A Great Wall of Patents: What is Behind China's Recent Patent Explosion?[1]

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Abstract

Over the past 20 years, patenting in China has grown at an annual double-digit rate, having further accelerated since 2000. 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 conditions that account for China's patent boom. While the overall intensification of research and development (R&D) in the Chinese economy tracks with patenting activity, is not the principal cause of the patent explosion. Instead, this paper finds that the growing intensity of foreign direct investment at the industry level, enterprise restructuring, and a shift in the industry structure of R&D toward complex R&D are raising R&D productivity and the propensity to patent in Chinese industry. Amendments to the patent law that favor patent holders also emerge as significant sources of China's surge in patent activity.

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I. Introduction

From 1986, the year following the reinstitution of China's Patent Law, patent applications grew at an average annual rate of 14 percent over the following decade. Then, during 1996 to 2004, the rate of patent applications further accelerated to an annual rate of 24 percent. 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 an average annual rate of 22 percent. 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 grown 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.[2] Since the mid-1980s, U.S. patenting has been growing at an annual rate of six percent – a modest rate in comparison 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 surge somewhat paradoxical and challenging to understand.

A confluence of events accompanied China's patent explosion. China has twice

[2] 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 (2005) for a synthetic analysis.

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?

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 later half of the decade, 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 surge of FDI can be expected to promote both the supply of patentable knowledge and the demand for patents. FDI is commonly assumed to lead to technology transfer to domestic firms thereby expanding their technological opportunities for patenting activity, even if most of the growing knowledge pool was created through imitation. Moreover, as competition stiffened in FDI rich industries, which also acquired diverse competing technologies, the need to protect 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 demonstrate 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 expanded technological opportunities for patenting while also increasing the stakes for owning patent rights for both foreign and domestic firms, thus leading to a higher propensity to patent.

This paper explores two other hypotheses that may explain the rapid rise in patenting activity in China. Each of these also potentially operates through both supply and demand channels. The first of these is enterprise restructuring, which accelerated during the latter half of the 1990s. This enterprise restructuring has facilitated legal and institutional changes that have produced more efficient systems of management and less ambiguous assignments of property rights in China's enterprise system. Some studies show that the return to patenting is higher in non-state enterprises, reflecting the ability of non-state enterprises to secure greater returns to their R&D resources as they do typically to production labor and capital. In addition, for a given R&D patent production technology, non-state enterprises are 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.

A final hypothesis examined in this paper is the 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, which include the beverage, textile, and chemical 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 new products that emerge within this growing sector would generate more patent applications, both due to the intrinsic nature of overlapping innovations and also due to the strategic advantage of creating portfolios of patents that can be used to gain the upper hand in competitive legal challenges.

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

1. The intensification of R&D in the Chinese economy channeled more resources into innovation activities that led to an increase in patentable technologies and the stream of patent applications and grants.
2. International economic integration, particularly the vast inflow of foreign direct investment, expanded technological and patenting opportunities for China's domestic firms. It also raised the stakes for protecting intellectual property rights in China for foreign firms and for domestic Chinese firms that can use patents as a strategic tool to compete with firms with foreign funds and technologies.
3. Economic reform that has extended and strengthened the role of management and private property in China's enterprise system has led non-state enterprises to produce patents more efficiently and to seek patent protection more aggressively than before.
4. Inter-industry differences, particularly differences between complex and discrete product industries and the shift toward complex products may result in a higher intensity of patenting activity in relation to new product innovation. Together with a legal system that is more sympathetic to patent rights, the shift toward complex product industries may be creating incentives to patent beyond the conventional objectives for patent applications.
5. The pro-patent amendments to the Patent Law in 1992 and 2000 raised the overall return to patent holders.

We investigate and differentiate these hypotheses by nesting them in a patent 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. Section five reviews the estimation results and draws inferences for the different explanations of China's patent explosion. Section six attempts to distinguish between the relative importance of competing explanations of the rise in the patent-R&D ratio, that is, increases in the knowledge production versus the propensity to patent out of a given body of knowledge.. Section seven presents our conclusions and related discussion.

II. China's patent system and the patent explosion

The Patent Law of the People's Republic of China, adopted on March 12, 1984, went into effect on April 1, 1985.[3] The law established a patent system that incorporated key features of those used in Europe and Japan. The priority in granting patents is based on the principle of "first-to-file" rather than the principle of "first-to-invent" used in the U.S. Chinese patent law also includes a pre-grant opposition system under which parties can file with the patent office objections to the grant of specific patents. 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. The amendments also extended the duration of invention patent protection from 15 to 20 years, while the duration of utility model and design patents increased from 5 to 10 years. Protection for manufacturing processes was extended to products directly obtained by the patented process. Also, a patentee has the right to prevent other persons from importing products covered by Chinese patents. The grounds for granting compulsory licenses were restricted. The pre-grant opposition was replaced by a post-grant revocation procedure – as a result,

[3] 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 signatory to the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS)[4], the National People's Congress again revised the Patent Law in August 2000.[5] In accordance with TRIPS requirements, the amendments provide patent holders with the right to obtain a preliminary injunction against an infringing party before initiating a lawsuit. The new law also stipulates standards for computing statutory damages where such standards had not previously existed. The amendments affirm that state and non-state enterprises enjoy equal treatment in obtaining patent rights. The amended law further simplifies the procedures of the application, examination, and transfer of patents and unifies the appeals system by removing the patent revocation procedure that had duplicated the invalidation procedure.

[Insert Figures 1a and 1b here]

2.2 The patent explosion

Both patent applications and grants took off in 2000. Although there was a small jump in patent applications and grants in 1993 following the first Patent Law Amendment, both patent applications and grants rapidly accelerated in 2000 coincident with the amendments enacted in that year. As shown in Figures 1a and 1b, the take-off is particularly striking for invention patents that are plotted against the right hand axis in both figures. Prior to 2000, applications for invention patents had been growing by less than 10 percent a year, while the rate of growth for all patent applications was 15 percent a year. Beginning in 2000 the annual rate of growth of

[4] 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).

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

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 2000 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 foreign applications pertained to invention patents, 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 1b shows similar patterns of growth for patents 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 2 here]

An immediate candidate explanation for the patent explosion is the intensification of R&D in the Chinese economy. During 1996-2003, the ratio of R&D expenditure to GDP rose to 1.3 percent, more than double the ratio of 0.6 percent in 1996. Figure 2 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 have both contributed to the substantial increase in the ratio of patents-R&D expenditure. Identifying the relative importance of the candidate hypotheses will require detailed analysis at the firm level.

