduct specialization, which prompted many multinational companies (MNCs) to transfer their assembly processing facilities to developing countries with rich resources and cheap labor (Lall 2000; Mani 2000; Mayer et al. 2002; Branstetter and Lardy 2006; Srholec 2007). However, when it comes to developing a more micro perspective—i.e., understanding how a Chinese industry or industry cluster is embedded into the global advanced-technology industry chain and the role it plays in international specialization—a case study is necessary. Only in this way can we find some patterns in the development of China's advanced-technology industry, which may provide useful lessons for other developing countries.

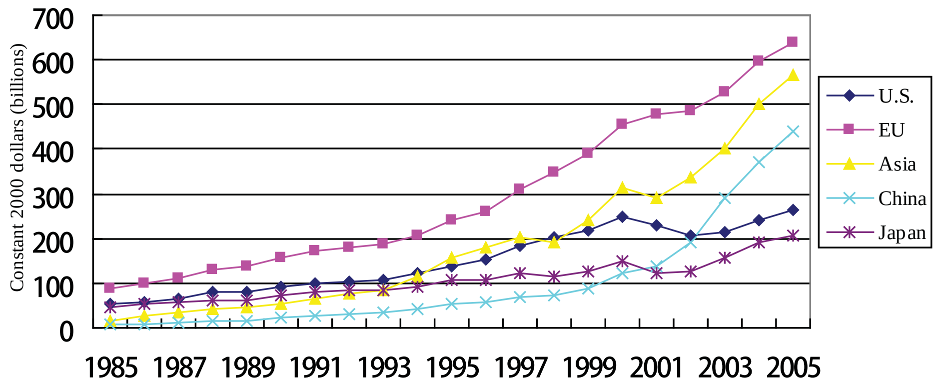
Pinghu is in Zhejiang province, which has served as a trade route to Arab and Southeast Asian areas since the 12th century. Once dominated by the textile and garment industry, Pinghu has now become the premier destination for Japanese investment in Zhejiang and is home to the province's largest opto-mechatronics industry cluster. China is well known for its effectiveness in using foreign investment to spur industry agglomeration. But how has Pinghu been able to make such substantial progress in just 10 years? Wang (2006) points out that the local government has played an important role in attracting investment and providing specialized services, which have helped Pinghu become, to a significant extent, an "exogenous industry cluster."[2]

However, two questions remain: (1) what was the original impetus to form the opto-mechatronics industry cluster in Pinghu? and (2) what is Pinghu's specialization in the global production chain? There is no empirical study based on company-level survey data that examines these issues. In this paper, we address these two questions with an analysis based on interviews with personnel in 120 opto-mechatronics companies. Our goal is to provide some information on Pinghu's experience and offer some suggestions to other developing countries interested in breaking into global advanced-technology industry chains and eventually upgrading to more advanced stages in those chains.

The paper consists of the following parts: section 2 outlines the current situation of the opto-mechatronics industry cluster in Pinghu and explains the research methodology. Section 3 analyzes the forces driving the industry's formation and growth, based on the survey data. Section 4 conducts cross-national comparisons to explore its international specialization status. Section 5 discusses several lessons that may be drawn from the study.

[2] As described by Zhou Hong et al. (2006), an exogenous industry cluster is started mainly by foreign direct investment, in contrast to an endogenous industry cluster, which is started by domestic investment. We found that the formation of Pinghu cluster benefited from both types of investment.

Figure 1 Export volume of advanced-technology manufactures, by region/country, 1985–2005



Notes: EU = European Union; Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand. China includes Hong Kong.

Source: Global Insight, Inc., World Industry Service database, special tabulations; Science and Engineering Indicators 2008

2. An overview of the Pinghu opto-mechatronics industry cluster and research design

2.1 Overview of the Pinghu opto-mechatronics industry cluster

With its origins in Liangzhu culture, Pinghu was given the name of "Golden Pinghu" in ancient times. Encompassing a number of smaller neighborhoods and towns, it is a city with a developed economy, society, and culture. Pinghu also enjoys a unique geographic location and good transportation. Because it is located in the Hangjiahu (Hangzhou, Jiaxing, Huzhou) plain, Pinghu is near Hangzhou Bay and has convenient access to water transportation. Moreover, Shanghai, Hangzhou, Suzhou, and Ningbo are all within about 100 kilometers distance.

The opto-mechatronics industry in Pinghu dates back to Pinghu's processing trade with a Japanese firm—Shibaura Co., Ltd[3]—starting in 1993. After Shibaura had developed a very good cooperative relationship with a state-owned firm processing electric transformers, Shibaura invested $200,000 and formed an

[3] Shibaura Co. Ltd of Japan is a world-renowned motor-producing company. For many types of motors, Shibaura's share of the world market exceeds 50 percent.

alliance with this local business in 1995. In 1998, Nidec of Japan took over the Shibaura manufacturing center. During a visit to Japan Electric Shibaura (Zhejiang) Co., Nagamori Shigenobu, president of Japan's Nidec Corporation, stated that he was motivated by the local government's support and decided to continue investing in the region. Thus began opto-mechatronics' rapid development in Pinghu.

By 2007, the gross output of Pinghu's opto-mechatronics producers reached 12.457 billion RMB, with 22.72 percent of the firms in the industry above the designated scale[4] (table 1). At present there are 128 opto-mechatronics companies in Pinghu, 17 of which have annual output exceeding 100 million units. Pinghu also has five important research and development (R&D) centers affiliated with these companies. Five companies are listed by the Ministry of Science and Technology as key enterprises for their excellent performance in technology innovation and new product development: Kanto Tatsumi Electronics (Pinghu) Co., Ltd, Zhejiang Hannao Digital Technology Co. Ltd, Pinghu Meijia Thermal Insulation Container Industrial Co., Ltd, Nidec Copal (Zhejiang) Co. Ltd, and Jiaxing Hengye Electronics Co., Ltd.

The opto-mechatronics industry cluster is centered in Danghu town, the site of Pinghu's economic and technology development zone. The cluster includes three nearby towns—Zhongdai, Lindai, and Huanggu—that are also part of Pinghu city (figure 2). Other industrial areas in the region, such as Shanghai, Anhui, and western Zhejiang, also benefit from its financial services and labor supply. From the construction schematic (figure 3), it can be seen that the main driving forces behind Pinghu's opto-mechatronics industry are the Japanese-funded enterprises in the economic development zone. At the center of figure 3 is Nidec Corporations. Vertical linkage companies provide it with upstream inputs; horizontal linkage companies make products that replace or complement those it produces; downstream firms buy its output. At the top is support from local government, while at the base are links between Nidec Corporations, banks, and technical schools that provide funds and labor to firms in Pinghu.

[4] Enterprises with annual output value of more than 5 million yuan.

Table 1 Total output of opto-mechatronics industry in Pinghu, 2002–07

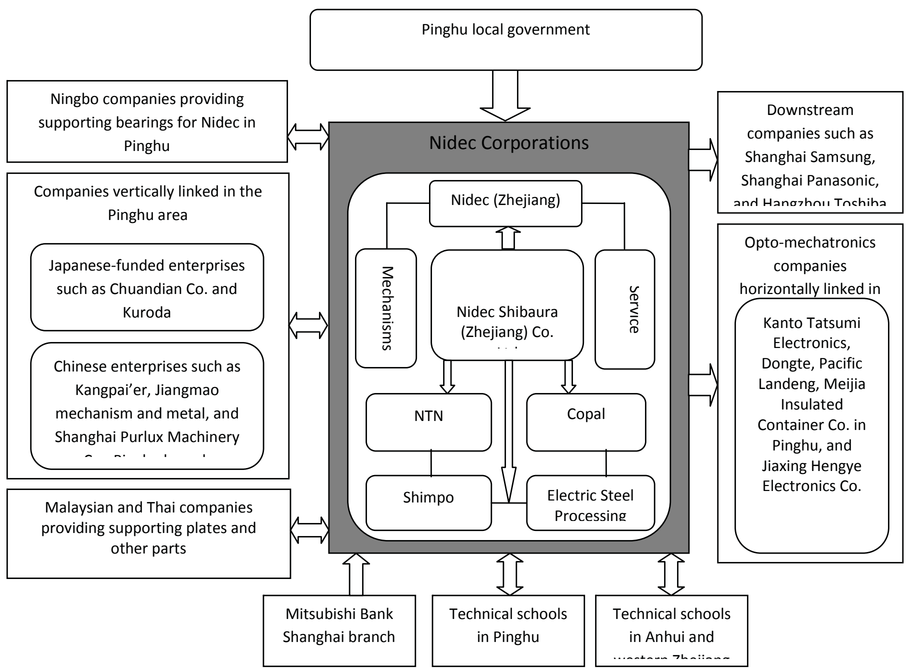
Year	Number of enterprises	Total output (billion yuan)	Proportion of the entire industry (%)	Growth rate (%)
2002	22	21.1	13.8	45
2003	65	40.2	17.9	85.2
2004	71	65.9	24.4	64
2005	91	78.6	19	21
2006	102	101.5	27.4	22.68
2007	120	124.57	22.72	21.9

Source: Web site of Pinghu opto-mechatronics industrial base, *http://www.zjgjd.com/index.asp*

Figure 2 Map of Pinghu showing location of opto-mechatronics industry cluster

The primary goods manufactured by Pinghu's opto-mechatronics industry include such advanced-technology products as digital camera shutters, phone cameras, flash disks, MP3 players, fiber optical transceivers, optical fiber branching devices, sophisticated hydrodynamic bearings, micromachines, precision molds, fiber optic cannulas, digital photo printers, overhead projectors, measuring instruments, and electronic part sensors. Many of these are competitive in the international market. For example, Nidec (Zhejiang) Co. Ltd has 70 percent of the global market for spindle motors of laptop hard drives; Nidec Copal (Zhejiang) Co. Ltd has 30 percent of the global market for mobile phone vibration motors, 70 percent of the market for digital camera shutters, and 80 percent of the market for polygon reflectors. Other world-class products also come from this cluster, such as hydrodynamic bearings from NTN-Nidec (Zhejiang) Co. Ltd, semiconductor measuring instruments from Nidec Mechanism (Zhejiang) Co. Ltd, and derailleurs from Nidec Copal (Zhejiang) Co. Ltd.

Figure 3 Schematic drawing of Pinghu's opto-mechatronics industry cluster



Source: Zhang 2006, 190.

2.2 Research design

We first collected publicly accessible information, including administrative divisions, geographic characteristics of Pinghu, and economic and social statistics published by the government body. We interviewed local officials, members of industry associations, and entrepreneurs so that we could design and improve our questionnaires. The final field investigation lasted one month, from June to July 2009. It targeted 108 opto-mechatronics companies in the Pinghu economic and technology development zone and 20 in Zhongdai, Huanggu, and Lindai towns. The first step was meeting with chief management staff to get information that could not be obtained through questionnaires, at which time we also asked them to fill out questionnaires. In total we visited 128 companies, receiving 120 effective questionnaires.[5] The information from the companies follows (table 2).

Table 2 Basic statistical information about companies surveyed

Type of company	Industry	Registered capital, in yuan	Value of annual output, in yuan	Number of employees
Wholly foreign-owned 38 (31.6%)	*Electronic information* 19 (15.8%)	*Over 10 million* 44 (36.7%)	*Over 100 million* 26 (21.7%)	*Over 3,000* 37 (30.8%)
Private 56 (46.7%)	*Opto-mechatronics* 88 (73.3%)	*5 to 10 million* 50 (41.7%)	*50 to 100 million* 47 (39.2)	*1,000 to 3,000* 44 (36.7%)
Joint venture 22 18.3%		*1 to 5 million* 8 (9.6%)	*10 to 50 million* 33 (27.5%)	*500–1,000* 12 (10%)
Others 4 (3.4%)	*Others* 13 (10.9%)	*Under 1 million* 18 (15%)	*Under 10 million* 14 (11.7%)	*Under 500* 27 (22.5%)

Note: In parentheses are ratios compared to overall samples. Although our questionnaire spanned the period from 2005 to 2008, respondents only provided data for 2008.

3. The driving force behind the opto-mechatronics industry cluster's formation and growth in Pinghu

Marshall (1920) argues that the forces of cluster formation are (1) knowledge spillovers, (2) markets for specialized machinery and the ability to use specialized machinery with economies of scale, and (3) the pooling of skilled labor with skills specific to an industry. Porter (1998) points out that the evolution of an industry cluster depends on its history and culture, demand stimulation, upstream and other related industries, and new and supporting enterprises. The strategies and structure of a company, as well as competition and opportunities, should also be considered. Brenner (2001) thinks human capital, technology spillovers, cooperation, public opinion, government policies, and venture capital need to be taken into account as well. Saxenian (1996) did a comparative study of the Silicon Valley and advanced-technology zones along Route 128 in the Boston area and found that specialization, competition, and corporate culture are important for the growth of industry

[5] There are 128 opto-mechatronics companies in Pinghu, according to statistics. But 8 of them are very small and didn't complete our questionnaire, so we excluded them from the sample.

clusters. Wang and Cai (2009) and Zeng (2006) studied cluster formation in China and reported that many elements are important, including industry traditions, geographic location, cultures of trust, government policies, foreign trade, natural resources, transaction costs, and more.

Table 3 Primary reasons for investment in Pinghu during various periods

	Reason for investment					
Year founded	**Government support and service**	**Preferential policy**	**Following up- and downstream companies**	**Market potential**	**Available supporting industries**	**Good geographic location**
1999–2001 (20)	9 (45%)	5 (25%)	2 (10%)	0 (0%)	1 (5%)	3 (15%)
2001–2004 (51)	16 (31.37%)	7 (13.73%)	5 (9.8%)	8 (15.69%)	10 (19.61%)	5 (9.8%)
2004–2007 (49)	10 (20.41%)	7 (14.29%)	6 (12.24%)	8 (16.33%)	11 (22.45%)	7 (14.29%)
2007–2008 (13)	2 (15.38%)	2 (15.38%)	2 (15.38%)	4 (30.77%)	7 (53.85%)	1 (7.69%)

Note: The number in parentheses in columns 2–7 is the share of firms. Some of these shares add up to more than 100 because some firms gave more than one answer.

Existing research generally equates the primary force forming the cluster with the sustaining force that pushes its development. However, our study shows that Pinghu did not follow this pattern. This can be seen from the different companies' responses to the question "What was your primary reason for investing in Pinghu?" From table 3 we can see that companies founded before 2004 put government support and service in first place, with location and preferential policies as secondary considerations. But for those set up after 2004, the primary concerns were supporting industries and market potential, which indicates that endogenous factors, such as distance to upstream and downstream companies and to consumer markets, had become the most important criteria in determining location.

In general, therefore, at the initial stage of the exogenous industry cluster's development, the local government plays the key role in attracting investment. At this point, important concerns for potential investors include whether government can offer investment-related services that are convenient and effective and whether it will fulfill commitments it has made to the investors so that investors need not worry about the risks from information asymmetry. After the cluster becomes large enough, the government's roles in terms of preferential policies, supporting measures, and its own credibility all become explicit information. Companies making investment decisions will then pay more attention to judging development opportunities and market potential, as well as to supporting industries.

The reasons given for investing in Pinghu may be divided into three groups: exogenous ("government support and service" and "preferential policy"), endogenous ("upstream and downstream companies," "market potential," and "available supporting industries") and others ("good geographic location"). Over time, as we have seen, the main driving force shifted from exogenous to endogenous factors. This shift had two defining aspects: first, the transition from dependence on outside or foreign capital, technology, and other factors to domestic sources, and second, the change from dependence on government policies to market-oriented competition.

3.1 Primary driving force

Pinghu's government has made a strong effort to promote the opto-mechatronics industry by implementing a series of policies that have greatly advanced the industry. Hence, the primary driving force in the first stage of industry cluster's development was the local government. First, the vigorous support of the government attracted some leading enterprises in the opto-mechatronics industry, particularly Japan's Nidec Shibaura (Zhejiang) Co. Ltd. Although to some extent Shibaura chose Pinghu quite by chance, undeniably a large part of credit should go to the local government. In 1998, as previously noted, Nagamori Shigenobu, president of Japan's Nidec Corporation, went to Pinghu to investigate the investment environment and was warmly received by the government. Though he was unable to completely research the issues surrounding investment in Pinghu, he was encouraged by the local authorities. However, he also talked about the unsatisfying transportation system—which forced him to take more than four hours to travel from Hongqiao airport, Shanghai, to Pinghu—and hoped it could be improved. The next year, when he returned, it only took him 45 minutes by highway. This giant step signaled a reliable government with which it would be worth cooperating in the long term. In the following years, Nidec established several wholly foreign-owned or joint venture companies one by one in this region, with Kanto Tatsumi Electronics Co. Ltd and Tokyo Special Electric Wire Co. Ltd coming later.

Second, the specialized services provided by the government prompted the growth of the optical-mechatronics industry cluster. When Nidec Shibaura (Zhejiang) Co. Ltd first arrived in Pinghu, the infrastructure was far behind that of other economic development zones like Suzhou Industrial Park and Kunshan. However, the government opened Japanese-language schools, trained staff for Japanese-led companies, and did a great deal to build a sound economic environment to promote the industry. Consequently, many companies were attracted to the region.

3.2 Sustaining driving force

After this first step, the government of Pinghu focused on establishing a public technology platform to promote self-innovation and to upgrade the local opto-mechatronics industry. In August 2003, the Opto-mechatronics Advanced Technology Industry Promotion Center and the Advanced Technology Business Service Center were established to provide technical support to the companies. Meanwhile, a special development fund was raised for the industry, with an annual allocation of 10 million yuan. Many local businesses were enlivened by the government's vigorous investments in science and technology. Jiaxing Hengye Electronic Co. Ltd made good use of the 500,000 yuan it received from the Jiaxing Science and Technology Department and invented an integrated meter-reading system for communities; Zhejiang Banyu Electronic Co. Ltd, relying on the 1.2 million yuan it received, introduced a new type of MP3 and flash disk, which later gained the support of China's key new products project.

To further encourage this trend, the Pinghu government is now building a service platform for public scientific innovation. In July 2003, Pinghu formed an alliance with Tsinghua University, founding the Pinghu Branch of the Zhejiang–Tsinghua Yangtze River Delta Research Center. Also known as the Integrated Optics Research Institute, it is China's first center specializing in the opto-mechatronics area. The institution is building a fiber optical sensor laboratory research center for developing and industrializing integrated optical technology and products. In four to five years, it is expected to be a leading center for R&D in new technology within China, with influence elsewhere in Asia and a good reputation around the world.

Other important investments have followed. On June 21, 2004, the Pinghu government signed a contract with CAS Shanghai Silicate Research Center, to found CAS Jiaxing Pinghu Nonmetallic Inorganic Material Branch Center. In addition, a total of 47.5 million yuan was invested in an integrated translucent alumina light tube project, conducted by Shanghai Silicate Centre and Pinghu Tianyi Co. These research projects have brought Pinghu many talented people, including nearly 20 eminent science experts and other researchers with advanced degrees, who will help drive not only Pinghu's opto-mechatronics business but also the entire advanced-technology industry.

Moreover, Pinghu is upgrading its industry structure by introducing, learning, and assimilating foreign advanced technologies. The proportion of self-innovation and R&D in Pinghu's economy is rising, and it generates a corresponding effect among other connected companies. To some degree, it reduces Pinghu's dependence on foreign capital. More importantly, Pinghu will not be just an enclave of foreign investors: even without foreign capital, local companies will be able to rely on themselves to develop.

4. The status of Pinghu's opto-mechatronics industry cluster in international specialization

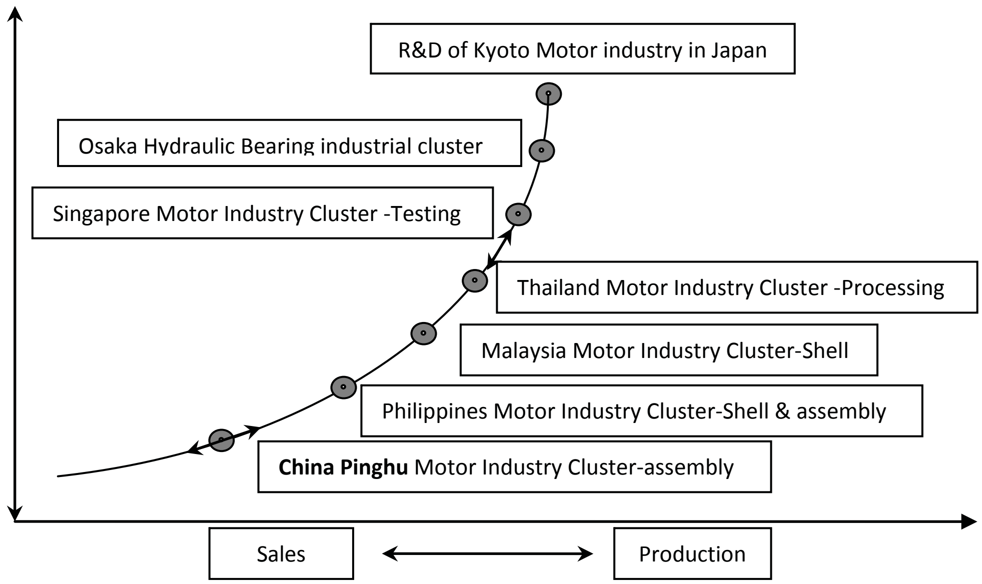
Zhang (2006), through an analysis of motors' basic production processes and the global industrial and value chains, found that Pinghu opto-mechatronics industries were in the lowest value-added sectors (figure 4) in the global value chain hierarchy. The research findings based on analysis of our data are almost the same as those of Zhang. There are some notable differences: mainly, private enterprises within the cluster have reached a level of more advanced development. Moreover, they perform better in R&D investment than the foreign investment-based firms and joint ventures.

4.1 Survey Data Analysis

Pinghu is the only advanced-technology opto-mechatronics industry base in Zhejiang province. In June 2009 Pinghu was officially chosen as a model demonstration area for massive economic transformation and upgrading to a modern industrial cluster. Having analyzed the dynamics of the formation and development of the opto-mechatronics industry cluster in Pinghu, this paper needs to explore another problem: the position of the Pinghu opto-mechatronics industry cluster in the global supply chain, and whether its competitiveness justifies the high market share that some of its products hold internationally.

Huang and Yang (2009), using a cross-country comparison of total domestic value added and labor productivity to explore the position of a country's advanced-technology industries in the international division of labor, argue that their method avoids the error of overvaluing a country's international division of labor in the advanced-technology sector caused by the "statistical illusion" problem. However, without noncompetitive input-output tables, we cannot analyze the status of an industry in a specific region of a country within the international division of labor. Following Huang and Yang, in our interviews with industry personnel we included questions on the average

Figure 4 Global value chain of motor production



Source: Zhang (2006), p. 215.

unit product price of major products, direct value added, labor productivity, and imported share of intermediate inputs, as well as production equipment, product design, R&D sources and inputs, main channels through which products are sold, and the like. Using the responses to these questions, we analyze the Pinghu optical and electrical machinery industries' position in the global supply chain.

As can be seen in table 4, our interviews showed that in 2008 the average direct value-added ratio was about 48 percent, and the average ratio of imports of intermediate inputs was about 28 percent. The average labor productivity was 76,821 yuan (about $11,240), while the average ratio of R&D investment was 10 percent. The direct value-added ratio of foreign-funded enterprises (FFEs) was the lowest of all types of enterprises (about 45 percent). This is consistent with the fact that the production of FFEs used the largest share of imported intermediate inputs—about 45 percent. As to R&D investment, private enterprises' maximum was approximately 12 percent of the value of output; joint ventures followed with about 11 percent, and foreign-funded enterprises trailed with only about 6 percent. By combining this information, we may conclude that while investments in FFEs led to the Pinghu opto-mechatronics industry cluster's formation and development, foreign firms now just regard Pinghu as a manufacturing base, doing very little R&D or high value-added activity locally.

Table 4 Production patterns of investigated enterprises in 2008

Items	Direct value-added ratio (%)	Labor productivity (USD)	Import ratio of Intermediate Inputs (%)	Input ratio of R&D (%)
Overall average	47.54	11,240	27.85	10.11
Wholly foreign-owned enterprises	44.96	10,960	44.55	6.37
Private enterprises	51.73	11,010	16.87	12.03
Joint ventures	47.05	10,710	31.09	11.3
Others	46.43	10,980	18.92	10.75

The information in table 5 further confirms the conclusion discussed above: in 2008, about 79 percent of enterprises in Pinghu assembled final products, 88 percent tested them, nearly one-third (32 percent) performed ordinary parts processing, and only about 5 percent processed core components. Moreover, of the three types of enterprises, domestic private enterprises were more engaged in core and general parts processing than other types of enterprises, and less engaged in assembly production lines.

As table 5 indicates, 61 percent of the companies' production equipment was imported, while their domestic purchase ratio was just about 24 percent, and their independent R&D ratio was about 13 percent. Wholly foreign-owned enterprises depended the most heavily on imported equipment (81 percent), followed by joint ventures (55 percent), while private enterprises' dependence on imports fell as low as 48 percent. Moreover, about 15 percent and 30 percent of production facilities of private enterprises and joint ventures respectively derived from independent[6] R&D and domestic purchases. In product design and R&D, only about 28 percent of the FFEs relied on independent R&D or design; the majority (about 71 percent) relied on foreign companies, most of which were probably their foreign parent companies. Joint venture enterprises had similar ratios of independent R&D and imports, about 22 percent and

[6] Independent R&D means the production equipment was designed and produced by the firms themselves.

Table 5 Production performance of investigated enterprises in 2008 (percent)

Items	Main processes of production	Source of production equipment	Source of product design and R&D	Main channel of sales
Overall average	Core components processing 5.16	Import 61.45	Inside of firms 35.72	Export 52.24
	General components process 32.5	Domestic purchase 23.51	Domestic firms 13.4	Domestic sales 47.76 (36.7 for Pinghu production)
	Final assembly 79.28	Independent R&D 13.44	Foreign firms 48.01	
	Finished product testing 88.12	Others 3.61	Others 5.54	
Wholly foreign-owned enterprises	Core components processing 4.52	Import 81.45	Inside of firms 28.3	Export 69.56
	General components processing 17.57	Domestic purchase 5.7	Domestic firms 8.9	Domestic sales 30.44 (24.5 for Pinghu production)
	Final assembly 78.4	Independent R&D 10.03	Foreign firms 70.51	
	Finished product testing 87.1	Others 2.82	Others 0.29	
Private enterprises	Core components processing 8.79	Import 47.9	Inside of firms 56.77	Export 19.34
	General components processing 75.5	Domestic purchase 33.81	Domestic firms 21.9	Domestic sales 80.66 (59.49 for Pinghu production)
	Final assembly 70.45	Independent R&D 13.3	Foreign firms 13.4	
	Finished product testing 82.26	Others 4.99	Others 7.93	
Joint ventures	Core components processing 2.18	Import 55	Inside of firms 22.09	Export 67.81
	General components processing 4.44	Domestic purchase 31.01	Domestic firms 9.4	Domestic sales 32.19 (26.12 for Pinghu production)
	Final assembly 89	Independent R&D 17	Foreign firms 60.12	
	Finished product testing 95	Others 3.01	Others 8.39	

Note: As one firm can engage in several processes of production, the sum of main processes of production does not equal 100 percent.

60 percent. Among private enterprises, however, more than half enjoyed independent R&D (about 57 percent), while more than 20 percent were supplied through domestic purchases (about 22 percent).

Product sales patterns were likewise diverse. Overall, export sales averaged 52.24 percent; and domestic sales 47.76 percent (with 36.7 percent of domestic sales going toward supporting manufacturing in Pinghu). Of the three kinds of enterprises, wholly foreign-owned companies and joint ventures showed the highest export ratio: 69.56 percent and 67.81 percent of their total outputs. For private enterprises, this ratio was only 19.34 percent. On the other hand, private enterprises contributed the highest percentage of home market sales, 80.66 percent (nearly 60 percent goes to Pinghu's supporting manufacturers), compared to about 30 percent from foreign and joint venture enterprises (25 percent going to Pinghu's supporting manufacturers).

In sum, enterprises in the Pinghu opto-mechatronics industry cluster do much more processing than product development and innovation, and therefore remain at the low-skill-intensive end of the production chain, where it is naturally difficult to obtain a strong advantage. Although some enterprises in Pinghu—such as Nidec NTN—have more advanced technological products and hold a larger share of the world market, few other enterprises have been able to do likewise.

4.2 International Comparison

In order to more clearly show the position of Pinghu's opto-mechatronics industries in the international production chain, we will compare our Pinghu survey data with those for advanced-technology firms in other countries. Using the OECD statistics database,[7] we extracted seven countries' data in 2000 and 2005 to calculate the relevant coefficients, as shown in table 6. Compared with the data in tables 4 and 5, Pinghu corporations' performance, in terms of their average direct value-added ratio, was better than the national average, with only a small gap between it and those of the developed countries. On the other hand, while average labor productivity for Pinghu enterprises was basically the same as the national average, comparison with Germany, Japan, and the United States reveals a big gap. The same holds true for R&D.

[7] OECD. Stat Extracts, www.stats.oecd.org.

The opto-mechatronics enterprises in Pinghu cluster performed better than the national average, but compared to firms in developed countries the average unit product prices and value-added were relatively low, with a higher proportion of imported intermediate inputs. This demonstrates that while Pinghu enjoys a leading position within China in the advanced-technology industry, it has fewer prospects in terms of international trade and remains largely concentrated in processing and assembly, at the low-skill-intensive end of the production chain.

5. Lessons from this case

5.1 The adjustment of the downstream industry layout is the condition for the formation of industry clusters

As one of seven well-known international centers of motor production, the Yangtze River Delta region has become a major destination for the relocation of downstream Nidec enterprises. For example, many electrical enterprises in Taiwan and Seagate Technology, such as Maxtor, Western Digital, Toshiba, Fujitsu, and Samsung, are transferring their manufacturing facilities to this area. Toshiba and Seagate Technology constructed production facilities in Wuxi, Maxtorare is coming to Suzhou, and Samsung is in Shanghai. As a large number of Nidec's downstream enterprises in the personal computer industry have transferred their production bases to the Yangtze River Delta region, the upstream parts of Nidec's electric products manufacturing have had to follow in order to be close to their buyers. This provided a rare opportunity for Nidec to invest in Pinghu and to form an opto-mechatronics industry cluster.

5.2 Geographic and cost advantages are the basis of industrial agglomeration

Areas offering geographical and cost advantages to businesses considering relocating their production processes often become magnets for foreign investment, allowing these areas to become the leaders of industry development. The distance between Nidec enterprises and its downstream components enterprises can be covered in about two hours by car. According to Porter's 2006 study, by locating near the customer, companies can supply speedy customized services that its more distant competitors cannot. In other words, the relatively short overland distance from Pinghu to Wuxi, Suzhou, Hangzhou, and Shanghai satisfies a necessary spatial condition. At the same time, lower costs of doing business are also vital. Despite the established

Table 6 Production performance of advanced-technology firms in different countries

Year	Country	Direct value-added ratio (%)	Labor productivity (thousand $)	Import ratio of intermediate inputs (%)	Input ratio of R&D (%)
2000	Brazil	48.91	–	58.44	
	China	43.53	10570	27.23	
	German	46.76	51640	67.68	
	Indian	53.76	–	13.15	
	Japan	46.43	75600	25.94	
	South Korea	47.47	20210	57.96	
	United States	46.5	71830	42.22	
2005	Brazil	47.42	–	79.13	
	China	41.32	10850	55.39	
	German	45.02	60490	78.87	17.7 (2004)
	India	–	–	–	
	Japan	51.43	48950	45.43	30.1 (2003)
	South Korea	–	–	–	50 (2004)
	United States	46.18	65970	52.54	23 (2004)

Note: Data for "input ratio of R&D" are from the Organisation for Economic Co-operation and Development, ANBERD database, *http://www1.oecd.org/dsti/sti/ stat-ana/stats/eas_ anb.htm* (accessed May 22, 2007). *Science and Engineering Indicators 2008*. Others were calculated using data from OECD.Stat.

infrastructure in Suzhou and Wuxi, the costs of business there are too high. The supply of electronic components there is unstable and cost-sensitive, so businesses interested in investing have looked to surrounding areas instead. Pinghu fully meets the necessary geographic and cost conditions, giving it a good basis for attracting foreign investment.

5.3 "Seed" enterprises drive the relocation of upstream enterprises and the emergence of local supporting businesses

Since Nidec settled in Pinghu, the NTN company—one of the three major bearing manufacturers, with headquarters in Osaka, Japan—has also jumped on the bandwagon. These enterprises have brought and will bring in many related enterprises from Japan, while also helping to support a number of local domestic suppliers. The arrival of these major corporations has made the Pinghu opto-mechatronics industry cluster boom. Following the successful lead of Nidec, 12 foreign-funded enterprises have already settled in Pinghu, with a total investment of $410 million. The local production of digital camera shutters, cell phone cameras, microprecision motors, fluid dynamic pressure bearings, and other products has reached an internationally competitive level, and many of these products are now exported.

The Pinghu city government did not have unrealistic expectations when courting Nidec, but Nidec nonetheless played a pivotal role in the creation of Pinghu's industry cluster. The example of Nidec shows that it is essential for governments to attract seed enterprises with a strong leading role to encourage the development of industry clusters.

5.4 Effective government support and service system provide a strong incentive for the development of industry clusters

Nidec's investing in Pinghu is inseparable from the local government's commitment to its promise to implement support policies. The realization of the Pinghu municipal government's commitment to improving traffic motivated Kanto Tatsumi Electronics Co., Ltd., and Tokyo Special Electric Wire Co., Ltd., to make the decision to invest in Pinghu. Pinghu City set up the Advanced-technology Center and the Advanced-technology Innovation Service Center to promote the development of the opto-mechatronics industry. In cooperation with Tsinghua University, the Pinghu city government founded the Zhejiang–Tsinghua Yangtze River Delta Research Center, Pinghu Branch, and set aside advanced-technology industry development and industrialization funds of 10 million yuan a year. This provided an attractive platform for R&D, supporting enterprises through the introduction, absorption, and then integration of the innovation necessary to achieve industrial restructuring and upgrading.

The Pinghu government has built a support system using the following plan. First, improve the infrastructure and make Pinghu a satellite town of Shanghai. In early 1999, the Pinghu government built the Shanghai-Hangzhou high-speed road, reducing the drive between Shanghai Hongqiao Airport and Pinghu from 4 hours to less than 45 minutes. At the same time, the Pinghu government invested heavily in urban renewal, improving the city's infrastructure and landscaping. This helped a number of optical and electrical machinery enterprises to consider Pinghu to be a Shanghai satellite town, which in turn encouraged them to establish production bases in Pinghu while setting up a number of R&D and service sector facilities in Shanghai. The convenient transportation between the two cities permitted them to enjoy both the business environment of a metropolis and the low production costs of a satellite town.

Second, create a living environment suitable for foreign investors—specifically, Japanese investors. After Japanese opto-mechatronics enterprises had begun to establish themselves in Pinghu, the local government built a street named Japan Street in the downtown area with a number of Japanese-style luxury villas, instituted Japanese captioning on the local cable TV news, added Japanese classes in vocational secondary school, and also asked government officials to master conversational Japanese—all in order to create a harmonious living and working environment for the foreign nationals working in Japanese enterprises.

Third, provide professional services through the relevant government departments to create a favorable environment for the opto-mechatronics industry. In order to promote the development of the optical, mechanical, and electrical industries, the relevant departments in Pinghu have taken the initiative to provide effective professional services. For example, the Development and Plan Bureau made a plan for the development of the Pinghu opto-mechatronics industry and issued related development policies. The Technology Bureau included a detailed electromechanical advanced-technology industrial base in the provincial development plan; formed the Light Electrical Industry Promotion Center, an optical and electrical machinery testing center; and facilitated the launch of a variety of scientific and technological projects by the optical and electrical machinery enterprises. To address the shortage of skilled workers, the Labor Bureau worked in two directions at once: on the one hand, it provided local courses to train light mechanical and electrical staff; on the other hand, it went to vocational secondary schools in Jiangsu, Anhui, Shanxi, Shaanxi, and other places to recruit qualified personnel. The Personnel Bureau gave the green light for senior light electrical and professional talents to work in Pinghu. The Development Zone Committee provided a full range of services, from developing zone infrastructure construction and low-cost supporting staff quarters to processing documents, such as the export tax rebate form. Future plans include building a business park for the opto-mechatronics industries.

5.5 Typical model of an exogenous advanced-technology industry cluster in China

From analyzing the formation and development of the opto-mechatronics industry cluster in Pinghu, we can propose the following development model. The government encourages the introduction of foreign capital to start the engine of industrial development. By providing supporting services for the foreign enterprises, domestic enterprises accumulate capital, technology, and management experience. Once the industry cluster has developed to a certain extent, the local government builds a public platform for R&D and innovation to promote the R&D and innovation capabilities of local enterprises, encouraging interactive development between foreign and local enterprises and thereby stimulating the growth of the industrial cluster. This is a typical model of exogenous advanced-technology industrial cluster growth in China.

Pinghu seized the opportunity offered by multinational companies' transferring their manufacturing bases to China to successfully embed itself in the MNCs' global production chain. Its development is both a typical model of China's exogenous advanced-technology industrial cluster growth and an archetype of industrial development in China's coastal areas. Although Pinghu's opto-mechatronics enterprises are categorized as advanced-technology firms and enjoy high annual output values as well as a large share of the world market, we find that most of the enterprises within the cluster serve only as the processing and assembly bases for multinational companies, doing very few high value-added production activities such as R&D and design. Therefore, several questions—how to increase the R&D and innovation roles of the cluster, how to upgrade the whole industry, and how to improve both its profitability in international trade and its position in the international production chain—remain urgent issues for industry clusters similar to that of Pinghu. This is a critical concern not only for Zhejiang province but for the whole Chinese economy: to change from a world processing factory to a world factory.

