A Great Wall of Patents: What is behind China's recent patent explosion? *

Albert Guangzhou Hu
Department of Economics
National University of Singapore
ecshua@nus.edu.sg

Gary H. Jefferson
Department of Economics
Brandeis University
jefferson@brandeis.edu

First version: 21 March 2005
This version: 15 August 2005

Abstract

China's patent explosion is seemingly paradoxical given the country's weak record of protecting intellectual property rights. Using a firm-level data set that spans the population of China's large and medium size industrial enterprises, this paper seeks to understand the factors that account for China's patent boom. While the intensification of research and development (R&D) in the Chinese economy - a doubling of the R&D to GDP ratio since 1985 - tracks with patenting activity, it is unlikely to be the principal cause of the patent explosion. Instead this paper finds that the growing intensity of foreign direct investment at the industry level in China is prompting domestic Chinese firms to file for more patent applications for their strategic competitive value. Amendments to the patent law that favor patent holders and ownership reform that has clarified the assignment of property rights also emerge as significant sources of China's surge in patent activity.

*We thank seminar and conference participants at Singapore Management University, Nanjing Workshop on Global R&D in China, May 28-29, 2005, and Second Summer Industrial Organization Workshop, Tsinghua University, June 8-9, for helpful comments. Hu acknowledges the National University of Singapore Academic Research Fund that supported this project. Jefferson acknowledges support from National Science Foundation (#450823) and the U.S. Department of Energy (contract # DE-FG02-00ER63030) that made available the Chinese firm-level data set used in this paper.

1 Introduction

Chinese patent applications have been growing at an annual rate of over 15 percent since the country reinstituted its Patent Law in 1985. The surge is not limited to patent applications from domestic Chinese inventors, which have increased by ten fold. Since China first amended its Patent Law in 1992, foreign inventors have seen their applications for Chinese patents growing at a rate of 22 percent every year. Nor is the surge confined to utility model and design patents that represent small and incremental innovations and that receive scant patent examination and limited legal protection. Following China's second amendment to its patent law in 2000, invention patent applications from both domestic and foreign inventors have been growing at an annual rate of 23 percent.

China's remarkable patent explosion invites careful examination. The speed of China's patenting growth has been extraordinary. A number of authors have observed a world wide surge in patenting, particularly that in the U.S.[1] Since the mid-1980s, U.S. patenting has been growing at an annual rate of six percent. This compares modestly with the magnitude of the Chinese patent explosion. That the dramatic upsurge in patenting in China has taken place in a legal environment where intellectual property rights protection continues to be weak and the rule of law not well established makes the causes of the surge less than obvious and challenging to unravel.

A confluence of events accompanied China's patent explosion. China has twice amended its patent law by expanding the scope of patent protection, including the introduction of new mechanisms to enforce patent rights. The amendments have largely brought China's patent law in line with international norms. However, China's legal system, particularly the enforcement mechanism and the informal norms that are needed to support it, is far from effective in protecting private property rights. Piracy remains rampant. What might lead inventors to seek out patent protection when such protection could turn out to be ineffective?

[1] Kortum and Lerner (1999) attributed the U.S. patent surge to higher innovation productivity partly due to new ways of managing research and development. On the other hand, Hall and Ziedonis (2001) found that pro-patent legislative changes had led the U.S. semiconductor firms to seek more patents out of concern for their bargaining position in potential patent litigations. Jaffe and Lerner (2004) analyzed how the seemingly innocent pro-patent legislative changes had turned patents from a means to encourage innovation to a strategic tool that may well stifle innovation. See Hall (2004) for a synthetic analysis.

The R&D intensity of China's economy, measured by the ratio of R&D expenditure to GDP, hovered around one-half percent for much of the 1990s before rising in the late 1990s, reaching 1.0 percent in 2000 and continuing to climb to 1.3 percent in 2003. China is now one of the few low or low-middle income countries whose level of R&D intensity has risen beyond one percent (Hu and Jefferson, 2004). One possibility is that China's rising R&D intensity may be creating more patentable new knowledge.

Also during the past decade, foreign direct investment of rising technological sophistication has been expanding into more Chinese industries and regions. As foreign invested firms expand and deepen their manufacturing activities in China, with some establishing R&D operations, the need to protect their intellectual property might also be expected to rise. Moreover, the use by foreign firms of legal weapons, now sharpened by the new pro-patent legislation, could be demonstrating to Chinese firms the strategic importance of patent rights. Therefore, in addition to the expansion of China's patent law and the growth of China's R&D intensity, a third hypothesis that potentially explains China's patent explosion is that the surge of FDI has raised the stakes for owning patent rights for both foreign and domestic firms leading to a higher propensity to patent.

This paper explores two other hypotheses that may explain the rapid rise in patenting activity in China. Differences in the inter-industry incidence of patenting are often associated with "complex" and "discrete" product industries. The former industries, which include machinery and electronics, develop new products or processes that consist of numerous separately patentable elements versus relatively few patentable elements in the discrete product industries. Firms in complex product industries typically build up portfolios of intellectual property rights in order to gain a competitive edge in licensing negotiations. If the intensity of complex product industries is growing in China, we should expect that the incidence of patenting too would rise.

A final hypotheses that we examine in this paper is the implications of enterprise reform for property rights. With the acceleration of ownership reform in the mid-1990s, legal and institutional changes have produced less ambiguous assignments of property rights in China's enterprise system. This is particularly true in the rapidly growing non-state sector, which is likely to be more aggressive in asserting legal rights over its intellectual property than state-owned enterprises. The 2000 amendment to China's patent law has also been more explicit in affirming the patent rights of non-state owned enterprises and their employees.

Based on the above overview, we propose five alternative hypotheses of what has led to the patent explosion:

- The pro-patent amendments to the Patent Law in 1992 and 2000 raised the overall return to patent holders.

- The intensification of R&D in the Chinese economy channeled more resources into innovation activities that led to an increase in patentable technologies.

- International economic integration, particularly the vast inflow of foreign direct investment, raised the stakes for protecting intellectual property rights in China for foreign firms. It also raised the stakes for domestic Chinese firms who can use patents as a strategic tool to compete with firms with foreign investment.

- Inter-industry differences, particularly those between complex and discrete product industries, together with a legal system that is more sympathetic to patent rights may have created incentives to patent beyond the conventional objectives for patent applications.

- Economic reform that has extended and strengthened the role of private property in China's enterprise sector has led non-state enterprises to seek patent protection more aggressively than before.

We investigate and differentiate these hypotheses by nesting them in a patents production function, which we estimate using a data set that spans the population of China's large and medium sized enterprises from 1995 to 2001. These enterprises are responsible for the bulk of China's industrial R&D.

The remainder of the paper is organized as follows. The next section describes China's patent system and the government's attempts to restructure the patent system. Section three provides summary evidence on the patenting behavior of China's large and medium size enterprises. We discuss the specification and estimation of the patents production function in section four. In section five we draw inferences for the different hypotheses of China's patent explosion based on the estimation results. Section six presents our conclusions and related discussion.

2 China's patent system and the patent explosion

2.1 China's patent system

The People's Republic of China adopted its first formal Patent Law on March 12, 1984, which went into effect on April 1, 1985.[2] The law helped to create a patent system that was similar to those used of Europe and Japan. The priority in granting patents is based on the principle of "first-to-file" rather than "first-to-invent". It also instituted a pre-grant opposition system under which parties can file request with the patent office to object to the grant of the patents concerned. China's patent office grants three types of patents: invention, utility model and design patents. Applications for invention patents need to pass a substantive examination for utility, novelty, and non-obviousness before the patents can be granted. The utility model and design patents generally cover more incremental innovations and are not subject to examination for novelty and an inventive step.

The first major amendments of China's Patent Law came into effect January 1, 1993. The amendments extended the scope of patent protection to cover pharmaceutical products, food, beverages, flavorings, and substances obtained by means of chemical processes. Duration of invention patent protection was extended from 15 to 20 years, while that of utility model and design patents increased from 5 to 10 years. Protection for manufacturing process has been extended to the product directly obtained by the patented process and a patentee has the right to prevent any other person from importing the patent related product. The grounds for granting compulsory licenses were restricted. The pre-grant opposition was replaced by a post-grant revocation procedure - as a result,

[2]The origin of patent legislation in China can be traced to a prototype of patent law entitled the Charter of Rewards on Invigoration of Industry and Art the Qing Dynasty promulgated in 1889.

the entire process of patent approval was shortened by an average of six to ten months.

In anticipation of China's accession to the World Trade Organization (WTO) and becoming a member nation of the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS),[3] the National People's Congress again revised the Patent Law in August 2000.[4] In accordance with TRIPS requirements, the amendments provide patent holders with the right to obtain a preliminary injunction against the infringing party before bringing up a lawsuit. The new law also stipulates standards to compute statutory damages that were non-existent before. The amendments affirm that state and non-state enterprises enjoy equal treatment in obtaining patent rights. The amended law simplifies the procedures of patent application, examination and transfer and unifies the appeal system by removing the patent revocation procedure that played similar roles as the invalidation procedure.

[Insert Figures 1 and 2 here]

2.2 The patent explosion

Both patent applications and grants took off in 2000, although there was a small jump in 1993 after the first Patent Law Amendment. The take-off is particularly striking for invention patents that are plotted against the right hand axis in both Figures 1 and 2. Prior to 2000, applications for invention patents had been growing by less than 10 percent a year, while all patent applications grew by over 15 percent a year. Since 2000 the annual rate of growth of invention patent applications accelerated to 23 percent, overtaking the growth rate of overall patent applications by 5 percent. The year 2000 is also a watershed for foreign patent applications, the growth of which jumped from 12 percent per annum prior to the year to 23 percent annually afterwards.

A major difference between the patenting behavior of domestic and foreign inventors is the composition of the three types of patents. In 2004, more than 85 percent of

[3] Over the years China has also joined a number of international conventions for IP protection. In 1984, China became a signatory party to the Paris Convention on the Protection of Industrial Property and the Treaty on Intellectual Property in Respect of Integrated Circuits in 1990. In 1994, China joined the Patent Cooperation Treaty (PCT). Other treaties that China has joined include: Budapest Treaty (1995), Locarno Agreement (1996), and Strasbourg Agreement (1997), International Convention for the Protection of New Varieties of Plants (UPOV) (1999).