III. Patenting by the large and medium size enterprises

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 (2001) provide a comprehensive description of this rich data set.[6] Our sample spans a period of seven years from 1995 to 2001 and includes data 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 3a – 3c here]

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 3a, 3b, and 3c 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),

[6] 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 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).

cultural and sports goods (24), food manufacture (14) and beverage (15), together account for about three quarters of all LME patent applications and over 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 3b and 3c. 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 4 here]

The rapid and expansive integration of China into the global economy and the fast growing domestic Chinese market has increased the importance of protecting intellectual property rights of multinational companies. As shown in Figure 4, 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.[7] Cohen, Nelson and Walsh (2001) described the key difference between the two kinds of technologies as "whether a new, commercializable product or process is comprised of numerous separately patentable

[7] See for example, Levin et al (1987) and Merges and Nelson (1990).

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 (2005) suggests that "…in complex product industries, firms are more likely to use patents to induce rivals to 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.

IV. 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 created technological spillovers while also raising 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 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 :

$$\Pr ob(Y_{it} = y_{it}) = e^{-\lambda_{it}} \lambda_{it}^{n} / y_{it}! \quad (1)$$

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

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 raises 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:

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

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

$$p_{it} = F(Z'\gamma) = \frac{1}{1-\exp(-Z'\gamma)} \tag{3}$$

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

$$\begin{aligned} L(\gamma, \beta; y, X, Z) = \sum_{y_i=0} \ln\{F(Z_i'\gamma) + [1-F(Z_i'\gamma)][-\exp(X_i'\beta)\} \\ + \sum_{y_i>0} \{\ln[1-F(Z_i'\gamma)] - \exp(X_i'\beta) + nX_i'\beta - \ln(y_i!)\} \end{aligned} \tag{4}$$

More general models of this type include the hurdle model of Mullay (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 (3).

Another issue that needs econometric treatment is firm heterogeneity. The variables we include in X 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 Levinthal 1992), 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.[8] There has been anecdotal evidence on Chinese firms taking

[8] 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

advantage of loopholes in the Chinese patent system in order to use patents to preempt competition from foreign firms.[9] 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.

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 and the incentive to create new intellectual property and to secure the rights to that property. 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 propensity to patent beyond what is induced by the

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distinction. For example, Cheung and Lin (2004) used provincial level patent applications data to investigate whether there is technology spillover from FDI and found supporting evidence.

[9] In a New York Times article (NYT, March 5, 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.

legislative changes.

[Insert Table 2 here]

V. Estimation results and discussion

5.1 The role of R&D

We first estimate a base-line version of the patents production function specified in equations (1) to (3) 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 is difficult to identify in time series data and within estimates.[10] 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 an extensive 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. By including both the log of R&D expenditure and the square of this variable, we test for the presence of scale economies in the patent production process. This functional form is similar to that used by Bound et al., who find evidence of scale economies in

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

patents production using U.S. manufacturing firm data.

Our preferred model in Table 2 is the ZIP model, the results of which are reported in column (2). 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 Poisson model in column (1) is 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 changes the estimation of the patents – R&D elasticity. ZIP generates a smaller elasticity estimate than Poisson does, i.e. 0.304 for the ZIP estimate versus 0.382 for the Poisson estimate. By comparison, the estimate of the patent-R&D elasticity obtained using the Poisson fixed effect estimation, which controls for firm heterogeneity, is substantially smaller than that obtained from either rthe Poisson or ZIP estimate. The estimate of 0.061 confirms finding in the R&D literature that once we dispose of the cross sectional differences across firms, the magnitudes of estimates of the patent-R&D elasticity substantially shrink. For this reason, and because 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 - we base our discussion and conclusion on the ZIP model.

The patents – R&D elasticity of 0.304 that we obtain by ZIP estimation in column (2) is quite small by OECD standards. 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. 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 an important contributor to China's patent explosion but not the only driving force behind this phenomenon. Indeed, given that during the relevant period, R&D spending doubled while patent applications trebled, in order to explain the entire increase in patent activity, the patent-R&D elasticity would need to be in the vicinity of 1.5, nearly five times the estimate that we obtain through the Poisson estimate.

Firm size, measured as the size of the non-R&D labor force, makes a significant contribution to patent production. Our estimate of the scale effect on patenting is similar to findings in the OECD literature. Several circumstances may explain the significant contribution of firm size, even after we control for R&D spending. One possibility is that larger manufacturing firms may benefit from learning by doing, that is the scale, and possibly scope, of manufacturing activity may serve as an important complement to the firm's R&D operation. Firms with high sales volume may also benefit more from securing patent rights than smaller firms. With larger incremental revenue streams associated with new products and processes, firm are more likely to incur the cost of the patent application process and the on-going renewal fees once their patents have been approved.

[Insert Figure 5 here]

We now analyze the contributions to patent production associated with factors other than R&D expenditure and firm size. These are enterprise restructuring, foreign direct investment, and the shift toward complex product production. In order to estimate the contribution of each of these to understanding the acceleration of patent activity from 1995 through 2001, we estimate a baseline measure of the of the contribution of R&D spending and firm size to patent production. We then add controls for enterprise ownership, industry FDI and shifts in industrial structure and evaluate the impact that the addition of each of these has on the increase in patenting activity that was attributed to the year dummies in the baseline regression. The baseline regression is shown in column (1) of Table 3. Relative to the initial estimate that included industry FDI and the ownership classifications, the baseline estimates yield an estimate of the patent-R&D expenditure elasticity of 0.354, similar to the 0.304 estimate of the initial estimate. The year dummies show a monotonic increase in the incidence of patenting after controlling for R&D and size. Relative to the productivity/propensity to patent in 1995, the increase becomes significant at the 95 percent level in 1997 and at the 99 percent level a year later. By 2001, the size of the estimated year dummy rises to 0.896, indicating that the incidence of patenting, other than that explained by R&D spending, was nearly 150 percent greater in 2001 than in 2005.

5.2 Foreign direct investment and patenting

We investigate how FDI has contributed to China's patent explosion in Table 3, where in addition to reporting results of the baseline regression, we report estimates when we include the FDI variable, again using the ZIP estimator. 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.

The effect of industry FDI on patents production is large. Column (2) of Table 3 shows that the elasticity of patent applications with respect to FDI is 1.51. This estimate indicates that a 10 percent increase in the foreign share of industry value added raises patent activity by fifteen percent.

The importance of FDI as a source of the patent explosion is also reflected in the change in magnitude of the year dummies as we move from column (1) of Table 3 to column (2). The upward trend in the patent residual survives as a robust result. However the magnitudes of the year dummies are considerably reduced with the introduction of the industry FDI variable. Comparing columns (1) and (2), the 2001 dummy declines from 0.896 to 0.650 once we control for industry FDI. This difference translates into a decline in the unexplained increase in patenting activity from 1995 to 2001 from 150 percent without the industry FDI control to 92 percent with the control. This result indicates that industry FDI by itself controls for about 39 percent of the unexplained portion of the patent explosion, after controlling for R&D spending.[11]

5.3 Enterprise restructuring and patenting

[11] Computed respectively as antilogs of 0.896 and 0.683.