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Appendix: Advanced-technology enterprises questionnaire

Basic Information	Date of registration		Registered capital		
	Square footage		Telephone		
	Your company is	A. State-level key advanced-technology company; B. Provincial-level key advanced-technology company; C. Key advanced-technology company of Jiaxing city			
	Type of company	1. state-owned; 2. collectively owned; 3. private; 4. joint-operation; 5.joint-stock; 6. joint-venture; 7. foreign-invested; 8. joint-venture with Hong Kong or Macao; 9. wholly owned by Hong Kong or Macao; 10. other			
	Your company belongs to the industry of	1. electronic information; 2. new materials; 3. biopharmaceuticals 4. opto-machatronics; 5. environmental protection; 6. new energy; 7. other			
Economic Index and Products		2005	2006	2007	2008
	Annual output value of main products				
	Annual output of main products				
	Proportion of added value in output				
	Export value ($10,000)				
	Value of raw materials and intermediate input (10,000 yuan)	__imported __	__imported__	__imported__	__imported__
	Market share	world ___ domestic___	world ___ domestic___	world ___ domestic ___	world ___ domestic ___
	Main sources of manufacturing facilities	A. imported; B. domestically purchased; C. internal R&D; D. others	Sources of product design and R&D	A. within the company; B. domestic companies; C. foreign companies; D. other	
	Primary sales channel	Export __%; domestic __% (produced by supporting companies %)			
	Major production process	A. key parts processing; B. general parts processing; C. final assembly; D. product testing			

<table>
<tr><td rowspan="3">Scientific Activity</td><td></td><td>2005</td><td>2006</td><td>2007</td><td>2008</td></tr>
<tr><td>Number of R&D staff</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Annual R&D input (10,000 yuan)</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Development</td><td>Reason for investing in Pinghu</td><td colspan="4">A. Efficient government service; B. preferential policies; C. sound geographic location; D. following up- and downstream companies; E. resources; F. new market opportunities; G. available supporting industries; H. other reasons ______</td></tr>
<tr><td>The most difficult situation in development</td><td colspan="4">A. Financing difficulties; B. lack of talent; C. excessive pressure of the company; D. environmental protection and adjustment of industrial policies</td></tr>
</table>

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On the Value Chain and International Specialization of China's Pharmaceutical Industry

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Abstract

This article studies the characteristics of the global pharmaceutical industry value chain and China's position in it, using the tools of value chain analysis, the Grubel & Lloyd (GL) index, and an input-output model. Research shows that in the global pharmaceutical value chain, proprietary medicine's value chain belongs completely to the producer-driven type, and the core added value is mainly from the input of research and development (R&D). Meanwhile, in the nonproprietary medicine value chain, raw medicine is comparatively independent and has a weak relation with the R&D stage. Based on the aforementioned findings, we conduct a concrete study of China's position in the global pharmaceutical

[1] This article represents solely the views of the authors and not the views of the United States International Trade Commission (Commission) or any of its individual Commissioners. This paper should be cited as the work of the authors only, and not as an official Commission document.

industry value chain. The results of the study show that China now mainly produces nonproprietary medicine and stands at the lowest point of the "smile curve." Based on this, we calculate the Vertical Specialization (VS) Index, and analyze China's position in the R&D stage of the world pharmaceutical value chain. We conclude that China's cheaper labor cost is the main reason why multinational companies move their clinical trials to China.

I. Preface

Since China entered the World Trade Organization, the Chinese pharmaceutical industry has experienced rapid progress. By 2008, the foreign trade volume of the Chinese pharmaceutical industry had reached $12.28 billion, almost 2.6 times the volume in 2002. The global pharmaceutical industry plays a very important role in maintaining healthy and rapid development of China's pharmaceutical industry. Therefore, it is important to use modern value chain theory and international specialization theory to analyze the Chinese position in the global pharmaceutical industry's value chain.

This article studies the Chinese pharmaceutical industry and China's international specialization in the world value chain. The article is divided into six parts: part 2 is a literature review, describing previous research and methodologies related to those used in this article; part 3 focuses on the characteristics of the pharmaceutical industry value chain; part 4 is empirical research on international specialization within the world pharmaceutical industry; part 5 is an empirical study of the position of the Chinese pharmaceutical industry in the global chain, i.e., China's international specialization within the industry; and part 6 contains conclusions.

II. Review of Previous Research

Research on the theory of the value chain

The value chain concept was first put forward by Michael E. Porter in 1985. He deconstructed production as a series of value creation "links"; thus the connection of these "links" is called a value chain. Porter concluded that most value chains share similar characteristics and contain both production and supporting links. The former mainly includes production and marketing links, while the latter mainly includes related supporting links, such as construction, research and development (R&D), human resources, etc.

Gereffi (1999) divided value chains into producer-driven and buyer-driven from the perspective of product characteristics. Kaplinsky and Morris (2000) further divided value chains into simple value chains and extended value chains. They pointed out that most value chains can be reduced to four interrelated links: R&D, production, sales, and consumption. The detailed value chain is much more complicated than the one mentioned above. It is normally related to several lines of business or industry, and thus forms a bigger value chain network. Gereffi (2005) put forward the world value chain concept, including the entire R&D design link of the upper stage, the spare parts manufacture and assembly found in the middle stage, and the sales, branding, and service found in the lower stage in the world production network. This provided a new perspective for analyzing every country's international specialization within the global chain.

Research on international specialization

The earliest conception of international specialization can be traced back to Adam Smith's Absolute Advantage Theory, David Ricardo's Relative Advantage Theory, and Heckscher and Ohlin's Resource Endowment Theory. Since the latter part of the last century, intra-industry trade has gradually increased and became a part of main stream trade theory. Verdoom (1960) first put forward the phenomenon of increased trade in the same standard international trade classification (SITC) product group. Balassa (1963) also provided European evidence of the same phenomenon. Gray (1979) and Krugman (1981) developed theoretical models of intra-industry trade. Grubel & Lloyd (1975) also put forward the concept of dividing intra-industry trade into horizontal and vertical trade, a convention that most scholars have adopted.

In recent years, as multinational companies produce via various value chain links worldwide, vertical specialization is becoming the new type of intra-industry division. Vertical specialization refers to international specialization in different production stages in the same industry. This can be carried out not only by multinational companies but also by nonrelated companies whose markets are in different countries. The vertical specialization (VS) index proposed by Hummels, Ishii, and Yi (2001) provided a method of measuring vertical specialization. Since then, many scholars have conducted deep research and measurement of every country's vertical specification status. This theory shares the same theoretical base as the world value chain and will gradually become one of the mainstream theories of international specialization.

Research on China's overall value chain and international specialization

Until now, many scholars have studied the value chain and international specialization of China's overall industry or an individual industry. Liu and Chen (2007) measured the domestic total value added (TVA) in Chinese exports in 41 sectors, using a noncompetitive input-output table. A research team led by Ping (2005) calculated the VS index for trade between China and the United States. However, an input-output table that includes 123 sectors is required to analyze the pharmaceutical industry, so there has not been research on the TVA and VS indices of the pharmaceutical industry until now.

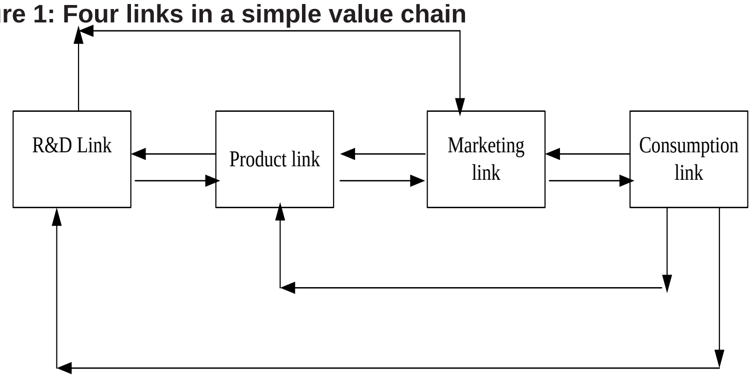
III. Study of the pharmaceutical industry value chain structure

Characteristics of the pharmaceutical industry value chain

Kaplinsky and Morris (2000) studied value chain structure and concluded that value chains can be classified as simple or extended. They maintained that most value chains can be described by the four-link model: R&D, production, sales, and consumption. However, the extended value chains of different products are more complicated. Kaplinsky and Morris used the timber industry as an example to illustrate an extended value chain link chart.

According to an investigation of six medical companies, including Jin Ling Medical Company in Jiangsu Province, and a medicine production link on the Web sites of Roche Company and Pfizer Incorporated, the simple value chain of medicine is similar to that of other finished products and follows Kaplinsky's model (2000), as illustrated in figure 1.

Figure 1: Four links in a simple value chain



However, the extended value chain of medicine has some noticeable particularities. First, there exist clear differences among the value chains of different medicines. There are various catalogues of medicines worldwide, such as proprietary medicine and nonproprietary medicine, which are divided by standards of intellectual protection. Though the above medicines are all final products, their production links' divisions show visible differences. In the automobile and IT industries, on the other hand, the production links of different types of final products share many similarities.

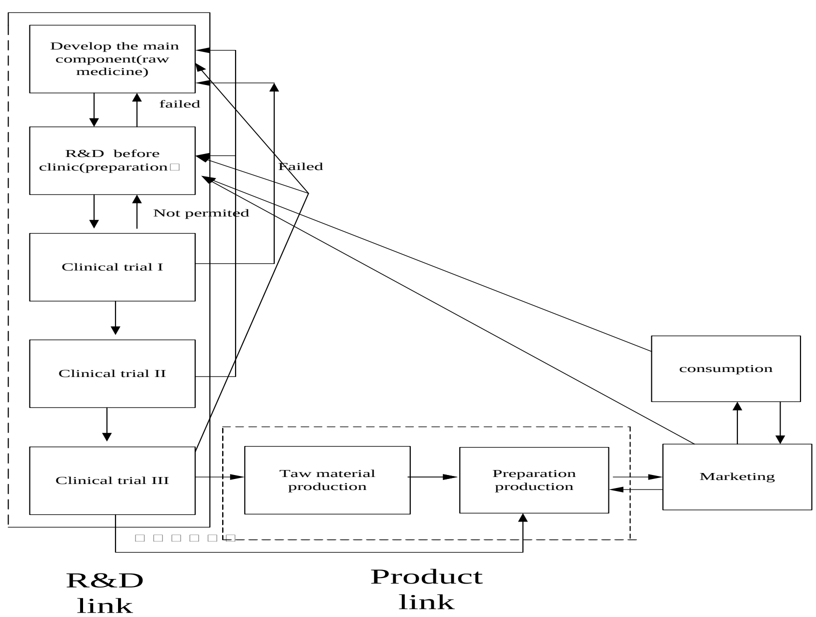
Second, the degree of modularization in medicine's value chain is relatively low. Currently, there are two modules in the production link of medicine's value chain: raw medicine production and preparation production. The former is a chemical link, while the latter is a physical link. Third, the R&D link of the medicine industry is more complicated, and the degree of modularization is comparatively high. According to Pfizer, the R&D link of one proprietary medicine will include many links; for example, finding the ingredients, clinical trial development, multiple phases of clinical trials, etc. Even after many years of clinical trials, a new medicine will not be sold on the market if it has not undergone a sufficient number of trials.

There are distinct characteristics in different R&D links in the pharmaceutical industry, of which the clinical trial is the most representative. In the above link, the clinical trial is the core link in the pharmaceutical industry and is also a particularly special link. The main function of this link is to transfer the trial medicines from the former R&D links into the human body, according to certain rules, and give feedback to the former R&D link. Therefore, this link requires not only high-tech talent, but also a large number of patients to participate in the trial, which greatly increases the cost of the entire R&D link.

Study of the extended value chain of proprietary medicine and nonproprietary medicine

The extended value chains of proprietary medicine and nonproprietary medicine are different. Figure 2 shows the extended value chain of proprietary medicine production. There is a long section of R&D links in proprietary medicine, which are indispensable for the follow-up link. Proprietary medicine production thus has high risk, high R&D input requirements, and high value added. According to PHRMA, in 2006, the R&D input of every proprietary medicine was about $1.3 billion. Because only large firms can afford such a high level of investment in R&D, the R&D and production links of proprietary medicine tend to be monopolized by multinational companies.

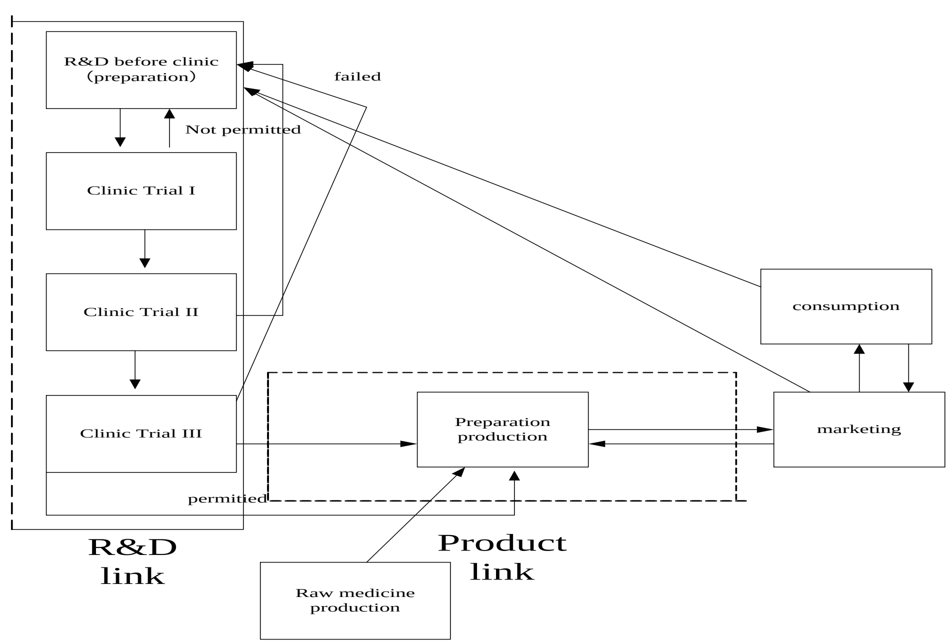
Figure 2: The extended value chain of proprietary medicine



Based on the above analysis, we draw some conclusions about the added value of various value chains of proprietary medicine. First, the R&D link is the link contributing the most added value in the proprietary medicine value chain. This can ensure the monopoly status of patent owners in the production. Second, the first two sublinks in the R&D link are the main value-added link, while the clinical trials are only an assistant link that provides data support to the first two links. Third, the production link is actually an auxiliary link to the R&D link, and exists to realize profits. Finally, due to an almost complete monopoly of multinational companies, the added value from the marketing link is far lower than that from the R&D link.

Figure 3 shows the extended value chain of nonproprietary medicine. A comparison of figures 2 and 3 reveals the following differences. First, the total value-added ratio of nonproprietary medicine is clearly lower than that of proprietary medicine. This is because nonproprietary medicine has no link of finding components, whereas for proprietary medicine, this link is located on the upper left of the "smile curve," and that is the maximum value-added link. Thus the value-added ratio of nonproprietary medicine is clearly lower than that of proprietary medicine.

Figure 3: The extended value chain of nonproprietary medicine



Second, nonproprietary medicine production is the link that is called “R&D before the clinical trial” and is also the main source of value-added in the chain. Figure 3 shows that raw medicine production for nonproprietary medicine is outside of the main value chain, and has no clear relation with the former R&D link, while the nonproprietary medicine pharmaceutical production has a direct connection with the R&D link. In fact, some nonproprietary medicine’s pharmaceutical formulation is the same as that of the proprietary medicine, so there is no second sub-link of the R&D link in their value chain.

Third, there is more competition in the nonproprietary medicine market than in the proprietary medicine market, thus adding more value to the marketing link. Due to the lower barriers to entry in nonproprietary medicine (relative to proprietary medicine), nonproprietary medicine production is done by many companies in developed countries, and some small and medium-sized pharmaceutical manufacturers in developing countries. Thus, a greater degree of competition exists than in proprietary medicine. This kind of market structure increases the added value of the marketing link.

Finally, the degree of competition in nonproprietary medicine raw materials production is the highest. For most medicines, the difficulty in producing these raw materials is the production technology. If the production technology is public, the difficulty of producing raw materials for nonproprietary medicine is far lower than that of manufacture of nonproprietary manufactured medicine. Because raw materials produced by many corporations are highly substitutable, the share of value-added attributable to the raw materials production link is the lowest, and the degree of price competition is high.

Based on the above, this article makes a judgment on the characteristics of the value chains of proprietary medicine and nonproprietary medicine, according to Gereffi’s method (1999). Gereffi holds that value chain can be judged by the system in table 1.

Table 1: Producer-driven and buyer-driven value chains

	Producer-Driven Commodity Chains	Buyer-Driven Commodity Chains
Drivers of Global Commodity Chains	Industrial Capital	Commercial Capital
Core Competencies	R&D; Production	Marketing; Design
Barriers	Economies of Scale	Economies of Scope
Typical Industries	Automobiles; Computers; Aircraft	Apparel; Footwear; Toys
Ownership of Manufacturing Firms	Transnational Firms	Local Firms, predominantly in developing countries
Main Network Links	Investment-based	Trade-based

Source: Gereffi, 1999b.

Using the above analysis, we can draw several conclusions regarding the value chains of proprietary medicine, nonproprietary medicine raw materials and nonproprietary manufactured medicine. Proprietary medicine's core competitive edge is mainly in R&D; it has high investment and technical input requirements, and is mainly produced by multinational companies. Therefore, it belongs to the producer-driven value chain. In nonproprietary manufactured medicine, sales links and production links are both important core competencies, and both multinational companies and local middle- and small-sized companies are involved in production. Thus, nonproprietary manufactured medicine shares characteristics of both producer-driven and buyer-driven value chains. The profit of nonproprietary medicine raw materials mainly comes from the sales link. Given the low barriers to entry, local small companies are the main producers of this kind of medicine. Thus, this value chain would be classified as a buyer-driven.

Analysis of the nature of three Chinese sub-pharmaceutical industries' value chains

The Chinese pharmaceutical industry has three sub pharmaceutical industries: the chemical medicine industry, the TCM industry, and the biological products industry. The value chain of the chemical medicine industry is very similar to the value chain above. The value chain of the TCM industry is a little different from the others.

The TCM industry (figure 4) has both consumer-driven and producer-driven value chain characteristics. Because sliced pieces of TCM can be produced without R&D, sales have an important status in the value chain of sliced pieces of TCM; thus, the value chain of sliced pieces is consumer-driven. The TCM product has both consumer-driven and producer-driven value chain characteristics.

Because of cultural differences and other reasons, currently, TCM has wide acceptance only in China and in the Chinese communities in East Asia, Southeast Asia, and some parts of South Asia. Europe and the United States, the major global markets of medicine, seldom accept TCM. As a result, TCM is not produced in a global supply chain. The value chains of TCM only exist within China's market and in the Chinese economic communities in Asia.

The value chain of biological products is also different from that of TCM. The raw material production link is the first link in the value chain and contributes the least added value. Almost no individual raw medicine research takes place in China, because the cost of R&D is very high. China's industry is mainly specialized in raw material production, and is essentially not competitive in the R&D link or the preparation link.

Analysis of the characteristics of the Chinese pharmaceutical industry value chain

The Chinese pharmaceutical industry has two important characteristics. First, the industry has a high degree of dispersion; no multinational company exists. According to the Chinese High-Tech Statistics Yearbook, the share of value-added attributable to Chinese multinational companies was 22.3 percent in 2007. According to a new U.S.-created pharmaceutical committee, the sales volume of the 30 largest multinational companies makes up to 76.9 percent of total pharmaceutical sales in the United States. This shows that the Chinese pharmaceutical industry is actually led by small and medium-sized companies, not multinationals.

Second, the Chinese pharmaceutical industry does not contribute much to the R&D link. Chinese R&D spending in the industry is low. The Chinese input of science activities in the pharmaceutical industry was only 6.3 billion yuan in 2007. In contrast, the Pfizer company spent $8.7 billion on R&D in 2008. In addition, the Chinese pharmaceutical industry's R&D intensity is low. The following table shows the differences in R&D intensity between China and developed countries in pharmaceutical manufacturing.

Figure 4: Value chain of Traditional Chinese Medicine (TCM)

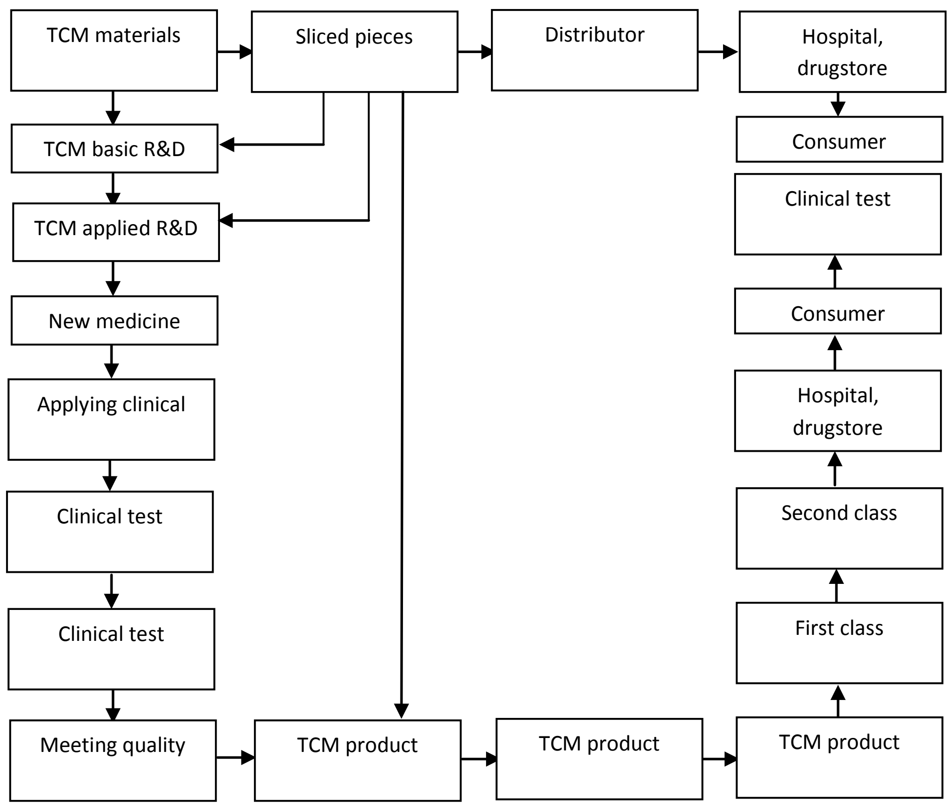


Figure 5: Value chain of Biological Products

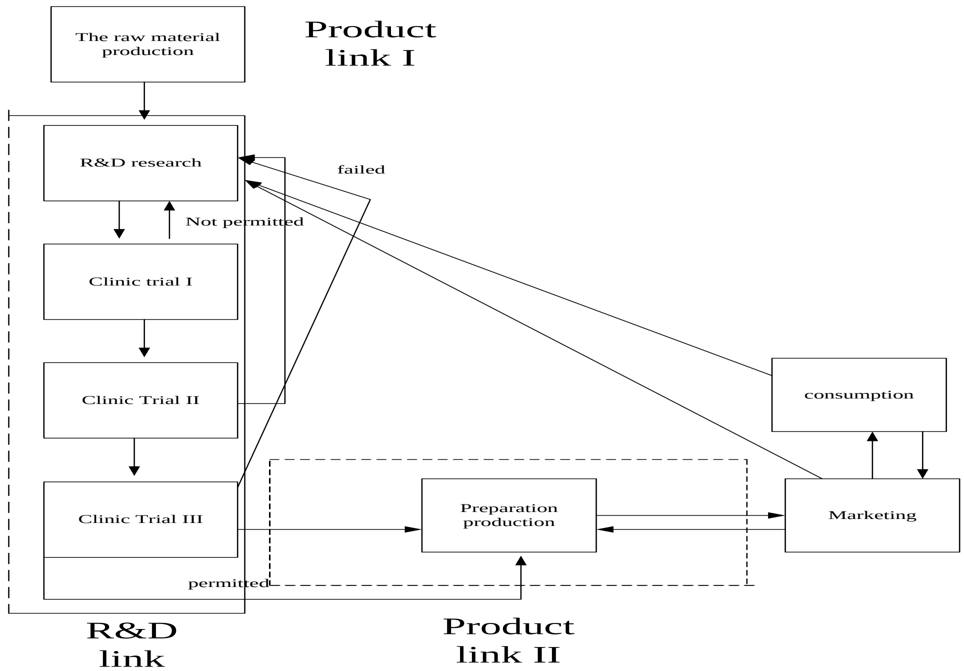


Table 2: Comparison of the R&D intensity of China and Selected Developed Countries

	China	USA	Japan	Germany	France	England	Korea
	2007	2006	2006	2006	2006	2006	2006
Manufacture	3.5	10.2	11	7.6	9.9	7	9.3
High-tech industry	6	39.8	28.9	21.5	31.9	26.6	21.3
Pharmaceutical industry	4.7	46.2	37.1	23.9	33.4	42.3	6.3

Source: Ministry of Science and Technology of the People's Republic of China

The R&D intensity of Chinese medicine manufacturers is just a bit higher than the average level of the manufacturing industry, which is far lower than developed countries, and also lower than the average level of the Chinese high-tech industry. Thus, the R&D stage is not China's comparative advantage within the medicine manufacturing industry. Using Gereffi's classification of value chains (table 1), we can conclude that the Chinese pharmaceutical industry's value chain is buyer-driven.

IV. Empirical research on international specialization in the global pharmaceutical industry

Given this analysis of the global pharmaceutical industry value chain, we make some hypotheses about international specialization in the industry:

Hypothesis 1: Intra-industry trade (IIT) is the dominant form of trade in global medicine among developed countries

We expect that medicine, especially the final product stage of the value chain, is typically technology- intensive, and has no labor intensive stages. Developed countries have a significant advantage in high-tech fields, compared to developing countries. Thus, we expect that the pharamceutical trade among developed countries is largely IIT.

Table 3 shows the breakdown of global pharmaceutical trade by country. Shares are calculated from United Nations Commodity Trade Statistics.[2]

Table 3: The distribution of global pharmaceutical trade

	Share of Global Exports	Share of Global Imports
	2008	2008
Developed Countries:	90.55%	80.15%
EU15 and Switzerland	80.02%	56.85%
USA	7.98%	15.73%
Canada	1.53%	2.84%
Australia	0.86%	1.84%
Japan	0.89%	2.90%
Other Countries:	9.45%	19.85%
India	1.51%	0.53%
China	1.81%	1.45%

Source: Calculated from U.N. commodity trade statistics.

[2] There is still no agreement on the statistical classification for various medicines in foreign trade. Given this limitation, this article uses the following rules of classification. Products in HS 2935-2941 cover 95 percent of chemical raw medicines; products in HS 3003-3004 cover almost all chemical preparations, plant preparations, Chinese medicine preparations and part of the biological preparations. This study does not include general medical supplies like bandages, medical splints, and medical boxes in the preparations product category.

The results show that most of the world pharmaceutical trade is conducted among developed countries; about 91 percent of medicine exports and 80 percent of medicine imports supply are in 20 developed countries. Developing countries, such as China and India, are beginning to develop an international specialization in this industry, but they still account for a very small portion of global pharmaceutical trade.

To assess how specialized developed countries are in the pharmaceutical industry, we use the 1975 Grubel & Lloyd (GL) index of IIT. The GL index is defined as follows:

$$GL_j = \frac{\sum_{i=1}^{N}(X_i + M_i) - \sum_{i=1}^{N}(|X_i - M_i|)}{\sum_{i=1}^{N}(X_i + M_i)} \times 100$$

X_i, export of the i product; M_i, import of the i product

The GL indices of manufactured medicine products and medicine raw materials of United States, United Kingdom, Switzerland, France, and Germany in 2004 and 2008 are provided in table 4. Every country's GL index is over 0.5 and some countries' GL index such as France and Germany shows a clear rising trend. This proves that the intra-industry division in developed countries is the main type of international specialization of the global pharmaceutical industry. From the perspective of product structure, we can see that the GL index of raw medicine as intermediate product is comparatively low, while the GL index of main trade product-pharmaceutical preparation is comparatively high.

Hypothesis 2: Most of global pharmaceutical trade is in final products. Intermediate products account for a small share of trade.

International trade theory shows that trade in intermediate product greatly relies on two points: the spatial separability of production, and differing factor intensities across the stages in the global chain. We expect that the degree of separability in production links in proprietary medicine is low; thus, final product trade will be the dominant type of global pharmaceutical IIT.

Table 4: The GL Index of Pharmaceutical products in Five Developed Countries

	Year	GL index of total pharmaceutical trade	GL index of raw medicine	GL index of manufactured products trade
France	2004	73.25	48.98	76.78
	2008	78.54	60.77	80.19
Germany	2004	59.2	57.8	59.33
	2008	61.34	40.41	63.08
Switzerland	2004	66.87	46.66	70.03
	2008	57.26	51.7	57.82
England	2004	77.97	57.48	79.36
	2008	75.8	80.06	75.6
USA	2004	69.58	77.66	67.96
	2008	63	65.91	62.51

Source: Calculated from U.N. commodity trade statistics.

We treat raw medicine as an intermediate product in the global pharmaceutical industry, and all kinds of prepared medicines as final products. In table 5 we show the ratio of final products and intermediate products in global pharmaceutical trade in 2008. The result demonstrates that hypothesis 2 is correct, and trade is mainly composed of trade in final products.

Table 5: The proportion of intermediate product trade and final product trade

	Prepared Medicine trade (2008)	Raw medicine trade (2008)
	(Final product)	(Intermediate product)
Proportion of export	90.40%	9.60%
Proportion of import	90.59%	9.41%

Source: Calculated from U.N. commodity trade statistics.

Hypothesis 3: Most of the trade between the developed countries is horizontal intra-industry trade.

Intra-industry trade can be divided in two parts: horizontal intra-industry trade (HIIT) and vertical intra-industry trade (VIIT). HIIT means the technological level of import and export is similar, while VIIT means the technological level is different. Fukao & Ishido (2004) proposes the following criteria to judge whether trade is HIIT or VIIT.

$$\frac{Min(M_{kk^{'}j}, M_{k^{'}kj})}{Max(M_{kk^{'}j}, M_{k^{'}kj})} \leq 0.1 \text{ unilateral trade;}$$

$$0.1 \leq \frac{Min(M_{kk^{'}j}, M_{k^{'}kj})}{Max(M_{kk^{'}j}, M_{k^{'}kj})} \leq 10 \quad 0.8 \leq \frac{P_{kk^{'}j}}{P_{k^{'}kj}} \leq 1.25 \text{ horizontal inter-industry trade}$$

$$0.1 \leq \frac{Min(M_{kk^{'}j}, M_{k^{'}kj})}{Max(M_{kk^{'}j}, M_{k^{'}kj})} \leq 10 \quad 0.8 \leq \frac{P_{kk^{'}j}}{P_{k^{'}kj}} \geq 1.25 \quad \frac{P_{kk^{'}j}}{P_{k^{'}kj}} \leq 0.8 \text{ vertical inter-industry trade}$$

$M_{kk^{'}j}$:country k export to country k$^{'}$ in commodity j $P_{kk^{'}j}$: the price, 0.1 1.25 and 0.8 threshold

Based on the method given by Fukao and Ishido, we calculate separately the proportion of unilateral trade, HIIT and VIIT, in the trade between France, Germany, and the United States, shown in table 6. The results support hypothesis 3.

Table 6: The proportion of unilateral trade, VIIT and HIIT

	Proportion of unilateral trade (2008)	Proportion of vertical intra-industry trade (2008)	Proportion of horizontal intra-industry trade (2008)
Germany and USA	20.89%	30.11%	49.01%
France and USA	16.28%	10.97%	72.75%

Source: Calculated from U.N. commodity trade statistics.

V. Empirical Study on the Chinese Pharmaceutical Industry Division

The pharmaceutical industry value chain production link is relatively simple, and is divided into raw medicine production and prepared medicine production. We can judge the position of the Chinese pharmaceutical industry in international specialization according to Trade Competitive Index (TC Index) (of Chinese raw medicine and prepared medicine).

We calculate the Trade Competitive Index (2004-2008) for China and India's raw and prepared medicine, as shown in tables 7 and 8. We can see from the chart that China and India both have a certain degree of overall competitiveness in the pharmaceutical industry, but the origin of the competitiveness differs greatly. The Chinese TC index is very high for raw medicine, showing that

China has absolute comparative advantage in raw medicine production; while India is located at a relatively low position. In prepared medicine, China is located at a low position and the TC index has a falling trend; while India has a remarkable advantage. Thus we can infer that since 2004, in the global pharmaceutical value chain production link, China is mainly specialized in raw medicine, while India is specialized in prepared medicine.

Table 7: The TC index of China's and India's pharmaceutical trade

Year	TC index of China	TC index of India
2004	0.19	0.55
2005	0.17	0.5
2006	0.17	0.49
2007	0.15	0.47
2008	0.13	0.52

Source: Calculated with data from U.N. commodity trade statistics and China's customs.

Table 8: The TC index of China and India intermediate product trade and preparation product trade

Year	Intermediate products		Preparation products	
	TC index of China	TC index of India	TC index of China	TC index of India
2004	0.73	-0.01	-0.56	0.76
2005	0.74	-0.11	-0.56	0.74
2006	0.78	-0.15	-0.58	0.7
2007	0.79	-0.13	-0.58	0.7
2008	0.8	-0.06	-0.6	0.71

Source: Calculated with data from U.N. commodity trade statistics and China Customs.

We can draw the same conclusion using the intra-industry trade analysis method. Because we calculate the TC index of both raw medicine and preparation, so we also can use intra-industry trade method to analyze the China's pharmaceutical trade. Tables 9 and 10 show the GL indices of China and India from 2004 to 2008, as well as both countries' bilateral trade, vertical inner trade, and horizontal trade ratio in pharmaceutical trade.

Table 9: The GL index of China's and India's pharmaceutical trade

Year	GL index of China	GL index of India
2004	34.45	38.26
2005	33.76	39.1
2006	31.16	40.04
2007	30.62	42.4
2008	29.32	40.11

Source: Calculated with data from U.N. commodity trade statistics and China Customs.

Table 10: The proportion of unilateral trade, VIIT and HIIT in China and India

		Unilateral trade (import)	Unilateral trade(export)	VIIT	HIIT
China	**Total medicine trade**	34.03%	53.12%	12.85%	0.00%
	Prepared medicine trade	87.95%	0.00%	12.05%	0.00%
	Raw medicine trade	0.00%	85.92%	14.08%	0.00%
India	**Total medicine trade**	8.96%	0.00%	89.86%	1.18%
	Prepared medicine trade	0.00%	0.00%	95.19%	4.81%
	Raw medicine trade	0.00%	12.74%	87.26%	0.00%

Source: Calculated with data from U.N. commodity trade statistics and China's customs.

The degree of IIT in Indian pharmaceutical products is obviously higher than that of China, and closer to developed countries in Europe or the United States. Using the method of Fukao & Ishido (2003), we can also see that China's raw medicine tends to be unilaterally exported, while the leading industry – manufactured medicine products – tends to be unilaterally imported. So these trade flows are not characterized by intra-industry trade. India's IIT is basically vertical in both raw medicine and prepared medicine, and the degree of participation in IIT is much higher than China's.

China's status in raw medicine in the global pharmaceutical value chain is not a good sign for the development of the Chinese pharmaceutical industry.

As described above, in the nonproprietary medicine field, raw medicine production has a weak connection with the core link of the value chain – the R&D link – while prepared medicine production has a closer connection. Thus, raw medicine production is the lowest end link in the nonproprietary medicine value chain, while R&D and production of prepared medicines are at the relatively high end. So we can conclude that China's international specialization within the nonproprietary medicine chain is at the lowest end of the "smile curve," while India is located at the relatively high end.

Because raw medicine production is one of the links in final production of prepared medicines, the Chinese pharmaceutical industry has the characteristics of vertical specialization. Vertical specialization refers to the international fragmentation of different production links in the same product in same industry, across countries. It is a new type of vertical industry division, and is also the main type of intra-industry division between developed countries and developing country. Raw medicine production in China embodies higher efficiency because of multinational companies' vertical specialization.

But there is a great difference between vertical specialization in the medicine industry and in the IT industry. On the one hand, though there is weak connection between raw medicine production and core R&D link, raw medicine production is still a capital intensive industry link and has higher technical and capital requirements than the assembly link of the IT industry. Therefore, though China is now located at the lowest end in the world medicine value chain, the added value in this link is much higher than in the assembly link of IT industry. On the other hand, the assembly link of the IT industry is located at the end of its value chain, and the products are directly for sale. In contrast, raw medicine is located at the front part of the medicine production chain. Outsourcing this link could reduce cost to some degree, but might produce more uncertainty for the subsequent high value-added links, thus enlarging production risk. Thus, the degree of vertical specialization in the Chinese medicine industry may be far lower than in the IT industry. Lastly, the relation between vertical specialization and processing trade is weaker than in manufacture industries such as IT.

We used the Input-Holding-Output Model of the Non-Competitive Imports Type Capturing China's Processing Exports by Chen Xikang and Zhu Kunfu (2008) to calculate the VS index and domestic value-added ratio. With their help, we constructed the Input-Holding-Output Model, which includes 43 sectors in 2002. We used the 42 sector Input-Holding-Output Model, the

123 sector Input-Holding-Output Model, and processing trade in Chinese medicine. All data are from 2002. The resulting VS share and domestic value-added share are shown in tables 11 and 12.

The results support our initial assumption. The Total VS index value for the pharmaceutical industry is 0.38, and for processing trade is 0.59—slightly higher than some light industries like food and textiles, but far lower than the IT or transport equipment industries. Therefore, the domestic value added of Chinese pharmaceutical production is very high (0.618). This implies that each $1,000 worth of pharmaceutical exports, yields China $618 worth of domestic value-added earnings—1.63 times that which is brought through communication equipment, computers, and other electronics equipment exports. All this demonstrates that the local added value of the domestic pharmaceutical industry is much higher than that of the IT industry, though they are both situated at the lowest end of the value chain.

Other data also support this conclusion. The main indirect evidence comes from processing trade in the Chinese pharmaceutical industry. The main way of participating in vertical specialization is by processing trade. But processing trade is comparatively low in foreign content. We compare the share of processing exports with general exports between China and the United States, using data provided by United States International Trade Commission. The results are in table 13.

Table 11: The VS index in the pharmaceutical industry in 2002

	Direct VS index			Total VS Index		
	General Trade	Processing Trade	Total	General Trade	Processing Trade	Total
Manufacture of food products and tobacco processing	0.0013	0.5075	0.1115	0.0081	0.5664	0.19
Textile goods	0.0025	0.6389	0.1991	0.0124	0.6977	0.273
Wearing apparel, leather, furs, down and related products	0.0022	0.5929	0.198	0.0113	0.6616	0.2829
Sawmills and furniture	0.0025	0.5831	0.1798	0.013	0.6514	0.3175
Paper and products, printing and record medium reproduction	0.003	0.5399	0.2059	0.0127	0.6147	0.341
Petroleum processing, coking and nuclear fuel processing	0.0546	0.7302	0.684	0.0705	0.7755	0.7326
Chemicals	0.0071	0.6416	0.3592	0.0237	0.7267	0.5303
Medicine industry	**0.0042**	**0.5253**	**0.2732**	**0.0129**	**0.5937**	**0.3816**
Nonmetal mineral products	0.0045	0.5512	0.2482	0.0175	0.628	0.3962
Metals smelting and pressing	0.0061	0.6917	0.281	0.0224	0.737	0.4715
Metal products	0.0034	0.7382	0.2323	0.0189	0.776	0.4589
Common and special equipment	0.0072	0.6944	0.3709	0.0213	0.7466	0.5284
Transport equipment	0.0066	0.6905	0.3257	0.0214	0.7552	0.5369
Electric equipment and machinery	0.0079	0.7239	0.3443	0.0227	0.7723	0.5189
Telecommunication equipment, computer and other electronic equipment	**0.0058**	**0.8221**	**0.5112**	**0.0201**	**0.8419**	**0.621**
Instruments, meters, cultural and office machinery	0.0489	0.6062	0.3626	0.0629	0.6408	0.5103

Table 12: The domestic value-added ratio in the pharmaceutical industry in 2002

	DVA			TVA		
	General Trade	Processing Trade	Total	General Trade	Processing Trade	Total
Manufacture of food products and tobacco processing	0.3403	0.1701	0.2132	0.9919	0.4336	0.81
Textile goods	0.2896	0.1357	0.1761	0.9876	0.3023	0.727
Wearing apparel, leather, furs, down and related products	0.3233	0.1346	0.1857	0.9887	0.3384	0.7171
Sawmills and furniture	0.3148	0.1494	0.1923	0.987	0.3486	0.6825
Paper and products, printing and record medium reproduction	0.3772	0.1843	0.2409	0.9873	0.3853	0.659
Petroleum processing, coking and nuclear fuel processing	0.1835	0.0942	0.1177	0.9295	0.2245	0.2674
Chemicals	**0.2754**	**0.1355**	**0.1735**	**0.9763**	**0.2733**	**0.4697**
Medicine industry	**0.4148**	**0.2397**	**0.2827**	**0.9871**	**0.4063**	**0.6184**
Nonmetal mineral products	0.355	0.1801	0.2254	0.9825	0.372	0.6038
Metals smelting and pressing	0.2596	0.1336	0.1671	0.9776	0.263	0.5285
Metal products	0.2665	0.1296	0.1678	0.9811	0.224	0.5411
Common and special equipment	0.314	0.1538	0.1948	0.9787	0.2534	0.4716
Electric equipment and machinery	0.2817	0.1322	0.1818	0.9773	0.2277	0.4811
Telecommunication equipment, computer and other electronic equipment	**0.2655**	**0.1151**	**0.1749**	**0.9799**	**0.1581**	**0.379**
Instruments, meters, cultural and office machinery	0.1883	0.2888	0.0891	0.9371	0.3592	0.4897

Table 13: The proportion of general trade and processing trade between China and the United States in the pharmaceutical industry

		2006	2007	2008
Total	Proportion of General trade	81.95%	87.42%	81.09%
	Proportion of Processing trade	11.25%	11.64%	16.60%
Raw medicine	Proportion of General trade	81.45%	87.11%	80.93%
	Proportion of Processing trade	18.02%	12.08%	16.81%
Prepared medicine	Proportion of General trade	98.53%	95.07%	82.77%
	Proportion of Processing trade	0.53%	0.52%	14.32%

Source: Calculated with data from China customs.