[4] It went into effect July 1, 2001.

foreign applications were for invention patents in 2004, while less than a quarter of domestic applications were for invention patents. However the growth of domestic patent applications since 2000 has come mostly from invention patents. In fact over the past five years the growth of domestic invention patents has outpaced even that of foreign invention patents.

Figure 2 shows similar patterns of growth for patent granted. A noticeable feature of the figure is that it shows different success rates for invention patent applications for domestic and foreign patent applications. While foreign and domestic inventors filed similar numbers of invention patent applications from 2000 onward, the numbers of patent grants diverged considerably, suggesting a potential drop in the quality of domestic invention patent applications.

[Insert Figure 3 here]

An immediate candidate explanation for the patent explosion is the intensification of R&D in the Chinese economy entailing more than a doubling during 1996-2003 of the ratio of R&D expenditure to GDP, reaching a level of 1.3 percent in 2003. Figure 3 shows that the number of domestic patent applications per billion yuan of real R&D expenditure nearly doubled in 15 years while the number of patent grants has more than tripled. Patenting growth has clearly outstripped real R&D expenditure. Higher innovation productivity and a greater propensity to patent may both have contributed to the substantial increase in the ratio of patents-R&D expenditure. Sorting the relative importance of the candidate hypotheses will require detailed information at the firm level.

3 Patenting by the large and medium size enterprises (LMEs)

The data for this research are drawn from the Survey of Large and Medium Size Enterprises (LMEs) that China's National Bureau of Statistical (NBS) conducts each year. Jefferson, Hu, Guan and Yu (2003) provided a comprehensive description of this rich data set.[5] Our sample spans a period of seven years from 1995 to 2001 and includes data

[5]To define large and medium-size enterprises, China's NBS uses either of two industry specific criteria: production capacity or original value of fixed assets. For example, an iron and steel firm must meet

for 29 two-digit manufacturing industries and over 500 four-digit industries.

In 1995 LMEs invested 7.5 billion Yuan on R&D, which accounted for 22 percent of total national R&D expenditure; by 2001, the share had risen to 38. LMEs were also responsible for 4.7 percent of all domestic patent applications in 1995 and 8.5 percent in 2001. Their share of patent grants rose from 3 percent in 1995 to 4.7 percent in 1999. The patent figures may understate technological capability of China's LMEs as it is reasonable to assume that relative to patents taken out by small enterprises and individual inventors LME patents are disproportionately invention patents.

[Insert Figures 4 - 6 here]

Firms patent for different reasons. According to the survey reported in Cohen, Nelson and Walsh (2000), the top reasons U.S. firms choose to seek out patent protection include preventing copying, blocking rival patents on related innovations, avoiding law suits, use in negotiations, and enhancing reputation. Using patents to earn licensing revenue is the least important reason for applying for patents.

The propensity to patent varies from industry to industry due to differences in the nature of technology and the ease of imitation. Is China's patent explosion an economy-wide phenomenon or is it driven by a few industries? If it is concentrated in a few industries, what are the characteristics of these industries that could have led to the patent surge? Figures 4 to 6 provide some clues to these questions by comparing the distribution of patent applications across China's 29 two-digit industries. Since annual patent applications are erratic at the two-digit industry level in our data, we use simple averages over two sub-periods of the sample, 1995 - 1997 and 1998 - 2001, to smooth out the fluctuations. Both figures indicate that ten industries, transportation equipment (37), electrical machinery and equipment (40), electronics and telecommunications equipment (41), ordinary machinery (35), special equipment (36), chemicals (26), pharmaceuticals (27), cultural and sports goods (24), food manufacture (14) and beverage (15), together account for about three quarters of all LME patent applications and over

or exceed a production capacity of 600,000 tons to qualify as a large enterprise. For semiconductor manufacturing firms, the original value of fixed assets of a large enterprise must exceed 50 million yuan. For further elaboration of the criteria used to classify firm size, see the web site of the China's NBS (www.stats.gov.cn).

80 percent of the increase in patent applications between the two sub-periods.

Ordinary machinery, special equipment, transportation equipment, electrical machinery and equipment, and electronics have been particularly aggressive in applying for patents. We compare patent applications of domestic and foreign invested enterprises in Figures 5 and 6. Although the industry distributions of foreign and domestic patents are similar, the patenting activity of foreign firms is smaller in scale and more concentrated than that of the domestic firms. Foreign invested enterprises in the electronics industry have been most aggressive in taking out patents, whereas the transportation equipment industry has seen the biggest increase in patenting by domestic firms.

[Insert Figure 7 here]

The rapid and expansive integration of China into the global economy and the fast growing domestic Chinese market has increased the importance of the protecting intellectual property rights of multinational companies. As shown by Figure 7, between 1995 and 2001, foreign invested enterprises have expanded their share of industry value added in all Chinese industries, including tobacco that had been monopolized by the Chinese government. Over this six-year period, the average increase in foreign invested firms' shares of value added is 18 percent. In the electronics industry foreign invested firms are responsible for as much as 65 percent of total value added. As foreign firms broaden their manufacturing activity in China, increasing their share of local production, the risk that their technologies will be imitated increases.

Various authors have contrasted complex and discrete products industries in explaining inter-industry differences in patenting.[6] Cohen, Nelson and Walsh (2000) described the key difference between the two kinds of technologies as "whether a new, commercializable product or process is comprised of numerous separately patentable elements versus relatively few." A consequence of this feature is that firms in complex product industries usually do not control all of the patented technologies used in the manufacture of a product. Firms patent to build up a portfolio of intellectual property rights in order to gain a competitive edge in licensing negotiations. Hall (2004) suggests that "in complex product industries, firms are more likely to use patents to induce rivals to

[6]See for example, Levin, Klevorick, Nelson and Winter (1987) and Merges and Nelson (1990).

negotiate for property rights over complementary technologies." Table 1 summarizes the differences between the two types of industries' R&D and patenting behavior.

[Insert Table 1 here]

We select beverage, textile, chemical, and pharmaceutical to represent the discrete product industries and special machinery, transport equipment, electric machinery, and electronics for complex product industries. The top three panels are based on all the firms in each of the three groups. The bottom panels are computed using an innovators sub-sample, where we define innovators as firms that have filed at least one patent application between 1995 and 2001. We compare patent applications, patent grants, R&D-labor ratios, and total employment among the groups of firms. The top three panels of Table 1 show that complex product firms conduct more than twice as much R&D as discrete product firms. They also take out nearly four times as many patent applications and grants.

4 In search of an explanation: a patent production function approach

We have identified five hypotheses with respect to China's patent explosion. The pro-patent amendments to the Patent Law in 1992 and 2000 may have raised the overall return to seeking patent protection. The intensification of R&D in the Chinese economy has channeled more resources into innovation activities that may have led to patentable technologies. International economic integration, particularly the vast inflow of foreign direct investment, has raised the stakes for protecting intellectual property rights in China for foreign firms. It has also raised the return to patenting for domestic Chinese firms who can use patents as a strategic tool to counter competition from foreign-invested firms. Inter-industry differences, particularly those between complex and discrete product industries, together with a patenting system that has become more sympathetic to innovators may have opened the door to patenting motivations that lie beyond the conventional reasons for applying for patents. Economic reform that has strengthened private property rights be causing non-state enterprises to seek patent protection more aggressively than before. We use a patents production function framework to test and differentiate these hypotheses.

4.1 The patents production function: specification and estimation issues

Following the tradition of Pakes and Griliches (1984), Hausman, Hall and Griliches (1984), and Hall and Ziedonis (2001), we estimate a patents production function, which assumes that patents production follows a Poisson process with parameter, λ:

$$E(Y_{it}) = \lambda_{it} = exp(X_{it}^{'}\beta) \quad (1)$$

$$Prob(Y_{it} = y_{it}) = e^{-\lambda_{it}}\lambda_{it}^{n}/y_{it}! \quad (2)$$

Where Y is the count of patents of firm i in year t, the vector X includes R&D expenditure, firm characteristics that influence knowledge production and propensity to patent, year dummies to capture the overall trend of propensity to patent, and industry characteristics that explain inter-industry differences in patenting.

The majority of firms in our sample do not do R&D and even fewer take out patents. This results in a large number of zero observations for patent counts. The large number of zero observations raise two concerns. First, the excessive number of zeros leads to a non-normal distribution, which biases the estimates of standard errors. More importantly, these zero observations possibly result from two quite different data generating processes: firms that do not innovate at all and those that attempt to innovate but fail to generate patents. The economic significance of the two types of zeros is quite different. We choose to model the two processes explicitly and separately by adopting the Zero Inflated Poisson (ZIP) model proposed by Lambert (1992). We assume that firms in our sample fall into two categories, the innovators and the non-innovators. Let the likelihood of a firm being a non-innovator be p; the probability of a firm being an innovator is therefore $1 - p$. With probability p, a firm's patent count will be zero; with probability $1 - p$, the patent count will be subject to the Poisson process in equation (1). The full model is therefore specified as follows:

$$Pr(Y_{it} = y_{it}) = \begin{cases} p_{it} + (1 - p_{it})e^{-\lambda_{it}} & y_{it} = 0 \\ (1 - p_{it})e^{-\lambda_{it}}\lambda_{it}^{n}/y_{it}! & y_{it} = 1, 2, ... \end{cases} \tag{3}$$

We further assume that the decision to innovate is determined by a logistic process with F being the logit link:

$$p_{it} = F(Z^{'}\gamma) = \frac{1}{1 - exp(-Z^{'}\gamma)} \tag{4}$$

In Z are variables that determine whether a firm chooses to innovate or not. The likelihood function to be maximized is therefore:

$$\begin{aligned} L(\gamma, \beta; y, X, Z) = & \sum_{y_{it}=0} ln\{F(Z_{it}^{'}\gamma) + [1 - F(Z_{it}^{'}\gamma)][-exp(X_{it}^{'}]\} \\ & + \sum_{y_{it}>0} \{ln[1 - F(Z_{it}^{'}\gamma)] - exp(X_{it}^{'}) + nX_{it}^{'}\beta - ln(y_{it}!)\} \end{aligned} \tag{5}$$

More general models of this type include the hurdle model of Mullahy (1986). Crepon and Duguet (1997) also considered a more general model that involves latent processes, of which the zero occurrences are realizations. Vuong (1989) proposed a test to determine whether there is a regime splitting mechanism at work or not in the ZIP model. We report the *Vuong* test statistics after estimating the ZIP model of equations (1) to (4).