The second half of the 1990s continuing into the early part of the current decade was marked by extensive restructuring of China's enterprise system. During this period, the number of state-owned enterprises classified as large and medium size declined from 68 percent in 1994 to just 38 percent in 2001. The data in Column (3) of Table 3 shows that relative to SOEs, jointly-owned enterprises show only a marginal advantage in patenting. In ascending order, other enterprises, foreign-owned enterprises, Hong Kong, Macao, and Taiwan (HMT) enterprises, public, private, and collective enterprises all show a greater incidence of patenting than their SOE counterparts. A comparison of the 2001 time dummy estimate in Column (3) relative to column (2) shows that when we add the ownership dummies, the unexplained rise in patent application activity falls to 0.565. The restructuring of Chinese enterprises, therefore accounts for another 13 percent of the unexplained acceleration in patent activity during 1995 to 2001.

5.3 Shift in industry composition

In column (4) of Table 3, we add a set of dummies, for the 28 two-digit industries included in our sample. We do not report these, but we do see from Table 3 that the dummy estimate for 2001 declines further to 0.519, thereby accounting for an additional 5 percent of the unexplained patent explosion. The complex product industries include special machinery, transport equipment, electric machinery, and electronics; the discrete products group includes the beverage, textile, chemical, and pharmaceutical industries. 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.

Within our population of LMEs, we find that from 1995 to 2001, the industry wide R&D to value added ratio rose from 1.09 to 3.06 percent, a total increase of 282 percent. The largest increase in R&D intensity was centered in the electronics and communication industry whose R&D/VA ratio rose from 1.35 percent in 1995 to 7.76 percent in 2001. Following the electronics and communication industries were the electronic equipment, machinery, and transportation equipment industries that together with electronics and communication rounded out the four most R&D intensive industries in 2001, while also exhibiting above average rates of growth of R&D intensity during 1995 to 2001. A shift in industry composition, including the relative intensification of R&D in the complex product industries appears to account for some portion of the rise in the incidence of patenting during following 1995.

5.4 Amendments to the patent law

The 2000 amendments were designed to bring China's patent law into closer conformance with TRIPS requirements. The domestic-foreign estimates shown in Table 4 shows an increase in the incidence of patenting in the domestic sector, but the increase from 1999 to 2000 is not highly statistically significant. By comparison, in the foreign sector, the increase in patenting from 1999 to 2000 is large and statistically significant at the 5 percent level. This comparison suggests that the foreign firms may have been, at least in their initial response to the patent amendments, more anxious and savvy in their ability to take advantage of the TRIPS conforming patent initiatives than their domestic counterparts. The retreat in patenting activity in the foreign sector from 2000 to 2001 as the domestic sector continued to increase its incidence of patenting, may suggest that as foreign firms rushed to patent a backlog of intellectual property to take immediate advantage of the conforming provisions of TRIPS, the domestic sector in turn responded to this surge of foreign patenting activity with a one-year lag.

5.5 Domestic versus foreign

In Table 4, we report the results for separate estimates of the domestic enterprise sample and the foreign sample. In particular, we examine whether foreign and domestic firms exhibit different patent production processes and whether they respond differently to concentrations of industry FDI. In particular, three contrasts between the domestic and foreign sector stand out.

First, the patent-R&D elasticity is smaller in the foreign sector. While Chinese patents for foreign firms are relatively weakly related to their R&D activity, R&D

makes a significant contribution to the patents production of domestic Chinese firms. The result reaffirms the general perception that the R&D conducted in China by foreign firms 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 may result from local innovation but the property rights of the patents are assigned to parent companies.

A second finding is that domestic firms are somewhat more sensitive to concentrations of industry FDI than their foreign counterparts. This finding is consistent with the expectation that domestic firms might benefit greater from technology spillovers from the foreign sector than FDI firms in the same sector. Also, in industries that are highly FDI intensive, we might anticipate that domestic firms more extensively engage in strategic patenting activity than their FDI counterparts in the same industries.

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 4a and 4b here).

VI. Productivity vs. propensity?

Firms patent for different reasons. According to the survey reported in Cohen, Nelson and Walsh (2001), 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.

Beginning around 1995, researchers observed a rapid increase in patenting in the

U.S. Documenting this jump in patent applications, Kortum and Lerner (1999) examine the hypothesis that the jump reflects an increase in the propensity to patent, driven by changes in the legal environment for patent holders. Specifically, in the U.S., in 1982 a special appellate court to hear patent cases was established by Congress. The new court's decisions have been widely regarded as being "pro-patent", leading to the notion that the friendly behavior of the new court has led to the surge in patenting. Kortum and Lerner contrast the friendly court hypothesis with a second alternative, which is that the jump in patenting reflects a widening set of technological opportunities, particularly in the biotechnology and software industries.[12]

Finding that the growth of patenting in the biotechnology and software industries explains little of the increase and also dismissing other competing hypotheses, Kortum and Lerner conclude that the management of innovation has changed involving a shift to more applied activities and also the more aggressive exploitation of the patent system as suggested by changes in the patenting and court procedures.[13] Overall, it appears that in the U.S. during the past decade, the propensity to patent has been a more important factor than productivity increase in explaining the rise in the ratio of patents to R&D effort.

There is no specific reason to believe that the hypothesis of an increase in patenting behavior that Kortum and Lerner stress for the U.S. should be applicable to China. However, there have been changes in the Chinese system that may invite the more aggressive use of the patenting system. We explore these as well as the arguments that productivity increases have driven China's patent explosion.

From the productivity perspective, there are well established reasons to expect that industry FDI, enterprise restructuring, and a shift in industrial structure toward industries with greater technological opportunity should result in an increase in R&R productivity. Industry FDI may serve as a production complement to R&D spending..

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[12] Kortum and Lerner also test a third hypothesis is the regulatory capture hypothesis. A variant of the friendly court hypothesis, the capture hypothesis sees the friendly attitude of the courts as an endogenous outcome of lobbying by large incumbent U.S. companies.

[13] These are explored in detail by Jaffe and Lerner (2004).

FDI may operate through its well-established channels to transmit and diffuse new technologies to the host country thereby increase opportunities for technology innovation and imitation among enterprises within the country, both domestic firms and FDI receiving firms. Likewise, by improving efficiency, enterprise restructuring may created more powerful incentives to use scarce R&D resources efficiently in for purposes of creating patentable knowledge. Finally, the shift toward complex production results in the creation of new products that include combinations of technology modules each of which may warrant patenting in order to secure the newly created intellectual property.