We can see that the share of exports in the medicine industry classified as processing is floating around 15 percent—far lower than the average share of processing across all Chinese exports, which exceeds 40 percent.

Additional evidence comes from the company structure of Chinese pharmaceutical exports. Multinational companies (MNCs) account for a smaller share of Chinese medicine exports than IT exports. It is estimated that only 33.1 percent of the medicine exported to the United States are done by foreign-invested companies. The other two-thirds are done by local companies. Even in processing trade, Chinese local companies have an advantageous position. In 2008, Chinese local companies' share of processing exports to the United States in medicine was about 68 percent. The proportion of foreign-invested companies is over 80 percent in overall processing exports.

These results show that the Chinese pharmaceutical industry, though participating in global vertical specialization to some degree, is not led by foreign-invested companies. Instead, it is the result of local companies seeking to maximize the benefits of, and actively participating in, international specialization.

This paper mainly analyzes China's position in the global pharmaceutical industry value chain. Within the R&D link, multinational companies intend to move clinical trials to China. As described above, the R&D trial link is different from the previous two links, which require not only high-tech talent but also large amounts of labor to generate sufficient experimental data. Therefore, China has a relative advantage in clinical trials. The cost of clinical trials is much higher in developed countries than in China, due to the high resident income of developed countries. Also, the clinical trial's function is mainly to offer database support. Thus technical spillover effects are far lower than in other links and multinational companies' monopoly in technology is far less important.

In order to support this conclusion, we provide some statistics on multinational companies' clinical trials and pharmaceutical companies' data based on the largest registered clinical trial database, "clinicaltrials.gov," and data from China's High-Tech Statistical Yearbook. The results in table 14 show that in 2007, multinational companies' clinical trials in China increased 74 percent over those in 2005, while the ratio of value added grew only 57 percent over the same period.

Table 14: Clinical trials in China

Year	Clinical trial number by MNC	MNC number	Value-added by MNC (100 MRMB)
2005	79	707	364.05
2006	123	739	432.9
2007	137	797	570.12

Due to the increasing demand for clinical trial candidates throughout Phases I to IV (from tens of candidates in Phase I to thousands in Phase IV), Phases III & IV have more expenditures for collecting sample data. Thus, we can prove the cost advantage in Chinese clinic trial by analyzing the structure of multinational companies' clinical trials in China. The results are shown in table 15. In MNC clinical trials in China, the labor cost proportions are higher in Phases III & IV than in MNC trials worldwide. We can conclude that the main reason for conducting clinical trials in China is because of the lower labor cost.

Table 15: Clinical trials I-IV in China and Worldwide by MNCs

Year	MNC trials in China				MNC trials Worldwide			
	Phase I	Phase II	Phase III	Phase IV	Phase I	Phase II	Phase III	Phase IV
2005	2.56%	16.67%	55.13%	25.64%	8.66%	32.14%	38.78%	20.41%
2006	5.79%	9.92%	69.42%	14.88%	15.04%	32.52%	34.68%	17.76%
2007	5.69%	17.89%	55.28%	21.14%	20.46%	35.33%	27.59%	16.61%
2008	8.21%	9.70%	53.73%	28.36%	25.07%	32.77%	25.94%	16.22%

Part 6 Conclusion

This paper is an empirical study of China's position, or international specialization, in the global pharmaceutical value chain. From our analysis, we draw the following conclusions. First, compared to other manufacturing industries, the pharmaceutical industry value chain has a complicated R&D link and a lower degree of modularization in its production link. These characteristics imply that the main type of division in the pharmaceutical industry is horizontal intra-industry trade among developed countries.

Second, proprietary medicine and nonproprietary medicine have clear differences in their value chain. The degree of modularization of the non-patent prepared chemicals value chain is higher than proprietary medicine, and nonproprietary medicine has less demand for R&D in the raw medicine production link. This gives the pharmaceutical industry some degree of vertical specialization.

Third, the unique clinical trials in R&D links in the pharmaceutical industry have the characteristics of strong modularity, low technical spillovers, and high labor intensity. These make outsourcing the main type of vertical specialization in the R&D links. Experimental results show that lower cost motivates multinational companies to transfer clinic trials to China.

Fourth, the characteristics of low R&D expenditures and small scale enterprises imply that China mainly participates in vertical specialization in nonproprietary raw medicine production. But the degree of vertical specialization is far less than in the IT industry. This link is the lowest end of the global value chain in pharmaceutical products.

Finally, the VS index shows a low level of foreign content and that processing trade is dominated by local companies. Though the pharmaceutical and IT industries are both in the lowest end of their value chains, the domestic value-added ratio for the pharmaceutical industry is higher than that of the IT industry.

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The Information Technology Agreement: An Assessment of World Trade in Information Technology Products

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Abstract

The Information Technology Agreement (ITA), a multilateral agreement emerging from the Uruguay Round, eliminates tariffs on specific technology and telecommunications products for member countries. Primary goals of the ITA are increased trade and competition through trade liberalization for information technology (IT) products, and the global diffusion of information technology. The ITA went into effect in 1997 with 29 WTO member countries and now includes 72 WTO members. It covers over 95 percent of total world trade in IT products, currently estimated at $4 trillion annually. The emergence of complex global supply chains for IT products, rapid deployment of new technologies, and technology convergence since the ITA's inception, shine new light on the role of the ITA in global trade. This paper provides an overview of the ITA, describes the level of tariff liberalization associated with membership, and discusses the changing composition of ITA membership. The paper further examines ITA trade between 1996 and

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2008, highlighting the changing composition of trade by leading exporting and importing nations and profiles ITA trade by product segment, focusing on computers, semiconductors, and telecommunications equipment. The paper finds a significant shift in ITA trade to Asia, particularly China, and to a lesser extent to Eastern Europe. Significant developments in global ITA trade include, increasing diversification of ITA members' trade and economic profiles and expanding trade participation by developing countries.

Introduction

The Information Technology Agreement (ITA or Agreement), a multilateral agreement emerging from the Uruguay Round, eliminates tariffs on specific technology and telecommunications products by signatory countries. Based on the most favored nation (MFN) principle, the benefits of ITA tariff liberalization are extended to all WTO members. Primary goals of the ITA are increased trade, global diffusion of information technology, and enhanced global economic growth and welfare through trade liberalization for information technology (IT) products. The ITA was concluded in late 1996 with 29 WTO member countries and now includes 72 WTO members. This paper provides a historical perspective on ITA product trade, examining global trade flows and accession of new member countries during the 12 years of the Agreement. Trade patterns for ITA products are examined in the context of increased trade and competition and diffusion of information technology as envisioned in the Agreement.

The paper begins with an overview of the ITA and the level of tariff liberalization associated with membership, continuing with a discussion of the changing composition of ITA membership. Then it examines ITA trade between 1996 and 2008, highlighting the changing composition of leading exporting and importing countries, and profiles ITA trade by product segment, focusing on computers, semiconductors, and telecommunications equipment. The paper highlights a threefold expansion of world trade in ITA products since 1996, facilitated by aggressive tariff liberalization and broadening ITA membership. It finds a significant shift in ITA trade to Asia (particularly China) and to a lesser extent Eastern Europe, evident in the displacement of traditional producers and exporters of IT equipment by rising Asian ITA members. Other key findings include the increasing diversification of ITA members in terms of trade and economic profiles and expanding trade participation by developing countries.[2]

The Agreement

In December 1996, at the WTO's Singapore Ministerial Conference, 29 signatory countries[3] concluded the Ministerial Declaration on Trade in Information Technology Products (Declaration),[4] establishing the ITA. Activation of the provisions in the Declaration was contingent on the ITA's member countries accounting for 90 percent of world trade in IT products by a deadline four months later (April 1, 1997). The original signatories' trade coverage, however, was only 83 percent. Through additional negotiations, several other countries signed the Declaration, bridging the gap in trade coverage by the Declaration's deadline. With the ITA in effect as of April 1, 1997, participants soon after commenced a schedule of phased duty reductions, with all duties slated for elimination by 2000.[5] Because commitments under the ITA are on a MFN basis, the bound zero duty rates for ITA products apply to all WTO members, including non-ITA members.

At the outset, the stated goals of raising living standards, enhancing global economic growth and welfare, and facilitating increased trade for IT products rested on aggressive tariff liberalization. In accordance with the ITA, member countries agreed to "bind and eliminate all custom duties and other duties and charges" for IT products specified in the agreement.[6] While ITA provisions call for periodic review and consultations on nontariff barriers, the only commitments in the ITA are for tariff elimination.

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[2] Developing countries status based on World Bank income classifications as noted herein.

[3] The European Communities (e.g., EU-15) are treated as individual members, with Switzerland and Liechtenstein a single customs union.

[4] WTO 1996.

[5] Several developing countries, including Costa Rica, India, Indonesia, South Korea, and Chinese Taipei, implemented extended duty staging to 2005 on a product-by-product basis as permitted in the Declaration.

[6] WTO 1996.

Tariff Rates

A primary objective of the Declaration was to improve market access and promote global trade through elimination of bound duties on IT products on an MFN basis. Initial participants agreed to a series of four equal tariff reductions between 1997 and 2000, with certain exceptions granted to developing countries. While many developed countries had maintained fairly low tariffs on IT goods prior to the Singapore Ministerial, tariff elimination on an MFN basis was central to achieving the trade and economic benefits envisioned in the ITA. Bora and Liu (2006) calculate that simple average tariffs over all ITA products before the Agreement was 3.6 percent for ITA members, compared with 11.2 percent for non-members. According to the WTO, average bound tariff rates for ITA products for developed countries were reduced from 4.9 percent to zero (WTO 2008, 15). These initial rates ranged from 1 percent to 12.1 percent, which compared with 1.2 percent to 66.4 percent for developing countries.[7] Because they had considerably higher bound rates before the Agreement, several developing countries implemented significant tariff liberalization to achieve duty free trade under the ITA. The largest concessions, based on pre-ITA bound rates, were by India (66.4 percent), Thailand (30.9 percent), and Turkey (24.9 percent). Similarly, for applied tariff rates, developing countries' pre-ITA tariffs were generally higher than the average 2.7 percent for developed countries. Notable average applied-tariff reductions for developing countries included those of India (from 36.3 percent), China (from 12.7 percent), and Egypt (from 12.1 percent).

Expanding Membership

Since the inception of the ITA with 29 original signatories, ITA membership has steadily expanded, reaching 72 members in 2009,[8] with increasing participation from developing countries. Developed countries accounted for nearly all of the original signatories, with Indonesia and Turkey the only

[7] Exceptions included Macao, China, and Hong Kong (China), which already maintained duty-free status for ITA products (WTO 2007).

[8] WTO 2008. Peru, the latest member entering the ITA, submitted its ITA schedule to participants for verification and approval in 2008 (USTR 2009).

TABLE 1 ITA member countries by economic status, 1996–2008

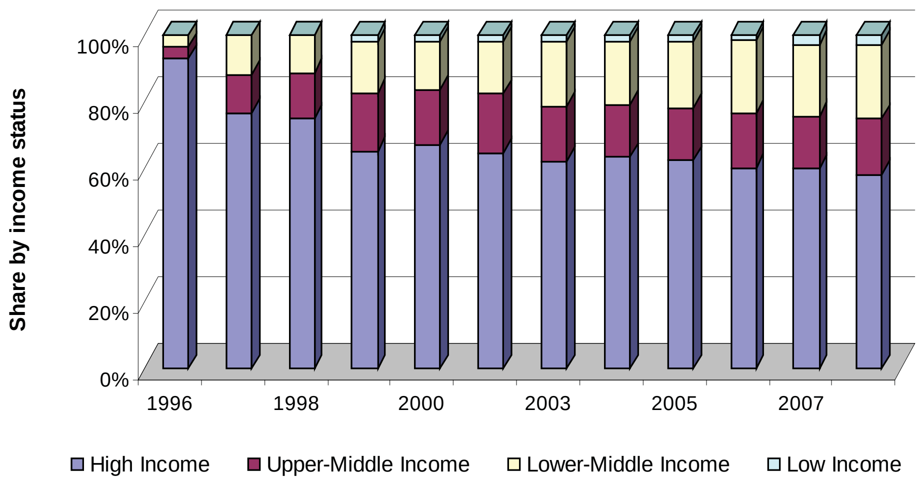
Year joined ITA	Developed countries	Developing countries		
	Economic status[a]			
	High income	Upper middle income	Lower middle income	Low income
1996	Australia, *Austria*, *Belgium*, Canada, *Denmark*, *Finland*, *France*, *Germany*, *Greece*, Hong Kong, Iceland, *Ireland*, *Italy*, Japan, South Korea, Liechtenstein, *Luxembourg*, *Netherlands*, Norway, *Portugal*, Singapore, *Spain*, *Sweden*, Switzerland, Chinese Taipei, *United Kingdom*, United States	Turkey	Indonesia	
1997	Czech Republic, Estonia, Israel, Macao, New Zealand, Slovakia	Costa Rica, Malaysia, *Poland*, *Romania*	El Salvador, India, Philippines, Thailand	
1998		Panama		
1999	Croatia	*Latvia*, *Lithuania*, Mauritius	Albania, Georgia, Jordan	Kyrgyzstan
2000	*Cyprus*, Oman, *Slovenia*			
2001		*Bulgaria*	Moldova	
2003	Bahrain		China, Egypt, Morocco	
2004	*Hungary*, *Malta*			
2005			Nicaragua	
2006	Saudi Arabia	Dominican Republic	Guatemala, Honduras	
2007	United Arab Emirates			Vietnam
2008		Peru	Ukraine	

Source: Compiled by USITC staff.
Note: EU members are in italics.
[a] Based on World Bank income classification.

developing countries formally adopting the Declaration (table 1).[9] Following the Singapore Ministerial in 1996, 11 additional countries signed the Declaration triggering the 90 percent trade criteria and the ITA entered into

[9] Developing countries include middle income and low income countries based on World Bank income classifications (World Bank 2009).

FIGURE 1 ITA membership composition, share by income status,[a] 1996-2008



Source: Compiled by USITC staff from UN Comtrade database.

[a]Based on World Bank income classification.

force April 1, 1997. In total, 14 members, more than half of them developing countries, joined the ITA in 1997, raising total membership to 43 countries. Between 1998 and 2008, developing countries accounted for 20 of the 29 new participants (68.9 percent); developing countries' participation expanded from 2 to 30 countries, or from 6.9 percent to 41.7 percent of ITA members (figure 1). While the present composition of ITA members, in terms of economic status, differs from that of the WTO (nearly two-thirds of WTO members are developing countries), the steady increase in participation by developing countries is a significant achievement, considering that pre-ITA trade in IT products was highly concentrated among developed countries (Mann and Liu, 4).[10]

The ITA participants that joined after the original signatory members also presented diverse trade and economic profiles, consistent with the increasing participation of developing countries after 1996. The diversification of membership profiles illustrates increasing interest in liberalized ITA trade. Using total ITA trade (exports and imports) and per capita gross domestic

[10] In 1990 Japan, Europe, and the United States accounted for nearly two-thirds (68 percent) of the global export market for IT products (Mann and Liu 2007).

product (GDP)[11] as indicators of trade activity and economic station makes its possible to illustrate the heterogeneity of the post-1996 entrants. For example, Bahrain and China entered the ITA in 2003 with highly divergent economic and ITA trade profiles. Bahrain, in accordance with its developed country status, showed a relatively high GDP ($13,726) but lower ITA trade activity ($273 million), compared to China's lower GDP ($1,270) and higher ITA trade activity ($250.2 billion) (table 2 and figure 2). Even within high-income, middle-income, and low-income groups, the economic and trade profile of countries upon ITA entrance varied considerably.

Among the high income countries, Hungary, Israel, and the United Arab Emirates displayed higher GDP and ITA trade activity than Estonia and Croatia. Within the middle-income group of developing countries, Malaysia and China entered the ITA with relatively strong GDP and ITA trade activity, compared with Georgia and Moldova's lower GDP and nascent ITA trade activity. Despite its developing income status, China's total ITA trade was $250.2 billion in 2003 when it joined the ITA, exceeding the ITA trade level of Japan ($153.6 billion) in 1996, when it entered the ITA. Notably, China was a leading manufacturer and trader of IT products prior to joining the ITA and deeply engaged in the global IT production chain even before tariff liberalization.

ITA Products

Recognizing the social and economic benefits derived from liberalized trade and diffusion of information technology products (WTO 1996), the drafters of the Ministerial Declaration identified specific products for which duties and other charges would be eliminated. Participants agreed to implement binding duty eliminations through a schedule of concessions covering products in categories such as computers, software, telecommunications, semiconductors, semiconductor manufacturing equipment, scientific and measuring equipment, and related parts. Products covered under the ITA are listed in two annexes to the Declaration, commonly referred to as Attachments A and B.[12] Attachment A is a positive list of items at the 6-digit Harmonized Schedule (HS) level, separated into two sections (A1 and A2). Attachment B includes product descriptions but not any corresponding HS code, whether

[11] IMF 2009.

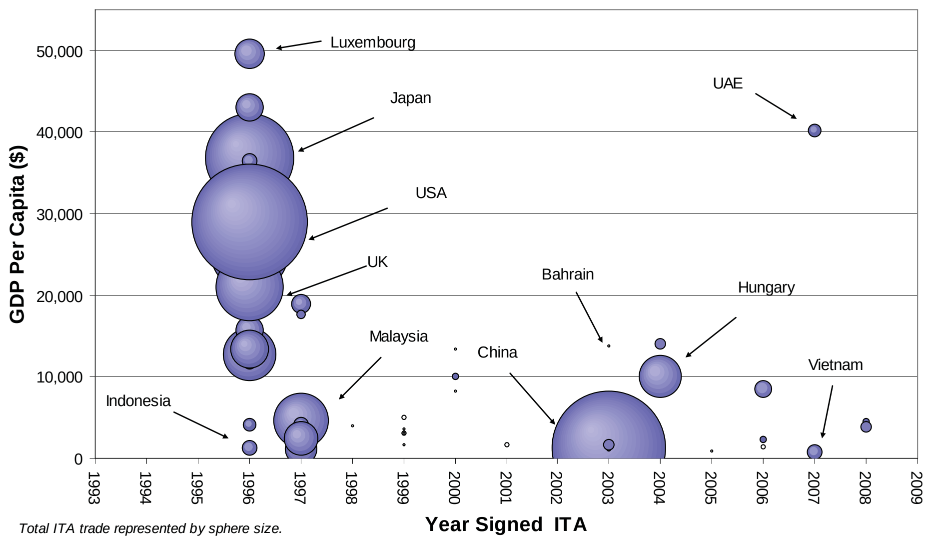
[12] Ibid., Annex.

TABLE 2 ITA membership countries by economic status, 1997–2008

Country	Year joined ITA	Economic status[a]	GDP per capita ($)	Total ITA trade (Million $)
Hungary	2004	High income	10,090	33,673
Israel	1997	High income	18,993	8,169
Saudi Arabia	2006	High income	8,490	6,600
Czech Republic	1997	High income	5,545	5,885
United Arab Emirates	2007	High income	40,147	4,000
Malta	2004	High income	13,987	2,770
New Zealand	1997	High income	17,656	1,942
Slovakia	1997	High income	3,984	1,406
Slovenia	2000	High income	10,045	1,148
Estonia	1997	High income	3,581	788
Croatia	1999	High income	5,058	617
Cyprus	2000	High income	13,425	278
Bahrain	2003	High income	13,726	273
Oman	2000	High income	8,271	255
Malaysia	1997	Upper middle income	4,693	58,416
Poland	1997	Upper middle income	4,064	4,542
Romania	1997	Upper middle income	1,567	948
Peru	2008	Upper middle income	4,453	948
Bulgaria	2001	Upper middle income	1,712	654
Costa Rica	1997	Upper middle income	3,508	629
Lithuania	1999	Upper middle income	3,098	361
Panama	1998	Upper middle Income	3,954	316
Latvia	1999	Upper middle income	3,038	275
Mauritius	1999	Upper middle income	3,571	144
China	2003	Lower middle income	1,270	250,202
Thailand	1997	Lower middle income	2,496	22,368
Philippines	1997	Lower middle income	1,170	21,460
India	1997	Lower middle income	410	3,077
Morocco	2003	Lower middle income	1,688	2,664
Ukraine	2008	Lower middle income	3,920	2,338
Guatemala	2006	Lower middle income	2,325	941
Egypt	2003	Lower middle income	1,197	625
Honduras	2006	Lower middle income	1,474	361
Nicaragua	2005	Lower middle income	843	173
Jordan	1999	Lower middle income	1,720	169
Moldova	2001	Lower middle income	407	46
Georgia	1999	Lower middle income	627	38
Albania	1999	Lower middle income	1,130	37
El Salvador	1997	Lower middle income	2,077	0
Vietnam	2007	Low income	835	5,375
Kyrgyz Republic	1999	Low income	260	26

Source: Compiled by USITC staff.
Note: EU members are in italics
[a] Based on World Bank income classification.

FIGURE 2 Profiles of ITA members, by income and trade levels



Total ITA trade represented by sphere size.
Source: Compiled by USITC staff from UN Comtrade database.

or not they are included in Attachment A. The descriptive approach in the Attachment B list is designed to cover products regardless of specific HS codes (Mann and Liu, 8) and to address divergent national positions in coverage of complex, multifunction products (Dreyer and Hindley, 4). Common products listed in Attachments A1, A2, and B, along with the number of 6-digit HS codes included in the original list, are noted in table 3. Notable IT products outside the scope of the ITA, mainly consumer electronic products, include CRT television sets, video cameras, and certain photocopiers.[13]

ITA Trade

Global IT trade has grown substantially under the ITA.[14] From 1996 through 2008 total ITA products trade (imports and exports) expanded 10.1 percent annually, albeit unevenly, growing from $1.2 trillion to $4.0 trillion. The strong

[13] For details on ITA negotiating history, including product coverage, see Fleiss and Sauvé 1997.

[14] Trade data are based on appropriate HS nomenclature for each year. See box 1 for further details regarding the dataset and attendant complexities.

TABLE 3 Representative ITA products and number of HS codes, by attachment		
	Number of HS codes	**Sample Products**
Attachment A1	112	Computers and computer peripherals: Personal computers, laptops, work stations, monitors, keyboards, hard drives, CD-ROM drives, smart cards, printers, scanners, and other input/output units
		Telecommunications equipment: telephone sets, cordless phones, mobile handsets, pagers, answering machines, switches, routers, hubs, modems, fiber optic cables
		Semiconductors: microprocessors, integrated circuits, printed circuits, diodes, resistors
		Software: magnetic tapes, unrecorded media
		Office equipment: certain photocopy machines, fax machines, cash registers, adding machines, calculators, automatic teller machines (ATM)
		Scientific and measuring devices: spectrometers, chromatographs, flow meters, gauges, optical radiation devices
		Other: Loudspeakers, still digital cameras, parts
Attachment A2	78	Semiconductor manufacturing equipment (SME): etching and stripping apparatus, vapor deposition devices, sawing and dicing machines for wafers, spinners, ion implanters, wafer transport, handling and storage machines, injection molds, optical instruments, parts and accessories
Attachment B	13[a]	Computers, electric amplifiers, flat-panel displays, network equipment, monitors, pagers, CD and DVD drives, plotters, printed circuit assemblies, removable storage devices, set-top boxes

Source: WTO, and data compiled by Commission staff.

[a] Attachment B products are covered regardless of where they are classified in the HS system. ITA Committee members have made attempts to narrow divergences in the customs classification of some Attachment B products (WTO G/IT/W6/Rev.3), though there is no agreed-upon list. This paper uses such codes as a proxy.

growth in ITA trade exceeded that of manufactures trade, which expanded 7.1 percent annually during the same period (figure 3). ITA trade expansion was steepest between 1996 and 2000, growing 17.5 percent annually, but declined between 2000 and 2002 (-2.8 percent) as the internet boom of the 1990s abruptly reversed, adversely affecting IT spending and investment (Friar, et

BOX 1 Data challenges and changing classifications

Changes to the HS system resulting from several factors, including technological developments impede attempts to pinpoint precise values in ITA trade. The HS system underwent nomenclature revisions in 2002 and more significantly in 2007, complicating the construction of a consistent times series for ITA product trade. As noted by the WTO, "The ITA committee has already started to discuss how to update the products list into the new nomenclatures, but it proved very difficult to reach an agreement due to the complexity of HS amendments and the remaining classification problems under the old nomenclature (HS1996)."[a] Quantifying trade in Attachment B products is additionally challenging because most countries provided their own list of tariff codes, usually at the national line level (i.e. the 8- or 10-digit level), where these products may be classified, and some countries have not provided a list.

Because no WTO-approved ITA product list exists for HS 2007, the authors have constructed estimates for this analysis. For example, 6-digit codes provided in the ITA for Attachments A1 and A2 reflect World Customs Organization (WCO) transpositions as a proxy. However, many such products are breakouts (i.e. ex-outs) at the 6-digit level and ITA members have identified specific national tariff lines within these subheadings to cover these products. In our estimation, the HS 2007 system includes 354 sets of changes, 70 impacting the ITA. In Attachment A1, 54 of 111 subheadings are affected, as are 53 of 58 subheadings in Attachment A2. For Attachment B, while there is no agreed-upon list, it is estimated that approximately 51 of 72 subheadings are affected for products where a code was listed. Consequently, the veracity of ITA trade data in 2007 and 2008 is likely affected by transposition challenges with HS 2007. For example, uneven 2007-2008 trade in office equipment stems in part from significant classification changes. Despite the challenges posed by the HS 2007 nomenclature, utilizing the HS 2002 list after 2006 may significantly understate trade, as the HS 2002 list fails to capture several ITA products starting in 2007.[b] To mitigate this, a constructed data set was employed, using the nomenclature appropriate for each year.[c] The data set also segregates products covered in both Attachments A and B to avoid possible duplication.[d] Finally, ITA product segments (e.g., computers, semiconductors) are based on HTS product descriptions, and in instances where products are covered in both Attachments and their use may span multiple segments (e.g., printed circuit assemblies), segmentation relied on USITC product digests.[e] Therefore, this paper presents a conservative approximation of the aggregate ITA trade data. The authors have used this data set to examine changes in trade patterns, product composition, and country market share, as new members adopted tariff liberalization embodied in the ITA.

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[a] http://www.wto.org/english/thewto_e/coher_e/wto_wco_e.htm.

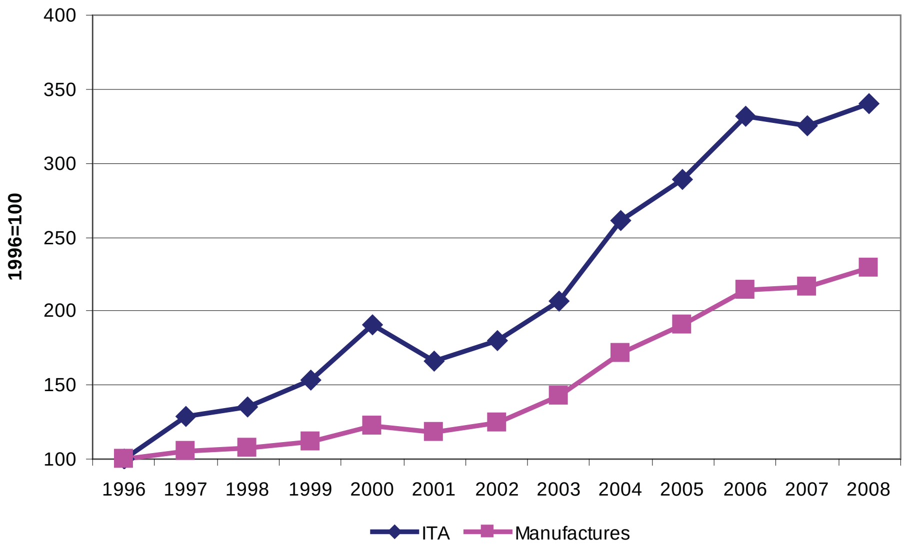
[b] For example, cellular telephones, classified in HS 2002 under 8525.20, are classified in HS 2007 under 8517.12, a new 6-digit subheading not contained in HS 2002.

[c] The data for 1996–2001 calculates the total base on the 1996 Ministerial Declaration, while the list for 2002-2006 calculates the total based on the WTO's transposition into HS 2002. For 2007–2008, the total is calculated using a list transposed into HS 2007. While imperfect and likely understating trade for certain ITA products, using the HS 2007 produces a more representative data set.

[d] Appendix A illustrates ITA total trade by segregated Attachment lists during 1996–2008.

[e] See Shifts in U.S. Merchandise Trade 2008 (2009).

FIGURE 3 ITA and manufactures total trade, 1996–2008



Source : Compiled by USITC staff from UN Comtrade database.

al. 2008, 4).[15] In 2002, however, ITA products trade growth resumed, but at a comparatively slower pace (10.4 percent).

As a share of global trade, ITA product trade peaked in 2001 at 18.4 percent. While the ITA's share declined slightly to 15.2 percent in 2008, it remains above the 1996 level of 13.8 percent (table 4). This share, however, likely understates the economic significance of this product group. Since the inception of the ITA, prices of technology products have trended downwards (WTO 2008, 16),[16] masking the increasing level of ITA trade.

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[15] U.S. technology investment was down 7 percent in 2001 and 9 percent in 2002, reacting sharply to excesses associated with the tech bubble (Friar, et al. 2008).

[16] Based on U.S. import values between 1996 and 2005, average unit prices for IT products declined 6 percent annually compared with a 1 percent increase for all other manufactured goods (WTO 2008).

TABLE 4 ITA trade compared with manufactures trade, share and growth rates, selected years

	Share of total trade (percent)	Compound annual growth rate (percent)		
	2008	1996–2008	1996–2000	2001–2008
ITA total trade	15	11	18	11
Manufactures total trade	66	7	5	10

Source: Compiled by USITC staff from UN Comtrade database.

Shifting Trade Patterns

Twelve years of duty-free trade in ITA products triggered substantial changes in trade patterns and market shares for ITA member countries. A prominent feature of expanding ITA trade is the broadening participation of Asian countries, particularly China, and an increasingly important role for other developing countries. While especially high growth rates[17] for ITA trade are observed throughout Asian countries, some ITA member countries benefited more than others. Among Asian and developing countries, the rapidly expanding role of China stands out: China has emerged to become the largest single player in the global ITA market. Outside of Asia, several Eastern European countries experienced an upsurge in ITA trade.

Broader Asia Shifts

Asia's role in ITA trade grew extensively during the last decade. While not all countries within Asia gained equally, several Asian ITA countries are now leading exporters, importers, and centers for global production networks ITA products.

Asian ITA exports grew rapidly between 1996 and 2008, led principally by China and to a lesser extent by Singapore, South Korea, and Thailand. Annual export growth rates were strongest for China (33.5 percent),[18] South Korea (13.1 percent), Chinese Taipei (9.8 percent), and Philippines (11.0 percent) (table 5).[19] Similarly, import growth rates were strong for several Asian countries, led by China (24.4 percent)[20] and including Thailand (9.6 percent),

[17] Growth rates are compound annual growth rates unless otherwise indicated.

[18] ITA exports from Hong Kong, China, grew 13.0 percent annually.

[19] Malaysia's ITA trade grew at an annual rate of 10.2 percent from 1997–2006, and then declined sharply, due largely to incomplete data reporting for HS 2007.

[20] ITA imports from Hong Kong, China, increased 14.3 percent annually.

TABLE 5 ITA exports, share of exports (2008), and growth rates (selected years) for top 30 ITA countries

Number	Exporter	Exports 2008, (thousand $)	Share of total, 2008	Compound annual growth rates 1996–2008[a]	1996–2000[a]	2001–2008
			Percent			
1	China	463,685,179	25	34	29	38
2	Japan	173,712,915	9	4	8	7
3	Singapore	146,781,694	8	7	6	12
4	Germany	142,524,685	8	9	7	11
5	United States	142,470,901	8	2	10	1
6	South Korea	124,747,772	7	13	18	17
7	Netherlands	80,490,648	4	10	13	12
8	Mexico	64,610,222	3	13	19	10
9	Chinese Taipei	53,435,374	3	10	40	0
10	Malaysia	43,475,140	2	3	12	0
11	France	42,985,486	2	4	8	5
12	United Kingdom	39,170,154	2	–0.8	8	–4.8
13	Thailand	37,657,450	2	11	13	13
14	Czech Republic	27,529,537	2	29	18	35
15	Hungary	27,516,996	2	37	82	23
16	Ireland	24,606,914	1	3	16	–4.3
17	Italy	23,684,093	1	2	–0.7	4
18	Sweden	22,399,212	1	5	8	11
19	Belgium	18,559,404	1	8	9	7
20	Finland	17,743,663	0	9	18	9
21	Austria	15,885,611	0	11	9	12
22	Philippines	15,582,762	0	11	57	–4.6
23	Canada	14,746,829	0	–0.5	13	–2.1
24	Switzerland	14,619,955	0	6	4	9
25	Slovakia	13,060,477	0	37	10	60
26	Poland	11,851,929	0	29	13	43
27	Spain	11,034,632	0	8	7	10
28	Israel	7,317,840	0	6	22	1
29	Denmark	6,967,475	0	7	9	7
30	Norway	4,568,130	0	10	3	16
	World	1,882,022,074		11	18	11
	EU-15	440,673,667	23	6	9	6
	EU-15 external only	199,487,510	11			9

Source: Compiled by USITC staff from UN Comtrade database.

Note: Belgian data in 1996 include Luxembourg.

[a] Data start in 1997 for Singapore, Malaysia, Russia, Brazil, Slovakia, and Philippines. Data start in 1998 for Thailand.

South Korea (9.0 percent), Singapore (6.2 percent), and Japan (5.7 percent) (table 6). Asian ITA members now represent 5 of the 10 largest exporters and importers of ITA products.

Japan, formerly the leading exporter of ITA products, is now the second largest Asian exporter behind China, ceding market share due to sharper growth in exports by other Asian countries. Japan's export market share fell from a 1996 high of 18.6 percent to only 9.2 percent in 2008. Despite the decline in ITA export shares in Japan, the robust increase in ITA market share for several other Asian countries, above all China, indicates a significant shift in manufacturing capabilities for ITA products towards Asian countries, particularly developing Asian countries.

The shifting ITA trade patterns in Asia are consistent with the increasingly fragmented production of goods across the Asian region. Diversified production chains allow producers to benefit from an individual country's comparative advantages (Capannelli, 3). Because the products covered by the ITA are conducive to this production model, they play a major role in global production networks (Slaughter 2003, 27). Fragmentation-based specialization has become a key component of the economic landscape in Asia (Athukorola, 15), with much of the change taking place since the inception of the ITA.

China

China's rise to preeminence in the global ITA market is the most significant shift in ITA trade in Asia—and the world. When the original member countries concluded the ITA in 1996, China accounted for 3 percent of total ITA trade. By 2008, China accounted for nearly 19 percent of total ITA trade, surpassing the United States, the next largest trader at 11.2 percent. During this period, China's total ITA trade value grew at a remarkable annual rate of 29.0 percent, more than twice the global average of 10.7 percent. Presently, China is the largest exporter and second largest importer of ITA products (tables 5 and 6). Through its WTO accession and commitment to join the ITA,[21] China gained MFN access to major markets and became an increasingly attractive location for export-oriented foreign direct investment (FDI) (Fung, et al. 2008, 9),[22]

[21] China's accession to the WTO in 2001 included a commitment to join the ITA, which occurred in 2003.

[22] China's WTO accession was the catalyst for a new surge in FDI inflows, focused on manufacturing, during a time when worldwide FDI was declining (Fung, et al. 2008).

TABLE 6 ITA imports, share of imports (2008), and growth rates, (selected years) for top 30 ITA countries

Number	Importer	Imports 2008 (thousand $)	Share of total, 2008	Compound annual growth rates		
				1996–2008[a]	1996–2000[a]	2001–2008
				Percent		
1	United States	305,082,078	14	6	12	7
2	China	279,582,232	13	24	25	25
3	Hong Kong, China	183,994,486	9	14	13	18
4	Germany	135,253,735	6	9	9	9
5	Singapore	106,436,489	5	6	6	11
6	Japan	95,821,222	5	6	10	7
7	South Korea	77,368,758	4	9	12	13
8	Netherlands	75,045,283	4	10	15	11
9	Mexico	71,774,690	3	14	24	10
10	United Kingdom	69,048,943	3	3	10	3
11	France	60,873,645	3	6	8	8
12	Malaysia	52,919,855	3	6	9	7
13	Canada	40,083,796	2	4	11	5
14	Italy	39,840,656	2	6	8	8
15	Spain	38,107,998	2	12	9	16
16	Thailand	33,837,547	2	10	9	12
17	Czech Republic	26,957,270	1	19	9	25
18	Russian Federation	25,146,828	1	18	–15.7	39
19	Hungary	24,583,846	1	25	47	18
20	Philippines	24,463,013	1	3	-0	6
21	Chinese Taipei	24,036,619	1	6	49	–7.6
22	Belgium	22,902,964	1	8	8	7
23	Brazil	22,173,634	1	8	3	14
24	Australia	21,238,066	1	7	5	13
25	Sweden	19,934,993	0	6	7	11
26	Switzerland	17,058,388	0	6	7	8
27	Austria	16,699,116	0	9	10	11
28	Ireland	16,230,409	0	4	16	-3
29	Slovakia	12,877,092	0	23	–1.3	39
30	Finland	12,678,786	0	9	13	11
	World	2,131,461,652		11	17	
	EU-15	472,359,584	22	7	10	
	EU-15 external only	302,642,656	14			

Source: Compiled by USITC staff from UN Comtrade database.
Note: Belgian data in 1996 include Luxembourg.
[a] Data start in 1997 for Singapore, Malaysia, Russia, Brazil, Slovakia, and Philippines. Data start in 1998 for Thailand.

contributing to China's rapidly growing export and import share in the ITA market. Indeed, China's ITA trade accelerated after implementing its WTO commitments to reduce trade impediments, including eliminating its tariffs on ITA products. In 2001, for example, the value of global ITA exports declined 13.0 percent, but the value of Chinese exports of ITA products grew 19.9 percent. By 2003, when China entered the ITA, it was already the third largest exporter and the fourth largest importer of ITA products. In 2004, China expanded its market share, becoming the world's largest exporter of ITA products. In 2005, China surpassed both the EU and the United States to become the largest country in terms of overall ITA trade.