Another issue that needs econometric treatment is firm heterogeneity. The variables we include in X_{it} may not capture all the firm specific characteristics that determine a firm's innovation and patenting decision and behavior. To the extent that some of these characteristics influence a firm's R&D decision, the patents-R&D elasticity estimate would be biased. For example, more capable and motivated managers may decide to conduct more R&D and be more forceful in maintaining a portfolio of patent rights. To the extent that such characteristics are time-invariant, we use the count data model equivalent of the fixed effect estimation developed by Hausman, Hall and Griliches (1984) to correct the bias that may be introduced to the patents production function estimates by the omitted firm-specific characteristics .

4.2 What is behind the patent explosion?

Assuming that a constant proportion of new knowledge generated can be transformed into patents, the production of which is given by equation (1), the first variable we consider to include in X_{it} is R&D expenditure. In the absence of guidance from a theoretical model, we follow the tradition of the literature and enter R&D expenditure in the patent production process in logs, therefore implicitly assuming a proportional relationship between R&D and patents. Estimating the elasticity of patent production with respect to R&D and comparing it with that obtained for the U.S. firms allows us to gauge the innovative efficiency of Chinese firms.

Although the debate over the relationship between firm size and innovation in the spirit of Schumpeter (1942) and Arrow (1962) is far from settled empirically (Cohen and Levin, 1989), we control for the scale effect from firm size on patents production by including the number of employees in the regression.

We then include a number of firm specific and industry specific variables to investigate the sources of the increase in the propensity to patent in Chinese firms. Given the time span of our sample, we can only use year dummies to identify the effect on propensity to patent of the 2000 amendment to the patent law.

We measure the presence of foreign direct investment in China's 3-digit industries by the share of industry value added accounted for by foreign invested firms. The status of foreign invested firms is determined by the National Bureau of Statistics depending on its ownership form at the time of registration. The statistical authorities distinguish between foreign investors who are from Hong Kong, Macau, and Taiwan (i.e. "overseas" firms) and those from other locations (i.e. "foreign" firms).

The surge of FDI in China and the aggressive enforcement of patent rights by foreign invested firms may demonstrate for domestic Chinese firms the strategic value of holding patents.[7] There has been anecdotal evidence on Chinese firms taking advantage of loopholes in the Chinese patent system in order to use patents to preempt competition from

[7] We cannot distinguish between knowledge spillover and increase in propensity to patent in the current context. Some authors have used patent applications to examine spillover from FDI without making such distinction. For example, CheungLin04 used provincial level patent applications data to investigate whether there is technology spillover from FDI and found supporting evidence.

foreign firms.[8] The utility model and design patents are particularly vulnerable to such abuses as they are not subject to substantive examination for novelty and inventiveness. Our data does not distinguish between invention patents and utility model and design patents. We are therefore unable to exploit the potential differences in the motivation to apply for utility model and design patents. However, by separately estimating the reaction to industry FDI by foreign and domestic firms, we examine indirectly whether and how the strategic incentive to patent is contributing to China's patent explosion.

The industry variation in technology opportunity and nature of technology makes it imperative to account for not just industry heterogeneity in the propensity to patent but also the knowledge production process itself. In addition to estimating an aggregate patents production function, we also estimate the individual patent production function for eight two-digit industries that have been most active in patenting. In particular, we are interested in investigating whether there is a discernible difference in the propensity to patent between complex and discrete industries.

China's economic reform and state-owned enterprise restructuring in particular has given rise to a spectrum of ownership structures that ranges from state ownership, local collective ownership, public-listed with majority of equity controlled by the state, private enterprises, foreign wholly owned and joint ventures. The gamut of ownership types in turn carries different implications with respect to the assignment of property rights. Patents taken out by state-owned enterprises belong to the state, unless the patents are a result of an inventor's effort outside his/her official duty. The two amendments to the Patent Law have clarified and affirmed non-state enterprises' entitlement to property rights over their intellectual property. We therefore expect the propensity to patent to vary across ownership types as well. Including the ownership dummies in the presence of the control for the economy-wide year effect allows us to capture differences in the

[8] In a New York Times article (French, 2005), a Chinese intellectual property rights lawyer was quoted as saying "Once upon a time, the counterfeiters in China ran away when you came after them. Today, they don't run away. Indeed, they stay put and they sue us. More and more Chinese companies are taking a so-called legal approach, taking advantage of serious weakness in the Chinese legal system." Some Chinese firms exploit loopholes in the patent system by takeing out a patent ahead of their foreign competitions in China and sue them for violating their patent rights. The time over which the legal battle will be dragged on would give Chinese firms sufficient time to exploit the copied technology particularly in industries with short product life cycles.

propensity to patent beyond what is induced by the legislative changes.

[Insert Table 2 here]

5 Estimation results and discussion

5.1 The overall trend

We first estimate a base-line version of the patents production function specified in equations (1) to (4) using the full sample. The patents production function is estimated using three estimators: Poisson, ZIP, and fixed effect Poisson. The results are reported in Table 2.

The number of patent applications measures the output of patents production. We base our discussion on the results using patent applications because patent grants data are missing for the last two of the seven years covered by the sample. We have estimated the models in Table 2 using patent grants. The results are consistent with the results in Table 2 and are available upon request.

We use real R&D expenditure as a proxy for innovation input. A number of authors have noted that R&D expenditures are highly correlated over time and usually the association between R&D expenditure and patents production exists only at the contemporaneous level.[9] Therefore current R&D expenditure is used to estimate the patents production function. We follow this approach after experimenting with distributed lags of R&D expenditures and finding past R&D expenditures insignificant in explaining patents production. Another practical concern is that our sample is extremely unbalanced. Including a comprehensive lag structure would require us to drop a large number of observations. So would the effort to construct a knowledge stock using historical R&D expenditures. Therefore we settle for using R&D expenditure as a determinant of patent counts.

Our preferred model in Table 2 is the ZIP model. We also report results from the normal Poisson estimation and the Poisson fixed effect estimation to contrast with the ZIP results. The *Vuong* test statistics indicate that the normal Poisson model is

[9] For example, see Pakes and Griliches (1984) and Hall and Ziedonis (2001)

rejected in favor of the ZIP model. The ZIP model also fits the data much better than the Poisson model - the log likelihood is much higher. Explicitly modeling the data generating process of the zeros considerably changes the estimation of the patents - R&D elasticity. ZIP generates a much smaller elasticity estimate than Poisson does, but the elasticity estimate and the estimates of the coefficients of the other variables are broadly consistent with those obtained using the Poisson fixed effect estimation, which controls for firm heterogeneity. We base our discussion and conclusion on the ZIP model since we would have to throw away a large number of observations if we were to use the Poisson fixed effect estimator - a large number of firms in our sample do not have patents in any year.

The patents - R&D elasticity of 0.032 that we obtain by ZIP estimation in column (3) is quite small by OECD standard. Even the Poisson estimate of 0.125 is much smaller than similar estimates for the U.S. and European firms. For example, For U.S. firms, Hall and Ziedonis (2001) reported an estimate of 0.989 similar to what was obtained in Hausman, Hall and Griliches (1984) - 0.87, and Pakes and Griliches (1984) - 0.61. Crepon and Duguet (1997) estimated a patents - R&D elasticity of 0.8 for French manufacturing firms. Licht and Zoz (2000) reported an elasticity estimate of 0.9 for German firms. The much smaller elasticity estimate could have been caused by either low productivity of R&D in Chinese firms or that Chinese firms patent a much smaller fraction of new knowledge generated by R&D than their OECD counterparts. In either case, the patents-R&D elasticity estimate implies that R&D intensification in Chinese industry is unlikely to be the primary driving force behind China's patent explosion.

Controlling for firm size makes a huge difference in estimating the patents - R&D elasticity. Large firms take out more patents because there are economies of scale from preparing patent applications and that they commit more resources to R&D. Including log of labor and replacing log of R&D expenditure with log of R&D - labor ratio substantially reduces the Poisson estimate of the patents-R&D elasticity to 0.011, whereas the scale coefficient is highly significant at 0.599. The log likelihood substantially increases with the inclusion of the size variable. Our estimate of the scale effect on patenting is similar to findings in the OECD literature.

[Insert Figure 8 here]

The propensity to patent varies considerably across ownership categories. We compute the marginal effect of ownership using the dummy estimates from both the normal Poisson and ZIP models and plot it in Figure 8. All the dummies are precisely estimated except that for jointly-owned enterprises, whose propensity to patent is similar to that of the reference group, state-owned enterprises. All non-state enterprises but the jointly-owned group have a higher propensity to patent than state-owned enterprises confirming our conjecture that ownership reform and pro-patent legislative changes have resulted in more clear property rights allocation and led the non-state firms to more aggressively assert their intellectual property rights. In the non-state sector, collective-owned and private enterprises have been most aggressive in applying for patents. There is little difference between the propensity to patent between foreign invested firms and Hong Kong, Macau and Taiwan invested firms.

[Insert Figure 9 here]

That the economy-wide propensity to patent has been increasing over time is clearly seen in Figure 9, where we plot the marginal year effect using the year dummy estimates from Table 2. All three estimation methods show a clear and consistent upward time trend. The highly significant year effects for 2000 and 2001 imply an economy-wide increase in the propensity to patent after 2000. The jump in both statistical significance and magnitude of the year effects indicates a structural change taking place on the eve of China's entry in WTO.

[Insert Table 3 here]

5.2 Foreign direct investment and patenting

We investigate how FDI has contributed to China's patent explosion in Table 3, where we include a measure of industry FDI in the ZIP estimation of the patents production function. Industry FDI is measured by the foreign invested firms' share of total industry value added at the three-digit SIC level. We use value added instead of sales or employment since the latter may be subject to bias due to industry variation in capital intensity. We then estimate the patents production function separately for domestic and foreign invested firms to examine whether foreign and domestic firms' patenting reacts differently to industry FDI.

The effect of industry FDI on the increase in propensity to patent is large. If the foreign share of industry value added increases by 10 percent, an average domestic firm would increase its patent applications by nearly 16 percent. There is competition in patenting amongst foreign firms too - a similar increase in industry FDI would lead to a 12.5 percent increase in patent applications in a foreign invested firm. Although the effect of industry FDI also applies to foreign invested firms, it is domestic firms that react much more aggressively to the presence of FDI in their industry. This lends support to the hypothesis that domestic firms use patents as a strategic tool to respond to the competition from foreign firms.