Alternatively, the surge of what appears to the growth of R&D productivity may in fact be an increase in the propensity of firm owners to convert knowledge into patents. We see in column (3) Table 4 that even though R&D plays a relatively weak role in patenting, foreign firms are also high motivated to patent in the presence of high concentrations of industry FDI. Moreover, the aggressive pursuit of patents and their subsequent enforcement by foreign invested firms may demonstrate for domestic Chinese firms the strategic value of holding patents.[14] 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 foreign firms.[15] 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

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[14] 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, Cheung and Lin (2004) used provincial level patent applications data to investigate whether there is technology spillover from FDI and found supporting evidence.

[15] In a New York Times article (NYT, March 5, 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 taking 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.

unable to exploit the potential differences in the motivation to apply for utility model and design patents

Enterprise restructuring that has the effect of strengthening incentives and managerial capabilities should be expected to enhance the productivity of knowledge production. Similarly, the strengthening of property rights associated with enterprise restructuring may motivate more restructured firms to seek to patent intellectual property, whether created within the firm or adopted from outside, in order to secure intellectual property and develop a strategic advantage.

Complex products, by their nature, possess components that are separable from the whole, interchangeable across products, and eligible to be patented separately. Hence, R&D that creates a similar number of products in discrete and complex industries can be expected to yield a larger number of patents in the discrete industry. However, the larger number of technology subcomponents and their interchangeability found in discrete R&D and manufacturing, also creates a premium of establishing intellectual property rights for those components that can serve a variety of functions. They fit into a portfolio of intellectual property in diverse ways that may invite competitive strategic patenting relative to discrete industries in which individual products typically have a single patent associated with them.

In conclusion, we are not able to draw a sharp quantitative distinction between the contributions of R&D productivity gains and the propensity to patent as explanations of China's ratio of patent to R&D effort. Industry FDI, a sharper definition of property rights, and the opportunities for strategic legal challenges associated with complex product patenting all lead us to believe that the growth of these factors – industry FDI, ownership restructuring, and changes in industry structure – have all given rise to more aggressive patenting behavior. Even if these factors have largely resulted in productivity gains, a substantial portion of the increase in the residual – about 40 percent – continues to be unexplained. Factors identified by Cohen et al (2001), including blocking rival patents on related innovations, avoiding law suits, use in negotiations, and enhancing reputation, may well explain a substantial portion of China's patent explosion.

VII. 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 coincides 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 labor. Studies for the U.S. usually generate elasticity estimates that are multiples of our estimate of around 0.30. 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. The growth of industry FDI, acceleration of enterprise restructuring, and a shift toward discrete product R&D are likely to contribute in some measure toward the rising productivity of R&D.

However, we have also identified reasons to believe that industry concentrations of foreign direct investment significantly contributes to the propensity to patent among both foreign and 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.

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 a developing economy; it is on our future research agenda.

References

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

Bound, John, Cummins, Clint, Grilishes, Zvi, Hall, Browyn H., and Jaffe, Adam. 1982, "Who Does R&D and Who Patents?" NBER Working Paper Series, no. 908, June.

Cheung KY, and Lin P, "Spillover effects of FDI on innovation in China: Evidence from the provincial data," *China Economic Review* 15 (1): 25-44 2004

Cohen, W. M., and Levin, R. C. "Empirical Studies of Innovation and Market Structure." In R. Schmalensee and R. D. Willig eds. *Handbook of Industrial Organization*. New York: North-Holland. 1989.

Cohen, Wesley W., Nelson, Richard R., and Walsh, John P., "Protecting Their Intellecutal Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)." *National Bureau of Economic Research Working Paper* No. 7552. Cambridge, MA. February 2000.

Crepon, Bruno and Duguet, Emmanuel. "Research and Development, Competition and Innovation Pseudo-maximum Likelihood and Simulated Maximum Likelihood Methods Applied to Count Data Models with Heterogeneity." *Journal of Econometrics*. 79: 355-378. 1997.

Hall, Bronwyn H. "Exploring the Patent Explosion," *Journal of Technology Transfer*, forthcoming.

Hall, Bronwyn H. and Ziedonis, Rosemarie Ham, "The Patent Paradox Revisited: an Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979-1995," *Rand Journal of Economics*, 32(1): 101-128. Spring 2001.

Hausman, Jerry., Hall, Bronwyn H., and Griliches, Zvi, "Econometric Models for Count Data with an Application to the Patents – R&D Relationship," *Econometrica*. 52: 909 – 938. 1984.

Jaffe, Adam and Lerner, Josh, *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.

Kortum, Samuel and Lerner, Josh, "What is Behind the Recent Surge in Patenting?" *Research Policy*, 28: 1-22, 1999.

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

Levin, R. C., Klevorik, A.K., Nelson, R. R., Winter, S. G., “Appropriating the Returns from Industrial Research and Development,” *Brookings Papers on Economic Activity: Special Issue on Microeconomics*, Pp. 783-831. 1987.

Licht, Georg and Zoz, Konrad, “Patents and R&D: an Econometric Investigation Using Applications for German, European and US Patents by German Companies,” in David Encaoua, Bronwyn H. Hall, Francois Laisney and Jacques Mairesse (eds.), *The Economics and Econometrics of Innovation*. Dordrecht, the Netherlands: Kluwer Academic Publishers. 2000.

Merges, R. P. and Nelson, R. R. “On the Complex Economics of Patent Scope,” *Columbia Law Review*. 90: 839-916. 1990.

Mullahy, John. “Specification and Testing of Some Modified Count Data Models,” *Journal of Econometrics*. 33: 341-365. 1986.

NYT. “Whose Patent is it, anyway?” by Howard French, New York Times, March 5, 2005.

Schumpeter, J. A. (1942) *Capitalism, Socialism, and Democracy*. New York: Harper.