Increased FDI had a major role in China's accelerating ITA exports, as multinational corporations sought to reduce costs by directly adding capacity in China (WTO 2008, 18). Once China joined the WTO, products exported from China were guaranteed MFN access to other countries, providing strong incentives for multinational corporations to establish production and assembly operations in China.

The ITA further improved China's export capabilities by lowering the cost of intermediate ITA goods through tariff elimination. China recognized that tariffs acted as a tax on Chinese firms seeking to enhance participation in global production networks (Borrus and Cohen 1997, 12–14). One example of China's expansion into global production networks is the Pearl River delta, which has become the largest location in the world for electronics contract manufacturing (Luthje, 1). Consequently, China has become a critical hub in global production networks for ITA goods and has emerged as the fastest-growing supplier to the world of many ITA products, including computers, telecommunications equipments, and associated ITA parts.[23]

The rise of China and other developing ITA members in Asia represents a major shift in ITA trade, but not the only shift. The increasing export shares of Eastern European countries are also significant and reflect similar characteristics to the rise of Asia.

Eastern Europe

Eastern European countries are rapidly expanding their share of ITA trade. Four countries, all ITA members, stand out: Hungary, Slovakia, the Czech Republic, and Poland. Between 1996 and 2008, total ITA trade grew by 30.0

[23] See section "Shifting Trade in Product Segments" in this article.

percent for Hungary, 27.5 percent for Slovakia, 22.9 percent for the Czech Republic, and 15.4 percent for Poland.

For each of these four countries, exports expanded faster than imports. For example, Slovakia's annual export growth was 60.1 percent between 2001 and 2008, whereas import growth was 38.5 percent over the same period. Slovakia, Czech Republic, Hungary, and Poland combined account for barely 4 percent of global ITA trade, yet their export growth rate is nothing short of remarkable.

The rise of Eastern European countries in ITA trade reflects continued restructuring of production networks in the IT industry (OECD 2008, 107). This region is a critical hub in global supply networks of ITA products, with corporations making export-oriented investments, setting up factories to export to western Europe and the world. For example, according to Radosevic 2002 (14), FDI was the primary vehicle for the integration of Eastern European electronics firms into global supply networks, and "EU demand is a strong focal point" in new production networks. ITA countries in Eastern Europe provide advantages of geographic proximity and cultural ties (Fung, et al. 2008, 7), and therefore have benefited from the location decisions of EU and multinational corporations, particularly following tariff liberalization under the ITA.

In addition to tariff liberalization, the EU integration process also helped to drive the expansion of ITA trade in Eastern Europe (WTO 2008, 18). According to the European Commission, large flows of FDI from traditional EU members have increased the technological content of new EU member countries'[24] export baskets (EU 2009, 53).

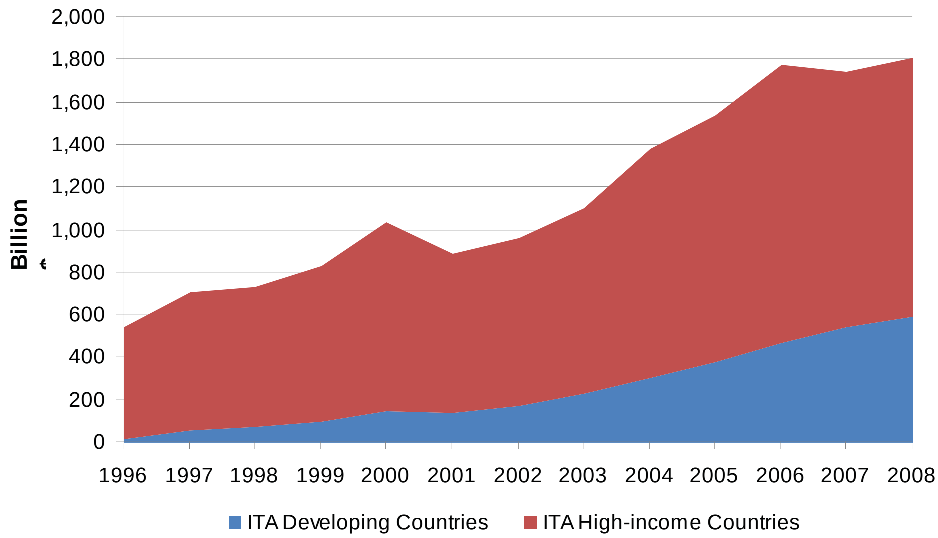
These shifting trade patterns towards Asia, China, and Eastern Europe illustrate the rise of developing countries and geographic diversification in global trade of ITA products.

Comparison of Developed and Developing Members

Since the launch of the ITA, developing countries have gradually gained market share from developed ones. Developed countries still account for 67.1 percent of world ITA exports, they have expanded at a much slower rate,

[24] Hungary, Slovakia, the Czech Republic, and Poland each joined the EU as part of the 2004 expansion.

FIGURE 4 Developing and developed (high-income) countries' ITA exports 1996–2008



Source: Compiled by USITC staff from UN Comtrade database.
Note: Includes only ITA members.

gradually ceding market share to developing countries, China in particular (figure 4). Developing-country ITA members generated 3.4 percent of total ITA exports in 1996, but climbed rapidly to generate 32.9 percent of total exports by 2008.

Between 1996 and 2008, developing countries' exports expanded at an annual growth rate of 33.6 percent, compared to 7.2 percent for developed countries. Although some of the apparent early growth for developing countries merely reflects improved consistency in reporting of export data, from 2001 to 2008, developing-country ITA exports still expanded more than three times as fast as developed-country ITA exports.

Based on year-over-year measurements of export growth, developing country ITA trade expanded faster than that of developed countries between 1996 and 2000, and declined less sharply during 2000–02. Developing-country ITA exports expanded 33.3 percent in 1999 and 43.6 percent in 2000. In contrast, developed-country ITA exports expanded 10.3 percent in 1999 and 22.5 percent in 2000. Following the peak in the technology boom, developing country exports declined at a slower rate—5.4 percent year-over-year, compared to a 15.6 percent decline for developed countries.[25] Broadening participation and increasing market share of developing countries in the ITA trade represents another major shift in ITA trade patterns.

Role of non-ITA countries

While ITA member countries account for the vast majority of total ITA trade, with a few non-ITA member countries expanded their share of ITA trade as well. In 2008, non-ITA countries accounted for only 6 percent of total ITA trade, yet several non-ITA countries have a significant and growing foothold. Despite their nonmember status, Mexico, Russia, Brazil, and South Africa have demonstrated strong ITA trade since 1996. Mexico's export role and Russia's import growth are both particularly noteworthy.

Mexico is the only non-ITA member in the top 30 ITA exporters, ranking eighth in 2008 (table 5). Since it is a WTO member, its exporters benefit from the MFN nature of the Agreement. Additionally, on the import side, Mexico unilaterally instituted "ITA plus," which eliminates duties on a wide variety of critical inputs, machinery, and finished products in the electronics and IT sectors (Padiema-Peralta, 2008 1). These lower-cost inputs provide a competitive price advantage to Mexican producers and exporters. Moreover, due to the North American Free Trade Agreement, there are established ITA production networks linking Mexico with the United States and Canada; in 2008, 87 percent of Mexico's ITA exports went to either Canada or the United States.

Russia is rapidly increasing imports of ITA products despite being outside the WTO and the ITA. While the rest of the world benefited from the technology boom of 1996–2000, Russia's ITA imports declined by 15.7 percent, with the country suffering a severe financial crisis in 1998. Yet, since 2001, Russian imports of ITA products have grown annually by 38.7 percent (table 6), albeit from a relatively small base. Russia is primarily an importer of ITA products; rather than export ITA goods, it is major exporter of information and communication services (OECD 2008, 91). The ITA does not cover services, but Russia's strong position in the related services industry may explain its

[25] It should be noted that these calculations include countries not yet signed onto the ITA in the given years; the MFN nature of the ITA gives all WTO members tariff duty-free access to all markets for ITA member countries.

demand for products covered by the ITA. Russia's main sources of ITA imports are China, Germany, and Hungary.

Product Segment Profiles

While many ITA products are readily identifiable, others are parts or intermediary products with functions across multiple broad categories. In examining the growth and composition of ITA products, the authors grouped the covered goods into eight general product segments, as noted in table 1, computers and peripherals ("computers") office equipment, scientific and measuring devices ("scientific devices"), semiconductors, semiconductor manufacturing equipment ("SME"), software, telecommunications equipment, and other ITA products and parts ("other").[26] While annualized growth rates for most product segments exceeded 10 percent, import and export growth rates were strongest for other products ("other ITA products and parts"), office machines,[27] semiconductors, and telecommunications during 1996–2008. Rapidly rising trade in other products is consistent with the proliferation of intermediary goods and parts trade fueled by expanding global product networks (Athukorala, 2008, 7). Strong growth rates in semiconductors and telecommunication segments reflects, in part, expanding uses of semiconductors in IT products and advances in cellular communications.

Semiconductors and computer trade dominated the composition of ITA trade during the past 12 years, despite ceding market share to other fast-growing products, including telecommunications and other products. The Internet boom of the 1990s and declining prices for personal computers and semiconductors (Aizcorbe, Flamm, and Khurshid, 2002, 12) spurred increasing demand and trade flows for these products.

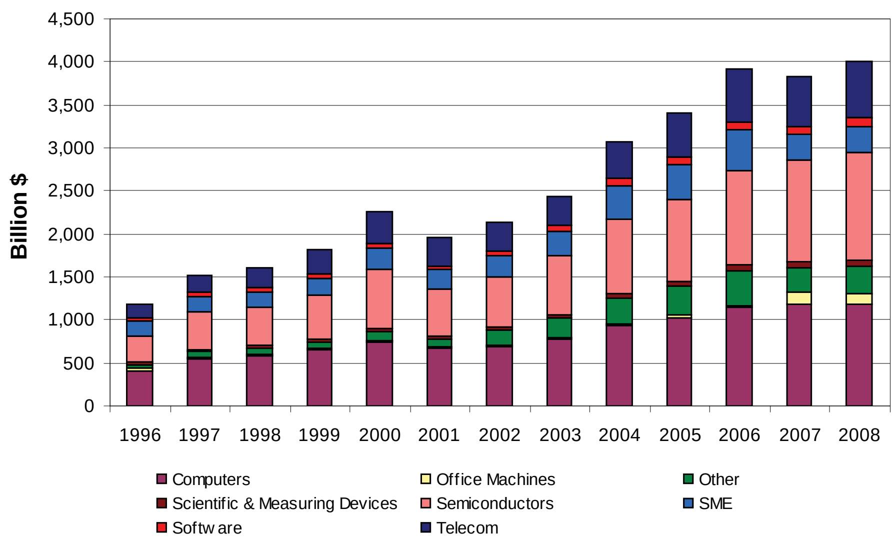
Product Segment Growth Rates

Across all ITA product segments, total trade increased by 10.7 percent annually between 1996 and 2008 (figure 5). Annualized growth of ITA trade peeked at 17.5 percent during 1996–2000, then slowed to 10.8 percent between 2001 and 2008; this decline reflected, in part, the sharp decline in IT spending following the Internet boom in the late 1990s. Import growth was led by other products and parts (17.0 percent), with expansion in global imports of

[26] Segmented according to 6-digit HS in accordance with USITC product classifications.

[27] Difficulties in reconciling trade data associated with complex HS 2007 nomenclature changes may account for some of the increase in office machine trade after 2006.

FIGURE 5 ITA total trade by product, 1996–2008



Source : Compiled by USITC staff from UN Comtrade database.

office equipment, semiconductors, and telecommunications ranging between 15.5 percent and 13.1 percent (table 7). Similar product growth patterns emerge in global exports, with office machines and other ITA products and parts exhibiting the strongest annual growth rates (16.4 percent and 16.0 percent, respectively). Increasing trade in parts reflected the increasing fragmentation of the global electronics and IT supply chains. Additionally, significant technology developments surrounding the internet and mobile communications were important drivers behind the rapid trade expansion for telecommunications and office machines.[28] [29] Further, trade in office machines and other ITA products and parts at the inception of the ITA was relatively low compared with trade in computers and semiconductors, which accounted for the majority of IT trade and attracted considerable attention in the negotiations leading up to the Singapore Ministerial (Fleis and Sauve, 1997, 29–32).

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[28] Examples of technology developments include the rapid adoption of cellular phones and the increased popularity of multifunction printing machines. Indeed, cell phones, and printing parts and accessories accounted for 35 percent and 88 percent of total imports for their respective product segments in 2008.

[29] The unevenness of the figures for 2007–08 trade in office equipment stems in part from significant HS classification changes.

TABLE 7 ITA imports and exports, growth rates, by product category, selected years

Category	Flow	1996	2000	2001	2008	Annual growth 1996–2008	Annual growth 1996–2000	Annual growth 2001–2008
		Thousands$				Percent		
Other	Import	25,755,884	54,044,287	50,593,669	170,142,725	17	20	19
Office Machines	Import	11,716,868	12,508,909	12,395,073	66,056,407a	15.5[a]	1.6[a]	27.0[a]
Semiconductors	Import	159,153,497	369,531,817	297,379,179	713,043,592	13	23	13
Telecom	Import	78,072,743	180,851,150	168,551,206	340,914,187	13	23	11
Scientific Devices	Import	12,064,397	16,580,565	17,895,020	40,171,254	11	8	12
Software	Import	19,430,181	25,569,836	25,045,653	52,362,180	9	7	11
Computers	Import	231,691,768	387,107,292	350,008,651	601,158,386	8	14	8
SME	Import	80,899,512	130,178,132	111,159,562	147,612,922	5	13	4
Office Machines	Export	9,673,615	11,207,972	10,864,082	60,086,400a	16.4[a]	3.7[a]	27.7[a]
Other	Export	23,385,248	46,501,635	44,323,728	138,769,407	16	19	18
Telecom	Export	79,823,837	175,432,546	159,056,944	321,572,875	12	22	11
Semiconductors	Export	143,321,320	323,924,248	247,443,755	541,211,042	12	23	12
Scientific Devices	Export	12,246,914	14,981,935	16,264,111	39,121,240	10	5	13
Computers	Export	182,684,635	349,687,303	316,379,366	579,872,049	10	18	9
Software	Export	22,403,227	26,097,693	25,469,977	46,382,620	6	4	9
SME	Export	87,203,921	127,583,670	106,186,643	155,006,442	5	10	6
TOTAL TRADE		1,179,527,569	2,251,788,989	1,959,016,618	4,013,483,726	11	18	11

Source: Compiled by USITC staff from UN Comtrade database.

[a] Difficulties in reconciling trade data associated with complex HS 2007 nomenclature changes may account for some of the apparent increase in office machines trade and for some of the apparent decrease in SME trade after 2006.

Shifting Trade in Products Segments

Computers and semiconductors dominated trade in ITA products, despite rising telecommunications and parts trade. The composition of total trade in ITA products was heavily weighted to computers and semiconductors (60.7 percent in 2008) though the share of computers declined and that of semiconductors increased during 1996–2008 (figures 6–7). In addition to computers, which declined 6 percentage points, the share of SME in total trade declined from 14.3 percent to 7.5 percent. Telecom and other products (other ITA products and parts) collectively represent 24.2 percent of 2008 trade, up from 17.6 percent in 1996.

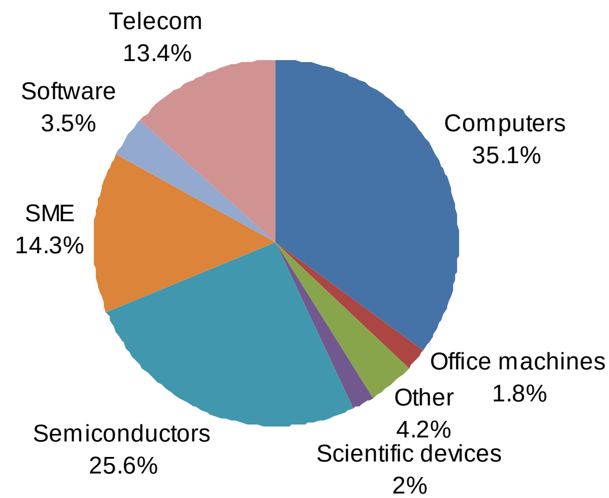
Examining imports separately, similar patterns emerge. Computer imports declined from 37 percent to 27 percent; computers' lost share was captured by imports of semiconductors. The share of import shipments of SME also declined, displaced by rising shares of telecommunications and other ITA products and parts imports. By contrast, the export share for computers increased modestly, from 33 to 36 percent, along with that of semiconductors. Shares of telecom SME, and, to a lesser extent, scientific devices slipped 4 percentage points collectively.

Product Composition by Country

Since the Agreement went into force, developing countries account for increasing export and import shares of leading ITA product segments. Further, ITA members continue to dominate world ITA trade relative to their non-ITA counterparts. Examining the three largest ITA product segments[30]—computers, semiconductors, and telecommunications—a clear pattern emerges of robust growth in exports and imports by ITA developing countries. This growth was most pronounced for exports and imports in Asia, notably China, as several post-1996 ITA members captured increasing market share from developed countries in these products. This momentous shift in global production is most evident in computers and telecommunications exports, where China and South Korea alone have displaced the United States, Japan, and several European countries as the leading producers and exports of these products. The elimination of tariffs under the ITA facilitated opportunities for many

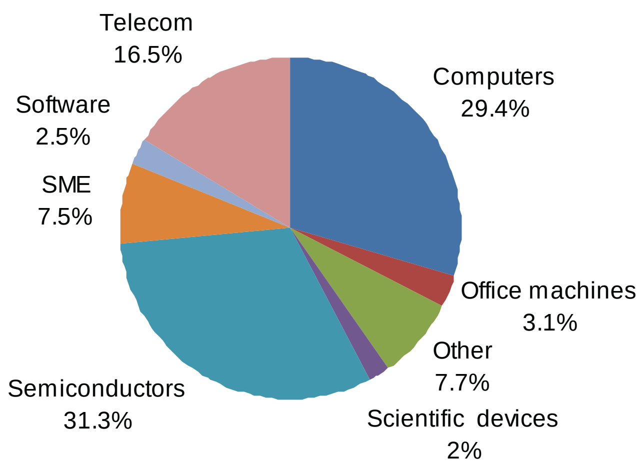
[30] Based on 2008 total trade (table 5).

FIGURE 6 ITA total trade by product segment, 1996



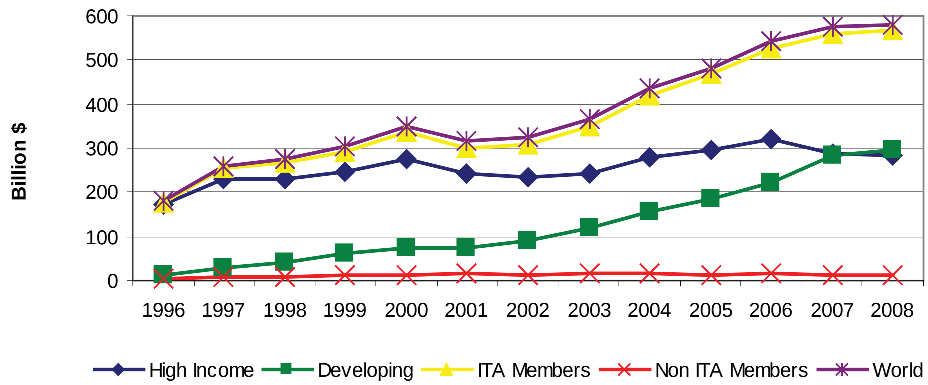
Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 7 ITA total trade by product segment, 2008



Source: Compiled by USITC staff from UN Comtrade.

FIGURE 8 ITA computer exports, by income and ITA status, 1996–2008



Source: Compiled by USITC staff from UN Comtrade database.

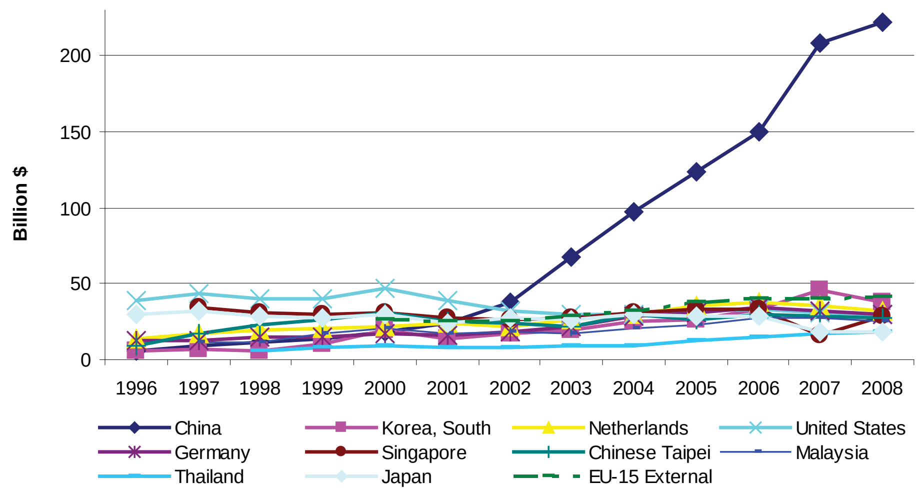
developing countries to enter global production networks,[31] driving shifting trade patterns for these products.

Computers

ITA members continue to dominate global computer trade, representing 98 percent of exports, a level unchanged from 1996. However, as with other ITA goods, the shift to developing ITA members as leading exporters of computers is striking. Led by several Asian countries, particularly China, developing countries' share of global computer exports surged from 6.5 percent in 1996 to nearly 51 percent in 2008 (figure 8). The rapid expansion of computer exports by developing countries was further characterized by a 30.6 percent annual growth rate, compared with 10.1 percent for developed countries between 1996 and 2008. The composition of the top 10 computer exporters similarly shifted to China and other Asian countries. In 1996, four countries—the United States, Japan, United Kingdom, and the Netherlands accounted for over 50 percent of computer exports. By 2008, China and South Korea alone accounted for nearly half (46.6 percent) of such exports, illustrating an increasing concentration of global computer production and exports (figures 9–10). Other developing ITA members, including Malaysia and Thailand,

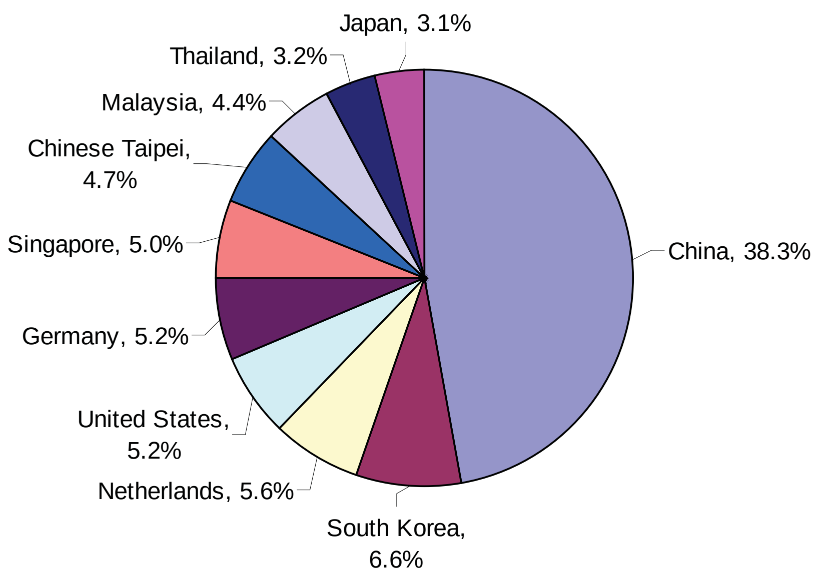
[31] According to Slaughter 2008, developing countries may enter global production networks by leveraging comparative advantages in importing intermediate goods, adding value through these advantages, and subsequently exporting outputs to other countries.

FIGURE 9 ITA computers: Top 10 exportering countries and the EU, 1996–2008



Source : Compiled by USITC staff from UN Comtrade database.

FIGURE 10 Computers: Top 10 exporters, 2008

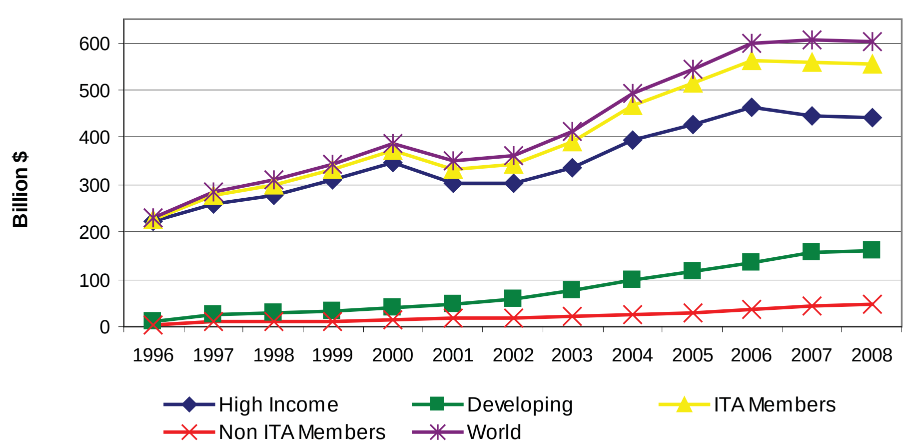


Source: Compiled by USITC staff from UN Comtrade database.

also experienced a rapid increase in computer exports since joining the ITA, accounting for 4.4 percent and 3.2 percent, respectively, of 2008 exports.

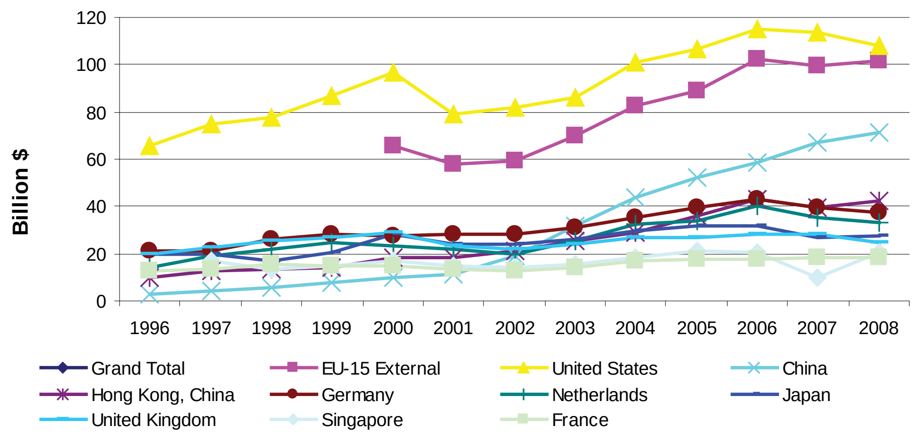
ITA members account for the vast majority of gains in computer imports since 1996 (92 percent of imports in 2008), despite increasing non-ITA member import trade (figure 11). Non-ITA members' share of computer imports increased 6 percentage points, principally driven by increasing imports from Mexico, Brazil, and Russia. These rising imports reflect two factors: duty-free access to computer products under the MFN principle of the ITA, and general economic expansion since 1996. The share of developing-country imports expanded to 26 percent from 4 percent. Based on annual growth rates, China (29.7 percent), Hong Kong, China (12.8 percent), Mexico (18.4 percent), and Russia (30.7 percent) were principal contributors to developing country import growth since 1996. Among the top 10 importers in 2008, U.S. imports increased to over $100 million, albeit unevenly. China became the second largest importer with the sharpest growth after the 2001–2002 period (figure 12). Overall, shifts in computer imports were less pronounced than those in computer exports. The United States, Japan, Germany, and other original ITA signatories were leading importers of computers in 1996. With the exception of China (12 percent), developed ITA members countries remained the leading importers of computer products in 2008 (figure 13).

FIGURE 11 ITA computer imports, by income and ITA status, 1996–2008



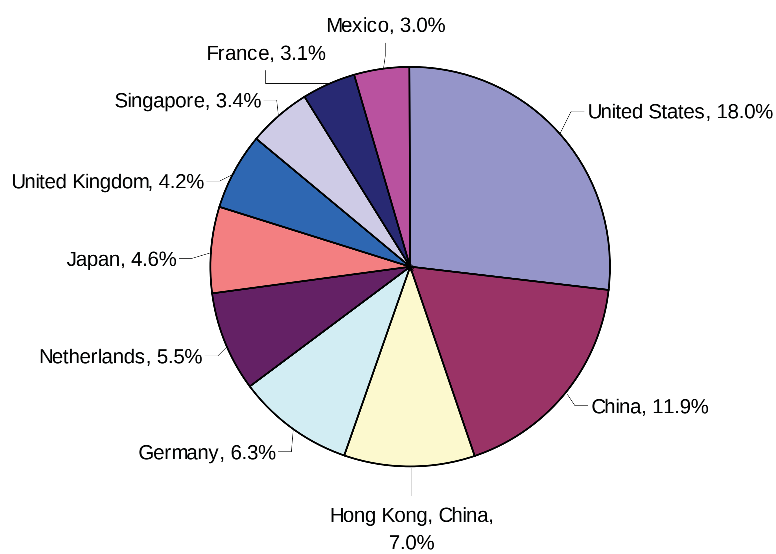
Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 12 ITA Computers: Top 10 importing countries and the EU, 1996–2008



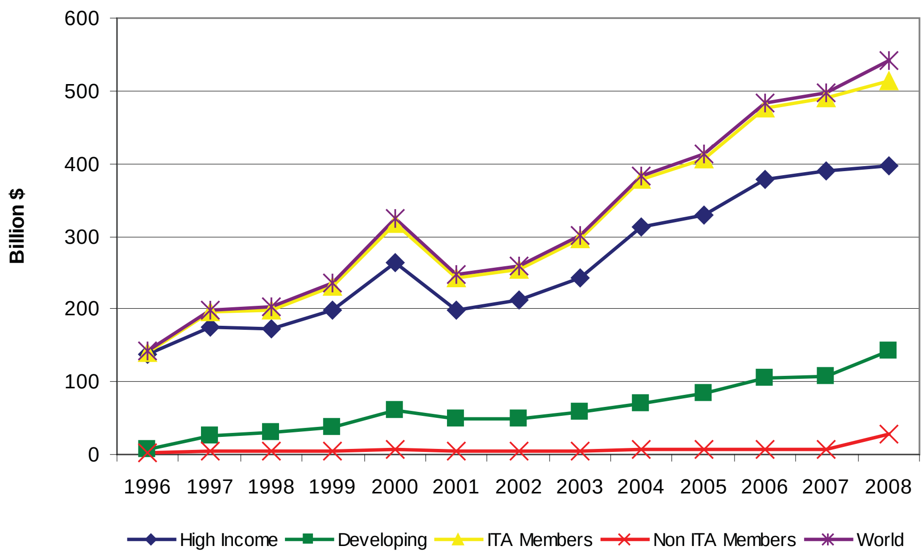
Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 13 Computers: Top 10 importers, 2008



Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 14 ITA semiconductor exports, by income and ITA status, 1996–2008



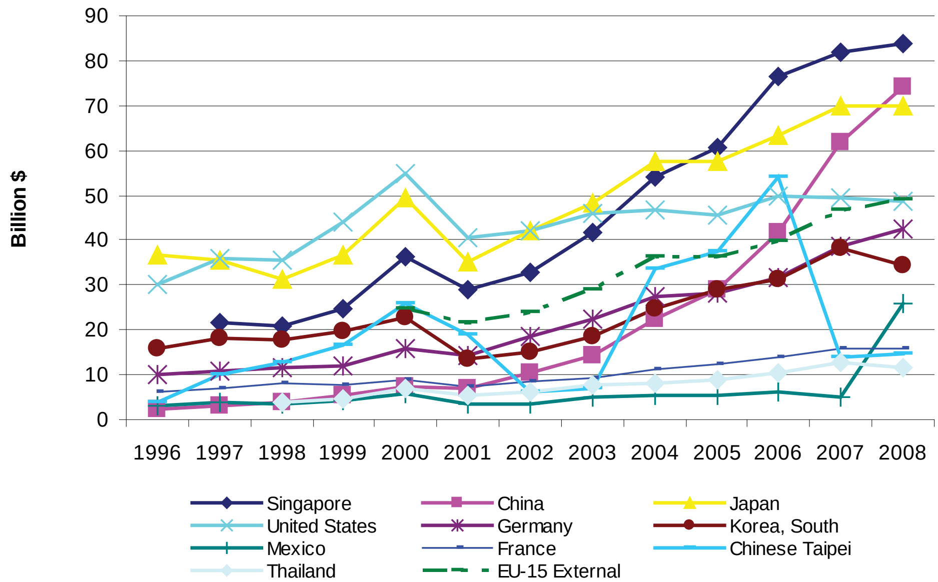
Source: Compiled by USITC staff from UN Comtrade database.

Semiconductors

The preponderance of the global semiconductor trade was conducted by ITA members, who accounted for 94.8 percent and 95.3 percent of exports and imports, respectively, in 2008. These shares have remained fairly constant, indicating that ITA members captured the vast majority of growth in semiconductor trade since 1996 (figure 14). Between 1996 and 2008, Singapore and China emerged as the largest semiconductor exporters, surpassing Japan and the United States (figure 16).[32] ITA developing-country members, and to a lesser extent Mexico, led the increase in developing countries' share of semiconductor exports, which rose from 4.2 percent to 26.5 percent during 1996–2008. However, with the exception of China (13.7 percent of exports), developed ITA members remained leading exporters

[32] Annual export growth rates during 1996–2008 were 13.2 percent and 33.9 percent for Singapore and China, respectively, compared with 5.5 percent and 4.1 percent for Japan and the U.S., respectively.

FIGURE 15 ITA semiconductor: Top 10 exporters and EU, 1996–2008



Source: Compiled by USITC staff from UN Comtrade database.

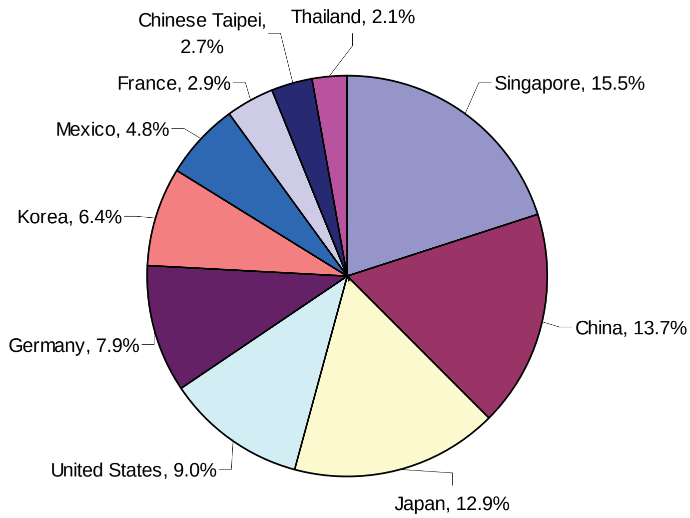
with Singapore (15.5 percent),[33] Japan (12.9 percent), and the United States (9.0 percent) the largest exporters based on 2008 export share (figure 15). The robust expansion of China's semiconductor exports in part reflects the global fragmentation of back-end production (i.e., packaging and testing) to lower-cost countries, China's policy shifts and incentives to encourage FDI in semiconductor manufacturing, and semiconductor manufacturers' desire for proximity to the world's largest market (Yinug).[34]

Similar to exports, ITA members accounted for the vast majority of the increase in semiconductor imports since 1996, generating over 95 percent of imports in 2008 (figure 17). The share of developing country imports expanded to 38.2 percent from 9.1 percent during 1996–2008, led principally by China, with an annual import growth rate of nearly 33 percent. Other ITA

[33] Singapore has a long history as a leading location for semiconductor device assembly, and more recently, computer peripherals, including hard disk drives (Athulkorala 2008).

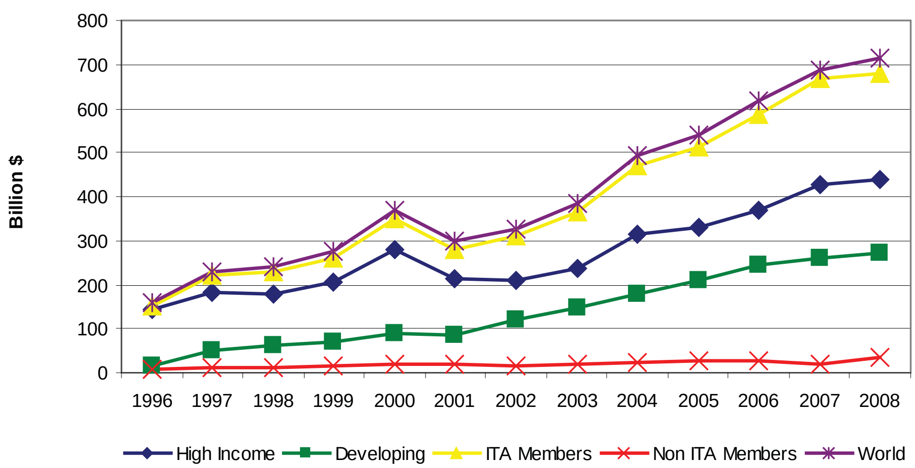
[34] Yinug 2009 notes that while front-end production (capital-intensive design and fabrication) is emerging in China, foreign semiconductor firms' investments in China remain limited and often entails the use of older-generation production technology.