The importance of FDI as a source of the patent explosion is also reflected in the change in magnitude of the year dummies of Table 3. The upward trend in the propensity to patent survives as a robust result. However the magnitudes of the year dummies are considerably reduced with the introduction of the industry FDI variable. Comparing the "All" estimates of Table 3 and the ZIP estimates of Table 2, the average patenting rate in 2001 declines from 2.70 times the 1995 level to 2.13 times when the effect of industry FDI is introduced. FDI apparently accounts for a significant portion of the increase in the propensity to patent over time.

A noticeable difference between foreign and domestic firms is in the patents - R&D elasticity estimate. While foreign firms' Chinese patents are unrelated to their R&D activity, R&D makes a significant contribution to the patents production of Chinese firms. The result reaffirms the general perception that foreign firms' Chinese R&D has more to do with local customization than with generating new technologies. The Chinese subsidiaries of multinationals may file for Chinese patent applications on behalf of their parent companies. But we are unable to rule out the possibility that the Chinese subsidiaries assign their patents to their parent companies. In other words, the patented technologies are locally invented but the property rights of the patents are assigned to parent companies.

Finally, Table 3 shows that controlling for R&D, firm size, industry FDI, and other firm and industry characteristics, patenting by foreign invested firms increases faster than that by domestic Chinese firms after 1999 with the difference being most striking in 2000. This is likely to be a result of a combination of foreign firms' anticipation of China's entry to WTO and the amendment to the patent law in 2000 that gave teeth to enforcing patent rights.

[Insert Tables 5 and 6 here]

5.3 Complex vs. Discrete industries

We select four each from the complex and discrete industries to examine how inter-industry differences may have contributed to the patent explosion. The complex industries include special machinery, transport equipment, electric machinery, and electronics; the discrete group includes the beverage, textile, chemical, and pharmaceutical industries. For each industry, we estimate the patents production function for domestic and foreign firms separately. The results reported in Tables 5 and 6.

The industries are different in almost all aspects of our analysis of the causes of China's patent explosion. A robust patents - R&D relationship only exists among domestic special machinery firms and foreign invested pharmaceutical firms. There is no systematic difference between complex and discrete products industries in the estimate of the patents - R&D elasticity, although for all domestic firms in the four complex product industries we obtain positive estimates of the elasticity, whereas for two of the discrete products industries, the estimate is negative for domestic firms.

The result from the whole sample that carries through in the most robust way is the scale effect. For domestic firms, the scale effect is present for all industries except textile and highly significant in six out of the eight industries. The result is less robust for foreign invested firms. An interesting difference in the scale effect falls on the line between domestic complex and discrete industries. The scale effect is invariably positive and significant at 1 percent level in the complex industries, whereas only beverage and pharmaceutical industries from the discrete group generate such results. Although this difference accords well with the hypothesis that larger complex product firms patent more given the economies of scale in dealing with patent-related legal issues, we need to be careful and not to over-generalize this difference.

The hypothesis that FDI increases domestic Chinese firms' propensity to patent finds support in both Tables 5 and 6. The evidence is most clear in the complex products industries. We obtain positive estimates for the impact of FDI on domestic firms' propensity to patent in all four cases and statistically significant in all but the special machinery industry. There is no such effect for foreign firms in these industries. The results for the discrete product industries are mixed. Chemical patenting is driven by FDI in both domestic and foreign firms with the effect being much stronger for foreign firms. Domestic beverage firms also patent more where there is more FDI around. But all the other estimates are either insignificant or in the case of foreign pharmaceutical firms, significant but negative.

The industry level evidence highlights the inter-industry differences in the economic forces behind the patent surge. The patents - R&D link is weak. But the scale effect and the competitive effect from FDI on domestic firms' propensity to patent carry through. These two effects also seem to be more robust in the complex product industries than in the discrete products industries.

[Insert Table 7 here]

5.4 The innovators

Compared with their mature market economy counterparts, Chinese industries are fragmented. A high degree of heterogeneity among Chinese firms means that high-flying innovators operate along side technology laggards. Inevitable future industry consolidation or shakeout will see the innovators coming out as winners. We take a close look at these innovators in this section.

We define innovators as firms that have more than one year's representation in the sample and have been granted at least one patent over the seven years. This leaves us with 4479 firms and 22559 observations. Summary statistics for this sub-sample are reported in the lower panels of Table 1. These firms are on average about twice as big as an average LME and invest nearly twice as much on R&D on a per capita basis. We run the regressions for the group of firms and the two sub-groups: complex and discrete products industries. Since this is a sample where excessive zeros of patent counts is unlikely to be a problem and the Poisson fixed effect estimator is feasible, our analysis will be based on the results generated by the Poisson fixed effect estimation, which are reported in Tables 7.

Most of the results carry through only in a much more robust way. The patents - R&D elasticity estimate is twice as big for the innovators as for the average LME. There is now a significant relationship between patents and R&D for foreign innovators firms where such relationship was non-existent.

Table 3 shows that both domestic and foreign firms respond to industry FDI by increasing their propensity to patent, but the former does so more than the latter. The contrast is even sharper now. Foreign firms do not increase their patenting rate as a result of operating in an FDI intensive industry. On the other hand, a ten percent increase in industry FDI increases the propensity to patent of a domestic innovator by 5.7 percent. This effect is smaller than that for an average domestic firm.

[Insert Tables 8 and 9 here]

Industry heterogeneity continues to dominate the industry-level results in Tables 8 and 9. A noticeable difference is the patents - R&D elasticity estimate. It is now positive and significant for domestic firms in seven of the eight industries. The scale effect remains robust in the complex production industries but less so in the discrete product industries. The result of FDI-induced increase in propensity to patent now shows some interesting inter-industry differences. In pharmaceutical, transport equipment, and electric machinery industries, foreign invested firms increase their patenting rate much more than domestic firms as a result of increased industry FDI. Domestic firms only show a greater response to industry FDI than foreign firms in the chemical industry, where a higher degree of FDI concentration leads foreign firms to patent less. This latter result also finds support in the industries of beverage, special machinery and electronics.

6 Concluding remarks

China's patent explosion has taken place in an institutional environment that is not known for the rule of law and rigorous protection of intellectual property rights. Such institutional deficiencies should have made it futile for inventors to obtain patents. This seeming paradox has prompted this investigation of the conditions that are motivating the rapid growth of patenting in China. A confluence of events coincide with the patent explosion. The continuing surge of FDI to China, pro-patent amendments to China's patent law, China's entry to the WTO, the deepening of enterprise reform that realigns incentive structures, and above all, the intensification of R&D in Chinese industry emerge as candidate explanations of the patent boom.

We use a data set that spans the population of China's large and medium size enterprises for the period from 1995 to 2001. Although not necessarily representative of all Chinese firms, these enterprises performed nearly 40 percent of China's R&D in 2001. We investigate the different hypotheses regarding the causes of the patent explosion by estimating a knowledge production function. ZIP and Poisson fixed effect estimators are used to obtain results that are robust to the presence of firm heterogeneity, including the large proportion of firms that do not patent.

A robust result is the rather small estimate of the incidence of patenting with respect to R&D. Studies for the U.S. usually generate elasticity estimates that are multiple of our estimate of around 0.02. The patents - R&D link is particularly weak among foreign invested firms. We infer from this result that China's recent R&D intensification is unlikely to be the primary force behind the patent explosion. On the other hand, we find a large firm size effect on the incidence of patenting that is comparable to that found in the OECD literature.

We have found that foreign direct investment significantly contributes to the rising propensity to patent among domestic Chinese firms. An increase in the FDI share of industry value added by 10 percent, increases the average domestic firm's patent applications by 15 percent. Competing with foreign firms has increased the awareness of Chinese firms of the strategic value of patents which in a highly competitive environment can serve as a strategic competitive instrument. This industry FDI effect is most conspicuous in the electric machinery, transportation equipment, beverage, and chemical industries.

We also find significant differences in the propensity to patent across different ownership groups that are consistent with our conjecture that the clarification of enterprise property rights leads to more aggressive assertion of patent rights. The robust estimates of the years 2000 and 2001 dummies after controlling for all the other factors corroborates the hypothesis that pro-patent legislative changes have raised the return to patenting despite an overall weak legal environment.

Clearly, China's patent explosion has not been detonated by any single event. Opening up, deepening economic reform, and a relatively stronger legal system have together created a more patents-friendly environment and have increased the return to patenting. An issue that the data does not allow us to deal with is to differentiate between invention patents and the less innovative utility model and design patents. These distinctions in the form of patenting are important to understanding the nature of patenting activity in a developing economy; it is on our future research agenda.

References

Arrow, Kenneth J., "Economic Welfare and the Allocation of Resources for Innovation," in Richard R. Nelson, ed., *The Rate and Direction of Inventive Activity*, Princeton: Princeton University Press, 1962.

Cohen, Wesley M. and Richard C. Levin, "Empirical Studies of Innovation and Market Structure," in Richard Schmalensee and Robert D. Willig, eds., *Handbook of industrial organization*, VOL 2, Amsterdam, Oxford and Tokyo: North-Holland, 1989, pp. 1059–1107.

_ **, Richard R. Nelson, and John P. Walsh**, "Protecting Their Intellectual Assets: Appropriability Conditions and Why US Manufacturing Firms Patent (or Not)," *NBER Working Paper*, 2000, *7552.*

Crepon, Bruno and Emmanuel Duguet, "Research and Development, Competition and Innovation Pseudo-Maximum Likelihood and Simulated Maximum Likelihood Methods Applied to Count Data Models with Heterogeneity," *Journal of Econometrics*, August 1997, *79* (2), 355–78.

French, Howard, "Whose Patent Is It, Anyway?," *New York Times*, 5 March 2005.

Hall, Bronwyn H., "Exploring the Patent Explosion," *NBER Working Paper*, 2004, *10605.*

_ **and Rosemarie Ham Ziedonis**, "The Patent Paradox Revisited: An Empirical Study of Patenting in the US Semiconductor Industry, 1979-1995," *RAND Journal of Economics*, Spring 2001, *32* (1), 101–28.