Figure 1a
Domestic and Foreign Patent Applications

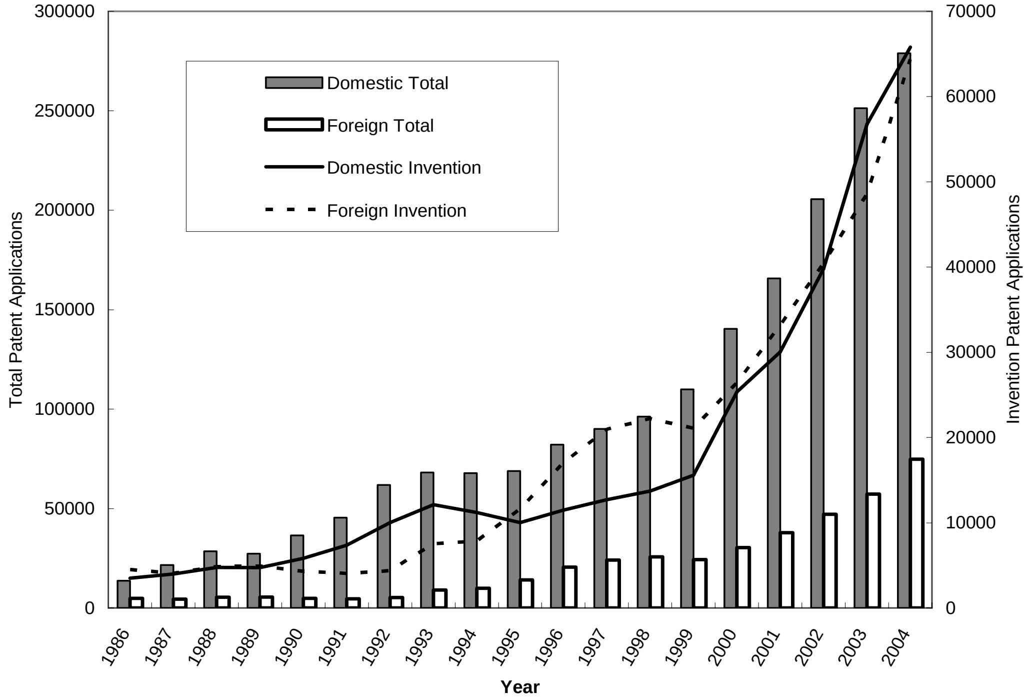

Figure 1b
Domestic and Foreign Patent Grants

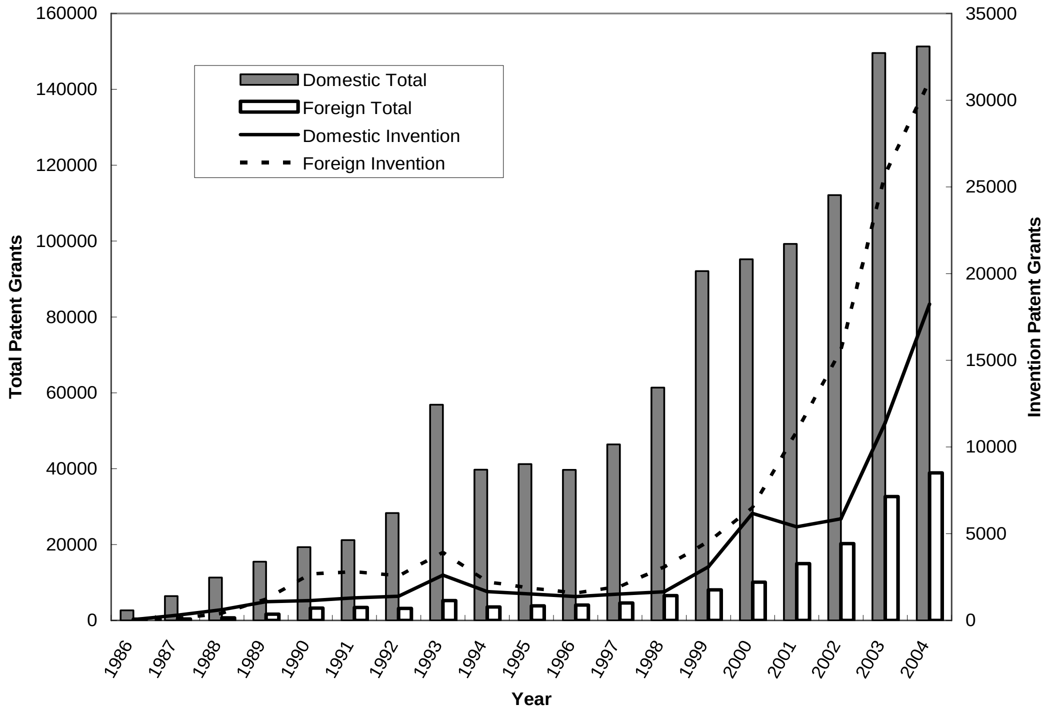

Figure 2
patents - R&D ratio and R&D - GDP ratio

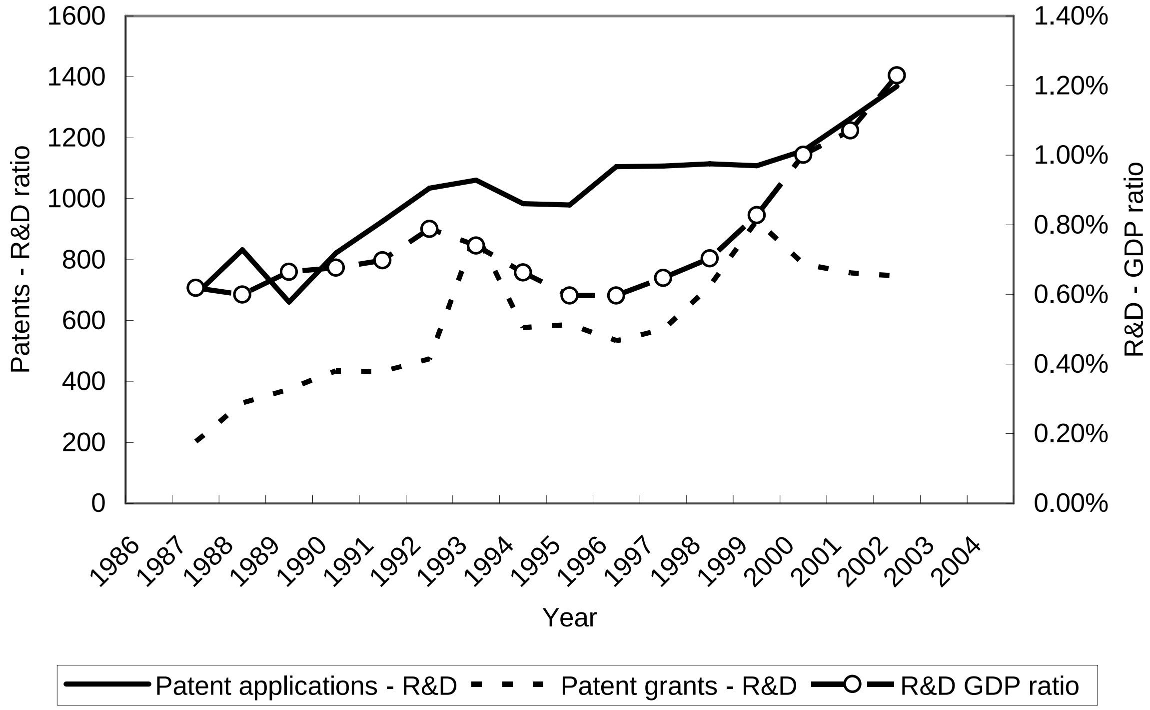

Figure 3a
Industry distribution of patent applications: 1995 - 01

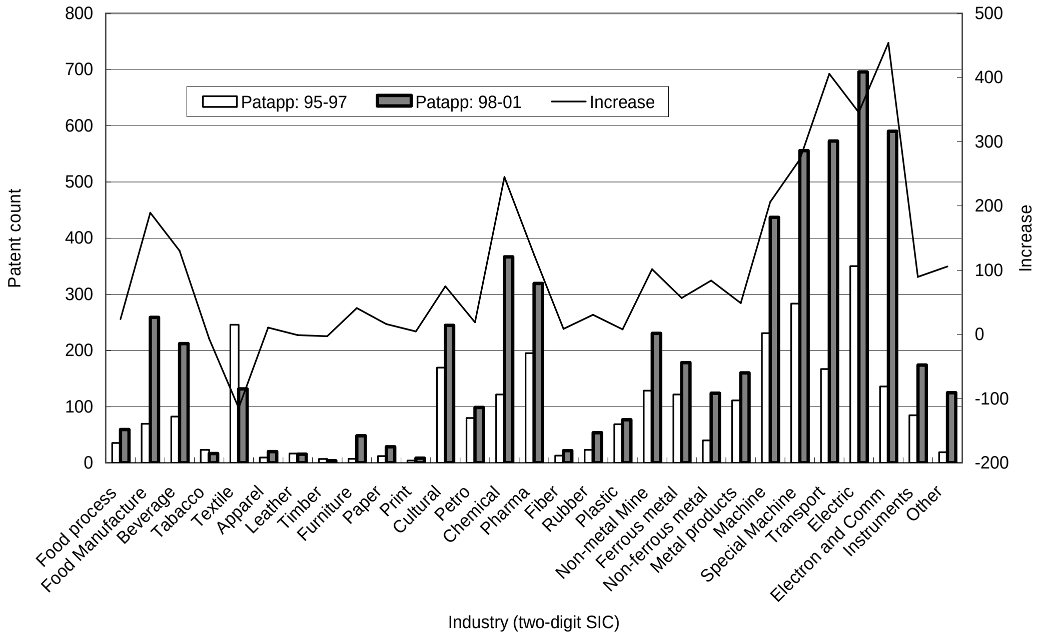

Figure 3b
Industry distribution of patent applications: domestic firms, 1995 - 01