FIGURE 16 Semiconductor: Top 10 exporters, 2008



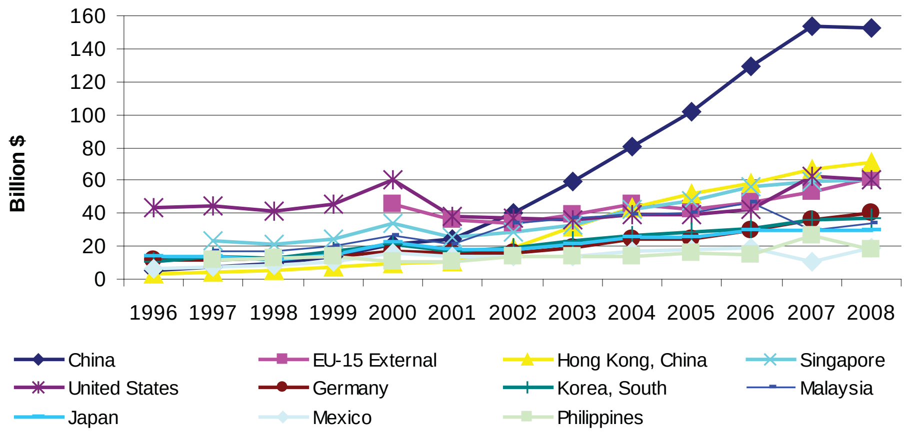
Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 17 ITA semiconductor imports, by income and ITA status, 1996–2008



Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 18 ITA semiconductors: top 10 importers and EU, 1996–2008



Source: Compiled by USITC staff from UN Comtrade

developing countries experiencing strong import growth since joining the ITA included, Malaysia (6.4 percent), the Philippines (4.2 percent), and Thailand (8.9 percent). The present composition of leading semiconductor importers was heavily influenced by China's exponential import growth. China's market share among the top 10 imports increased to 21.5 percent, from 3.2 percent, surpassing the United States and Singapore (figures 18–19) to become the largest importer.[35] Along with tariff liberalization under the ITA, the increasing concentration of electronics assembly and production in China (McClean, 2006, 2-50 to 2-54), along with the shifting global semiconductor production patterns, contributed heavily to China's becoming the largest semiconductor market (Yinug, 2008 10–13).[36]

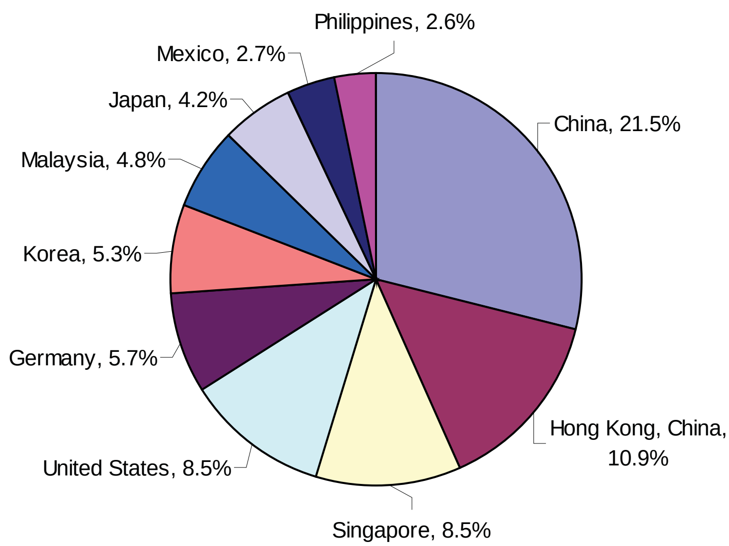
Telecommunications

ITA members accounted for over 90 percent of global telecommunications equipment trade in 1998, down slightly from 1996. Non-ITA countries' share of telecommunications exports and imports were 7.4 percent and 12.5 percent, respectively, in 2008. Developed countries, including South Korea, the United States, Germany, and Finland traditionally dominated

[35] China accounted for nearly one-third (32.4 percent) of semiconductor imports in 2008 when Hong Kong is included.

[36] See Yinug 2009 for more details on semiconductor manufacturing stages and increasing global fragmentation of production.

FIGURE 19 Semiconductor: Top 10 importers, 2008



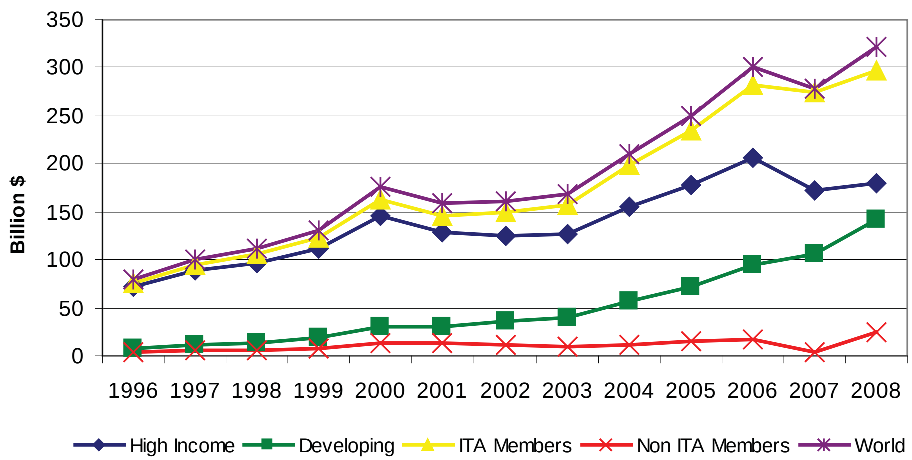
Source: Compiled by USITC staff from UN Comtrade.

telecommunications trade, but a sizeable shift towards developing-country exporters, namely China, occurred after China joined the WTO and ITA. Developing countries' export share climbed from 9.5 percent in 1996 to 43.8 percent in 2008 (figure 20). Propelled by robust export growth, China and South Korea moved past the United States as the leading telecommunications exporter (figure 21).[37] While leading European exporters collectively accounted for nearly 20 percent of exports, China was the source of one-third (33.4 percent) of world telecommunications exports in 2008, followed by South Korea with 11.4 percent (figure 22), revealing a significant shift in global telecommunications production and export patterns. The elimination of tariffs on several intermediary products, coupled with the strengthening of global electronics production networks in Asia, were catalysts behind China's exponential export growth.[38]

[37] China and South Korea's exports grew an annualized 35.0 percent 27.2 percent, respectively during 1996-2008.

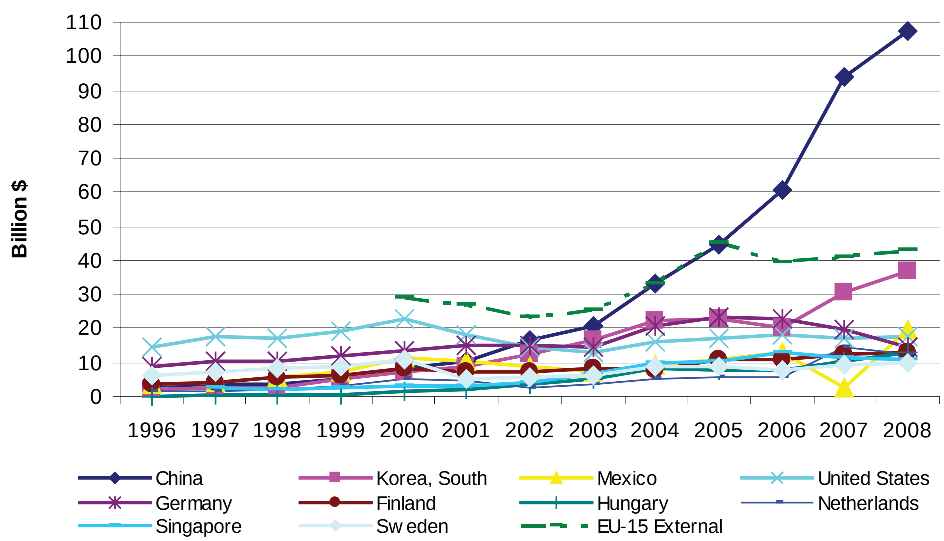
[38] See Luthje 2004 for an illustration of China's role in the global production network of cell phones for a major manufacturer.

FIGURE 20 ITA Telecom exports, by income and ITA status, 1996–2008



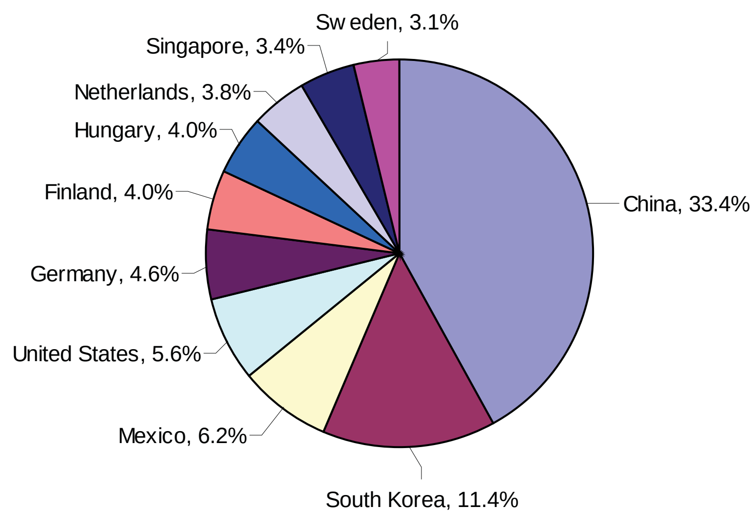
Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 21 ITA Telecom: Top 10 exporters and EU, 1996–2008



Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 22 Telecom: Top 10 exporters, 2008

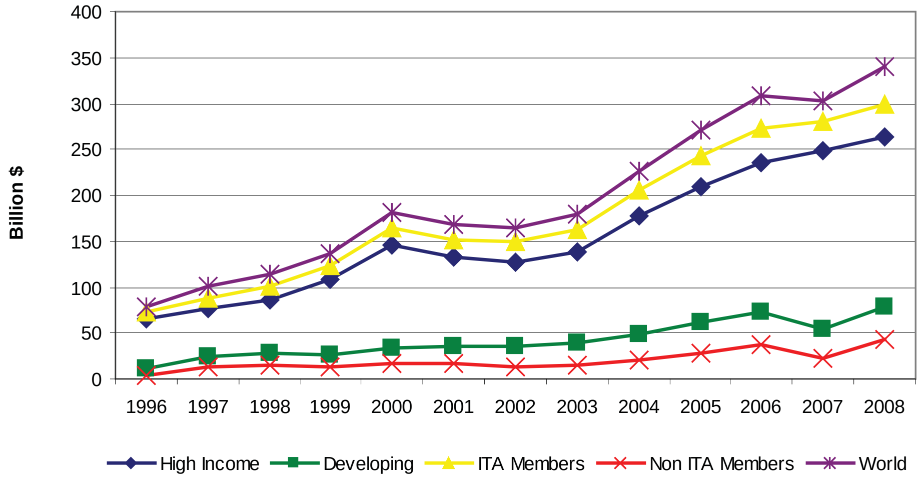


Source: Compiled by USITC staff from UN Comrade database.

Led by developed countries, ITA members' share of telecommunications imports was 87.5 percent in 2008, down slightly from 94.1 in 1996, as non-ITA members, namely Mexico, expanded imports to meet growing demand for telecommunications technology (figure 23). Increasing imports from China and, to a lesser extent, Malaysia, Mexico, and the Philippines account for the jump in developing countries' share of import trade, from 15 percent to 23 percent between 1996 and 2008. The United States and a group of four EU members (Germany, United Kingdom, the Netherlands, and France) remained leading telecommunications importers during the period examined, accounting respectively for 20.4 percent and 16.8 percent of 2008 imports, followed by China (including Hong Kong) at 14.1 percent (figures 24-25). The consistently high import level of developed ITA members seems consistent with the rapid growth in broadband internet and broadband wireless subscribers over the period.[39]

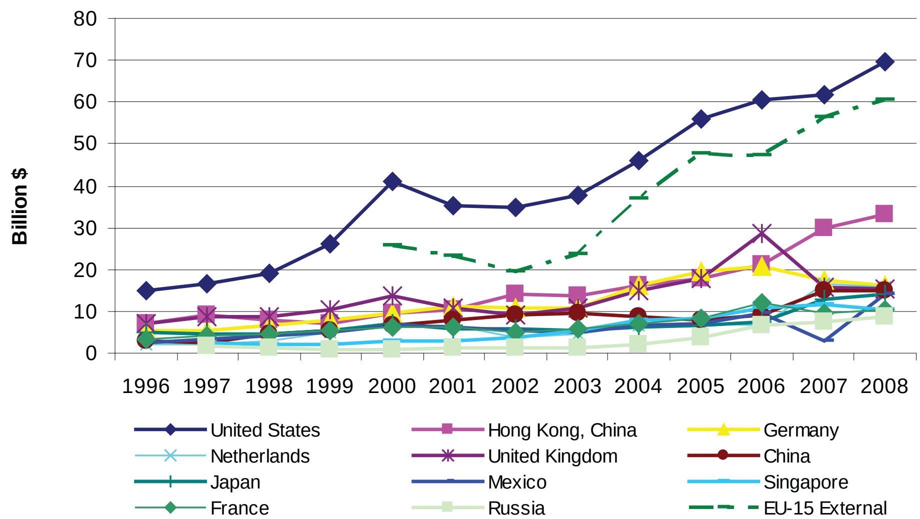
[39] Worldwide broadband wireless subscriptions surged from 20.5 million to 32.5 million between 2001 and 2008 and wireless subscriptions increased to 3.1 billion from 0.8 billion during the same period (TIA 2008).

FIGURE 23 ITA telecom imports, by income and ITA status, 1996–2008



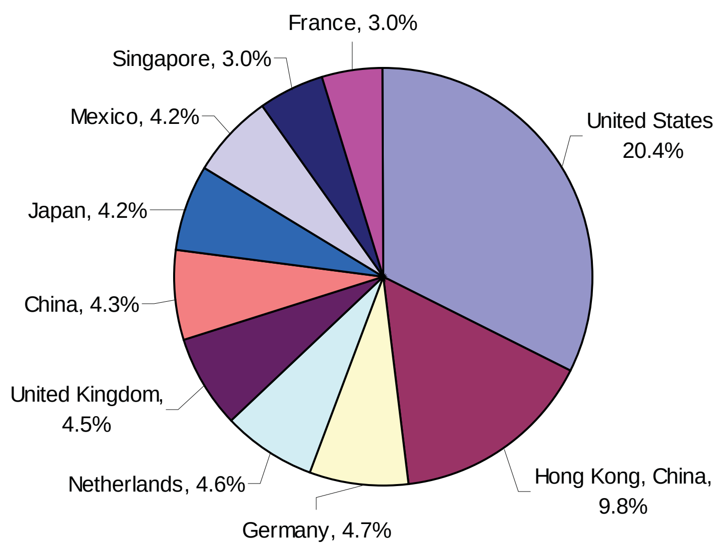
Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 24 ITA telecom: Top 10 importers and EU, 1996–2008



Source: Compiled by USITC staff from UN Comtrade database.

FIGURE 25 Telecom: Top 10 importers, 2008



Source: Compiled by USITC staff from UN Comtrade database.

Achieving objectives of the ITA

To what extent have the ITA's objectives of increasing world IT production and trade, and promoting diffusion of technology, particularly among developing countries been achieved? The social and economic benefits of trade liberalization are well documented, suggesting a positive outcome from the ITA. However, in the case of tariff liberalization framed under the ITA, systematically capturing the effects of increased market access and technology diffusion through tariff elimination remains complex and imperfect (box 2). Most non-empirical work, however, suggests that the ITA has enhanced IT trade and technology diffusion, including among developing countries (Dryer and Hindley, 11–12). Reduced prices for IT products and heightened competition stemming from lower tariffs are commonly linked to the ITA (Suh

BOX 2 Empirically estimating the ITA's impact on global trade

While empirically estimating the overall impact of the ITA remains outside the scope of this paper, several analytical challenges are noted here, which have likely helped to limit empirical research measuring the impact of the ITA on world trade and competition in IT products. A brief review of the challenges and associated literature is provided.

Analytical challenges

The beneficial effects of the ITA are difficult to quantify owing to the complexity of data and several external factors. Because duty elimination on ITA products was staged over multiple years, with differing stages for each country, capturing a single point of full implementation is elusive. Changes in product classifications since 1996 for several ITA products under the WCO pose transposition challenges as well, particularly changes made in 2007.[a] Further, data that isolate other duty-free mechanisms outside the ITA encompassing IT products was generally not available. Because the majority of trade data available at the 6-digit HS level is recorded in U.S. dollars, adequately addressing fluctuations in exchange rates for numerous trading partners poses additional analytical burdens. Finally, the analysis is further complicated by several exogenous factors during the period under examination. Since 1996, the Asian financial crisis, the Internet bubble, the September 11, 2001 terrorist attacks, and the recent global economic slowdown significantly affected values of world trade, and by extension, ITA products.

Limited empirical analysis

A review of prior work empirically assessing the impact of the ITA is limited. Two initial assessments at the outset of the ITA focused on the benefits to consumers and downward pressure on prices expected from tariff liberalization on ITA products. These estimates ranged between $50 billion and $100 billion in savings from duty free access to ITA goods (UNCTAD 1999, 4). In perhaps the most rigorous assessment of the ITA, Bora and Liu (2006) find significant trade creation under the ITA for developing countries. Comparing trade levels among WTO members participating and not participating in the ITA, they conclude that the value of bilateral trade has increased through ITA participation, and that developing countries account for most of the progress in ITA trade liberalization. They find that a non-ITA WTO member would increase imports from other WTO members by 14 percent under if it joined the ITA. (Bora and Liu 2006, 1, 14).[b, c] On the other hand, an assessment covering ITA trade during 1997–2002 concluded that "joining the ITA had no statistically significant impact on the rise in IT imports" (Ares). This analysis examined the economics behind a country's decision to the join the ITA and postulated that recent growth of IT trade was not closely correlated to ITA tariff reductions. (Continued on page 148.)

(Continued from page 147.) Another study examined the extent to which lower prices stemming from ITA tariff liberalization was a catalyst for increasing demand and diffusion of ITA products in developing countries (Joseph and Parayil, 7–8). In comparing ITA trade among developed versus developing countries during 1999–2003, the authors found that the ITA had “only a negligible or negative impact in promoting world demand for ICT goods,” based on declining world exports during 2001–03. They further noted that examining IT diffusion in developing countries showed that certain non-ITA countries have achieved greater success than many ITA member countries.[d]

The paucity of conclusive research on the impact of the ITA on global trade attests to the difficulties in empirically measuring the effects of the ITA and signals that further work remains.

[a] According the WTO, the transposition of HS 1996 to HS 2002 for listed ITA product codes had limited impact, as only 14 subheadings were affected, most of which were simple mergers or splits. However, the HS 2007 amendments significantly altered the structure of the HS codes for a significant number of ITA products: 158 of the 241 (over 50 percent) of the HS 2002 subheadings were amended. Owing to the breadth and complexity of the HS 2007 amendments, ITA members continue to review and address these changes.

[b] Bora and Liu (2006) conclude that a country’s ITA imports would be 7 percent higher if it were an ITA member and the exporter is a non-ITA member of the WTO than if neither trade partner were a WTO member (base line). Conversely, if the importer is not an ITA member, its ITA imports would be 6 percent less compared to the baseline.

[c] Mann and Liu (2007) conclude, based on a review of the empirical literature that ITA participation results in increased bilateral trade.

[d] Joseph and Parayil (2006) used a Network Readiness Index, household IT spending, and measures of telephone usage, among others, to assess ICT diffusion.

Source: Compiled by USITC staff from UN Comtrade database.

and Poon 2006, 388).[40] Further, the ITA is often is credited as a catalyst for rapid growth in technological advancements and technology diffusion beyond that which would have otherwise occurred (AEA 2008, 2; Slaughter 2003, 26). While considerable discussion and analysis are still needed to determine the magnitude of the ITA's impact on IT trade and technology diffusion, changes in trade patterns and ITA membership over the past 12 years demonstrate elimination of tariffs on ITA products contributed importantly to these developments in global IT trade.

Conclusions

During the 12 years after the Declaration stated the ITA's objectives of increased trade and technology diffusion through tariff elimination for many IT goods, remarkable growth in ITA trade occurred. Aggressive tariff liberalization facilitated growth in ITA trade from $1.2 trillion to $4.0 trillion. Notably, the growth in ITA trade was nearly 11 percent annually, despite the bursting of the Internet bubble and the advent of the current global economic downturn. Primarily a domain of developed countries at its inception, the ITA greatly expanded the number of developing countries and, in turn, enhanced IT trade for those countries. WTO member participation in the Agreement more than doubled between 1996 and 2008, with developing countries representing over one-third of the 72 members by 2008. The diversification of ITA membership, previously dominated by developed countries with high trade levels in technology products, reflects significant assimilation of developing countries into the largest WTO sectoral trade agreement and continued liberalization of tariffs in the global IT sector. Further, the increasing diversification of the economic income and trade levels of new ITA entrants after 1996, both for developing and developed countries, suggests an expanding role for ITA products in global IT trade and production.

Commensurate with their expanding membership, developing-country members' ITA trade has increased substantially, in terms of both volume and share. Developing countries now represent more than one-third of ITA trade,

[40] The results of a 2003 survey of Korean computer firms showed that firms attributed a large portion of the WTO's impact directly to the tariff reductions that occurred under the ITA. Firms surveyed viewed the WTO as a major factor contributing to improved Korean export performance from 1995 to 2002, compared to 1990–1994 (Suh and Poon 2006).

with growth rates frequently outpacing those of their developed-country counterparts. The robust expansion of ITA trade by developing countries is most evident in Asia, with China consistently a dominant force. Already a strong trader in ITA products, China's ascension to its current position as a leading exporter and importer accelerated in conjunction with implementation of its WTO and ITA obligations. Although China's role is the most prominent, other developing countries, including other Asian countries, also realized expanded trade opportunities following ITA membership. Further, growth in developing countries' ITA trade exceeded that of the largest non-ITA countries, demonstrating a positive proposition from ITA membership. Highlighting the changes in the composition of ITA products' trade, was the expanded share of trade in computers and telecommunications products as a percentage of total ITA trade. However, strong growth in imports and exports for all ITA products occurred, with the most significant growth in telecommunications products, office equipment, and semiconductors, paralleling the increasing fragmentation of global production networks for all IT products. The shift in global production and trade patterns is most striking in computers and telecommunications products, where China and South Korea alone have displaced the United States, Japan, and several European countries as the leading producers and exporters.

In conclusion, remarkable growth in global trade of ITA products and appreciably expanding participation in these trade flows by developing countries, with a significant shift to Asia, has occurred in the wake of tariff liberalization under the ITA.

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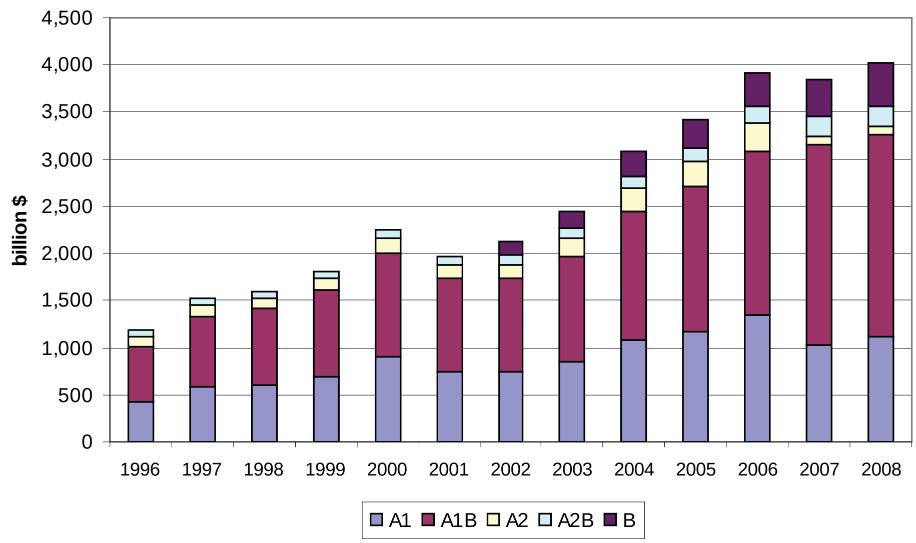
Appendix A

FIGURE APPENDIX A.1 ITA total trade by attachment, 1996-2008



Source: Compiled by USITC staff from UN Comtrade database.

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Understanding China's High Investment Rate and FDI Levels: A Comparative Analysis of the Return to Capital in China, the United States, and Japan

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Abstract:

This paper analyzes aggregate return to capital statistics for China, the United States, and Japan in order to investigate the causes of an unusually high investment rate and increasing foreign direct investment (FDI) inflows to China. We also analyze labor's share of

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output and capital-output ratio statistics to predict future trends in the return to capital in China. Our findings allow us to come to four conclusions: (1) China's high investment rate corresponds to a high return to capital in the country, just as high investment rates in the United States and Japan historically correspond to a high return to capital. (2) A comparatively higher return to capital attracted FDI to China. (3) Investment rates among these three countries show no signs of convergence so far. These differences will likely persist, encouraging FDI to continue to flow into China in near future. (4) The return to capital in China will likely decrease in the long run, as the experiences of Japan and the United States indicate, but will only decrease and become stable after a certain level of capital stock and development is reached.

Keywords: return to capital; investment rate; FDI

Introduction

Over the last decade and a half, China maintained an investment rate higher than that of more advanced economies, including both Japan and the United States. Over the same period, foreign direct investment (FDI) inflows to the Chinese economy grew at an average rate of 19.97 percent per year, increasing from $3.5 billion in 1990 to $92.4 billion in 2008.

What made China so attractive to investors? In the past few years, this question has been heavily debated. China's National Development and Reform Commission (2005) concluded that rapid industrialization, a high savings rate, a low consumption rate, and a low efficiency of investment led to the high investment rate. Subsequent studies by Li (2007), Hu (2007), Yu (2008) and many others have further explored the high investment rate and the low consumption rate in China. Fan (2009) discussed the same topic, comparing the political systems of China and the United States, and concluded that China's local governments always paid more attention to the interests of capital and less to those of labor, resulting in a high investment rate and a low consumption rate. Concerning factors that attract FDI flows into China, Shen et al. (2002) found that the human capital stock significantly affected the location choice and investment scale of FDI. Xu et al. (2002) concluded that FDI was mainly affected by market demand, the capital stock, and the exchange rate. Fan and Xu (2009) also discussed the exchange rate's role in attracting FDI. Li (2004) argued that there was a positive correlation between foreign trade and FDI. Huang et al. (2006) pointed out that the transaction costs of foreign trade, technology spillovers, and market demand significantly affected the choice of location for FDI. Luo (2009) studied the source countries for FDI and concluded that the source country's market size and bilateral trade influenced FDI inflow.

In this paper, we expand on these findings and seek to understand the effect of the return to capital and international differences in the return to capital on the investment rate and level of FDI in China. Our main question is whether the high investment rate and FDI in China are sustainable. To answer this question, the most intuitive approach is to estimate the return to capital in China and compare it with that in other major countries, such as the United States and Japan. If the return to capital in China is consistently high, we may conclude that the high investment rate in the country is likely to last for a number of years. And if the return to capital in China is significantly higher than that for other major countries, we can conclude that foreign capital will continue to flow into China. This paper therefore estimates the return to capital in China, the United States, and Japan; studies key factors that affect the return to capital; and investigates changes in these factors in order to reveal the trends in China's return to capital and the future investment climate.

Methodology

In this paper we consider a transaction by a firm, a price taker, to purchase a unit of capital at the margin.[2] The real return from this transaction is:

[2] This methodology has its origins in the Hall-Jorgenson rental price equation and has been used in Bai, Hsieh, and Qian (2006). Details on this methodology are given in the appendix.

$$r(t) = \frac{P_Y(t) MPK_j(t)}{P_{K_j}(t)} - \delta_j - \hat{P}_Y(t) + P_{K_j}(t) \quad \ldots\ldots \textbf{(1)}$$

Where,

$r(t)$: The real rate of return to capital;

$P_Y(t)$: The price of the output;

$P_{K_j}(t)$: The price of capital *j;*

$MPK_j(t)$: The marginal physical product of capital *j*;

δ_j : The depreciation rate of capital *j*;

$\hat{P}_Y(t)$: The growth rate of $P_Y(t)$;

$\hat{P}_{K_j}(t)$: The growth rate of $P_{K_j}(t)$

This methodology is simple and straightforward: it relies only on the assumption that firms take output prices as given. More importantly, this methodology is not dependant on economic structure and thus can be used to estimate the return to capital both in China, an emerging market economy, and in Japan and the United States, which are advanced economies. It is unlikely that one could observe the marginal physical product of capital directly, but it can be inferred from data on labor's share of income. Note that labor's share of total income equals total wages over aggregate output. Further note that while equation (5) in the appendix is used for calculations in this paper, it is equivalent to equation (1) above.

Data sources

China

For the Chinese Gross Domestic Product (GDP) data, we use two sources: the *Chinese Statistical Yearbook 2007* for 1978–2006 and the *Comprehensive*

Statistical Data and Materials on 55 Years of New China (1949–2004) for 1953–1977. For the investment goods deflator, we use the price indices for investment in fixed assets released by China's National Bureau of Statistics since 1990; for those before 1990, we simply use the indices from Bai, Hsieh, and Qian (2006).[3] Labor's share, theoretically, should be measured as aggregate compensation to employees over total income. However, the NBS only provides data on the basic condition of China's labor market in the industrial sectors. These data do not necessarily reflect the true condition of the aggregate labor market. Therefore, we estimate labor's share instead, using provincial annual labor share data, weighted by the share of provincial GDP in the aggregate GDP.

To estimate the capital stock in China, we use the perpetual inventory method (PIM). PIM has been widely used to estimate capital stocks (Gerhand, Verbiest, and De Wolf, 1998; Huang, Ren, and Liu, 2002). As appendix equation (6) indicates, the application of PIM requires estimates and assumptions about three parameters: (1) the service life of the investment goods, (2) depreciation, and (3) the constant price of capital invested. For the capital stock in China, we mainly have to consider two kinds of investment goods: (1) construction and installation, and (2) machinery and equipment. According to the estimates in Wang and Wu (2003), the useful life of construction and installation goods is 38 years and that of machinery and equipment is 12 years. This paper employs the declining-balance method of depreciation, which applies gradually decreasing depreciation charges over the service life of the asset and thus might provide a more realistic reflection of actual depreciation. Therefore, the average annual depreciation rate of construction and installation is 8 percent and that of machinery and equipment is 24 percent.[4]

In China, the series frequently used to measure annual capital invested is "investment in fixed assets," which is disaggregated into two types of investment: construction and installation, and purchase of equipment and instruments. However, Xu (2000) and Bai, Hsieh, and Qian (2006) argued that this widely used statistic might not provide an accurate estimate of aggregate

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[3] Bai, Hsieh, and Qian (2006) assumed that the price of structures during 1978–89 equals the deflator of value added in the construction industry, and that of machinery and equipment equals the output price deflator of the domestic machinery and equipment industry; for the years before 1978, Bai, Hsieh, and Qian (2006) assumed investment goods deflator equals the growth rate of the aggregate price of fixed capital formation.

[4] In China, the residual value rate ranges from 3 to 5 percent; in this paper we use 4 percent as the residual value rate.

investment in China because the series includes the value of purchased land and expenditures on previously owned machinery and preexisting structures. These should not be regarded as part of reproducible capital stock; doing so might lead to biased estimates of the change in China's capital stock. Furthermore, the statistic counts only large investment projects, an approach that underestimates aggregate investment.

To circumvent these problems, many researchers recommend another statistic, "gross fixed capital formation," as an alternative to estimate the change in the capital stock. This statistic subtracts the value of land sales and the expenditure on preexisting machinery and equipment from the figure for investment in fixed assets, and adds expenditures on small investment projects. Because the gross fixed capital formation statistic is not disaggregated into different types of investment, we assume that the shares of the two types of capital are the same as those for investment in fixed assets[56].

The United States

In the National Economic Accounts, the U.S. Bureau of Economic Analysis (BEA) provides data for current-dollar and real GDP from 1929 to 2008. The BEA also provides data on compensation to employees for the same period, which includes wages, salary, and supplements to wages and salary. The BEA disaggregates fixed assets into private equipment and software, private non-residential structures, residential structures, durable goods owned by consumers, and government-owned fixed assets. Like China and Japan, the United States uses geometric depreciation methods for most asset types. The BEA determines the geometric rate for specific types of assets by dividing the appropriate declining-balance rate for each asset by the asset's assumed service life. The declining-balance rates used by the BEA are primarily derived from estimates made by Hulten and Wykoff, who divided assets into three major types: type A assets with extensive data for estimating geometric rates of depreciation; type B assets with limited studies or other relevant data to support estimates of the rate of declining balance; and type C assets with

[5] The data from 1953 to 1977 are from Hsieh and Li (1999), data from 1978 to 2004 are from Bai, Hsieh, and Qian (2006), and data from 2005 to 2006 are from China Statistical Yearbook 2007.

[6] We initialize the capital stock of 1952 as the ratio of investment in 1953 to the sum of the average growth rate of investment in 1953–58 and the depreciation rate.

no data.[7] In this paper, we do not have to conduct in-depth research into the depreciation rates for different types of assets in the United States, as the U.S. BEA provides data series on capital stock as well as depreciation in the National Economic Accounts. To obtain the average depreciation rate, we simply divide the depreciation by the capital stock.

Japan

The Economic and Social Research Institute (ESRI), which produces the Japanese national account in the *Japan Statistical Yearbook,* publishes several estimates of GDP. The national accounts of the *Japan Statistical Yearbook* for 2009 provide data on aggregate output for 1965–2006, whereas the national accounts of the *Historical Statistics of Japan* (2010) provide data on GDP for 1980–2003 under the 1993 System of National Accounts (93SNA) and for 1955–98 under the 1968 System of National Accounts (68SNA). In this paper, we use the data of aggregate output in the *Japan Statistical Yearbook* 2009 for 1965–2006 and the data in the *Historical Statistics of Japan* for 1955–64. For data on compensation to employees, we use the *Japan Statistical Yearbook* 2009 for 2003–06, 93SNA for 1980–2002, and 68SNA for 1955–79.

One of the primary categories of capital stock for which estimates are given in the *Japan Statistical Yearbook* is net capital stock (NCS), which covers such items as buildings, structures, transport equipment, and machinery. A second is gross capital stock of private enterprises (GCSPE), which covers all fixed assets, excluding residential buildings owned by private corporations or unincorporated enterprises and fixed assets owned by private nonprofit institutions. The main limitation of the NCS is that it is disaggregated into only six categories of tangible assets: (1) dwellings, (2) other buildings, (3) other structures, (4) transport equipment, (5) other machinery and equipment, and (6) cultivated assets. The current asset classification is too aggregated to fully satisfy our research needs, as high- and low-depreciation assets are bundled together in some of the classifications. However, the GCSPE, which is frequently used as the main data source for analysis of production by industry, is also a flawed measure of productive capacity because it does not have asset categories. Moreover, the GCSPE only counts the capital stock for private enterprises, which does not provide an appropriate measure for the capital stock of the aggregate economy. Because of this, we chose to use NCS as the capital stock of Japan in this paper, and added total inventories.

[7] This information is primarily extracted from "BEA Depreciation Estimates" at the BEA website.

According to the ESRI, depreciation in NCS is based on the geometric method for dwellings, transport equipment, etc. The residual value rate is 50 percent for cultivated assets and 10 percent for other assets. We calculate the corresponding depreciation rate in table 1[8] and compute the aggregate depreciation rate as a weighted average of depreciation rates by types of assets, using the capital stock shares as weights.

Return to Capital in China, the United States and Japan

With the above-mentioned data in hand, we can estimate the return to capital. In table 2, we provide our estimates of the return to capital in China and list the variables used to calculate it. In tables 3 and 4, we do the same for the return to capital in Japan and in the United States.

Return to Capital in China

As shown in figure 1, the return to capital in China varied between 23.17 percent in 1978 and 21.82 percent in 2006, averaging over 20 percent during this 28-year period. However, there was a drastic fluctuation in the return to capital in China between 1992 and 1994, with a sharp increase in 1993 and a rapid decline in 1994. The spike in 1993 was likely due to a sharp increase in the growth rate of investment goods prices in 1993, which rose from 15.52 percent in 1992 to 29.35 percent in 1993. The rapid drawdown in the return to capital in China in 1994 was likely due to a rapid decline in the growth rate of investment goods prices in 1994, which fell from 29.35 percent in 1993 to 10.25 percent in 1994.

Return to Capital in Japan

As shown in figure 2, the return to capital in Japan was extremely volatile between 1956 and 2006, with a high point of 39.43 percent in 1961 and a low of 5.4 percent in 1994. This metric seems strongly correlated with the country's economic cycle. From 1956 to 1974, as Japan rebuilt its lost industrial capacity and experienced a series of economic booms, the return to capital in Japan was at its highest level, averaging above 31 percent. In the mid-1970s,

[8] All tables and figures are located after the Appendix.

Japan faced a severe economic challenge—the 1973 world oil crisis—which shocked its heavily petroleum-dependent economy. During this period, the return to capital plunged from 30.38 percent in 1974 to 13.94 percent in 1975. Throughout the last five years of the 1970s, this figure fluctuated around 14 percent. In the mid-1980s, the return to capital in Japan began another period of increase that continued until the country entered a recession in 1992. From 1993 to 2006, the return to capital in Japan remained relatively stable, albeit relatively low, with an average of 9 percent.

The Return to Capital in the United States

As shown in figure 3, the return to capital in the United States fell from around 15 percent after the Second World War to around 5 percent in the last decade. During the late 1920s, the United States enjoyed a period of sustained prosperity known as the Roaring Twenties. Even in the first three years after the Wall Street Crash of 1929, the United States maintained a return to capital as high as 15 percent. This, however, was likely due to the negative growth rate of the GDP deflator. As the Great Depression devastated the United States' economy, the return to capital dropped to around 6 percent by the mid-1930s. However, the depression also led to U.S. government efforts to restart the economy, and the return to capital from 1935 to 1945 averaged around 10 percent. During the period of postwar prosperity from 1945 to 1973, the return to capital in the United States fluctuated between 12 and 4 percent, averaging roughly 8 percent. The oil crisis in 1973, which caused the soaring inflation of the 1970s, badly hurt the U.S. economy. The return to capital in the United States averaged below 1 percent for a decade starting in 1974. To stimulate the American economy after a recession in the early 1980s, Ronald Reagan introduced expansionary fiscal policies, which led to an economic recovery starting in 1983. The return to capital in the United States averaged about 6 percent from then until the Clinton administration. The six-year span from 1994 to 2000 witnessed the emergence of a technology-driven "new economy," and the return to capital in the United States during this period averaged above 7 percent. Between 2000 and 2007 the U.S. return to capital remained relatively stable, averaging around 6 percent.

Investment Rates and FDI: From the Perspective of Return to Capital

The Investment Rate in China

Figure 4 shows that the investment rate in China increased from 29.46 percent in 1978 to 42.75 percent in 2006. In the intervening period, as noted earlier, the return to capital in China fluctuated around 22 percent. This indicates a positive relationship between the return to capital and the investment rate. We believe the investment rate in China was high during the period of 1978 to 2006 because the return to capital in China was the highest in the world, which heightened investors' willingness to invest in the country.

The Investment Rate in Japan

As shown in figure 5, the investment rate in Japan increased from 26.80 percent in 1956 to 39.02 percent in 1970 and declined to 23.46 percent in 2006, with an average of 30.45 percent over the entire period. From 1956 to 1970, as discussed earlier, the return to capital in Japan increased from 31.95 to 38.38 percent, averaging 32.36 percent. After 1970, the return to capital in Japan dropped to 12.79 percent by 2006, averaging only 13.62 percent. The evidence from Japan indicates that investors were willing to invest more when the return to capital was high and invest less when the return to capital was low.

The Investment Rate in the United States

From 1929 to 2007, the investment rate and the return to capital in the United States were highly correlated. Figure 6 shows that the investment rate in the United States declined during the Great Depression in the early 1930s but increased in the following years, rising from 15.60 percent in 1933 to 29.68 percent in 1950, the year that marked the highest investment rate in the United States for 1930–2007. After 1950, the investment rate in the United States fluctuated between 24 and 30 percent, with an average of around 27 percent. As discussed above, the return to capital in the United States, after a decline during the Great Depression period, increased from 1.27 percent in 1934 to 11.08 percent in 1950, with a slight decrease in the late 1940s when the investment rate fell. Between 1950 and 2007, the return to capital in the United States remained relatively stable except the period during 1974-1982.