Hausman, Jerry, Bronwyn H. Hall, and Zvi Griliches, "Econometric Models for Count Data with an Application to the Patents-R&D Relationship," *Econometrica*, July 1984, *52* (4), 909–38.

Hu, Albert Guangzhou and Gary H. Jefferson, "Science and Technology in China," November 2004. mimeo.

Jaffe, Adam B. and Josh Lerner, *Innovation and Its Discontents: How Our Broken Patent System is Endangering Innovation and Progress, and What To Do about It*, Princeton: Princeton University Press, 2004.

Jefferson, Gary, Albert Guangzhou Hu, Xiaojin Guan, and Xiaoyun Yu, "Ownership, Performance, and Innovation in China's Large- and Medium-Size Industrial Enterprise Sector," *China Economic Review*, 2003, *14* (1), 89–113.

Kortum, Samuel and Josh Lerner, "What Is behind the Recent Surge in Patenting?," *Research Policy*, January 1999, *28* (1), 1–22.

Lambert, Diane, "Zero-Inflated Poisson Regression, with an Application to Defects in Manufacturing," *Technometrics*, February 1992, *34* (1), 1–14.

Levin, Richard C., Alvin K. Klevorick, Richard R. Nelson, and Sidney G. Winter, "Appropriating the Returns from Industrial Research and Development," *Brookings Papers on Economic Activity*, 1987, pp. 783–820.

Licht, Georg and Konrad Zoz, "Patents and R&D: An Econometric Investigation Using Applications for German, European and US Patents by German Companies," in David et al. Encaoua, ed., *The economics and econometrics of innovation*, Boston, Dordrecht and London: Kluwer Academic, 2000, pp. 307–38.

Merges, Robert P. and Richard R. Nelson, "On the Complex Economics of Patent Scope," *Columbia Law Review*, May 1990, *90* (4), 839–916.

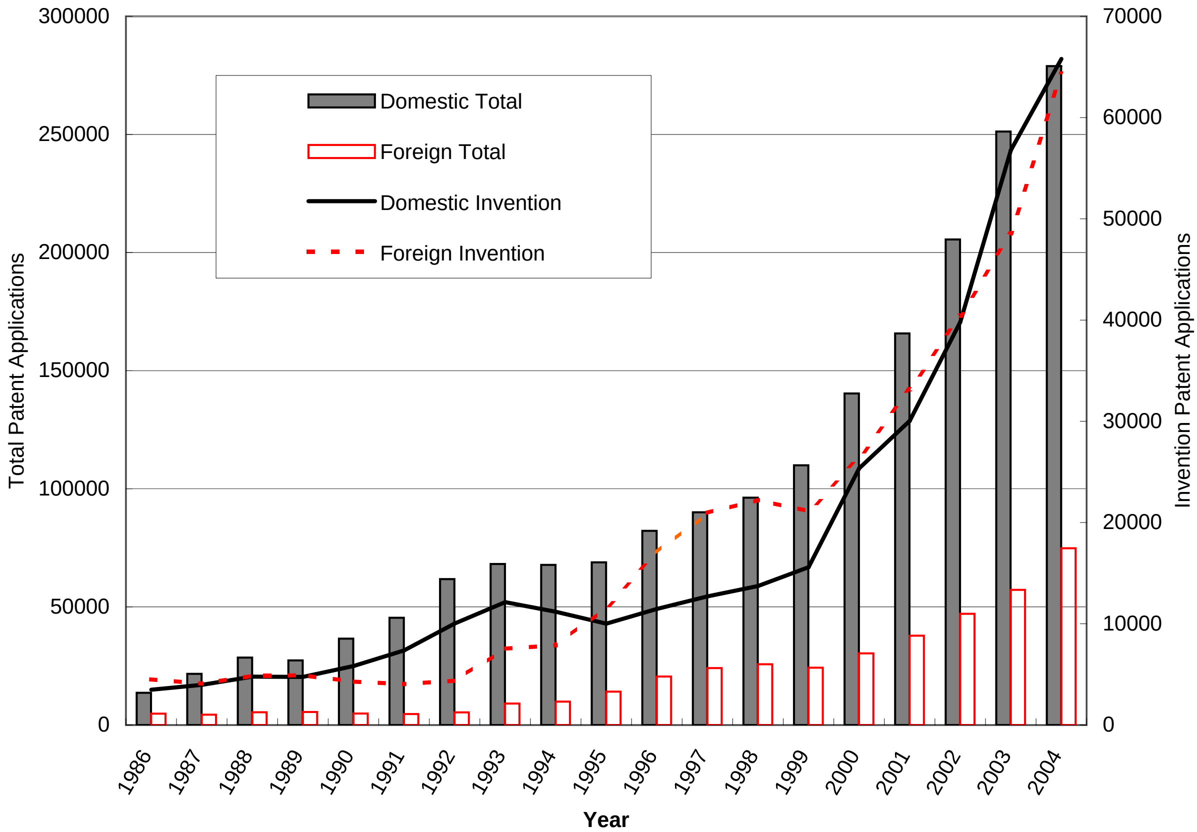
Mullahy, John, "Specification and Testing of Some Modified Count Data Models," *Journal of Econometrics*, December 1986, *33* (3), 341–65.

Pakes, Ariel and Zvi Griliches, "Patents and R&D at the Firm Level: A First Look," in Zvi Griliches, ed., *NBER Conference Report*, D, University of Chicago Press, 1984, pp. 55–72.

Schumpeter, Joseph A., *Capitalism, Socialism, and Democracy*, New York: Harper, 1942.

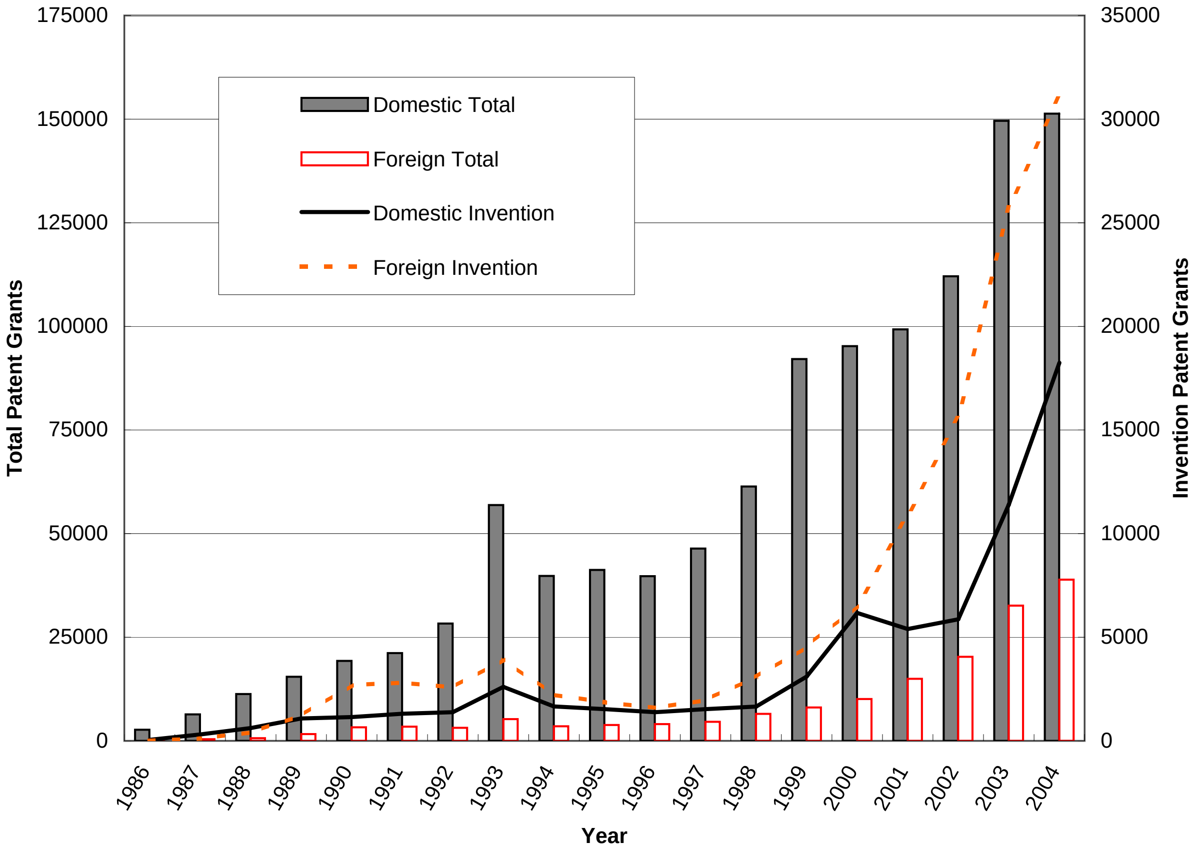
Vuong, Quang H., "Likelihood Ratio Tests for Model Selection and Non-nested Hypotheses," *Econometrica*, March 1989, *57* (2), 307–33.

Figure 1: Chinese Patent Applications, 1986-2004



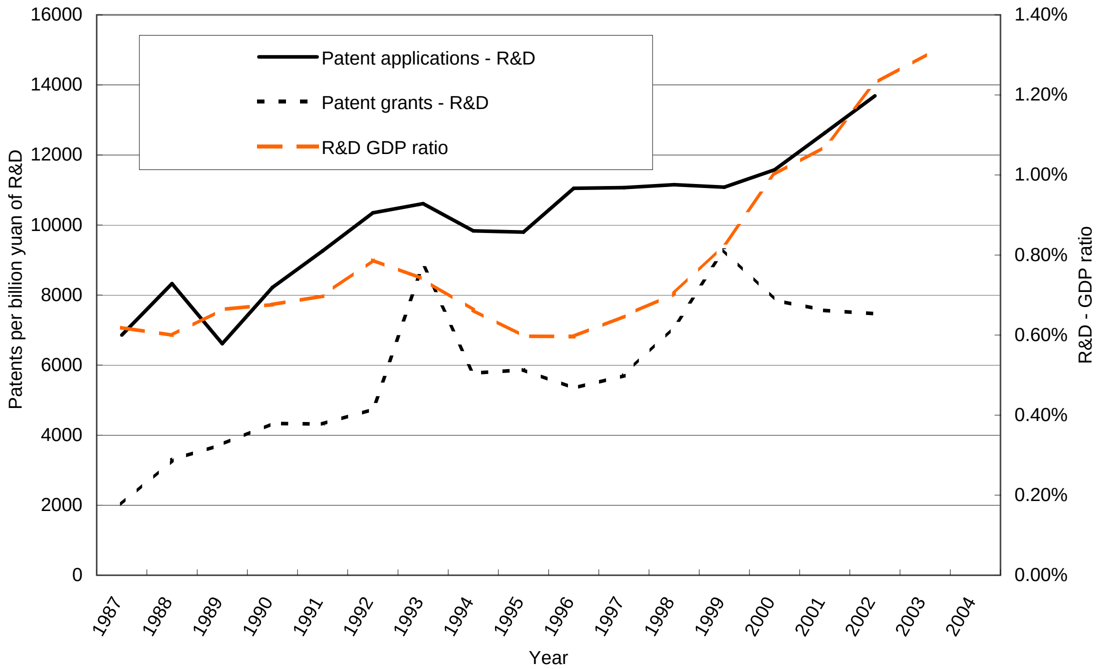
Source: web site of China's National Bureau of Statistics - www.stats.gov.cn.