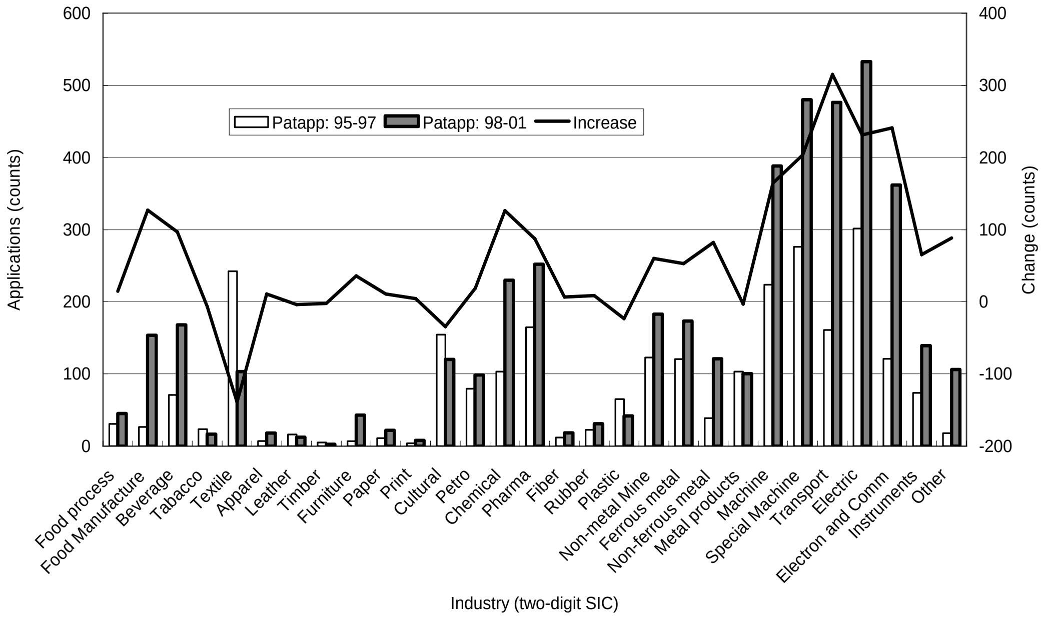

Figure 3c
Industry distribution of patent applications: foreign, 1995 - 01

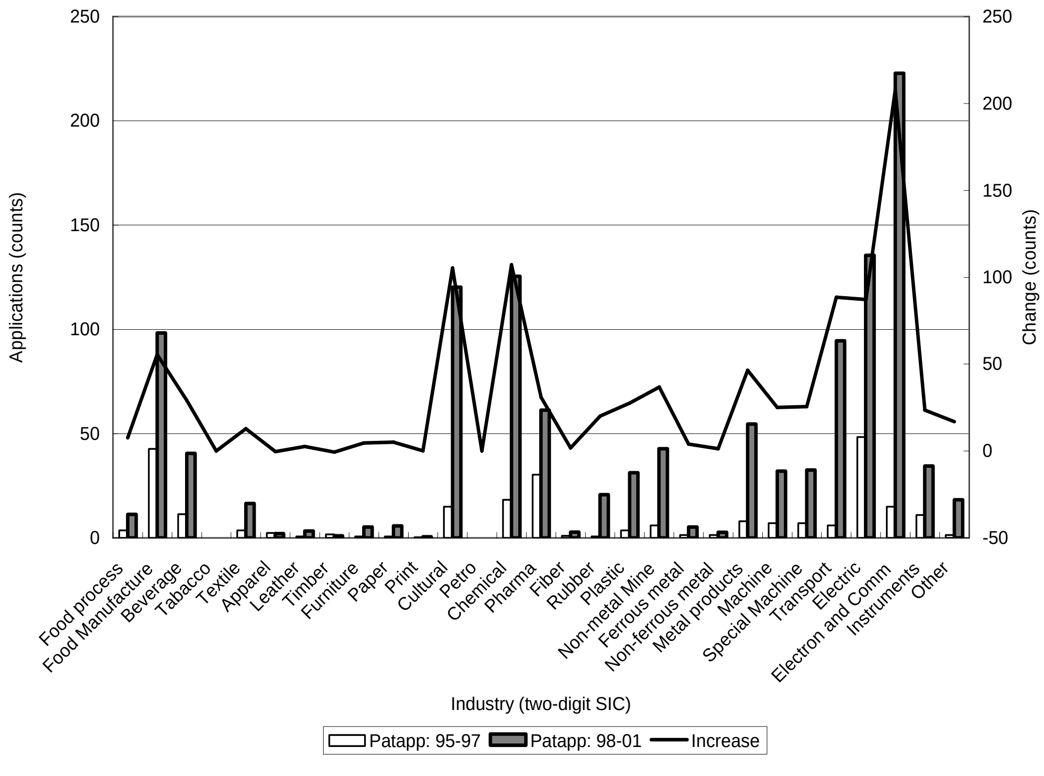

Figure 4
Industry FDI: 1995 - 2001

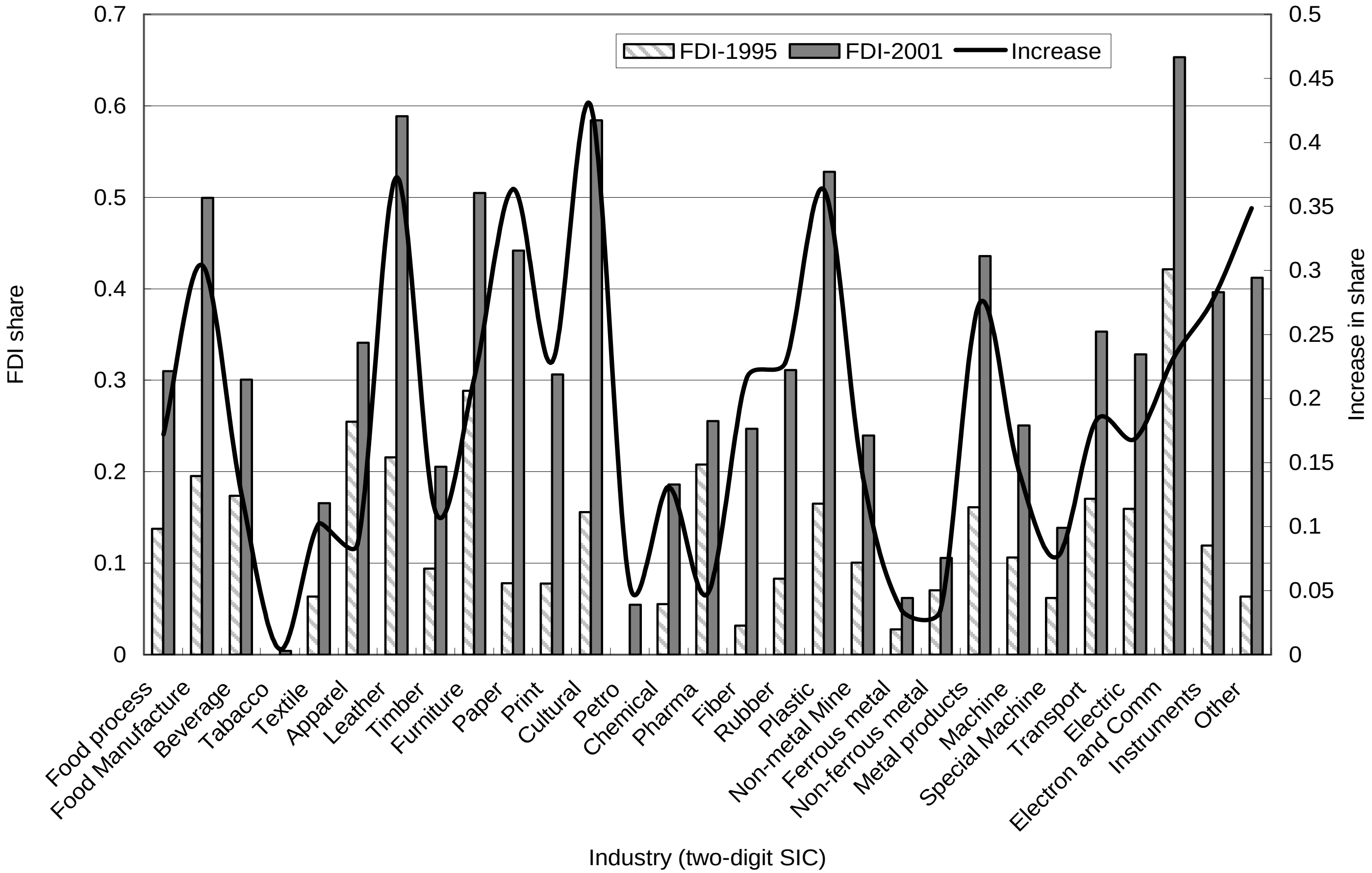

Table 1
Summary statistics

	Patent Applications	Patent Grants	R&D – labor Ratio	Labor
Full sample: N = 133444				
Mean	0.369	0.165	0.586	1266.820
St. Dev.	5.384	2.764	4.406	3085.726
Min.	0	0	0	51
Max.	622	497	538.2266	197048
Full sample of selected discrete industries: N = 36940				
Mean	0.212	0.090	0.472	1274.800
St. Dev.	2.513	1.326	3.386	2002.747
Min.	0	0	0	51
Max.	250	120	232.2623	85099
Full sample of selected complex industries: N = 29525				
Mean	0.763	0.324	1.121	1360.083
St. Dev.	10.063	4.897	5.975	2956.661
Min.	0	0	0	51
Max.	622	497	419.5119	181143
Full innovator sample: N = 22598				
Mean	2.013	0.917	1.254	2595.066
St. Dev.	12.640	6.598	5.058	6768.394
Min.	0	0	0	53