Impacts on FDI inflows to China

In the observed period, FDI played a determining role in investment in China: its high level contributed to the high investment rate. One important factor that affected cross-border capital flows was the disparity in the returns to capital across countries. Figure 7 shows the differences in the returns to capital between China and the world's two largest capital export/import countries, Japan and the United States, as well as the growth rate of FDI inflows in China. We can see that the growth of FDI inflows in China increased significantly when the return-to-capital disparities between China and Japan and China and the United States widened, which is especially evident from 1992 to 1993. The correlation coefficient between the growth rate of FDI inflows and the difference between the return to capital in China and Japan was as high as 0.819; for the United States and China, the correlation was 0.799.

Factors That Affect Return to Capital

Marginal Effect of Factors

Figures 8 and 9 show that the marginal effects of labor's share and the capital-output ratio on the return to capital are always negative, which suggests that an increase in labor's share of income and the capital-output ratio will lead to a decrease in the return to capital. In the long run, however, the marginal effects of labor's share and the capital-output ratio seem to converge to zero. The return to capital changes significantly when it is at a high level, and changes little when it is at a relatively lower level. The return to capital is thus able to become stable again after a sharp decline. In the short run, the change in marginal returns results from the changes in labor's share of income and the capital-output ratio. In the following section, we will discuss how these factors change over time and how they affect the return to capital.

Trends in Key Factors

As appendix equation (9) indicates, the marginal impact of an increase in labor's share of income on the return to capital is always negative—i.e., the return to capital decreases as labor's share increases. Figure 10 shows that labor's share of income in Japan rose from 41.44 percent in 1956 to 51.6 percent in 2006, while that of the United States rose from 51.43 percent in

1930 to 56.63 percent in 2007. However, labor's share of income in China fell from 49.67 to 40.61 from 1978 to 2006. Labor's share of income in China is much lower than those in either Japan or the United States, which is why the country's return to capital is higher. This is very intuitive: when labor receives less compensation, capital will earn more, which leads to a higher return to capital.

There are two major reasons that labor's share of income is so low in China. China has a large manufacturing sector, and laborers are paid less than those who work in the service industry. Also, an abundance of rural migrant workers provide a steady flow of cheap labor for manufacturers; this is the chief reason that labor's share of income in China has actually decreased during the last two decades. In the future, as the economy develops, workers in China will undoubtedly seek better compensation. This will lead to an increase in labor's share of income in China, just as Japan and the Unites States saw increases in the past. The increase of labor's share of income will ultimately reduce the return to capital in China. However, it seems likely that Chinese labor's share of income will remain at a lower level than the Japanese or American for a number of years, given China's manufacturing-based economy and its persistently large flow of rural workers into manufacturing.

What is the economic meaning of a high capital-output ratio? Does it indicate a low GDP, or imply a high capital stock? In the cases of Japan and the United States, the two largest economies in the world, the answer should be a high capital stock. It's natural that Japan and the United States attracted significant amounts of investment during the 20th century, which led to the accumulation of large capital stocks in the two countries. Figure 11 shows that the capital-output ratio in Japan increased from 1.71 in 1956 to 2.41 in 2006, while that of China rose only a slightly—from 1.47 in 1978 to 1.74 in 2006. Although the capital-output ratio in the United States experienced no remarkable change during the period of 1930 to 2007, it persisted at 3.4, which was much higher than both China's and Japan's.

From the experiences of Japan and the United States we can predict that the capital stock in China will increase in the future, which potentially may lead to an increase in the capital-output ratio. The high return to capital in China is likely to attract more investment, which will increase the capital stock and lead to a high capital-output ratio. However, it seems unlikely that the capital-output ratio in China will experience a significant increase in the near future because China has the world's third largest GDP and a fast-growing economy.

The lower capital-output ratio in China relative to those of Japan and the United States will likely cause the return to capital in China to remain the highest of the three countries in the years ahead.

Trends in Return to Capital and the Future Investment Climate in China

As shown in figure 12, the return to capital in Japan decreased from 31.95 percent in 1956 to 12.79 percent in 2006, while that of the United States decreased from 15.28 percent in 1930 to 6.94 percent in 2007, indicating that the return to capital seems to decline in the long run. Increases in labor's share of income and the capital-output ratio seem to follow the development of the economy, leading to a decline in the return to capital. Also, the evidence from Japan and the United States indicates that the return to capital remains high during the early stages of economic booms. From 1965 to 1980, for example, the period that marked the economic booms of Japan, the return to capital in Japan averaged above 28 percent. From 1978 to 2006, the period that marked China's "Reform and Opening Up" movement, the return to capital in China was also very high.

As stated above, the experiences of major developed countries indicate that the return to capital in China will decrease in the future because of increases in labor's share of income and the capital-output ratio. However, it seems that the return to capital in China will remain higher than that of Japan and that of the United States in the near future because labor's share and the capital-output ratio are still very low and are unlikely to significantly increase any time soon. Considering the experience of Japan, whose return to capital converged to that of the United States after more than 40 years of economic development, we can conclude that, considering the size of its economy, China will still be able to enjoy a high return to capital for at least 10 more years. In addition, as the return to capital in China is significantly higher than those of other major countries, foreign capital will continue to flow into China, especially as China increasingly opens more sectors to foreign investors as part of the commitments it made toward entry into the WTO.

Discussion

In this paper, we take labor's share of income and the capital-output ratio to be the primary determinants of the high return to capital observed in China. They therefore have a direct impact on the calculations used. However, there are also many other secondary considerations that may indirectly affect the return to capital, but which are beyond the scope of this paper.

For example, because China's financial market is not fully developed, financing costs are high. There are also many investment inefficiencies in China (NDRC 2005). In addition, because China is still a transition economy, there are many investment uncertainties, including regulations, pricing mechanisms, and the level of market development. Businesses face more risk because of these factors, and as a result they demand a higher return to capital as compensation. Moreover, many sectors in the Chinese market are still monopolies: this imperfect competition allows the return to capital in those sectors to be comparatively high. In the long run, as China's economy develops, changes in these factors will contribute to decreases in the return to capital.

Theoretically, a high investment rate and a quickly growing stock of FDI in China will have a negative effect on the return to capital, taking the form of a lagging effect rather than a current effect. When capital stocks increase, the return to capital decreases. This is supported by the experiences of the United States and Japan. According to our estimates for China over the past 30 years, we have not yet seen a significant decrease in the return to capital, excepting a slight decline after 1994. However, we can assume that a high investment rate and large FDI inflows, while not causing the return to capital to decrease to any large extent, have had a dampening effect.

We consider the return to capital to be sufficient for evaluating the relative size of FDI inflows and for predicting future trends. However, it is insufficient for determining actual quantities of FDI in China due to the complexity of the factors which affect capital flows. China's infrastructure, reform path, and FDI competitors all need to be taken into account to predict investment and FDI with more accuracy.

Since China's entry into the WTO in 2001, the country has become increasingly open to outside investment. In addition, local governments have often adopted preferential taxation and loan policies to attract FDI to their regions. Many studies have discussed the impact of globalization on FDI inflows in China. The specific actions of these governmental bodies merit further research, as they could be used to further analyze the stylized conclusions made in this paper.

Conclusion

By estimating the aggregate return to capital in China, the United States, and Japan, this paper studies the impacts of the return to capital on the investment rate. We use our findings to better understand the unusually high investment rate and flow of FDI to China. Our findings show that the return to capital in China maintained a high level of 21.9 percent during the last three decades—even higher than those in Japan, which was over 10 percent. The investment rate in China increased from 29.46 percent in 1978 to 42.75 percent in 2006, again a level much higher than those found in Japan and the United States. We also find that the investment rate was always high when the return to capital was high and low when the return to capital was low, suggesting that the investment rate was significantly affected by return to capital. Thus, we believe that China maintained a higher investment rate during the last 30 years precisely because of its higher return to capital.

The disparities among the returns to capital in China, Japan, and the United States may persist into the near future, maintaining current trends of a high investment rate and high FDI in China. Although in the long run the increase in labor's share of income and in the capital-output ratio will likely cause the return to capital in China to decline, our analysis shows that China should continue to have much higher return to capital than that in Japan or the United States. Return to capital statistics for the United States, China, and Japan show no evidence of convergence, and neither labor's share of income nor the capital-output ratio in China is likely to experience a significant increase in the near future.

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Appendix

$$r(t) = \frac{P_Y(t)MPK_j(t)}{P_{K_j}(t)} - \delta_j - \hat{P}_Y(t) + P_{K_j}(t) \quad \ldots\ldots \textbf{(1)}$$

Where

$r(t)$: The real rate of return to capital;

$P_Y(t)$: The price of the output;

$P_{K_j}(t)$: The price of capital *j*;

$MPK_j(t)$: The marginal physical product of capital *j*;

δ_j : The depreciation rate of capital *j*;

$\hat{P}_Y(t)$: The growth rate of $P_Y(t)$;

$\hat{P}_{K_j}(t)$: The growth rate of $P_{K_j}(t)$.

Note that labor's share in total income equals total wages over aggregate output. Thus, the share of capital in total income is:

$$\alpha(t) = 1 - \frac{W(t)L(t)}{P_Y(t)Y(t)} \quad \ldots\ldots \textbf{(2)}$$

Where $W(t)$ is wages and $L(t)$ is employment.

Additionally, the share of payments of capital can be given as:

$$\alpha(t)=\frac{\sum_j P_Y(t)MPK_j(t)K_j(t)}{P_Y(t)Y(t)}$$

$$=\frac{\sum_j \frac{P_Y(t)MPK_j(t)}{P_{K_j}(t)}K_j(t)P_{K_j}(t)}{P_Y(t)Y(t)}$$

Substituting equation (1) into $\alpha(t)$, we get:

$$\alpha(t)=\frac{\sum_j\left(r(t)+\delta_j+\hat{P}_Y(t)-P_{K_j}(t)\right)K_j(t)P_{K_j}(t)}{P_Y(t)Y(t)}$$

$$=\frac{\sum_j\left(r(t)+\hat{P}_Y(t)\right)K_j(t)P_{K_j}(t)+\sum_j\left(\delta_j-P_{K_j}(t)\right)K_j(t)P_{K_j}(t)}{P_Y(t)Y(t)}$$

$$=\frac{\left(r(t)+\hat{P}_Y(t)\right)K(t)P_K(t)+K(t)P_K(t)\left(\frac{\sum_j\delta_jK_j(t)P_{K_j}(t)}{K(t)P_K(t)}-\frac{\sum_j\hat{P}_{K_j}(t)K_j(t)P_{K_j}(t)}{K(t)P_K(t)}\right)}{P_Y(t)Y(t)}$$

$$=\frac{K(t)P_K(t)\left(r(t)+\hat{P}_Y(t)+\delta(t)-P_K(t)\right)}{P_Y(t)Y(t)} \quad \ldots\ldots \textbf{(3)}$$

Where

$K(t)P_K(t)=\sum_j K_j(t)P_{K_j}(t)$: The aggregate produced assets;

$\hat{P}_K(t)=\sum_j\frac{K_j(t)P_{K_j}(t)}{K(t)P_K(t)}P_{K_j}(t)$: The growth rate of the investment goods deflator;

$$\delta(t) = \sum_j \frac{K_j(t) P_{K_j}(t)}{K(t) P_K(t)} \delta_j$$: The depreciation rate;

From equation (3) we can get the real return to capital as:

$$r(t) = \frac{\alpha(t)}{K(t)P_K(t) \big/ P_Y(t)Y(t)} + \left(\hat{P}_K(t) - P_Y(t)\right) - \delta(t) \quad \ldots\ldots \textbf{(4)}$$

Substituting equation (2) into equation (4), we get:

$$r(t) = \frac{1 - \dfrac{W(t)L(t)}{P_Y(t)Y(t)}}{K(t)P_K(t) \big/ P_Y(t)Y(t)} + \left(\hat{P}_K(t) - P_Y(t)\right) - \delta(t) \quad \ldots.. \textbf{(5)}$$

$$K_t = \sum_{\tau=0}^{d-1} w_\tau * I_{t-\tau} \quad \ldots.. \textbf{(6)}$$

Where

K_t is the capital stock at time t;

d is the service life of the investment goods;

$I_{t-\tau}$ is the constant value of the investment goods invested τ years before;

w_τ is the weight of the investment goods invested τ years before.

According to equation (5), we have:

$$r(t) = \frac{1 - \dfrac{W(t)L(t)}{P_Y(t)Y(t)}}{K(t)P_K(t) \big/ P_Y(t)Y(t)} + \left(\hat{P}_K(t) - P_Y(t)\right) - \delta(t)$$

$$\Rightarrow r(t) = \frac{1-\beta(t)}{\varphi(t)} + \left(\hat{P}_K(t) - P_Y(t)\right) - \delta(t) \quad \text{..... \textbf{(7)}}$$

Where

$\beta(t) = \dfrac{W(t)L(t)}{P_Y(t)Y(t)}$ is labor's share

$\varphi(t) = K(t)P_K(t) \big/ P_Y(t)Y(t)$ is the capital-output ratio.

By taking a partial derivative on return to capital with respect to each of the five factors, we have:

$$dr(t) = \frac{\partial r(t)}{\partial \beta(t)} d\beta(t) + \frac{\partial r(t)}{\partial \varphi(t)} d\varphi(t) + \frac{\partial r(t)}{\partial \hat{P}_K(t)} d\hat{P}_K(t) + \frac{\partial r(t)}{\partial P_Y(t)} dP_Y(t) + \frac{\partial r(t)}{\partial \delta(t)} d\delta(t) \quad \text{.. \textbf{(8)}}$$

Where

$\dfrac{\partial r(t)}{\partial \beta(t)} = -\dfrac{1}{\varphi(t)}$, the marginal return of labor's share;

$\dfrac{\partial r(t)}{\partial \varphi(t)} = -\dfrac{1-\beta(t)}{\left(\varphi(t)\right)^2}$, the marginal return of capital-output ratio;

$\dfrac{\partial r(t)}{\partial \hat{P}_K(t)} = 1$, the marginal return of investment goods deflator;

$$\frac{\partial r(t)}{\partial \hat{P}_Y(t)} = -1$$, the marginal return of GDP deflator;

$$\frac{\partial r(t)}{\partial \delta(t)} = -1$$, the marginal return of depreciation rate.

$$\Rightarrow dr(t) = -\frac{1}{\varphi(t)} d\beta(t) - \frac{1-\beta(t)}{\left(\varphi(t)\right)^2} d\varphi(t) + d\hat{P}_K(t) - dP_Y(t) - d\delta(t) \quad \text{..... (9)}$$

Table 1: Depreciation rates used in *Japan Statistical Yearbook* (by types of assets)

	Service life	Depreciation rate
Dwellings	28.0	7.9
Other buildings	37.4	6.0
Other structures	33.7	6.6
Transportation equipment	7.6	26.2
Other machinery and equipment	10.6	12.1
Cultivated assets	5.4	9.9

Source: Nomura and Futakami, 2005.

Table 2: Variables and return to capital in China (%)

Year	Labor's share	Capital output ratio	Depreciation rate	Growth of investment deflator	Growth of GDP deflator	Return to capital
1978	49.67	1.39	12.10	0.93	1.92	23.17
1979	51.38	1.37	11.97	2.15	3.58	22.07
1980	51.15	1.35	11.82	4.95	3.78	25.41
1981	52.68	1.44	11.43	1.78	2.25	20.98
1982	53.57	1.45	11.06	2.34	-0.21	23.62
1983	53.54	1.43	10.82	3.76	1.04	24.44
1984	53.68	1.33	10.67	4.80	4.96	23.92
1985	52.90	1.24	10.69	8.62	10.24	25.77
1986	52.82	1.31	10.86	7.52	4.70	27.91
1987	52.53	1.33	10.81	6.98	5.17	26.60
1988	51.72	1.27	10.84	12.50	12.10	27.49
1989	51.51	1.41	10.88	9.55	8.55	24.58
1990	53.36	1.48	11.00	7.31	5.80	21.96
1991	50.03	1.44	10.91	9.05	6.87	26.09
1992	50.09	1.35	10.79	15.52	8.20	33.37
1993	50.37	1.31	10.72	29.35	15.16	41.47
1994	51.11	1.38	10.65	10.25	20.63	14.29
1995	52.56	1.37	10.74	4.97	13.71	15.25
1996	52.80	1.39	10.71	4.51	6.43	21.42
1997	52.89	1.47	10.61	2.12	1.52	22.01
1998	53.12	1.57	10.61	0.02	–0.89	20.23
1999	52.42	1.64	10.59	–0.15	–1.27	19.59
2000	51.48	1.63	10.59	1.60	2.03	18.75
2001	51.46	1.65	10.56	0.70	2.05	17.52
2002	50.92	1.67	10.55	0.37	0.60	18.62
2003	49.62	1.65	10.55	3.09	2.59	20.48
2004	45.51	1.63	10.54	6.86	6.93	22.83
2005	41.40	1.71	10.53	1.42	4.14	21.00
2006	40.61	1.72	10.65	1.20	3.24	21.82

Source: China Statistical Yearbook, various years, and author's calculations.

Table 3: Variables and return to capital in Japan (%)

Year	Labor's share	Capital output ratio	Depreciation rate	Growth of investment deflator	Growth of GDP deflato	Return to capital
1956	41.55	1.71	10.34	14.39	6.22	31.95
1957	40.81	1.54	10.00	11.59	7.16	32.79
1958	42.91	1.67	9.92	-5.64	-0.91	19.46
1959	42.47	1.56	9.92	1.57	5.50	23.15
1960	40.48	1.29	9.76	4.95	9.48	31.76
1961	39.53	1.17	9.83	7.96	10.21	39.43
1962	41.90	1.17	9.93	0.00	5.55	34.09
1963	42.34	1.24	10.10	0.00	7.18	29.03
1964	42.44	1.19	10.07	2.19	6.85	33.66
1965	44.12	1.22	10.04	-0.53	13.94	21.48
1966	43.96	1.21	10.00	3.76	5.34	34.86
1967	43.12	1.15	9.92	4.92	5.50	39.09
1968	42.43	1.12	9.94	2.22	5.83	37.74
1969	42.51	1.13	10.11	2.66	4.93	38.59
1970	43.49	1.11	10.18	4.47	6.87	38.28
1971	46.86	1.21	10.39	1.35	5.40	29.32
1972	47.65	1.31	10.52	3.56	5.60	27.44
1973	49.05	1.25	10.30	16.31	12.71	34.17
1974	52.15	1.31	10.17	24.72	20.81	30.38
1975	55.00	1.64	10.16	3.85	7.18	13.94
1976	55.24	1.83	9.99	4.84	8.01	11.30
1977	55.38	1.79	9.76	4.76	6.75	13.16
1978	54.34	1.86	9.60	2.85	4.60	13.23
1979	54.19	1.87	9.45	6.68	2.75	19.01
1980	53.84	1.88	9.27	8.51	-1.08	24.81
1981	54.13	2.04	9.35	1.74	4.52	10.33
1982	54.50	2.22	9.27	1.18	1.76	10.65
1983	55.10	2.24	9.24	0.11	1.71	9.16
1984	54.62	2.22	9.22	1.16	2.48	9.94
1985	53.11	2.11	9.26	0.73	3.01	10.65

Table 3: Variables and return to capital in Japan (%) — Continued

Year	Labor's share	Capital output ratio	Depreciation rate	Growth of investment deflator	Growth of GDP deflator	Return to capital
1986	52.89	2.11	9.33	-0.83	1.66	10.51
1987	52.57	2.09	9.37	-0.73	-0.36	12.92
1988	51.72	1.99	9.34	0.32	1.00	14.19
1989	51.48	1.95	9.37	1.89	2.32	15.06
1990	51.68	1.92	9.38	2.89	2.99	15.62
1991	52.49	2.01	9.42	2.20	2.94	13.43
1992	52.82	2.14	9.42	1.27	1.63	12.26
1993	53.55	2.28	9.42	-0.19	0.53	10.27
1994	54.35	2.35	9.36	-1.55	3.09	5.40
1995	54.51	2.37	9.26	-1.48	-0.50	8.97
1996	54.22	2.36	9.25	-1.18	-0.57	9.52
1997	54.44	2.33	9.23	0.41	0.60	10.12
1998	55.01	2.46	9.27	-1.56	0.03	7.45
1999	54.88	2.57	9.27	-2.14	-1.29	7.44
2000	54.68	2.52	9.23	-1.23	-1.73	9.23
2001	54.93	2.54	9.18	-2.13	-1.23	7.67
2002	54.30	2.60	9.15	-2.05	-1.55	7.94
2003	52.74	2.57	9.08	-1.77	-1.60	9.12
2004	51.44	2.51	9.00	-0.21	-1.08	11.25
2005	51.51	2.49	9.02	-0.07	-1.23	11.58
2006	51.60	2.41	9.05	0.82	-0.94	12.79

Source: Japan Statistical Yearbook, various years, and author's calculation.

Table 4: Variables and Return to Capital in the United States (%)

Year	Labor's share	Capital output ratio	Depreciation rate	Growth of investment deflator	Growth of GDP deflator	Return to capital
1930	51.43	3.37	4.82	1.99	-3.67	15.28
1931	52.03	3.47	4.63	0.56	-10.36	20.14
1932	52.98	4.16	4.53	-0.77	-11.80	17.81
1933	52.48	4.60	4.84	-1.19	-2.68	6.99
1934	51.97	4.02	4.75	-0.34	5.60	1.27
1935	51.02	3.67	4.79	0.37	1.98	6.94
1936	51.19	3.55	4.94	1.68	1.17	9.31
1937	52.23	3.41	4.91	1.89	4.31	6.68
1938	52.26	3.67	4.60	1.11	-2.97	12.50
1939	52.17	3.50	4.63	1.87	-0.91	11.81
1940	51.48	3.46	4.80	2.42	1.11	10.56
1941	51.14	3.16	5.57	3.88	6.69	7.10
1942	52.69	2.82	5.20	5.77	7.81	9.55
1943	55.19	2.56	5.57	5.79	5.38	12.37
1944	55.19	2.47	5.79	4.59	2.37	14.57
1945	55.27	2.63	6.46	1.84	2.65	9.76
1946	53.85	3.09	6.95	0.33	11.99	-3.69
1947	53.24	3.26	6.88	1.58	10.89	-1.82
1948	52.71	3.15	6.52	2.28	5.63	5.14
1949	53.05	3.22	5.83	2.76	-0.18	11.68
1950	52.83	3.28	6.11	3.90	1.09	11.08
1951	53.46	3.49	5.71	4.09	7.18	4.54
1952	54.76	3.45	5.49	3.95	1.71	9.87
1953	55.40	3.37	5.47	4.31	1.24	10.84
1954	54.99	3.49	5.63	3.70	0.95	10.03
1955	54.44	3.45	5.74	4.24	1.78	9.94
1956	55.91	3.54	5.87	3.65	3.46	6.77
1957	55.87	3.52	5.71	3.43	3.32	6.94
1958	55.57	3.58	5.77	2.65	2.30	6.99
1959	55.49	3.43	5.69	3.58	1.23	9.64
1960	56.34	3.40	5.72	3.22	1.40	8.93
1961	56.07	3.40	5.69	3.05	1.12	9.16
1962	55.87	3.30	5.69	3.54	1.36	9.86
1963	55.90	3.24	5.72	3.74	1.06	10.58
1964	55.86	3.20	5.80	4.08	1.53	10.56
1965	55.56	3.15	5.79	4.46	1.83	10.96
1966	56.18	3.12	5.88	4.53	2.85	9.83
1967	57.06	3.18	5.87	4.01	3.09	8.56
1968	57.62	3.19	5.99	4.10	4.27	7.14
1969	58.66	3.21	5.97	3.89	4.96	5.83
1970	59.43	3.30	5.95	3.17	5.29	4.22
1971	58.46	3.34	5.95	3.28	5.00	4.77

Table 4: Variables and Return to Capital in the United States (%)— Continued

Year	Labor's share	Capital output ratio	Depreciation rate	Growth of investment deflator	Growth of GDP deflator	Return to capital
1972	58.56	3.34	5.86	3.73	4.34	5.92
1973	58.67	3.41	5.87	4.02	5.58	4.70
1974	59.35	3.72	5.92	3.10	9.03	-0.93
1975	57.94	3.67	5.71	2.32	9.43	-1.37
1976	58.04	3.59	5.79	2.75	5.78	2.87
1977	58.13	3.61	5.91	3.26	6.35	2.60
1978	58.23	3.62	5.96	3.67	7.03	2.20
1979	58.55	3.74	5.99	3.59	8.29	0.41
1980	59.22	3.90	5.91	2.69	9.07	-1.82
1981	58.37	3.81	5.83	2.54	9.39	-1.76
1982	59.17	3.84	5.71	1.91	6.10	0.71
1983	57.76	3.66	5.61	2.39	3.96	4.36
1984	57.35	3.49	5.74	3.29	3.75	6.03
1985	57.46	3.42	5.87	3.48	3.04	7.00
1986	57.63	3.43	5.99	3.39	2.20	7.54
1987	58.06	3.43	6.01	3.14	2.73	6.62
1988	58.15	3.39	6.06	3.02	3.41	5.87
1989	57.37	3.34	6.15	2.83	3.78	5.66
1990	57.56	3.31	6.12	2.52	3.86	5.37
1991	57.51	3.27	6.13	1.80	3.50	5.14
1992	57.41	3.23	6.22	1.91	2.30	6.59
1993	57.15	3.23	6.21	2.21	2.31	6.97
1994	56.58	3.23	6.30	2.41	2.13	7.45
1995	56.74	3.23	6.20	2.59	2.05	7.71
1996	56.22	3.20	6.19	2.88	1.90	8.46
1997	56.19	3.17	6.20	3.03	1.66	8.99
1998	57.44	3.17	6.21	3.32	1.11	9.42
1999	57.86	3.19	6.27	3.52	1.45	9.04
2000	58.95	3.20	6.33	3.52	2.18	7.83
2001	58.72	3.26	6.33	2.93	2.40	6.85
2002	58.23	3.30	6.13	2.62	1.75	7.39
2003	57.76	3.32	6.07	2.62	2.13	7.15
2004	57.01	3.42	6.14	2.69	2.87	6.26
2005	56.65	3.52	6.17	2.57	3.26	5.45
2006	56.46	3.57	5.71	2.71	3.22	5.99
2007	56.63	3.38	5.58	2.37	2.69	6.94

Source: National Economic Accounts of U.S. Bureau of Economic Analysis; authors' calculations.

Figure 1: Return to capital in China 1978–2006 (%)

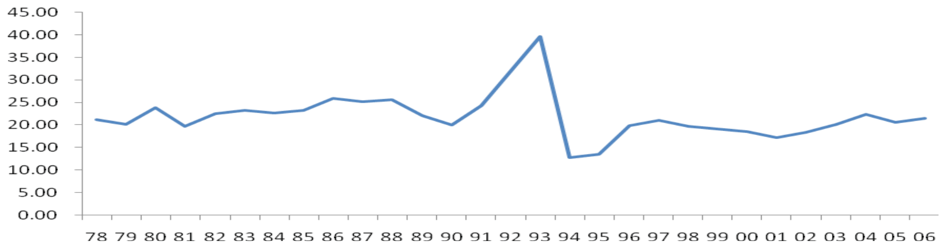


Figure 2: Return to capital in Japan 1956–2006 (%)

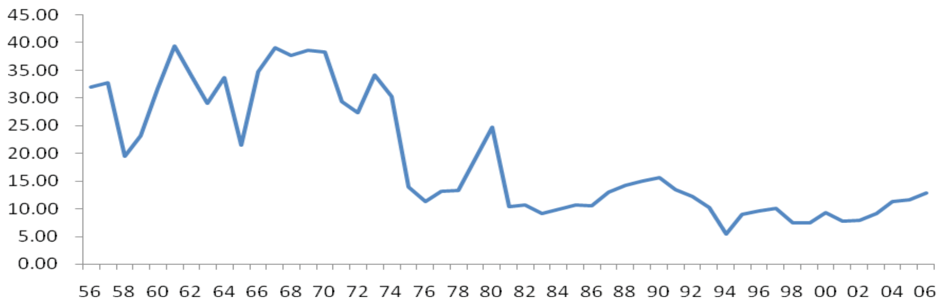


Figure 3: Return to capital in the United States 1930–2007 (%)

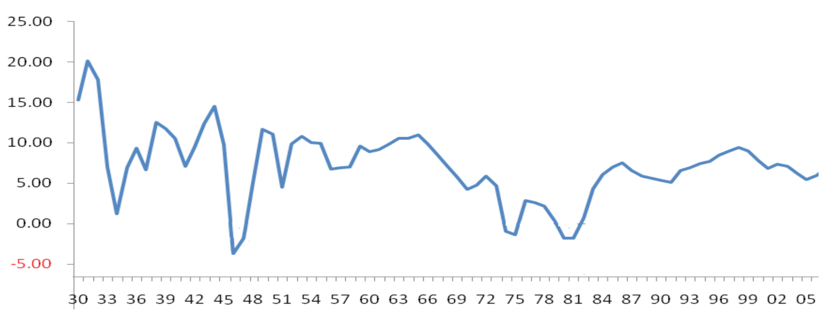


Figure 4: Investment rate in China 1978–2006 (%)

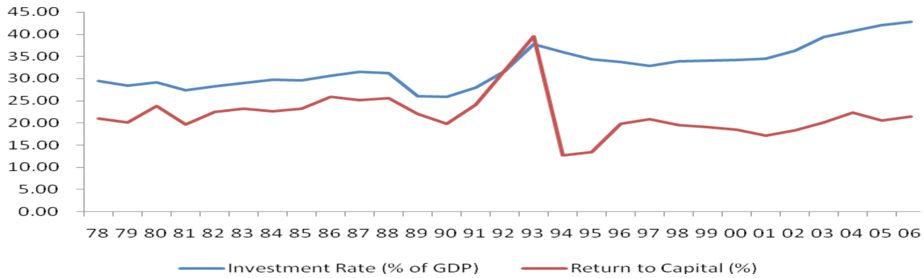


Figure 5: Investment rate in Japan 1956–2006 (%)

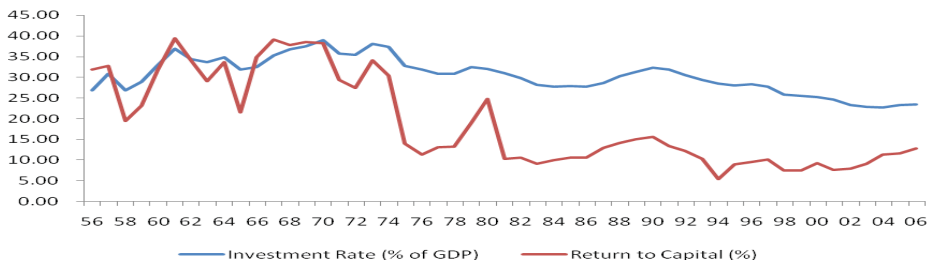


Figure 6: Investment rate in the United States 1930–2007 (%)

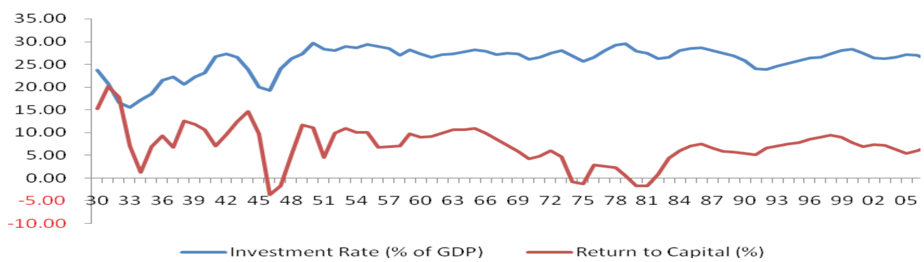


Figure 7: Discrepancy of return to capital and growth rate of FDI in China 1985–2006

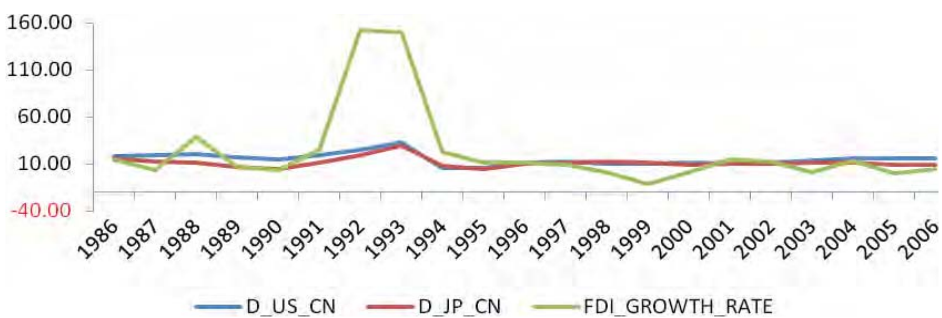


Figure 8: Marginal effect of labor's share on return to capital in in China, Japan, and the United States 1930–2006

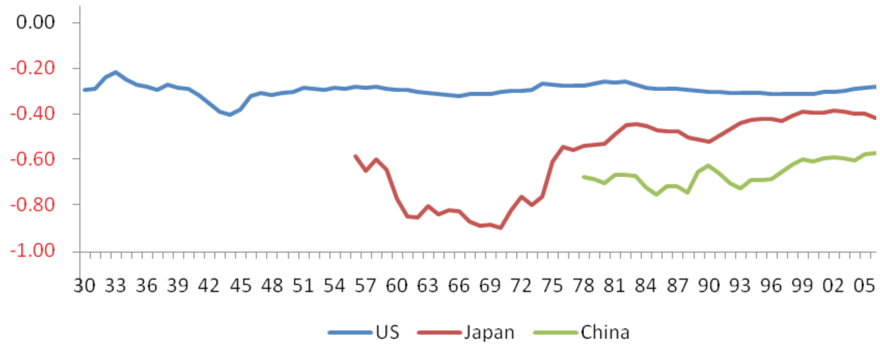


Figure 9: Marginal Effect of Capital-Output Ratio on Return to Capital in China, Japan, and the United States 1930–2006

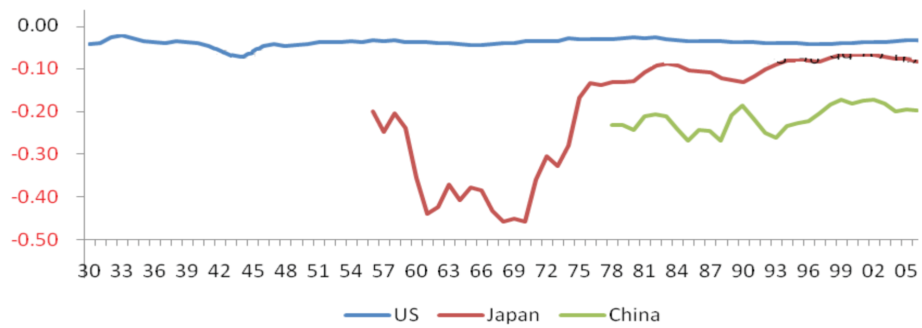


Figure 10: Labor's share of national income in China, the United States and Japan 1930–2006 (%)

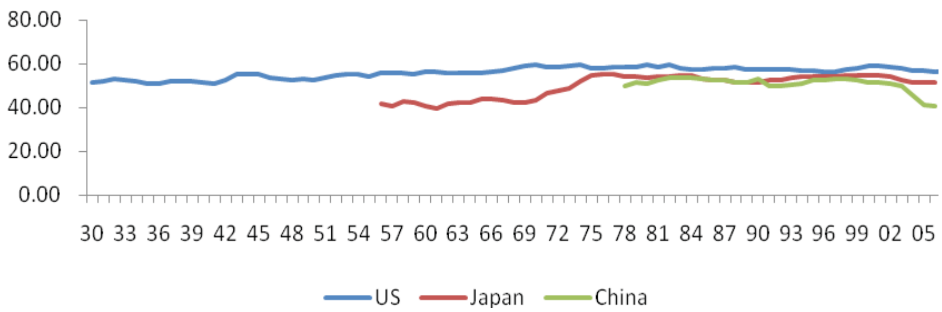


Figure 11: Capital-output ratio in China, the United States and Japan 1930–2006 (%)

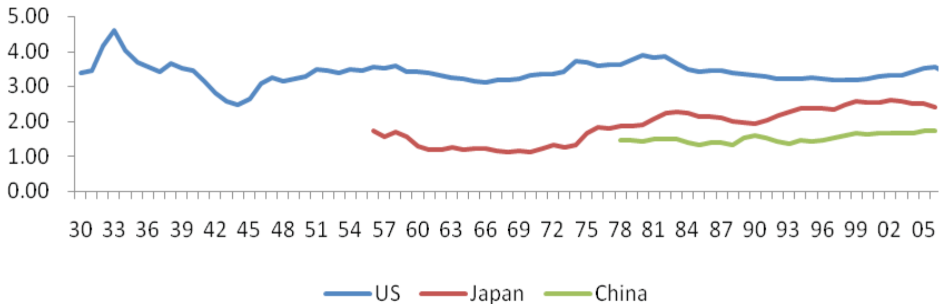
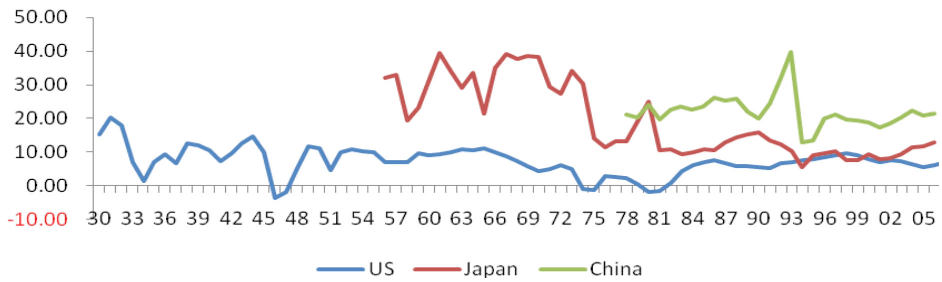


Figure 12: Return to Capital in China, the United States and Japan 1930–2006 (%)



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Innovation in Biotechnology Seeds: Public and Private Initiatives in India and China

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ABSTRACT

This paper compares and contrasts how innovation—the successful introduction of new products, services, or techniques—is occurring in biotechnology seeds in China and India. We begin with an overview of the agricultural challenges faced by China and India and the substantial investments that both countries are making in agricultural research and development (R&D) and biotechnology to address these challenges. We next describe each country's approach to three factors identified by industry as important to innovation in biotech seeds: market access, intellectual property (IP) protection, and efficient regulatory review processes. We find substantial problems in all three areas including limited market access for foreign firms in China and significant price caps in India; limitations and gaps in IP protection and enforcement; and lengthy delays in regulatory review. We conclude with a case study highlighting how the three factors shaped the introduction and adoption of the first widely commercialized biotech crop in China and India, Bt cotton.