Figure 2: Chinese Patent Grants, 1986-2004



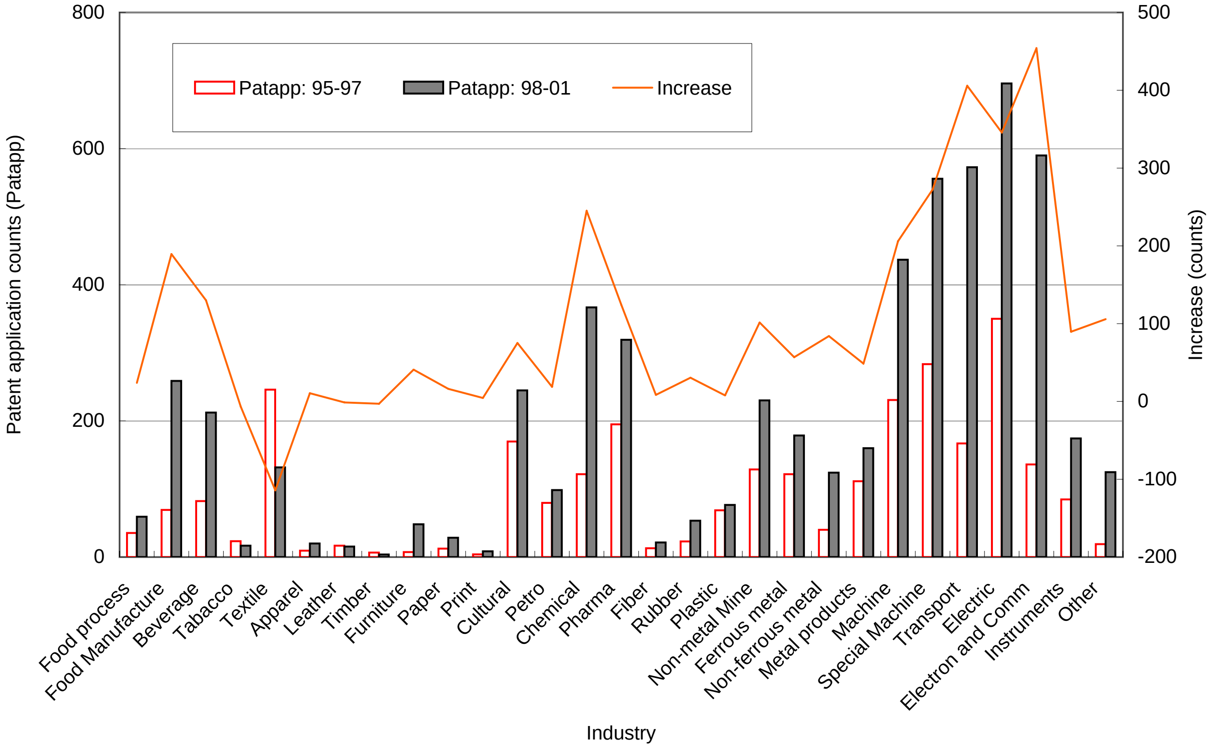
Source: web site of China's National Bureau of Statistics - www.stats.gov.cn.

Figure 3: Chinese Patents-R&D and R&D-GDP Ratios



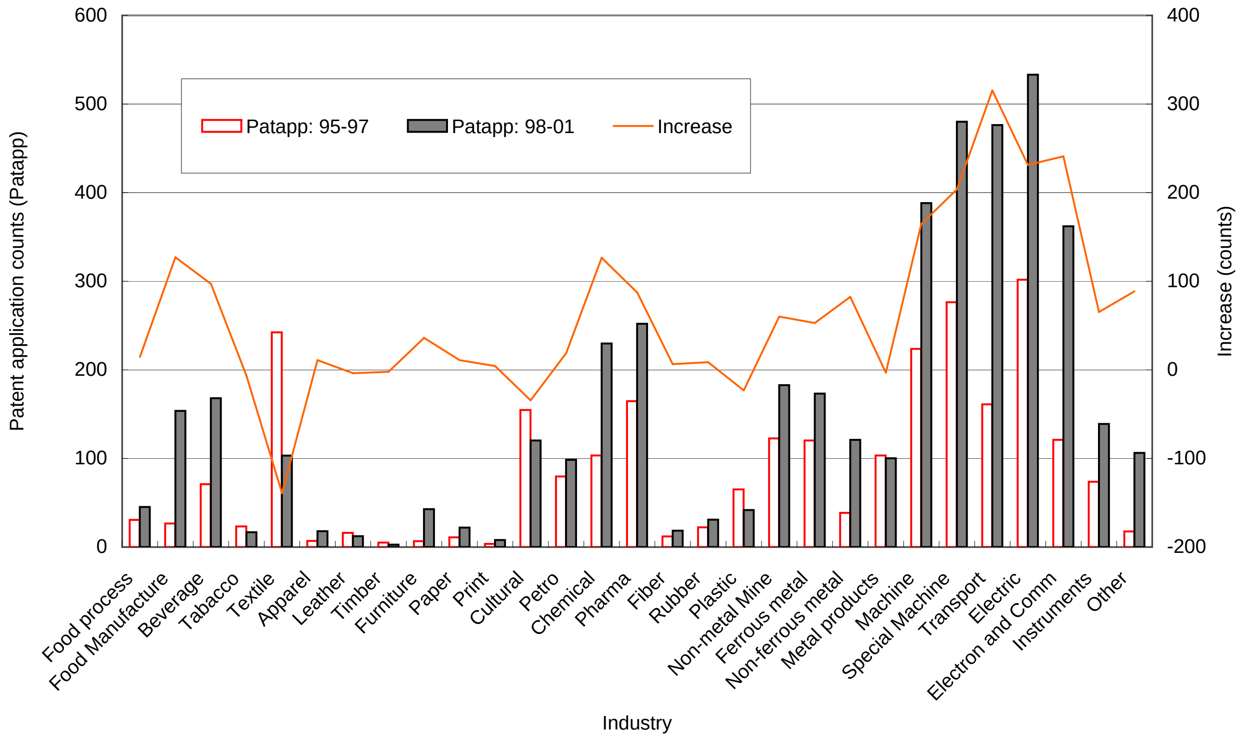
Source: web site of China's National Bureau of Statistics - www.stats.gov.cn.

Figure 4: Industry Distribution of Patent Applications



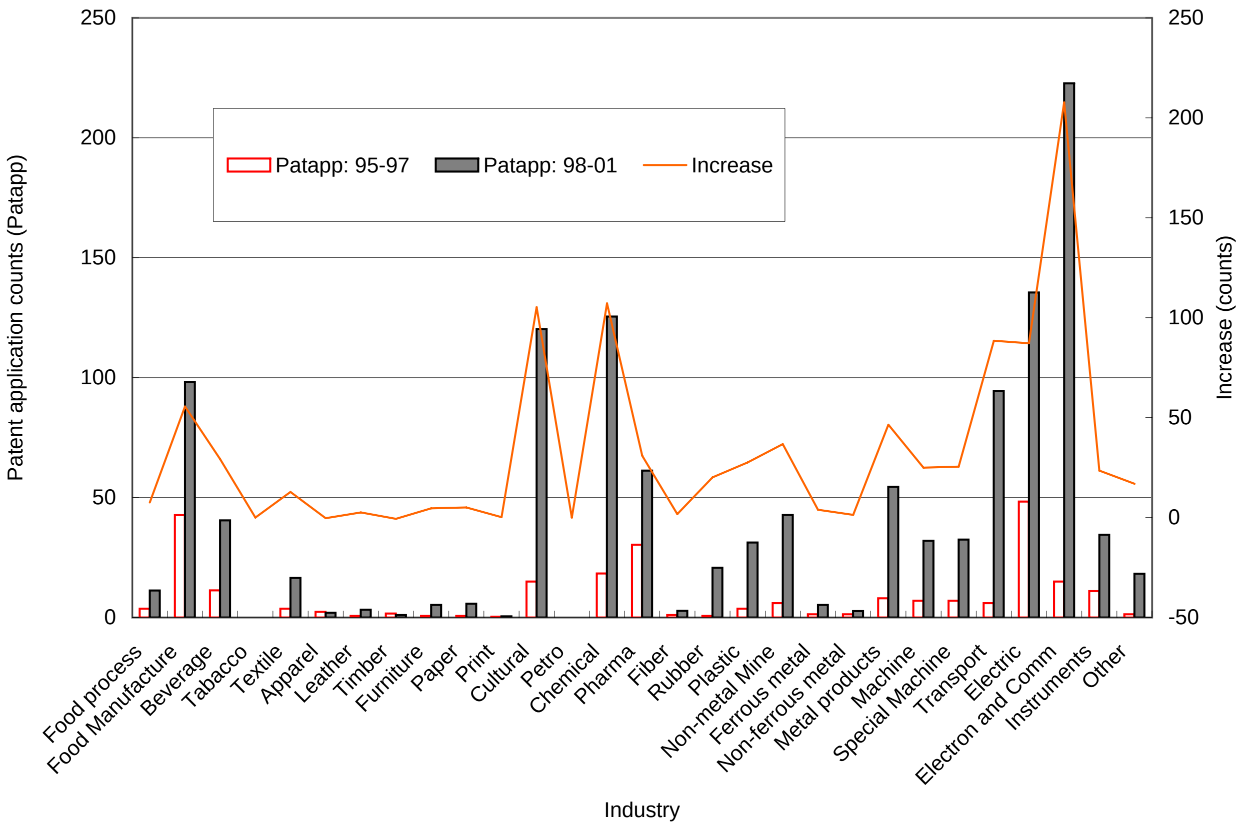
Source: authors' own tabulation using the LME data.