Max.	622	497	216.6831	197048
Innovator sample of selected discrete industries: N = 4778				
Mean	1.528	0.680	1.159	2049.236
St. Dev.	6.635	3.640	4.020	4025.461
Min.	0	0	0	54
Max.	250	120	95.48544	85099
Innovator sample of selected complex industries: N = 7916				
Mean	2.621	1.119	1.737	2372.893
St. Dev.	18.866	9.238	6.359	5208.772
Min.	0	0	0	53
Max.	622	497	216.6831	181143

Table 2

Poisson and ZIP estimates: patent applications

	(1) Poisson	(2) ZIP	(3) Poisson – FE
Log(R&D)	0.144**	0.066**	0.035*
	[0.007]	[0.006]	(0.001)
$[Log(R\&D)]^2$	0.018**	0.018**	0.002**
	(0.001)	(0.001)	[0.0003]
Log(labor)	0.644**	0.329**	0.566**
	(0.039)	(0.038)	[0.019]
Industry FDI	1.719**	1.496**	0.505*
	(0.192)	(0.199)	(0.072)
Ownership dummies	yes	yes	yes
Industry dummies	yes	yes	yes
Year dummies	yes	yes	yes
Observations	130,603	130,287	22,556
Log likelihood	-116081.9	-72082.09	-30960.86
Total elasticity	0.382	0.304	0.061