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Innovation in Biotechnology Seeds: Public and Private Initiatives in India and China

Introduction

This paper compares and contrasts how innovation—the successful introduction of new products, services, or techniques—is occurring in biotechnology seeds in China and India. We begin with an overview of the agricultural challenges faced by China and India and the substantial investments that both countries are making in agricultural research and development (R&D) and biotechnology to address these challenges. We next describe each country's approach to three factors identified by industry sources as important to innovation in biotech seeds: market access, intellectual property (IP) protection, and regulatory review processes. In considering these three factors, we find a number of problem areas:

- **Market access**: China significantly limits the market access of foreign firms, while India has liberalized its seed sector and permits foreign and domestic firms to participate on equal terms. However, price restrictions implemented by Indian state governments severely limit the ability of all firms to charge market prices for biotech seeds.

- **IP protection**: Both countries have patent and plant variety protection laws that provide some protection for new plant technologies, although with limitations that discourage private sector activities. Foreign firms are active in seeking patent protections in both countries, but domestic firms are not. The public sector is an important user of IP protection systems, particularly in China.

- **Regulatory review**: Biotech seeds sponsored by the public and private sectors have languished for long periods in the review pipeline. Both countries consider factors unrelated to biosafety in determining whether to approve new biotech seeds, a practice that causes delays and undermines the predictability of the regulatory process. In addition, both countries have difficulties with the enforcement of IP and regulatory laws. The sale and use of illegal seeds—those that violate IP laws or those that have not undergone regulatory review—is an ongoing and substantial problem in India and China.

We conclude with a case study highlighting how these three critical factors shaped the introduction and adoption of the first widely commercialized biotech crop in China and India, Bt cotton.[2]

Agricultural Challenges in China and India

India and China have achieved remarkable economic growth over the last decade, although growth in the agricultural sector has lagged behind growth in the general economy.[3] In both countries, the agricultural sector faces the tremendous challenge of producing more with fewer resources. According to the United Nations (2009), global food production must double by 2050 to meet the needs of the world's growing population. Diminishing arable land and water per capita, climate change, plant diseases and pests, pollution, and ecosystems depleted by the application of fertilizers and pesticides present substantial additional challenges (Tuli et al. 2009, 319). To address these challenges, the Chinese and Indian governments have made investing in agricultural R&D, and particularly in agricultural biotechnology, a priority.

Biotechnology is broadly defined as the use of the biological processes of microbes and plant and animal cells for the benefit of humans (USDA, ERS 2009a). Agricultural biotechnology provides a more sophisticated and precise means of modifying plant genetics than that practiced by plant breeders for centuries through breeding and crossbreeding. Instead of transferring thousands of genes using traditional methods, biotechnology enables breeders to transfer only selected genes. Moreover, by expanding the possible universe of transferable genes to include essentially any living organism, biotechnology enables the introduction of beneficial traits that would be difficult or impossible to create through traditional breeding methods (Giddings and Chassy 2009).

The first-generation of biotech crops include those that have been genetically engineered to improve resistance to insects and tolerance to herbicides,

[2] Bt cotton is a genetically modified crop that includes a gene from the soil bacterium *Bacillus thuringiensis*. The bacterium produces a protein that is toxic to certain lepidopteran insects, particularly the bollworm. Cotton containing the Bt gene is able to produce the toxin, making the plant insect resistant (USDA, ERS 2009a).

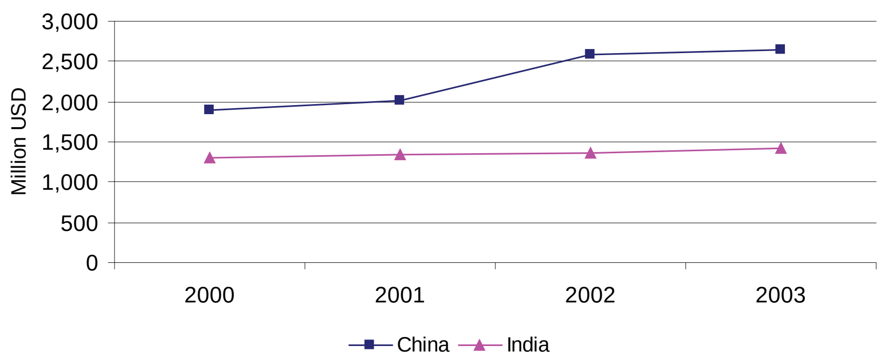
[3] Since 2000, India has experienced average real GDP gains of about 7 percent, and China of almost 10 percent (IMF 2009). In Indian agriculture, however, annual GDP growth rates declined to 2.5 percent during the period 1997–2007 (compared to 3.7 percent in the previous five-year period) (Government of India, Ministry of Finance 2008). By contrast, in China agricultural output grew about 7 percent per year during the period 1997–2007 (USDA, ERS 2009b).

thus enabling farmers to use less pesticide and obtain higher yields. Genetic engineering to increase a plant's tolerance to drought or to high salinity levels, or to improve the nutritional content of crops, are promising emerging areas of agricultural biotechnology (CEI 2008, 13).

Government Investments in Agricultural Biotechnology

Increased agricultural productivity depends on R&D to support innovation. China and India have made significant investments in this area; they rank third and fourth, respectively, in public sector agricultural R&D spending, behind the United States and Japan. In 2000, the United States invested the equivalent of about $4.4 billion in agricultural R&D, compared to $2.5 billion for Japan, $1.9 billion for China, and $1.3 billion for India (Beintema et al. 2008, 1). Since 2000, agricultural R&D spending has grown much more rapidly in China, reaching $2.6 billion in 2003. By contrast, as figure 1 shows, public sector R&D spending in India remained relatively unchanged during the period.

FIGURE 1 China and India total public sector agricultural R&D spending (million, PPP $), 2000-03



Source: ASTI database.

Within the general field of agricultural R&D, China and India have identified biotechnology as a critical tool for overcoming the significant challenges to increasing productivity. According to an official in India's agricultural R&D program, "The search, characterization, isolation and utilization of new genes through application of biotechnology are essential for the revitalization of Indian agriculture" (Rai 2006). During the years 2002–06, the Indian Ministry of Science and Technology's Department of Biotechnology (DBT) implemented 481 agricultural biotechnology programs. Going forward, the

DBT has identified as R&D priorities the development of biotech crops that are disease and pest resistant, drought and salinity tolerant, and nutritionally enhanced (Government of India, Ministry of Science and Technology 2006, 8, 180).[4] There are few published estimates of India's total R&D expenditures on agricultural biotechnology across relevant agencies. One exception is James (2008, 60) who estimates that India's public sector investments in crop biotechnology R&D have been approximately $1.5 billion over the last five years, or $300 million per year.

Like India, China has promoted biotechnology as an important tool for boosting agricultural productivity, food security, and rural incomes. Agricultural biotechnology R&D programs are overwhelmingly financed and implemented by China's public sector. As of 2001, there were more than 150 national and local laboratories in more than 50 research institutes and universities working on agricultural biotechnology, under the direction of the Ministry of Science and Technology (MOST) and the Ministry of Agriculture.[5] One important public funding programs for agricultural biotechnology is the National High Technology Research and Development Program (known as the 863 program). Agricultural biotechnology funding under the 863 program has grown significantly, from $4.2 million when the program began in 1986 to $55.9 million in 2003 (Huang et al. 2004, 3, 7).

In recent years, China has elevated the status of agricultural biotechnology and stressed the importance of developing domestic IP in the field. As Chinese Premier Wen Jiabao stated in 2008, "To solve the food problem, we have to rely on big science and technology measures, rely on biotechnology, rely on GM [genetic modification]" (James 2008, 93). In July of 2008, the State Council approved a budget increase for government funds allocated to genetically modified crops of $584–$730 million per year. The aims of this new initiative reportedly are for China to "obtain genes with great potential commercial value whose intellectual property rights belong to China, and to develop high quality, high yield, and pest resistant genetically modified new species" (James 2008, 93; Shuping 2008). Government policies in the IP area have had a significant impact on the course of innovation in agricultural biotechnology in China and India, as set forth below.

[4] Other Indian public sector institutions substantially involved in agricultural biotechnology R&D include the Indian Council of Agricultural Research (ICAR) and the state agricultural universities (SAUs) (Beintema et al. 2008, 2).

[5] More recently, MOA has taken over from MOST the management of central government funds directed to agricultural biotechnology R&D (Petry and Rohm, 2009, 2).

Government Policies Affecting Agricultural Biotechnology

Industry sources have identified government policies in three areas as important to successful innovation in agricultural biotechnology in India and China: market access conditions; the availability of IP protections; and the speed and manner in which regulatory systems review new biotech products. In this section we will outline how the two countries stand with regard to these factors.

Private Sector Access to Seed Markets in India and China

Until recently, seeds have predominantly been a public sector business in both India and China. And while this is still the case in China, in India the situation has changed dramatically. Until the late 1980s, private firm participation in the seed industry in India was limited by two factors: economy-wide policies that restricted foreign investment and licensing, and seed-specific policies that limited the sector to "small scale" participants and severely restricted imports of research or breeder seeds. With India's implementation of the Seed Policy of 1988, the "small scale" limitation was removed, large domestic and foreign firms were permitted entry, and import restrictions were substantially lifted. Economy-wide liberalization occurred in India in 1991, including the abolition of the industrial licensing system and the easing of restrictions on foreign direct investment (FDI) (Pray, Ramaswami, and Kelley 2001, 589).

These reforms effectively opened the market to private participation. Pray, Ramaswami, and Kelley (2001) found that as a result of the reforms, new foreign and domestic firms entered the market, competition increased, and private sector R&D expenditures grew rapidly as domestic firms spent more on technology to compete with the entry of new research-intensive foreign firms. Another important motivation for firms' increased R&D expenditures has been the market's transition away from open-pollinated varieties (OPVs), which farmers can save and reuse in subsequent years, to hybrids, which cannot be reused without a significant reduction in yield and quality. Farmers' need to purchase seeds each year enables firms to recoup R&D investments (Pray, Ramaswami, and Kelley 2001, 596–97).

U.S. and other global seed companies with a substantial presence in the Indian hybrid and biotech seed markets include Monsanto (United States), Bayer CropScience (Germany), DuPont/Pioneer (United States), Syngenta (Switzerland), and Dow AgroScience (United States). Leading Indian firms include Rasi Seeds, the Maharashtra Hybrid Seed Company (Mahyco), Nuziveedu Seeds, and JK Agri-Genetics (Bayer CropScience 2006). The agricultural biotechnology sector in India reportedly had total revenues of about $318 million in 2008, an increase of 353 percent in the last five years (BioSpectrum 2009).

The Indian seed market is competitive. Murugkar, Ramaswami, and Shelar (2007) found that the cotton seed market, which accounts for about one fourth of the overall seed market, has low levels of market concentration, a diverse group of foreign and domestic firms of various sizes, and market leadership that fluctuates over time and across Indian states. Nonetheless, they noted two factors that detracted from healthy competition: state-level price caps placed on biotech cotton seeds, and a substantial market in illegal seeds.[6]

The state government of Andhra Pradesh was the first to implement price restrictions. Its 2006 directive capped prices for biotech cotton seeds at less than one-half the prevailing market price. Today, price caps have spread to important cotton-growing states throughout the country including Maharashtra, Gujarat, Tamil Nadu, Karnataka, Madhya Pradesh, and West Bengal (Mishra 2006). The U.S.-India Business Council (2009, 6) identifies non-market-based pricing as one of the most significant disincentives to the commercialization of new biotech seeds by global seed firms in India. According to the founder of Rasi Seeds, continued state government interference in pricing also is harming the ability of indigenous companies to develop and commercialize biotech seeds (Suresh and Rao 2009, 299). Price caps have been found particularly problematic for new domestic firms seeking to enter the market (Murugkar, Ramaswami, and Shelar 2007, 19–21).

Even with significant price controls, however, India's seed market is more liberalized than that of China. Despite the enactment of a seed law in 2000 creating a role for private firms, China continues to severely restrict FDI and the trading of certain types of seeds (USCIB 2009, 32–33). Moreover, due to the historic role of state planning, Chinese seed markets are fragmented by geography and function. Historically, each province or prefecture had its own seed company, which generally had monopoly rights within its geographic domain. Although the 2000 seed law is intended to facilitate the marketing of seeds across geographic areas, local markets remain difficult for nonlocal firms to access, according to field research conducted by Keeley (2003, 33–

[6] Illegal seeds are discussed in the regulatory review section of the paper.

34). Fragmentation across functions is also the norm: few firms are vertically integrated across the R&D, breeding, production, sales, and marketing functions (Sanchez and Lei 2009, 5).

FDI restrictions are severe and, not coincidentally, arose at the same time that Monsanto began to successfully market its biotech cotton seed in China. In 1997, the year Monsanto's product was first approved, a new seed regulation required that any foreign company wishing to produce and sell cotton and other seeds had to enter into a partnership in which the Chinese partner maintained the controlling interest; invest prescribed amounts of capital; and obtain central government permission (Reddinger 1997, 1). This new regulation required Monsanto to reduce its initial controlling interest in its cotton joint venture, reportedly so that the Chinese partners could obtain more economic benefits from the partnership (Keeley 2003, 33).

FDI laws became even more restrictive in 2002 when China's Foreign Investment Guidance Catalogue prohibited any new foreign investment in the development and production of genetically engineered planting seeds (Gifford, Qing, and Branson 2002, 3). These prohibitions are maintained in the most recent FDI catalogue issued in 2007. Moreover, although foreign firms may invest in the development, breeding, and production of new varieties of conventional seeds, their investment must be limited to minority shareholder status in joint ventures with Chinese partners (Petry 2007, 2).

These FDI restrictions reportedly arose out of Chinese government concerns about food security and the competitiveness of its domestic industry in light of the commercial success that Monsanto experienced with its biotech cotton product (Thomas 2007, 55–56). Concerns about multinational companies dominating the seed industry persist today. The Chinese Academy of Science and Technology for Development (CASTED), for example, recently stated that the seed industry is a strategic one and that the opening up of the industry threatens the survival of domestic firms and the security of China's germplasm resources (CASTED 2009).

Notwithstanding the market access restrictions, foreign firms have been permitted to undertake several new biotech R&D projects in China. New investments reportedly are permitted if they are limited to research and experimentation, and do not extend to the commercialization of new products.[7]

[7] Industry representative, e-mail message to Commission staff, August 18, 2009.

Syngenta, for example, is building a research center in Beijing for the early evaluation of genetically modified traits in key crops, and has a number of ongoing collaborations with Chinese research universities (Syngenta 2008). Bayer CropScience has entered into a memorandum of understanding with the Chinese Academy of Agricultural Science (CAAS) for the "joint development and global marketing of new agricultural products" using the latest plant breeding and biotechnology processes (Bayer CropScience 2008). Although FDI restrictions remain in place, foreign firms appear to have concluded that the R&D they do in China today ultimately will lead to products they can commercialize there in the future. [8]

The Importance of IP Protection

IP protection for biotech seeds is an important framework condition for innovation, because the development and commercialization of new products involves large research expenditures, uncertain outcomes, and lengthy and costly regulatory procedures (Maskus 2004, 721). Monsanto, for example, estimates R&D investments for new biotech corn products at $5–10 million for the proof-of-concept phase and $10-15 million for early product development (Monsanto India Ltd. 2009, 7). Kalaitzandonakes, Alston, and Bradford (2007, 510) found that to obtain regulatory approval, global seed firms incurred compliance costs ranging from $7 million to $15 million for herbicide-tolerant and insect-resistant corn submitted to regulators in 10 countries. The initial innovating firms cannot obtain a return on their heavy R&D and regulatory compliance costs if competitors are permitted to free-ride on their work.

An additional challenge arises from the "natural appropriation problem" of seeds (Maskus 2004, 722). OPVs can be reproduced simply by cultivating and reusing them, and biotech seeds can be relatively easily copied by competitors employing the latest biotechnology techniques. By contrast, hybrid seeds have some built-in protection mechanisms: they lose their superior yield potential and other valuable characteristics in subsequent plantings, thus reducing the motivation of farmers to save seed. Moreover, commercial competitors cannot reproduce hybrid seeds without access to the parental lines used to develop them; keeping those lines physically secure reduces the appropriation problem (World Bank 2006, 7–8). However, even these built-in protections have their

[8] Other observers are less sanguine, emphasizing the substantial (and strategic) uncertainty that is created by China's approval of particular projects while severely restrictive FDI regulations remain in place. Industry representative, telephone interview by Commission staff, November 23, 2009.

limitations. Seed production in India and China tends to be concentrated in geographic zones with favorable agronomic conditions; the presence of many competing firms working in a relatively small area creates numerous opportunities for misappropriation (Tripp, Louwaars, and Eaton 2007, 360).

As WTO members, China and India must make IP protection available for seed-related inventions. The WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) requires that member countries make patents available for inventions, whether products or processes, in all fields of technology without discrimination, subject to the normal tests of novelty, inventiveness, and industrial applicability (TRIPS, art. 27.1). Although there is an exception to this general rule of patentability for plants and animals, it is limited: members must still allow inventors to patent microorganisms and microbiological and non-biological processes for the production of plants and animals. It is left to each member's legislators, courts, and patent offices, however, to define critical terms and to determine if a particular biotechnology product or process is novel, inventive, and has an industrial application.

Moreover, if a member country does not provide patents for plant varieties, it must provide an effective alternative system (TRIPS, art. 27.3(b)). Some countries, including the United States, offer both patents and an alternative system to protect plants. Most developing countries, including India and China, provide only an alternative system, using the model supplied by the International Union for the Protection of New Varieties of Plants (UPOV).

Patents in India and China

Both India and China exclude plants and seeds from patent protection but provide some patent protection for microorganisms and for non-biological and microbiological processes used to produce plants. However, global seed firms have expressed concern about the actual scope of the coverage given to biotechnology products and processes in both countries. Global firms also have expressed concern about the requirement in both countries that patent applications identify the source and geographic origin of biological materials used to make an invention, stating that it is ambiguous and burdensome. Patent law provisions in both countries that permit compulsory licensing under a wide variety of circumstances also give rise to significant industry concerns.[9]

India and China have granted some agricultural biotechnology patents. According to online records of the Indian Patent Office, Monsanto holds the largest number of recently granted patents for seed technologies.[10] For example, it has obtained a patent for "Cotton Event Mon15985," the genetics underlying the second generation of its biotech cotton seed product, as well as patents for biotechnology processes used in producing plants with herbicide tolerance, improved germination rates, and other valuable traits. Biotechnology patents for improved traits for rice, cotton, corn, and other crops, as well as biotechnology-based seed coatings and treatments, have been issued to Bayer and Syngenta. Global seed firms also have a substantial number of biotechnology patent applications pending. [11]

By contrast, most large Indian seed companies, such as Rasi Seeds and Nuziveedu, do not hold patents or pending applications for seed-related technologies. One exception is Mahyco, which has a number of seed biotech applications pending. Public sector research institutions, such as ICAR and the Council for Scientific and Industrial Research (CSIR), also hold few seed biotech patents or applications at the Indian patent office. [12]

In China, there is substantial patenting of seed biotechnologies by foreign firms (figure 2).[13] Monsanto has the largest number of granted patents and pending applications. For example, it has obtained patents related to its insect-resistant

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[9] See BIO 2009, 2-3; industry representatives, e-mail message to Commission staff, June 19 and August 18, 2009; industry representatives, telephone interviews by Commission staff, August 10, 2009 and November 23, 2009; and industry representative, interview by Commission staff, Beijing, October 23, 2009.

[10] The Controller General of Patents, Designs, and Trademarks (Indian Patent Office) has online search facilities that permit the searching by applicant name of "new records" of granted patents. See Indian Patent Office, Public Search for Patents, *http://ipindia.nic.in/pat-sea.htm* (accessed July 12, 2009). Although date parameters for new records are not provided, they appear to comprise patents granted since 2007.

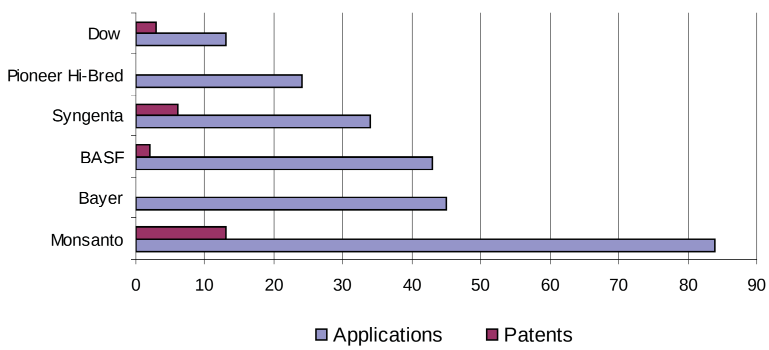
[11] India Big Patents Web site, *http://india.bigpatents.org* (accessed July 20, 2009).

[12] CSIR patents in the fields of agriculture and biological sciences can be accessed on its patent database, *http://www.patestate.com/* (accessed September 8, 2009). See also India Big Patents Web site, *http://india.bigpatents.org* (accessed July 20, 2009).

[13] Agricultural biotechnology patents were identified by reviewing patents issued and applications made by the leading global seed firms, using the following search terms—"seed," "plant," "bacillus," "corn," "rice," "cotton," or "transgenic"—on the China patent database, *http://search.cnpat.com.cn* (accessed August 15, 2009).

cotton and for genetic sequences in corn, bentgrass, and soybeans that confer tolerance to herbicides, improved trait qualities, and other benefits. Other global seed firms have only a handful of granted patents in China and a larger numbers of applications pending. These pending applications are in areas such as climactic stress tolerance, yield improvement, herbicide tolerance, insect and virus resistance, and other valuable traits.

FIGURE 2 China: Global Firms' Seed Biotech Patents and Applications, 1984–2009

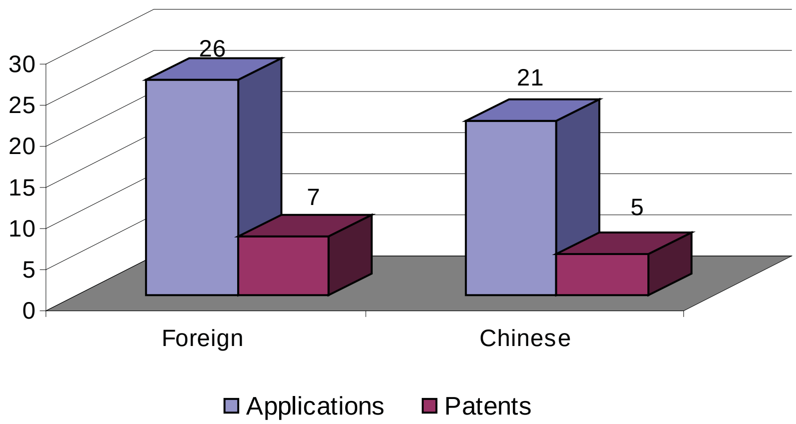


Source: China Patent Database: http://search.cnpat.com.cn.

Unlike in India, China's government-supported research institutions and universities are also important players in biotech seed patents. For example, a review of patents and applications related to Bt cotton shows substantial activity by Chinese research institutes and universities (figure 3). The research institutes of CAAS, including the Biotechnology Research Institute (BRI), all hold multiple patents or applications for Bt-related technologies, as do Huazhong Agricultural University and Central-China Agricultural University.[14] By contrast, few domestic Chinese firms hold patents or applications in the Bt technology area. China and India are thus similar in limited patenting activities by domestic companies compared with strong patenting by global firms. They differ in that Chinese research institutions and universities do engage in substantial patenting.

[14] The BRI reportedly generated about 15 percent of its income through patents in 2006 and expected to increase that share significantly going forward (World Bank 2006, 38). As will be seen in the case study, China's public sector actors have licensed Bt cotton technologies to firms that market and distribute the seeds.

FIGURE 3 China: Bt-Related Patents and Applications, 1985–2009



Source: China Patent Database: http://search.cnpat.com.cn.

Plant Variety Protection in India and China

China and India have enacted plant variety protection (PVP) laws as an alternative to offering patent protection for plant varieties. These laws provide marketing rights to developers of new plant varieties that are distinct, uniform, and stable.[15] China enacted its Plant Variety Protection Act (PVPA) in 1997 and began accepting applications to register new varieties in 1999.[16] India enacted legislation—the Protection of Plant Varieties and Farmers' Rights Act, 2001 (PPV&FR law)—in 2001, but did not begin accepting applications for the protection of plant varieties until May 2007. [17]

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[15] A variety is "distinct" if it is clearly distinguishable from another variety; "uniform" if it has relevant characteristics that can be defined for the purpose of protection; and "stable" if its relevant characteristics remain unchanged after repeated propagation. Together, these are known as the DUS criteria. UPOV Web Site. *http://www.upov.int/en/about/upov_system.htm#P177_18977* (accessed September 23, 2009).

[16] China, Ministry of Agriculture, Office for the Protection of New Varieties of Plants Web site. *http://www.cnpvp.cn/en/index.html* (accessed September 8, 2009).

[17] Government of India, Protection of Plant Varieties and Farmers' Rights Authority Web site. *http://www.plantauthority.gov.in/index.htm* (accessed September 8, 2009).

Major differences between PVP laws in India, China, and the United States are highlighted below. Plant variety rights have significant limitations and are generally considered weaker than patent rights (table 1).[18]

India provides the shortest term of protection for plant varieties, followed by China and then the United States. China and India are phasing in coverage of the law to include new crops each year; however, because India's law is of recent vintage and its application was delayed several years, relatively few crops are covered. China did not include cotton on the list of crops entitled to PVP until 2005—a delay labeled "strategic" by Keeley (2003, 23), as it appears to have been intended to enable the unrestricted spread of the first generation of biotech cotton technologies.

The most significant difference between PVP laws in the three countries is in the breadth of farmers' privileges. Under India's law, farmers are permitted to save, use, sow, exchange, share, and even sell protected seed. The only limitation is a prohibition on the sale of "branded seed." China's law permits farmers to save and informally exchange seed, but prohibits commercial sales. U.S. law is significantly more restrictive; farmers can save seed only under specific conditions, and a new variety cannot be "essentially derived" from a protected variety without sharing the benefits with the source variety's owner. Global seed firms state that the broad farmers' privileges and breeders' exemptions render PVP laws of limited commercial value in both India and China. [19]

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[18] UPOV was established in 1961 with the International Convention for the Protection of Plant Varieties (the UPOV Convention). The UPOV Convention has undergone several revisions since its enactment in 1961. The United States follows the latest revision, the 1991 UPOV Convention, which is the most protective of the rights of plant breeders. China follows an earlier version, the 1978 UPOV Convention. India's PPV&FR law, while loosely based on the 1978 UPOV Convention, contains broader exceptions intended to protect farmers. India's application to join UPOV has not been approved to date, reportedly because of deviations from the 1978 UPOV Convention. Government official, interview by Commission staff, Alexandria, VA, July 20, 2009.

[19] Industry representative, e-mail messages to Commission staff, June 19, 2009, and August 18, 2009; U.S. government official, telephone interview by Commission staff, July 24, 2009.

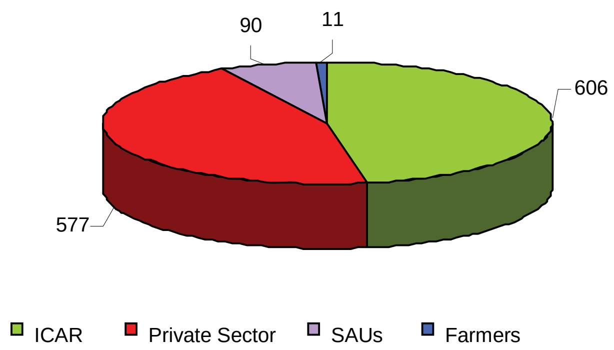
TABLE 1 Major differences in PVP laws in India, China, and the United States

	India	China	United States
Length of protection	18 years for trees and vines; 15 years for other crops and extant varieties.	20 years for vines, fruits, and ornamentals; 15 years for all other crops.	25 years for trees and vines, 20 years for other crops.
Coverage	18 crops currently eligible.	73 crops currently eligible.	No crops excluded.
Farmer seed saving and exchange	Seed saving, exchange, and sale by farmers are broadly permitted. Farmers are only prohibited from selling "branded seed."	Farmer seed saving and exchange are permitted, if noncommercial.	Seed saving and sole use by the farmer to produce a crop are permitted, subject to the legitimate interests of the breeder. Farmers cannot sell or share seed without the permission of the breeder and payment of royalties.
Breeder's exemption	Protected varieties may be used for breeding.	Protected varieties may be used for breeding.	Breeding activities permitted provided that the benefits of new varieties that are "essentially derived" from protected varieties are shared.

Sources: Indian Protection of Plant Varieties and Farmers' Rights Act (2001); U.S. Plant Variety Protection Act, 7 U.S.C. §§ 2321–2582 (2007); Regulations of the People's Republic of China on the Protection of New Varieties of Plants (1999); and World Bank 2006, 7.

Perhaps because of this limited value, the dominant users of the PVP systems in India and China are public research institutions and universities, generally seeking protection for conventional hybrids and OPVs rather than biotech plants. In India, most applications have been filed by ICAR (figure 4). The combined share of ICAR and the state agricultural universities (SAUs) equals 54 percent of all applications. Most of the remaining applications are filed by the private sector, which includes both domestic and foreign firms; few applications are filed by farmers.

FIGURE 4 Plant variety protection applications filed in India, 2007–present



Source: Indian PPV&FR Authority.

Similarly, according to data compiled in China by Hu and others (2006), 66 percent of PVP applications were filed by government research institutes during the period 1999–2004. This figure actually understates public sector involvement, as approximately half of the applications filed by the private sector were for plants developed by the public research institutions and then licensed to private firms for purposes of the application (Hu et al. 2006, 261, 264). Public sector efforts to protect and commercialize IP are not surprising, given that government research institutes in China often are expected to generate a significant portion of their own budgets. Some provincial governments motivate researchers to develop new varieties for commercialization by awarding bonuses or other privileges based on the number of applications filed (Hu et al. 2006, 265).

The public sector dominance of the PVP system in India and China stands in stark contrast to the situation in the United States, where private firms account for 75 percent of PVP filings, universities and the government only 15 percent, and foreign applicants the remainder (Strachan 2006, 2). The PVP systems in China and India stimulate some private sector R&D of new varieties but also—even more importantly, based on user statistics—motivate public sector participation.

Regulatory Review

Biotech seeds cannot be marketed until they have been reviewed and approved for release by the regulatory system. The goals of the Chinese and Indian regulatory systems are wide-ranging. In China, they are to promote biotechnology R&D, tighten the safety controls on genetic engineering work, guarantee public health, prevent environmental pollution, and maintain ecological balance. In India, they are to ensure that biotech crops pose no major risk to food safety, environmental safety, or agricultural production, and that they will not harm farmers economically. The Indian goal of protecting farmers generally is not part of the regulatory framework in developed countries (Pray et al. 2006, 142–43).

Like the United States, India and China have detailed regulatory frameworks for the review of biotech seeds, encompassing multiple agencies and numerous stages. In China, for example, these stages are intended to take place over a number of years and include laboratory development (variable, 2–4 years), contained field trials (1–2 years), environmental release trials (2–4 years), and pre-production trials (1+ years), followed by the approval or rejection of the product for commercial release (Karplus and Deng 2008, 116; Monsanto 2009, 7). In addition to biosafety review, separate procedures also exist at the state and provincial level for the registration of biotech seeds before they can be marketed. These procedures can add another 2–3 years to the time to market in China (Petry and Bugang 2008, 8).[20]

High costs and lengthy procedures can result in products being withdrawn from consideration if the costs of compliance outweigh the benefits the firm can obtain in a particular market. Bayer CropScience, for example, reportedly withdrew its biotech mustard seed from regulatory consideration in India in 2003 after approximately nine years of review and millions of dollars in costs. Bayer reported that the continued costs, uncertainty about whether the product would ever be approved, and potentially small market size all contributed to

[20] By contrast, regulatory compliance procedures take less time in the United States. Jaffe (2006, 748) calculated the time elapsing from the official submission of a regulatory package for a biotech crop to the final agency decision allowing the product to be commercialized. The U.S. Department of Agriculture (USDA), which is responsible for assessing the environmental safety of biotech crops and oversees field testing and trials, took on average 8.6 months to issue a final decision during the period 1994–2005. However, the actions of U.S. regulators have been overturned by the courts when they act too hastily and approve biotech seeds for release, for example, without the preparation of an environmental impact statement. See for example Geerston Seed Farms v. Johanns, 570 F.3d 1130 (9th Cir. 2009).

the decision not to continue with commercialization of the product in India (Pray, Bengali, and Ramaswami 2005, 273). Moreover, lengthy regulatory proceedings can have the unintended effect of encouraging the growth of illegal seed markets to fill unmet demand during protracted review periods, as occurred in India when illegal versions of Bt cotton reached the market while the legitimate product was still under review (box 1).

Both the public and the private sectors in India and China have been conducting field trials of new biotechnology crops since the late 1990s. However, no new biotech crops have been approved in India since Bt cotton in 2002. Table 2 identifies crops undergoing field trials in India. In China, Bt cotton, approved in 1996, is the only widely planted biotech crop. According to reports, stress-tolerant rice, disease-resistant cotton, insect-resistant corn, herbicide-tolerant soybeans, virus-resistant wheat, improved potato, insect-resistant poplar trees, and many other crops have undergone or completed trials and testing since 1996 (Karplus and Deng 2008, 104). Significant developments occurred in November 2009 when China's Ministry of Agriculture announced that it had issued biosafety certificates to domestically developed biotech rice and phytase corn (used for animal feed), although further approvals are required before the crops can be grown on a commercial scale (Batson and Areddy 2009).[21]

A science-based, efficient, and transparent regulatory system is essential for private and public sector firms seeking to introduce new biotech seed technologies on the market, as well as for farmers and the consuming public. In both China and India, however, regulatory systems reportedly have been used to block market access for global firms and to favor domestic ones. Regulatory review in India has been reported to take into account the way in which a product will be commercialized, including whether a global firm would have market exclusivity in the event of an approval and thus the ability to charge particularly high prices. Regulatory approval reportedly has been delayed or denied to avoid such a possibility. [22]

[21] China's actions may have been motivated in part by European Union reports that, as early as 2006, genetically modified rice had begun to show up in China's exports. China may have a significant interest in avoiding the perception that its regulatory system is not appropriately reviewing and controlling biotech crops. Industry representative, interview by Commission staff, Beijing, October 22, 2009.

[22] Industry representative, telephone interview by Commission staff, June 10, 2009.

TABLE 2 India: Biotech crops in field trials, 2006–2009

Crop	No. of Public/Private Organizations	Trait
Eggplant	Public (3) Private (3)	Insect resistance
Cabbage	Private (2)	Insect resistance
Castor	Public (1)	Insect resistance
Cauliflower	Private (2)	Insect resistance
Corn	Private (3)	Insect resistance, herbicide tolerance
Cotton	Public (1) Private (4)	Insect resistance, herbicide tolerance
Groundnut	Public (1)	Virus resistance Drought tolerance
Okra	Private (4)	Insect resistance
Potato	Public (2)	Disease resistance
Rice	Public (4) Private (3)	Insect resistance Disease resistance Virus resistance Drought tolerance Fortified food Hybrid improvement
Sorghum	Public (1)	Insect resistance
Tomato	Public (1) Private (2)	Virus resistance Insect resistance Drought resistance

Sources: Indian GMO Research Information System Web Site; James 2008.

The product that appears closest to regulatory approval in India is Bt eggplant, which uses technology similar to that in Bt cotton and is sponsored by Mahyco. Mahyco also has donated the Bt eggplant technology to public research institutions in India that are developing OPVs (rather than hybrids) that will be made available to poor farmers for saving and reuse. Mahyco started R&D work on Bt eggplant in 2000, and the product has moved slowly through the regulatory pipeline (Choudhary and Guar 2009, 43-45, 54). Although the Genetic Engineering Approval Committee (GEAC) approved the product October of 2009 after lengthy review, shortly thereafter India's environment minister put the approval on hold pending further consultations (GMO Safety 2009).

In China, the Ministry of Agriculture recently announced biosafety approvals for genetically modified phytase corn and rice. Phytase corn, developed by the Chinese Academy of Agricultural Science and sponsored by Origin Agritech, is intended for use in animal feed to limit the need for phosphate supplements, and thereby reduce feed costs and environmental impacts. Origin has noted in its corporate filings that the fact that foreign-funded companies are restricted to early-stage R&D activities has given it a substantial competitive advantage over global biotech companies (Origin Agritech 2008, 69). With regard to biotech rice, the Ministry of Agriculture noted that its recent approval: "is an important achievement in independent intellectual property from our country's research into genetic modification technology" (Batson and Areddy 2009). Both India and China thus have recently focused on moving domestically developed products forward in their regulatory pipelines.

Illegal Seeds in India and China

The spread of illegal seeds remains a substantial and ongoing problem in China and India. Some illegal seeds violate IP laws while others violate regulatory requirements that biotech products be reviewed and approved before commercial release. Examples of illegal seeds that violate IP laws are those mislabeled to confuse the consumer into believing that he is buying a legitimate product, as well as legitimate products that have been misappropriated, for example by theft from breeders' fields. A description of the market for illegal cotton seeds in India is provided below, box 1.

Illegal seeds are also a significant problem in China. With regard to biotech cotton, the problem may be even more prevalent than in India because the genetics were originally inserted into OPVs—which can be saved and reused in subsequent seasons—rather than hybrids. Based on a sample of farmers surveyed in five provinces in Northern China in 1999–2001, Hu and others (2009) measured the incidence of legitimate and illegitimate versions of domestic Bt cotton (the public sector variety developed by CAAS) and foreign Bt cotton (the Monsanto product marketed by Chinese joint ventures). Illegitimate seed was more prevalent than legitimate seed in Henan (83 percent of sampled households), Shandong (60 percent), and Jiangsu (56 percent) provinces, while legitimate seed dominated markets in Hebei and Anhui provinces (where Monsanto's joint ventures had a strong local presence).

BOX 1 Illegal and counterfeit cotton seeds in India

Illegal cotton seeds reportedly were grown in the Indian state of Gujarat beginning in 1999 and officially discovered in 2001, all while a legitimate Bt cotton product from Mahyco-Monsanto Biotech (MMB) was under regulatory review. The illegal seed was identified as NB 151, a variety registered as a conventional hybrid by NavBharat Seeds but containing the Bt genetics developed by MMB.

NavBharat Seeds was banned from the cotton seed business and prosecuted for violating biosafety laws, but the production, distribution, and widespread use of NB 151 reportedly continues. The seed is produced and distributed through a network of seed companies, producers, and agents, many of whom are former contract growers for NavBharat Seeds.

Illegal Bt cotton seed production and sales are thought to be concentrated in Gujarat and, to a lesser extent, in Punjab, Maharashtra, and Andhra Pradesh. According to surveys conducted by Lalitha, Pray, and Ramaswami (2008), the area covered by illegal Bt exceeded the legal Bt area from 2002/03 until 2005/06. The area planted in illegal seeds declined to 34 percent of the total area planted in Bt cotton in 2006/07, and was forecast to further decline to 27 percent in 2007/08. While illegal seeds are still prevalent, price restrictions appear to be having the positive effect of making the legal product more price competitive with illegal Bt cotton.

Counterfeit cotton seeds also are a substantial problem. Dealers label counterfeits with names similar to well-known Bt cotton sources—for example, “Mahaco” rather than “Mahyco.” The counterfeits do not carry the insect-resistant trait of legitimate products. “Brown bagging,” where farmers and others sell repackaged proprietary seed and seed of unknown origin in village markets, is also a common practice, with Bt and non-Bt cotton seeds mixed indiscriminately.