Figure 5: Industry Distribution of Domestic Patent Applications



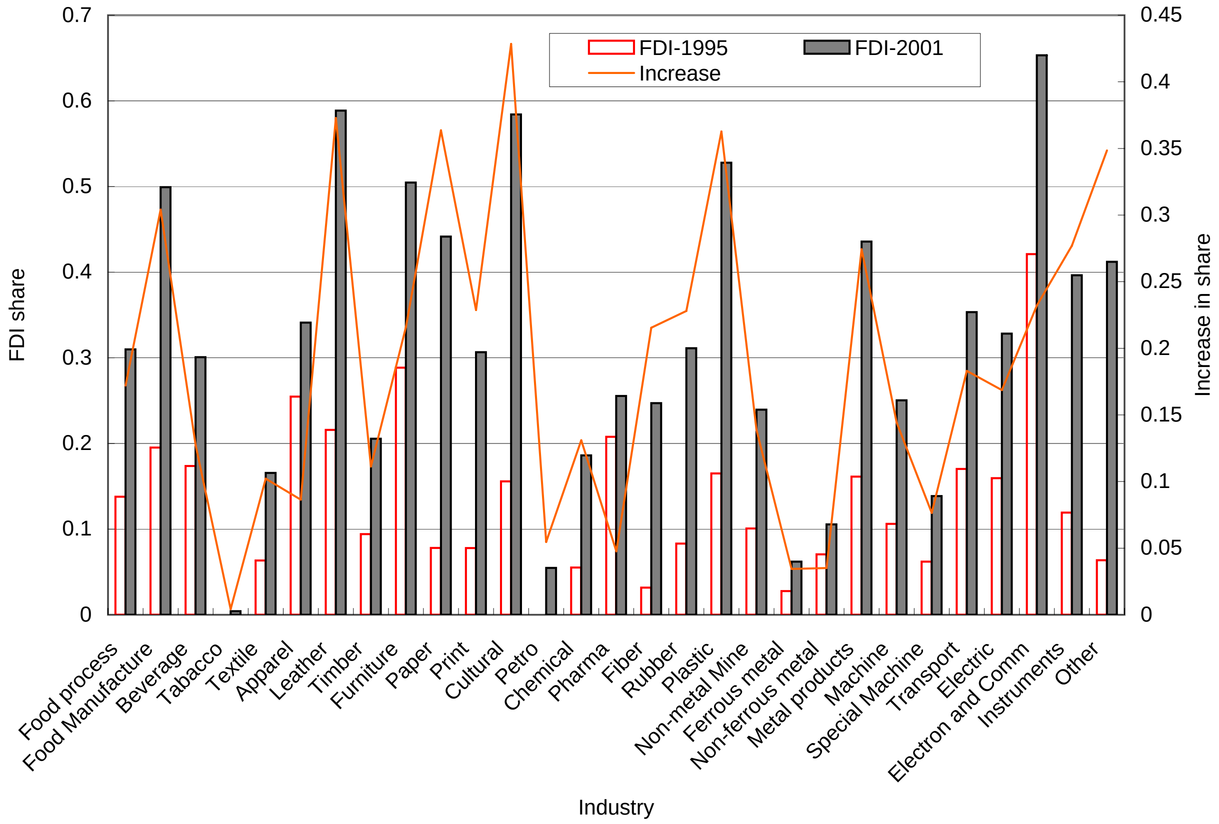
Source: authors' own tabulation using the LME data.

Figure 6: Industry Distribution of Foreign Patent Applications



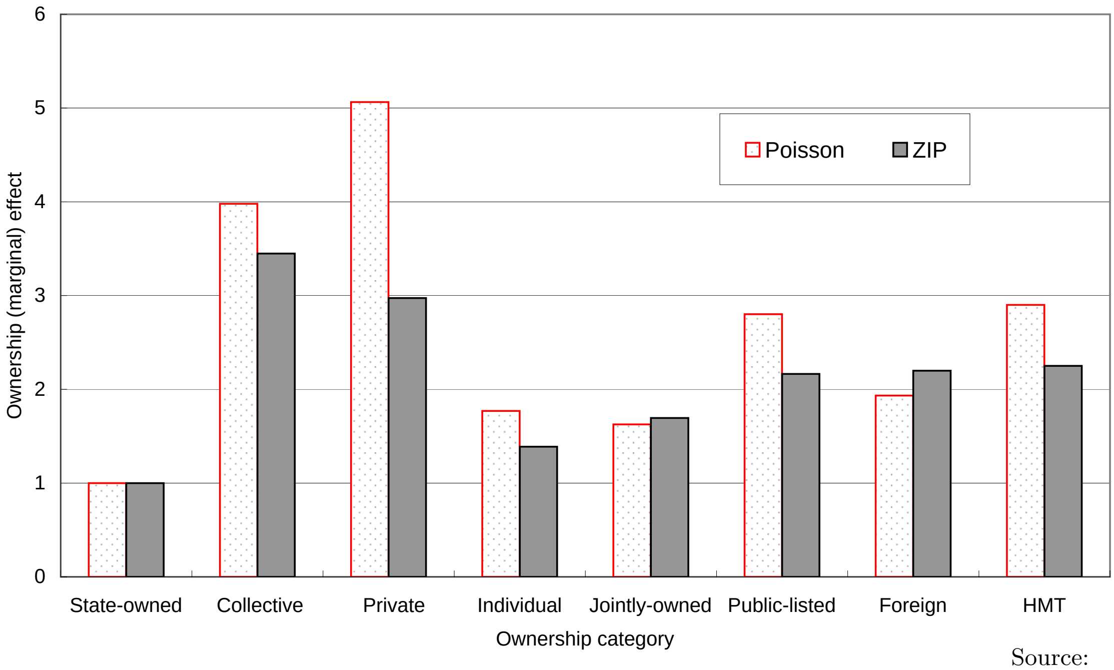
Source: authors' own tabulation using the LME data.

Figure 7: Industry Distribution of Foreign Direct Investment



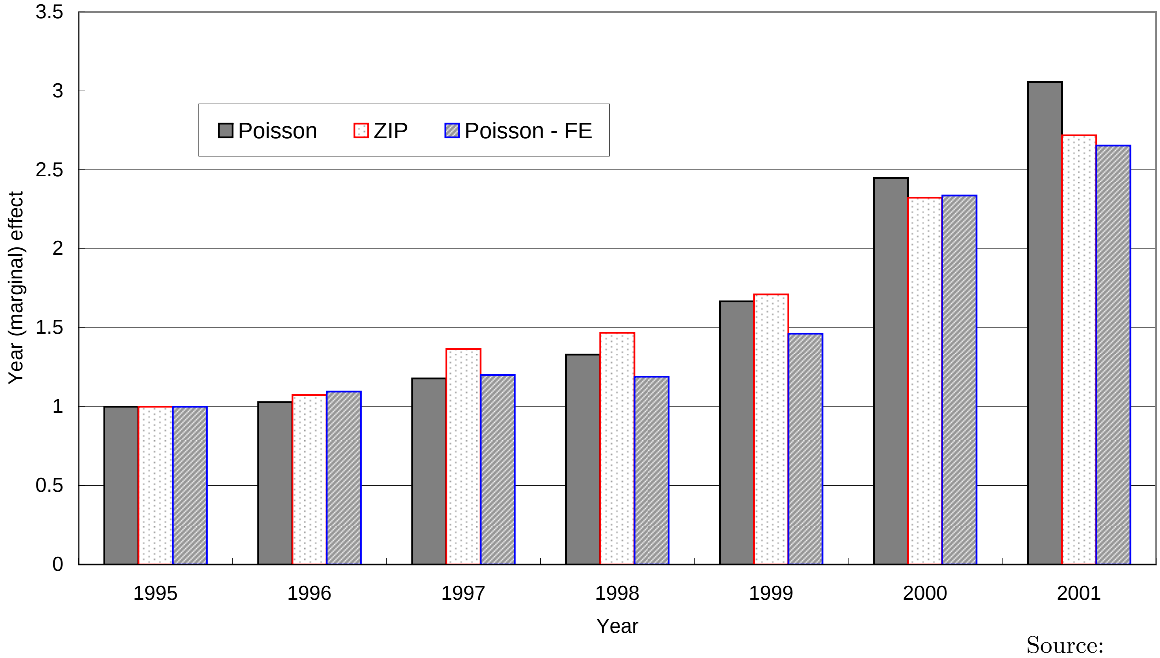
Source: authors' own tabulation using the LME data.

Figure 8: Enterprise Ownership and Propensity to Patent



Source: authors' own tabulation based on estimates in Table 2.

Figure 9: Propensity to Patent Over Time



Source: authors' own tabulation based on estimates in Table 2.