Sources: Lalitha, Pray, and Ramaswami (2008); and Herring (2009).

The prevalence of illegal seeds reduced benefits from the adoption of Bt cotton. Using regression analysis, Hu and others found that farmers who used legitimate seeds used fewer pesticides and obtained higher yields when compared to those who used illegitimate seeds. Moreover, farmers who obtained their seeds from commercial channels rather than from state actors or seed exchange obtained better yields, as did farmers who chose the Monsanto rather than the CAAS varieties (Hu et al. 2009, 801). These empirical results provide strong support for the conclusion that better IP enforcement and regulatory oversight to ensure that farmers are using legitimate and approved products, as well as reform of the seed industry to permit more foreign participation in China, could improve the production efficiency of cotton and other biotech crops.

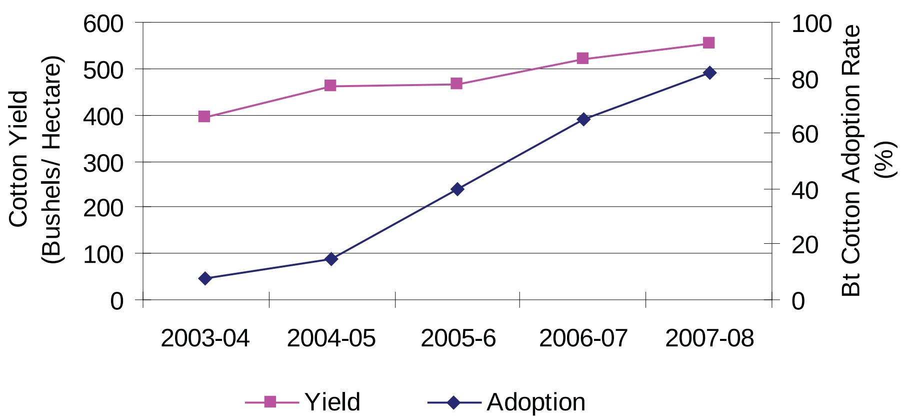
The Adoption of Bt Cotton in India and China: A Case Study

Bt cotton has been the first, and only, widely commercialized biotech crop planted in India and China. While the product has been developed and introduced differently in the two countries, one commonality is notable: the accrual of benefits to farmers in terms of increased profits and yields. We begin with a discussion of these benefits, and then turn to a description of the uptake of Bt cotton in both countries, with a focus on the factors identified as important—market access, IP protection, and regulatory review. The paper concludes with a general assessment of the ways the two countries' policy environments support (or fail to support) seed innovation.

Benefits from the Adoption of Bt Cotton in India and China

Bt cotton was approved for commercial release in India in 2002, and farmers grew about 50,000 hectares of it in the first year. Adoption increased rapidly over the next years. By 2008, 7.6 million acres were planted in Bt cotton, representing 82 percent of all cotton planted that year. Increases in yield went hand in hand with increased adoption. Prior to Bt cotton, India had one of the lowest cotton yields in the world—308 kg per hectare in 2001/02; yields are expected to reach 591 kg per hectare in 2008/09 (figure 5). India also moved from being an importer of cotton in 2002 to a substantial exporter by 2008 (James 2008, 52).

FIGURE 5 India Cotton Yield and Bt Cotton Adoption Rate, 2003–08

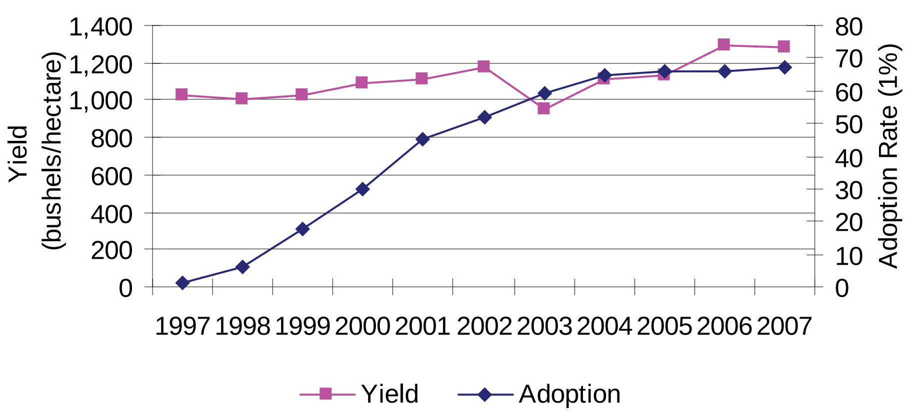


Source: Indiastat.com

The increased use of Bt cotton also has coincided with a significant decrease in pesticide use. Historically, cotton had consumed more insecticides than any other crop in India. The market for insecticides for bollworm (the pest to which Bt cotton is targeted) declined from $147 million in 1998 to $65 million in 2006, despite the fact that the total area planted in cotton increased. As a result of the increased yields and the decreased use of pesticides, cotton farmers made more money. The adoption of Bt cotton reportedly generated economic benefits of $3.2 billion from 2002 to 2007 (James 2008, 43, 51).

In China, Bt cotton was approved for use in 1996, making China one of the six "founder biotech crop countries" that approved biotech crops in the first year of their global commercialization (James 2008, 88). Cotton is primarily grown in the provinces of Hebei, Henan, Shandong, Anhui, Jiangsu, and Shanxi; Bt cotton adoption rates in these provinces are generally above 80 percent. Adoption rates are much lower (about 10–15 percent) in Xingjiang province, where the cotton bollworm is not considered to be a major problem (James 2008, 90). Overall, the adoption rate in China has held relatively steady in recent years at about 66 to 69 percent, figure 6.

FIGURE 6 China cotton yield and Bt cotton adoption rate, 1997–2007



Source: CEIC China Database.

China did not start from the same low levels of productivity in cotton as India and thus has not experienced such dramatic yield increases. Based on studies conducted by the Center for Chinese Agricultural Policy, Bt cotton has increased average yields by 9.6 percent, reduced insecticide use by 60 percent and, at the national level, increased income by approximately $800 million per year (James 2008, 97). The substantial benefits derived from Bt cotton underscore the importance in both countries of getting the policy environment right for innovation in biotech seeds.

The Impact of Government Policies on the Adoption of Bt Cotton

Domestic and foreign firms spearheaded the adoption of Bt cotton in India. The Indian public sector had little involvement in the product's R&D and commercialization; the Indian government's Department of Biotechnology (DBT) rejected an offer from Monsanto to collaborate on biotech crops (table 3). In 1995, Mahyco obtained permission to import Bt cotton technology from Monsanto. R&D began, and in 1998 Monsanto purchased a 26 percent share in Mahyco. The two companies then formed Mahyco-Monsanto Biotech (MMB), a 50:50 joint venture to commercialize biotech products in India (Scoones 2003, 7).

MMB obtained regulatory approval for Bt cotton in 2002, about six years after it began field testing of the product. Thereafter, MMB licensed the technology to other domestic and foreign firms for use in their own hybrids. Today, Bt cotton products have been commercialized in India by 30 companies in a total of 274 hybrids. Domestic firms also have obtained approval for two new Bt cotton "events,"[23] including one sourced from CAAS. In 2008, the Indian public sector obtained regulatory approval for its Bt cotton event, with genetics inserted into OPVs that farmers can save and reuse (James 2008, 56).

IP protections did not play a central role in the initial introduction of Bt cotton in India. The MMB Bt cotton events were inserted into hybrids, which have natural, built-in protection mechanisms against appropriation by farmers and competitors. Moreover, patent protections were not available for biotech products at the time Bt cotton was introduced, and the plant variety protection system was not put into place until 2007. [24]

[23] Biotechnologists refer to the transfer of a particular genetic sequence into a plant as an "event."

[24] Patent protection was available for some biotechnology processes rather than products, and Monsanto and other firms obtained patents for processes. However, the infringement of process patents generally is more difficult to detect than that of product patents because it requires knowledge of a competitor's manufacturing methods rather than a comparison of the commercially available products.

TABLE 3 Bt Cotton in India: Chronology of Events

Date	Events
1990–1993	Monsanto approaches the Indian government's Department of Biotechnology (DBT) to collaborate on the development and commercialization of Bt technology. Indian government rejects offer.
1995	Mahyco granted permission to import Bt cotton genetics from Monsanto.
1996	Monsanto's Bt cotton approved for commercial release in the United States.
1996	Mahyco develops three backcrossed lines using Monsanto genetics and its own cotton hybrids and begins biosafety testing.
1998	Monsanto acquires a share of Mahyco and they form MMB to jointly develop and commercialize biotech products in India.
1996–2002	MMB carries out field and biosafety trials to support the regulatory approval of Bt cotton.
2002	GEAC approves commercial release of MMB's Bt cotton for a three-year trial period in six states.
2006	GEAC approves Bollgard II, the second generation Monsanto product, and genetic events from JK Agri-Genetics and Nath Seeds.
2006–2008	GEAC approves a total of 274 Bt cotton hybrids commercialized by 30 different companies.
2008	GEAC approves Bt cotton genetics developed by public sector and inserted into OPV that can be saved and reused by farmers.
2009	Monsanto obtains Indian patent for genetics underlying the second generation of its Bt cotton product, Bollgard I.I

Sources: Scoones 2003; James 2008.

The slow-moving regulatory system did give some first-mover advantages to the MMB product. Domestic firms with Bt cotton events did not obtain regulatory approval to commercialize their Bt cotton technologies until 2006, four years after the approval of MMB's first product, Bollgard I. However, delayed approval of the MMB product also fostered a market in illegal seeds to satisfy unmet demand for the technology. Today, Bollgard II is patented in India, but illegal seeds are an ongoing problem because of the inadequate enforcement of IP laws and regulatory requirements.

The public sector has played a much larger role in the development and adoption of Bt cotton in China; the role of foreign firms has been substantially circumscribed (table 4). As in India, Monsanto initially attempted to collaborate with the government on biotech cotton but was turned down (after the technology was shared and field tests conducted). Monsanto and Delta & Pineland (another U.S. firm) then formed a joint venture called Jidai with the Hebei Provincial Seed Company to develop and distribute biotech seeds. The U.S. partners initially held a 67 percent share in the venture. Jidai obtained approval to market the Monsanto variety in 1997. The adoption of the Monsanto varieties was rapid in Hebei and later in Anhui and Shandong provinces (Karpus and Deng 2008, 88–89). In 1997, the Chinese government reduced to 49 percent the stake that a foreign firm could hold in a Chinese seed company, based on concerns that the foreign firms had too much of an upper hand in the Bt cotton collaboration (Keeley 2003, 22).

TABLE 4 Bt Cotton in China: Chronology of Events

Date	Events
Early 1990s	Monsanto and the Chinese government's Cotton Research Institute begin a joint research program on biotech cotton. The joint program dissolves in 1995.
Mid-1990s	Monsanto and Delta & Pineland form a joint venture with the Hebei Provincial Seed Company and set up a new company, Jidai, to test, obtain regulatory approval, and commercialize Bt cotton varieties. CAAS begins field-testing and commercialization of its own BT cotton varieties.
1996	Two CAAS Bt cotton varieties are approved for commercialization in nine provinces.
1997	Jidai obtains approval to market Bt cotton in Hebei province only. Rapid adoption of Monsanto product.
1997	Government reduces to 49 percent the maximum foreign ownership in seed companies.
1997–99	Slow initial adoption of CAAS products by local seed companies. CAAS sets up Biocentury Transgene Corporation to manage seed sales and licensing.
2002	CAAS receives marketing approval for its varieties in the Yangtze River Region; Monsanto joint venture does not receive approval.
2002	Chinese government issues FDI guidelines prohibiting foreign firms from setting up new joint ventures to commercialize biotech seeds.
2004–09	Bt cotton-related patents issued in China to CAAS, Monsanto, and other public and private sector firms.

Sources: Karplus and Deng 2008; Keeley 2003.

CAAS had its own public sector Bt cotton varieties in development simultaneously with the Monsanto product. The CAAS varieties obtained regulatory approval first and over a wider geographic area. However, CAAS had difficulties with marketing its products. As a government research institute, it reportedly did not have the distribution networks or relationships needed to efficiently bring its varieties to market. CAAS addressed the problem by taking a major stake in Biocentury Transgene Corporation, a company formed to handle the sales of Bt cotton seeds (Karplus and Deng 2008, 88). Biocentury received substantial funding from the 863 program and other government funding programs. As a MOST official stated: "We gave them a title, they are a 'National Development Base of the 863 programme,' not an ordinary company, a national development base, that helps their business" (Keeley 2003, 19). Origin Agritech acquired a 34 percent stake in Biocentury in 2006, and now markets the CAAS Bt cotton varieties (Origin 2008, 45, 48).

The market position of the CAAS varieties has improved significantly in recent years. Today, domestic varieties of Bt cotton are estimated to hold 80 percent of the market, although official data are not available (Sanchez and Lei 2009, 5). Keeley attributes much of the CAAS success to strategic decisions by regulators to deny approval to the Monsanto product in a number of provinces, particularly in the Yangtze River cotton region. Although regulatory authorities justified the decisions on biosafety grounds, industry representatives were skeptical (Keeley 2003, 24). FDI guidelines issued in 2002 prohibiting foreign firms from commercializing biotech products further preserve the market dominance of Chinese firms.

IP protection did not play a central role in the initial introduction of Bt cotton into China. Plant variety protection has been in place since 1997; however, cotton was specifically excluded from coverage until 2005. Patent protection for biotech products was not available at the time of the initial release of the Monsanto and CAAS products. The fact that the Bt cotton events were in OPVs in China rather than hybrids as in India appears to have encouraged even more widespread use of illegitimate seeds in China.

Recently, Monsanto, CAAS, and others have obtained patents for their latest Bt cotton events. However, enforcement of IPR laws and regulatory requirements is an ongoing problem. While the initial regulatory approval of the Bt cotton technology occurred more quickly in China than in India, at the provincial level, the Monsanto product faced regulatory delays and denials that appear to have been unrelated to biosafety issues. These practices may undermine confidence in the regulatory system's ability to regulate new biotech seeds in a fair and science-based manner.

Conclusions

This paper has compared and contrasted government policies in India and China to support innovation in the field of biotech seeds. Both countries have determined that biotech is an important tool for responding to substantial challenges in their agricultural sectors, and have put in place institutions and funding mechanisms to support R&D in agricultural biotechnology. India and China also have adopted policies in the areas of market access, IP protection, and regulatory review that have both fostered and discouraged innovation in biotech seeds.

China has established a central role for the public sector in controlling biotech seed innovation. Market access for foreign firms is severely limited. China's public sector takes a leading role in R&D and in the formation and support of firms charged with marketing biotech seeds. China's government research institutions and universities also are leading users of the patent and plant variety IP protection systems. China's apparent strategic use of regulatory review to deny market access to foreign firms has also buttressed the position of the public sector and its affiliated firms.

If judged by the strong market position of domestic varieties of Bt cotton, China's strategy of public sector dominance of biotech seeds has been successful. However, the fact that no other biotech products have been widely commercialized in the 13 years since the approval of Bt cotton suggests weaknesses in China's approach. China's recent decision to permit FDI in some biotech seed R&D projects is perhaps a recognition that closing the market to foreign participation also shuts off access to valuable technologies needed to address serious agricultural challenges. More cynically, it may represent an attempt to obtain access for domestic firms to the latest technologies. Improved enforcement of regulatory and IP laws is critical to ensure that only safe and legitimate products are permitted on the market.

By contrast, India has opened its seed sector to foreign participation on terms equal to those of domestic firms. However, strict price controls at the state level have undermined India's liberal investment environment and undermined the innovative efforts of both foreign and domestic firms. India's public sector has been much less active than China's in R&D and in obtaining IP protection for biotech innovations. The recent focus on the development and commercialization of genetic events for OPVs that will be made available to farmers at a reduced cost is an exception to otherwise lower levels of public sector participation. The enforcement of IP protections and regulatory requirements also remains a significant problem in India. Significant delays, and decisions that focus on factors other than biosafety, undermine confidence in India's regulatory system. Timely, science-based review of products that have languished in the regulatory pipeline for years would be an important improvement in India's innovation policy environment.

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Innovation and Job Creation in a Global Economy: The Case of Apple's iPod

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Abstract

Globalization skeptics argue that the benefits of globalization, such as lower consumer prices, are outweighed by job losses, lower earnings for U.S. workers, and a potential loss of technology to foreign rivals. To shed light on the jobs issue, we analyze the iPod, which is manufactured offshore using mostly foreign-made components. In terms of headcount, we estimate that, in 2006, the iPod supported nearly twice as many jobs offshore as in the United States. Yet the total wages paid in the United States amounted to more than twice as much as those paid overseas. Driving this result is the fact that Apple keeps most of its research and development (R&D) and corporate support functions in the United States, providing thousands of high-paid professional and engineering jobs that can be attributed to the success of the iPod. This case provides evidence that innovation by a U.S. company at the head of a global value chain can benefit both the company and U.S. workers.

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Introduction: Does U.S. Innovation Help U.S. Workers?

Innovation is widely touted as the key to long-term economic prosperity, and concerns have been raised as to whether the United States is investing enough in innovation to drive future growth (Hamm 2009). A related but different issue is the extent to which innovation by U.S. companies will benefit American workers in an era when production and even research and development (R&D) are increasingly done offshore. Concerns about the location and quality of jobs have taken on a new policy relevance in light of proposals to support innovation and American competitiveness (Obama 2011). How many of the jobs created by innovative industries receiving public funds are likely to remain in the United States?

In order to shed some light on this issue, we look in detail at the global value chain (Gereffi et al. 2005) that designs, builds, and brings iPods to consumers and estimate the jobs and wages sustained by this innovative product line. Electronics is one of the most global industries, with vast quantities of goods consumed in the United States imported from Asia, especially China. Yet we find that most of the high-paying jobs in the iPod value chain are still in the United States, even though more jobs overall are offshore. Furthermore, according to our estimates, the total wages paid to the U.S. workers are more than double those paid overseas. This article presents and discusses our findings. Although the iPod has been superseded in Apple's activities by iPhones and iPads, there have been no changes in Apple's value chain that would lead us to expect any qualitatively different outcome to the findings here with respect to the share of U.S. employment and wages.

Jobs in the U.S. high-tech industry

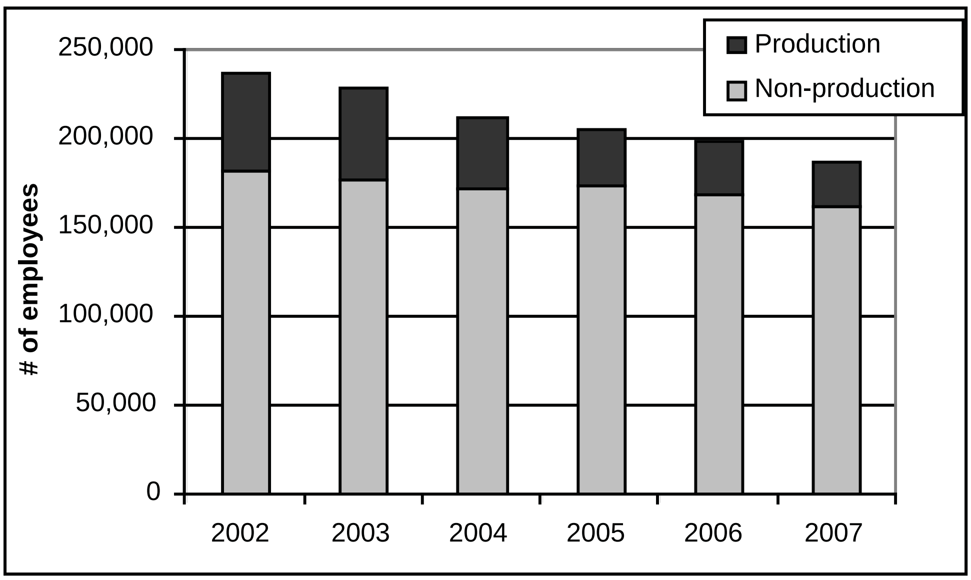
For over two decades the U.S. economy has been marked by growing income inequality and concerns about the "vanishing middle class." The factors driving these developments are complex. For the hard-hit blue-collar sector, the causes of decline in jobs include increased use of automation and the continued expansion of manufacturing jobs in low-wage countries. Recently, white-collar workers like engineers are feeling similar pressures.

One industry that has seen a dramatic shift of manufacturing out of the United States is computers and peripherals. As recently as 2000, over one-third of the jobs in the U.S. computer industry were production jobs. By 2007, the number of production workers had fallen to less than one-sixth of total U.S.

employment, and total production jobs had been cut in half just since 2002 (figure 1). At the same time, white collar employment in the U.S computer industry was falling much more slowly, by about 10 percent in total from 2002 to 2007.

Most of the factory jobs for high-volume electronics are gone and unlikely to return. Automation has limited the growth of manufacturing jobs worldwide, even as output continues to expand.[2] Small electronic goods like iPods and cell phones use tiny components with extremely tight tolerances in fit and quality that require machine precision and thus cannot be assembled by hand.

Figure 1 U.S. employment in the computer and peripherals industry



Source: Bureau of Labor Statistics, Occupational mployment tatistics for NAICS 334100 (Computer and Peripheral Equipment Manufacturing), various years.

[2] Economic studies have found that the negative impact of automation on jobs for less-educated workers is typically several times that of trade or outsourcing (e.g., Paul and Siegel 2001).

Yet, despite the decline in U.S.-located manufacturing of computers and peripherals from $90 billion in 2000 to just $56 billion in 2006 (Reed Electronics 2008), U.S. companies continue to be leaders in PCs, printers, networking equipment, and new categories such as portable music players, tablets, and smart phones. U.S. companies such as Apple and Hewlett-Packard have successfully coordinated global value chains to develop and manufacture their products while focusing their own efforts on design, marketing, branding, and distribution.

What is not known is whether innovative U.S. companies will continue to keep white-collar jobs in the United States to benefit from agglomeration economies and the highly-skilled workforce even as the knowledge base improves in overseas locations where production is outsourced.[3] If white-collar jobs such as engineering stay close to headquarters, then innovation can serve as a driver of high-wage employment in the United States. But if globalization leads to a hollowing out of professional jobs as well as manufacturing in the United States, then U.S. innovation will only benefit shareholders, consumers, and a small number of top managers and professionals in the United States.

Data at the national level, such as those in figure 1, point to trends in U.S. employment, but do not allow us to understand it in a global context. To develop a better understanding of how the value of innovation is distributed across the global value chains of high-tech companies, we have conducted a two-stage study of the distribution of value in the global value chain of Apple's iPod product line.

In the first stage, we looked at which companies and countries capture *financial value*, using higher-end Apple iPods as a case study (Linden et al. 2009). We found that the largest share of financial value (defined as gross margin) went to Apple, which captures a large margin on each iPod. Although the iPod is assembled in China, the value added in China is very low.

In the current stage of our research, we examine the value of innovation defined in terms of *jobs and wages* associated with the design, manufacturing, and distribution of all Apple iPods and major components in 2006. In this report, we estimate the number of jobs supported by the iPod in the United States and overseas, broken down as production, nonprofessional, and

[3] For a discussion of these issues as they relate to engineering jobs, see National Academy of Engineering (NAE). Committee on the Offshoring of Engineering (2008).

professional jobs. We also estimate the total earnings paid to workers in each of those categories by country.

Jobs in the iPod value chain

Table 1 presents our estimates, made without the participation of Apple Inc., of jobs at various steps of the iPod value chain by country in 2006. We estimated that there were nearly 14,000 U.S. jobs, mostly Apple employees and workers in the retail channel. Outside the United States, there were about 27,000 jobs, mostly in China and elsewhere in the Asia-Pacific region where the iPod and its components are manufactured, and also in countries where the iPod is sold and distributed.

Table 2 shows how those jobs were distributed by country and category. In the United States, there were 7,789 nonprofessional jobs (primarily in retail and distribution) and 6,101 professional jobs (primarily at Apple's headquarters), including management, engineering, computer support, and a variety of other categories. The 30 production jobs (and a similar number of the professional jobs) reflect the fabrication of some of the iPod's chips in U.S. plants.

The many retail and distribution jobs are not all attributable to Apple's innovation, since retailers would be selling something else, possibly from a non-U.S. company, if iPods did not exist. The majority of the professional jobs, however, can be attributed to the fact that Apple is a U.S.-headquartered company with a high concentration of managerial and R&D activities in the United States.

In the Asia-Pacific region, we estimated that iPod-related manufacturing accounted for over 19,000 production jobs and over 3,000 professional jobs. In Asia, Europe, and elsewhere, we estimated another 4,825 jobs in distribution, retail, transportation, and other post-manufacturing activities.

Earnings in the iPod value chain

Next we looked at the wages earned by the estimated 41,170 workers involved with the iPod. For production workers, we used international comparative rates compiled by the U.S. Bureau of Labor Statistics (BLS). Average professional and nonprofessional wages were found in various sources detailed in the Appendix. Table 3 presents average earnings for the United States and Asia-Pacific countries in each category. Wages for Apple employees used a more fine-grained estimation procedure also described in the Appendix.

Table 1 iPod-related jobs in the value chain, 2006

	U.S.	Non U.S.	Locations
Hard drive (HDD) manufacturing	0	2,200 2,200	China Philippines
HDD inputs	0	2,550 2,550 840 800 800	China Philippines Japan Thailand Singapore
Flash memory	0	1,200 20	Korea China
Other chips	110	140 25	Taiwan Various
PCB assembly and test	0	600	China
Display panels and modules	0	900	Japan
Other inputs	0	3,500 100 100	China Japan Taiwan
Final iPod assembly	0	3,400 100	China Taiwan
Apple engineers	700		U.S.
Apple managers/professionals	5,046	75 75	Singapore Various
Apple nonprofessional	1,554	75 75	Singapore Various
Distribution	150	150	Various
Freight	250	250	Various
Apple Stores	1,785	200	Various
Other retailers	3,675	3,675	Various
Third party online sales	650	650	Various
Total	**13,920**	**27,250**	

Source: Authors' calculations. See Appendix for methodology.

Table 2 iPod-related jobs by country and category

	Production	Retail and other nonprofessional	Engineering and other professional	Total
U.S.	30	7,789	6,101	13,920
China	11,715	*	555	12,270
Philippines	4,500	*	250	4,750
Japan	700	*	1,140	1,840
Singapore	825	*	100	925
Korea	600	*	600	1,200
Thailand	750	*	50	800
Taiwan	70	*	270	340
Other	0	4,825*	300	5,125
Total	**19,190**	**12,614**	**9,366**	**41,170**

Source: See Appendix.

*Includes all non-U.S. retail and other nonprofessionals.

Table 3 Average annual employee earnings by job category, $, 2006

	Production	Other non-professional	Engineering and other professional
U.S.	47,640	25,580	85,000
Japan	40,400	20,000	65,000
Korea	29,440	15,000	30,000
Taiwan	12,860	7,000	20,000
Singapore	17,110	9,000	20,000
Philippines/Thailand	2,140	1,500	15,000
China	1,540	1,000	10,000

Source: See Appendix.

Table 4 uses the job and wage estimates, with adjustments detailed in the Appendix, to calculate the total earnings paid by country and category. We estimated that workers received over $1 billion in earnings from iPod-related jobs in 2006, or about $25 per unit sold. Of this total, nearly $750 million went to U.S. workers and about $320 million, less than half as much, to workers outside the United States.

Table 4 iPod-related wages by country and category, $, 2006

	Production	Other non-professional	Engineering and other professional	Total
Apple (overhead)	0	61,728,000	488,410,000	550,138,000
Apple Stores	0	43,486,000	7,225,000	50,711,000
Other U.S.	1,429,200	114,010,060	29,580,000	145,019,260
Total U.S.	**1,429,200**	**219,224,060**	**525,215,000**	**745,868,260**
Japan	28,280,000	0	74,100,000	102,380,000
Korea	17,664,000	0	18,000,000	35,664,000
Taiwan	900,200	0	8,100,000	9,000,200
Singapore	14,115,750	0	2,000,000	16,115,750
Philippines	9,630,000	0	3,750,000	13,380,000
Thailand	1,605,000	0	750,000	2,355,000
China	18,041,100	0	5,550,000	23,591,100
Other	0	96,500,000*	19,500,000	116,000,000
Total non-U.S.	**90,236,050**	**96,500,000**	**131,750,000**	**318,486,050**

Source: Authors' calculations. See Appendix.

*Includes all non-U.S. retail and other nonprofessionals.

Over two-thirds ($525 million) of the earnings in the United States went to professional workers, and an additional $220 million to nonprofessional workers. While most of the nonprofessional jobs were relatively low-paying retail positions, we estimated that nearly $50 million went to administrative jobs at Apple for which we used the national average wage of $38,000 a year; actual Silicon Valley wages were probably even higher.

Outside the United States, total earnings were divided more evenly between the production and professional categories. Over half the professional earnings were paid in Japan and Korea, where the suppliers of most of the high-value components (hard drives, flash memory, and displays) are headquartered. Retail and distribution jobs were spread around the world in countries where the iPod is sold.

Conclusions: Globalization's impact on U.S. workers

- The relationship between innovation by U.S. companies and employment in the United States is more complex than phrases such as the "vanishing middle class" suggest. When innovative products are designed and marketed by U.S. companies, they can create valuable jobs for American workers even if the products are manufactured offshore. Apple's tremendous success with the iPod and other innovative products in recent years has driven growth in U.S. employment, even though these products are made offshore. These jobs pay well and employ people with college degrees. They are at the high end of what might be considered middle-class jobs and appear to be less at risk of vanishing from the United States than production jobs.

- Production jobs are unlikely to recover in the United States, and, in any case, they form an uncertain basis for job creation in the future. Even China is losing some new factory investments to lower-cost locations like Vietnam. Production jobs in the rapidly changing electronics industry can also be undermined by obsolescence. For example, the 12,000 jobs in Asia we estimated for iPod-related hard drive production were at risk because Apple shifted the storage in most of its iPod models to flash memory, which requires far fewer workers to produce.

- It is more important than ever that all children receive an education that prepares them for 21st-century jobs. Retail jobs are no substitute for higher-paying information jobs such as computer programming. For instance, according to the BLS, the average hourly wage for "computer support specialists" is $22, while a retail salesperson makes only $12.[4] Unfortunately, the continuing loss of manufacturing jobs, which pay better than retail jobs, means fewer opportunities for non-college educated workers. Even the administrative jobs that pay reasonably well at companies such as Apple often require education beyond the high school level.

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[4] *http://www.bls.gov/oes/current/oes_nat.htm* for occupation codes 15-1041 and 41-2031.

- Professional jobs are at risk on multiple fronts. Many U.S. high-tech companies are investing in white-collar job creation offshore to tap pools of low-cost talent and gain access to growing markets (NAE. Committee on the Offshoring of Engineering 2008). The offshore jobs often support high-value jobs in the United States, but this may not always be the case. Also, if U.S. companies lose their innovation leadership to foreign competitors, those competitors do not typically employ many engineers or other professionals in the United States.

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Appendix: Methodology

This appendix details our methodology for calculating estimates of iPod-related jobs and wages for Apple and its partner companies during calendar year 2006.

The firms directly involved will not provide data, and we have found no systematic third-party source of data on employment by firm or by industry. Our task was further complicated by the fact that we were looking at jobs associated not with an industry but with a single product line, which to our knowledge had never been done before. To arrive at our estimates, we used company reports, interviews with similar companies, government data, data from industry analysts, and other sources. We were conservative about the U.S.-overseas gap by "rounding up" overseas estimates and "rounding down" for the United States.[5]

Job estimation

We began by estimating the number and wholesale value of iPods sold in 2006. As described in detail below, we apply these numbers to various data sources to generate our estimates of manufacturing and other lower-pay workers in the value chain. We then used percentages derived from company reports and interviews to determine the corresponding number of higher-pay workers.

For Apple, we estimated the number of total jobs by starting from iPod sales as a percentage of Apple's total sales and applying this ratio to Apple's total employment. We then divided the jobs at Apple among higher- and lower-paying job categories, as discussed below.

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[5] We were estimating how many workers around the world were supported by the iPod value chain. We were not investigating the trickier question of how many incremental jobs existed solely because of the iPod. For final assembly and for major components like flash memory chips, the iPod accounts for so many jobs that most can safely be considered incremental. For components like displays, for which iPods account for a smaller share of factory output, the answer was less clear. For example, the number of production workers might have varied with output, while the supervisory and other professional employees might have been a fixed cost of running the factory.

We now present a more detailed description of the process:

1. We began with estimates of the number and wholesale value of iPods of various types sold in 2006. From the first stage of our research, in which we analyzed the value of the components in the iPod, we were able to calculate how many of each component was used over the course of 2006. For example, each of some 30 million Nano iPods contained eight flash memory die assembled in two packages of four die each.

2. For total employment at most points along the value chain, our estimates derived from at least one of the two following methods:

   (a) Factory Fraction Method: Given the quantity of a given type of component used in 2006, we determined the percentage it represents of the output of a typical plant (as determined by discussions with industry experts for the major inputs). We applied this percentage to the staff level of that plant. For example, the 240 million flash die were equivalent to the output of a medium-sized microchip factory, which would have required a staff of roughly 1,200.

   (b) Revenue Fraction Method: Given the total value of a given type of component used in 2006, we determined the percentage this represented of the sales of a company specializing in that component. We applied this percentage to the company's total employment. For example, we estimated that approximately $1 billion worth of iPods were sold online globally in 2006. That year, Amazon (with $10.7 billion in sales and 13,900 employees) required roughly 1,300 employees to sell each $1 billion in goods. Using that as our benchmark, we apportioned the employees between the United States and overseas, since iPods are sold through a variety of Web sites worldwide and overseas sales were about half the total of all iPod sales.

   In practice, method (a), which ignores support and overhead staff, always yields a lower number than method (b). To the extent possible, we applied both methods and looked at multiple factories or multiple firms to improve the accuracy of the estimate.

3. For higher-paying engineering and management jobs, our estimates were based on firm interviews and site visits, wherein we developed ratios of engineering and management staff to manufacturing jobs. Applying these ratios to the staff estimates from step (2) enabled us to generate estimates of the number of managerial and technical people related to manufacturing. For example, in a microchip factory, roughly half the workers were highly-paid engineers and managers, so the 1,200 workers in method 2a above, were split evenly between lower-pay and higher-pay.

4. For the iPod-specific jobs at Apple itself, which included many high-paying jobs in design, software, marketing, and administration, we started from iPod sales as a percentage of Apple's total sales and applied this ratio to Apple's total employment, as in method 2b above. Our method for determining the distribution of jobs among several pay grades of Apple professionals, managers, and non-professionals employees is described below under "Wage estimation."

5. The number of Apple engineers and of Apple's own retail store employees are separate in Table 1 because we had specific sources of information about these subcategories.

Wage estimation

For non-Apple jobs, we used the following sources for the wage rates in table 3:

Production: The production earnings were based on the hourly rates given in table 2 of the Bureau of Labor Statistics (BLS) news release "International Comparisons of Hourly Compensation Costs in Manufacturing, 2006" (http://www.bls.gov/news.release/pdf/ichcc.pdf). Thailand was not listed, so we assumed the same rate as the Philippines. The 2006 hourly rates were annualized by assuming 2,000 paid hours per year. For China, we used a 2004 rate, reported separately on page 4 of the same document.

Nonprofessional: For the United States, we used the average wage for "retail salespersons" at electronics stores from BLS "May 2006 National Industry-Specific Occupational Employment and Wage Estimates" (http://www.bls.gov/oes/2006/may/naics3_443000.htm#b41-0000). For other countries, we applied the ratio of the U.S. production and nonprofessional wages to the production wage of each country, rounding the result to reflect lack of precision. In practice, the only non-U.S. nonprofessional wage that mattered was Japan's. We applied this to the total of non-U.S. nonprofessional employees because it produced the largest possible total for non-U.S nonprofessional wages, and we wanted to be conservative about estimating the difference between total wages in the United States and in the rest of the world.

Professional: We used "professional" to designate all higher-wage jobs, including managers. The "professional" wages in table 3 were based on engineering salary estimates reported in Dedrick and Kraemer (2008, table 5). For the countries not covered there (South Korea, Singapore, the Philippines, and Thailand), we extrapolated based on our knowledge of the level of development of the electronics industry in each country, as well as consulting salary reports about other professional job categories. We liberally rounded the estimates upward so as not to overstate the difference with the United States.

All of Apple's iPod-supported jobs can be regarded as "overhead" (nonproduction) workers. Of this group, we had information from a well-placed source that Apple's iPod division employed approximately 700 engineers (software, engineering, and engineering managers) in 2006.

To estimate Apple's total iPod overhead employment (perhaps including some who might not be directly related to the iPod but can be thought of as employed by Apple because of the iPod's success), we started with the ratio (about 51 percent) of iPod sales (but not music sales) to total sales (excluding Apple Stores, which we estimated and reported separately) and applied it to Apple's total employment (excluding Apple Stores) of 14,400. After subtracting out the 700 engineers mentioned above and choosing a lower round number to be conservative, we were left with an estimate of 6,600 overhead employees other than engineers.

To estimate the distribution of these non-engineer overhead employees across a range of occupations, we apportioned them based on the frequency of non-production jobs listed for NAICS 334100, Computer and Peripheral Equipment Manufacturing, in May 2006 as reported by the BLS (http://www.bls.gov/oes/2006/may/naics4_334100.htm).

To calculate the total wage bill, we applied the national average wages for each job category in the BLS data to our employment estimates. When calculated using these national averages, which are probably lower than the actual wages paid in Silicon Valley, the average wage for engineers and the other high-salary categories worked out to be $89,978. To be conservative, we capped these job categories at the $85,000 wage listed in Table 3, which was also used to calculate the earnings of the 433 other U.S. professionals included in table 2.

The national averages were used for the categories listed as "Nonprofessional" in table A1, since this employment, mostly office jobs, is different from the retail work of most others in the nonprofessional category, and their average annual salary works out to $39,722. The earnings of the remaining U.S. nonprofessionals were calculated at the $25,580 wage shown in table 3.

Table A1 Estimated iPod-related jobs at Apple, 2006

Job category	Estimated number of employees	National average annual wage	Total wages
Engineering	352	$81,770	$28,763,679
Software (apps and system)	304	$96,945	$29,467,427
Engineering managers	44	$133,030	$5,890,105
Engineer total	**700**		**$64,107,640***
Business and financial	1,430	$73,780	$105,505,400
Computer support	1,236	$79,620	$98,410,320
Management (exc. engineering)	1,208	$125,003	$151,003,624
Sales and related	676	$83,800	$56,648,800
Life, physical, social sciences	309	$82,330	$25,439,970
Arts, design, sports, media	142	$73,500	$10,437,000
Legal	35	$136,220	$4,767,700
Training and library	6	$66,320	$397,920
Health care	4	$75,000	$300,000
Other Professional total	**5,046**		**$452,910,734***
Office and administrative support	1,240	$38,600	$47,864,000
Installation, maintenance, repair	282	$45,170	$12,737,940
Building and grounds maintenance	14	$26,170	$366,380
Construction	10	$44,520	$445,200
Protective service	8	$39,310	$314,480
Nonprofessional total	**1,554**		**$61,728,000**
Grand Total	**7,300**		**$578,746,374**

Source: Authors' calculations as described in the text.

* For reference only; the calculation reported in the main text used the average earnings from table 3.