Table 1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Full sample					
Patent Applications	0.369	5.384	0	622	133444
Patent grants	0.165	2.764	0	497	97240
R&D/Labor	0.586	4.406	0	538.227	133349
Labor	1266.82	3085.726	51	197048	137618
Full sample: select discrete industries					
Patent Applications	0.212	2.513	0	250	36940
Patent grants	0.09	1.326	0	120	27456
R&D/Labor	0.472	3.386	0	232.262	36905
Labor	1274.8	2002.747	51	85099	38052
Full sample: select complex industries					
Patent Applications	0.763	10.063	0	622	29525
Patent grants	0.324	4.897	0	497	21194
R&D/Labor	1.121	5.975	0	419.512	29510
Labor	1360.083	2956.661	51	181143	30287
Full sample: domestic firms					
Patent Applications	0.365	5.673	0	622	111210
Patent grants	0.166	2.874	0	497	84128
R&D/Labor	0.466	3.37	0	538.227	111125
Labor	1383.065	3333.648	51	197048	114788
Full sample: foreign firms					
Patent Applications	0.386	3.441	0	181	19499
Patent grants	0.156	1.963	0	142	11708
R&D/Labor	1.285	8.164	0	419.512	19489
Labor	689.248	1090.007	51	25715	20029
Innovator sample					
Patent Applications	2.013	12.64	0	622	22598
Patent grants	0.917	6.598	0	497	16332
R&D/Labor	1.254	5.058	0	216.683	22594
Labor	2595.066	6768.394	53	197048	22833
Innovator sample: select discrete industries					
Patent Applications	1.528	6.635	0	250	4778
Patent grants	0.680	3.64	0	120	3417
R&D/Labor	1.159	4.020	0	95.485	4776
Labor	2049.236	4025.461	54	85099	4831
Innovator sample: select complex industries					
Patent Applications	2.621	18.866	0	622	7916
Patent grants	1.119	9.238	0	497	5703
R&D/Labor	1.737	6.359	0	216.683	7916
Labor	2372.893	5208.772	53	181143	8001

Table 2: Knowledge Production Function Estimation

	Poisson	ZIP	Poisson Fixed Effect	ZIP-domestic	ZIP-foreign
lgrd-nrdp	0.066**	0.007	0.027**	0.008	-.011
	(0.006)	(0.006)	(0.001)	(0.007)	(0.012)
log non-R&D labor	1.006**	0.588**	0.633**	0.631**	0.347**
	(0.045)	(0.051)	(0.018)	(0.056)	(0.059)
aFDI-va-3	2.121**	1.640**	0.467**	1.826**	1.409**
	(0.239)	(0.244)	(0.075)	(0.279)	(0.409)
lgrd-FDI	0.056**	0.021	-.002	0.038	0.024
	(0.021)	(0.019)	(0.004)	(0.028)	(0.025)
collective	1.306**	1.173**		1.168**	
	(0.147)	(0.161)		(0.162)	
private	1.496**	0.971**		0.978**	
	(0.217)	(0.197)		(0.21)	
individual	0.612**	0.358**		0.364**	
	(0.103)	(0.105)		(0.105)	
jointly owned	0.426	0.437		0.458	
	(0.311)	(0.324)		(0.324)	
public	0.968**	0.7**		0.71**	
	(0.104)	(0.104)		(0.107)	
foreign	0.517**	0.661**			
	(0.104)	(0.096)			
HMT	0.867**	0.625**			0.042
	(0.114)	(0.11)			(0.119)
1996	0.015	0.053	0.074**	0.041	0.293
	(0.101)	(0.109)	(0.025)	(0.115)	(0.279)
1997	0.154	0.305*	0.178**	0.318*	0.309
	(0.135)	(0.146)	(0.025)	(0.155)	(0.286)
1998	0.178	0.299	0.148**	0.29	0.466

	(0.146)	(0.157)	(0.025)	(0.174)	(0.244)
1999	0.354**	0.417**	0.337**	0.395**	0.632**
	(0.122)	(0.127)	(0.025)	(0.142)	(0.229)
2000	0.691**	0.671**	0.797**	0.6**	1.100**
	(0.108)	(0.115)	(0.025)	(0.13)	(0.231)
2001	0.826**	0.752**	0.913**	0.738**	0.992**
	(0.105)	(0.117)	(0.025)	(0.131)	(0.227)
Obs.	130603	130287	22556	110888	19399
e(ll)	-122757.7	-77619	-31001.2	-66679.48	-9581.85
e(ll-0)	-198220.8	-98590.5		-86748.03	-11501.57

Robust standard errors in brackets. Poisson and ZIP regressions include industry dummies.
* - significant at 95% level; ** - significant at 99% level.

Table 3: Patent Explosion and FDI

	All	Domestic	Foreign
log R&D/labor	0.012**	0.016**	-.001
	(0.004)	(0.005)	(0.006)
log Labor	0.611**	0.654**	0.37**
	(0.052)	(0.056)	(0.059)
Industry FDI	1.582**	1.727**	1.250**
	(0.214)	(0.233)	(0.355)
1996	0.05	0.035	0.274
	(0.109)	(0.115)	(0.28)
1997	0.291*	0.299	0.286
	(0.145)	(0.154)	(0.286)
1998	0.29	0.277	0.443
	(0.157)	(0.173)	(0.243)
1999	0.401**	0.374**	0.611**
	(0.127)	(0.142)	(0.23)
2000	0.659**	0.582**	1.073**
	(0.114)	(0.128)	(0.23)
2001	0.754**	0.739**	0.97**
	(0.114)	(0.129)	(0.226)
Obs.	130296	110895	19401
Log likelihood	-77462.18	-66591.43	-9546.604

Robust standard errors in brackets
All regressions include ownership and industry dummies.
* - significant at 95% level; ** - significant at 99% level

Table 4: Patent Explosion: Discrete Industries

	Beverage		Textile		Chemical		Pharmaceutical	
	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign
log R&D/labor	-.003	0.037	-.033	-.034	0.012	-.025	0.019	0.052*
	(0.009)	(0.022)	(0.027)	(0.023)	(0.015)	(0.021)	(0.014)	(0.022)
log Labor	0.706**	0.346*	-.303	0.372*	0.289*	0.812*	0.504**	0.33
	(0.131)	(0.16)	(0.2)	(0.166)	(0.14)	(0.316)	(0.094)	(0.189)
Industry FDI	1.757**	-.331	-.880	-.679	1.330**	5.404**	0.92	-4.259**
	(0.496)	(0.703)	(1.825)	(1.923)	(0.408)	(1.356)	(0.78)	(1.562)
Obs.	4153	914	13346	1589	10394	1128	3931	653
Log likelihood	-1808.817	-319.422	-2443.809	-154.741	-3569.909	-387.504	-2976.978	-605.32

Robust standard errors in brackets. All regressions include ownership dummies.

* - significant at 95% level; ** - significant at 99% level

Table 5: Patent Explosion: Complex Industries

	Special Machine		Transport Equipment		Electric Machinery		Electronics	
	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign
log R&D/labor	0.017*	-.007	0.019	-.018	0.019	-.025*	0.121	0.025
	(0.007)	(0.027)	(0.03)	(0.012)	(0.013)	(0.011)	(0.066)	(0.015)
log Labor	0.186**	-1.228**	0.357**	0.208	1.209**	0.564**	1.136**	0.841**
	(0.063)	(0.432)	(0.129)	(0.11)	(0.058)	(0.124)	(0.12)	(0.151)
Industry FDI	0.048	-.879	1.097**	2.450	4.007**	1.394	1.641*	4.650
	(0.646)	(2.197)	(0.355)	(1.347)	(0.978)	(1.105)	(0.716)	(3.291)
Obs.	7290	509	6833	1064	6031	1465	3815	1883
Log likelihood	-5718.707	-348.712	-5018.034	-544.093	-7055.946	-1090.982	-4107.094	-1218.042

Robust standard errors in brackets. All regressions include ownership and year dummies.
* - significant at 95% level; ** - significant at 99% level

Table 6: Patent Explosion and FDI: Innovators

	All	Domestic	Foreign
log R&D/labor	0.025^{**}	0.029^{**}	0.011^{**}
	(0.0008)	(0.0009)	(0.002)
log Labor	0.71^{**}	0.78^{**}	0.235^{**}
	(0.019)	(0.021)	(0.055)
Industry FDI	0.445^{**}	0.566^{**}	-.034
	(0.072)	(0.086)	(0.164)
1996	0.08^{**}	0.038	0.409^{**}
	(0.025)	(0.027)	(0.095)
1997	0.174^{**}	0.143^{**}	0.464^{**}
	(0.025)	(0.026)	(0.097)
1998	0.147^{**}	0.102^{**}	0.628^{**}
	(0.025)	(0.027)	(0.092)
1999	0.343^{**}	0.277^{**}	0.895^{**}
	(0.025)	(0.027)	(0.09)
2000	0.803^{**}	0.603^{**}	1.835^{**}
	(0.025)	(0.027)	(0.087)
2001	0.916^{**}	0.786^{**}	1.774^{**}
	(0.026)	(0.027)	(0.09)
Obs.	22559	19271	2431
Log likelihood	-30873.15	-24650.31	-4480.907

Standard errors in brackets
* - significant at 95% level; ** - significant at 99% level

Table 7: Patent Explosion: Innovators in Discrete Industries

	Beverage		Textile		Chemical		Pharmaceutical	
	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign
log R&D/labor	0.024**	0.087**	0.02**	0.131**	0.035**	-.013	0.018**	0.045**
	(0.005)	(0.017)	(0.005)	(0.048)	(0.005)	(0.009)	(0.006)	(0.015)
log Labor	0.805**	-.086	-.433**	2.693**	0.759**	-1.871**	1.250**	0.142
	(0.178)	(0.591)	(0.131)	(0.728)	(0.109)	(0.512)	(0.13)	(0.215)
Industry FDI	-.111	-4.583**	1.937	5.723	2.258**	-6.551*	1.042*	8.097**
	(0.822)	(1.241)	(1.845)	(4.216)	(0.512)	(2.706)	(0.45)	(1.645)
Obs.	732	129	722	70	1486	112	1107	167
Log likelihood	-810.221	-124.939	-987.277	-74.506	-1301.688	-213.533	-1260.749	-311.231

Standard errors in brackets. All regressions include year dummies.

* - significant at 95% level; ** - significant at 99% level

Table 8: Patent Explosion: Innovators in Complex Industries

	Special Machine		Transport Equipment		Electric Machinery		Electronics	
	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign
log R&D/labor	0.027**	0.014	0.056**	0.051**	0.004	-.010	0.049**	-.016**
	(0.003)	(0.015)	(0.003)	(0.01)	(0.002)	(0.006)	(0.005)	(0.005)
log Labor	0.764**	-1.686**	1.636**	2.591**	0.482**	0.362**	0.884**	0.903**
	(0.085)	(0.619)	(0.098)	(0.415)	(0.063)	(0.117)	(0.057)	(0.214)
Industry FDI	0.7	-5.632*	2.004**	12.110**	-.013	3.230**	-.503	-3.624**
	(0.586)	(2.405)	(0.53)	(2.128)	(0.319)	(0.719)	(0.31)	(0.786)
Obs.	2356	149	1676	225	1525	296	987	243
Log likelihood	-2507.688	-136.376	-2008.681	-220.786	-2455.904	-568.891	-1191.95	-599.985

Standard errors in brackets. All regressions include year dummies.

* - significant at 95% level; ** - significant at 99% level