Robust standard errors in brackets. * significant at 5%; ** significant at 1%

Figure 5
Ownership effect

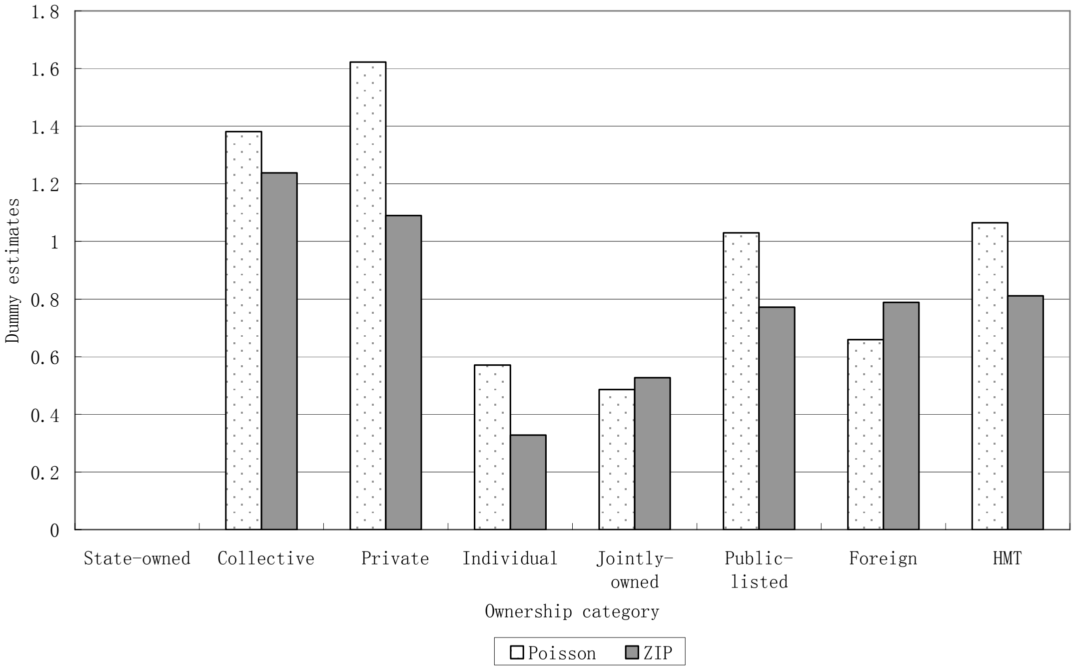

Figure 6
Time trend of propensity to patent

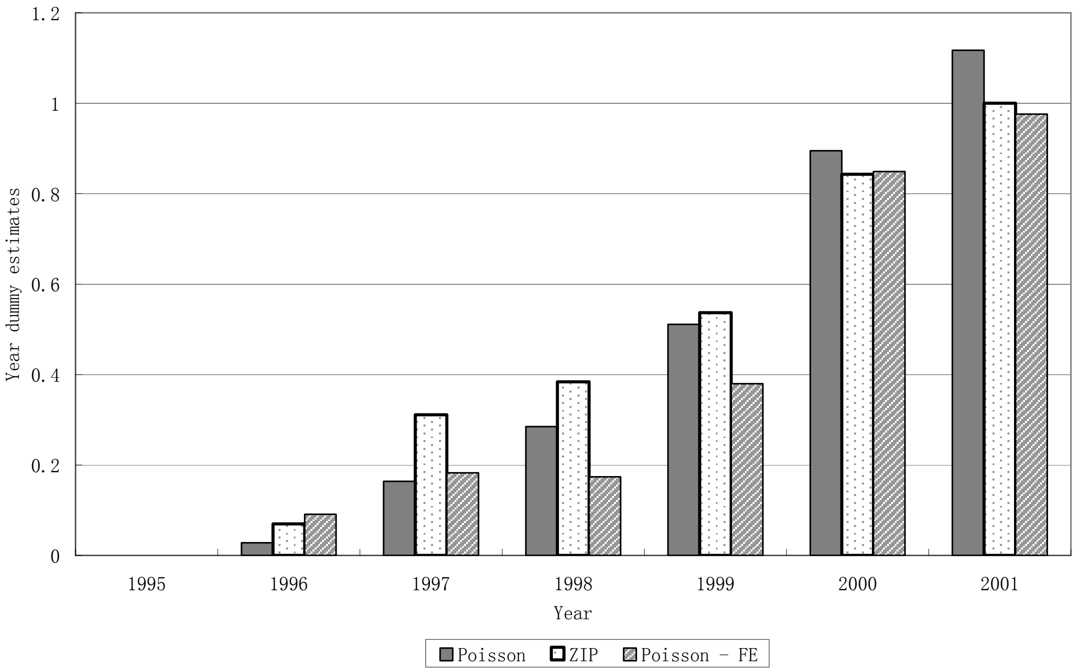

Table 3: Patent explosion: candidate explanations

	(1) baseline	(2) FDI	(3) ownership	(4) industry
Log(R&D)	0.076**	0.064**	0.062**	0.066**
	(0.007)	(0.007)	(0.007)	[0.006]
$[\text{Log(R\&D)}]^2$	0.021**	0.018**	0.017**	0.018**
	(0.002)	(0.002)	(0.002)	(0.001)
Log(labor)	0.108**	0.209**	0.301	0.329**
	(0.026)	(0.030)	(0.034)	(0.038)
Industry FDI	-	1.510**	1.360**	1.496**
	-	(0.155)	(0.153)	(0.199)
collective	-	-	1.250**	1.003**
	-	-	(0.158)	(0.114)
private	-	-	1.130**	0.936**
	-	-	(0.200)	(0.187)
jointly owned	-	-	0.431	0.315
	-	-	(0.342)	(0.337)
public	-	-	0.722**	0.585*
	-	-	(0.098)	(0.100)
foreign	-	-	0.430**	0.390**
	-	-	(0.106)	(1.102)
HMT	-	-	0.000	0.511**
	-	-	(0.735)	(0.108)
Other	-	-	0.316**	0.283**
	-	-	(0.088)	(0.087)
Industry dummies	no	No	no	yes
1996	0.075	0.063	-0.027	-0.038
	(0.120)	(0.119)	(0.114)	(0.108)
1997	0.358*	0.336*	0.228	0.200
	(0.156)	(0.156)	(0.149)	(0.143)
1998	0.532**	0.408**	0.320	0.295*
	(0.150)	(0.153)	(0.153)	(0.145)
1999	0.643**	0.503**	0.386**	0.338*
	(0.122)	(0.125)	(0.122)	(0.115)
2000	0.818*	0.650**	0.524**	0.477**
	(0.109)	(0.107)	(0.108)	(0.105)
2001	0.896**	0.683**	0.565**	0.519**
	(0.105)	(0.104)	(0.106)	((0.106)
Observations	133016	130296	130287	130287
Log likelihood	-83045.52	-77462.18	-76047.21	-72082.09

Robust standard errors in parentheses: * significant at 5%; ** significant at 1%

Table 4
Domestic-foreign difference

	(1) All	(2) Domestic	(3) Foreign
Log(R&D)	0.066**	0.074**	0.018*
	[0.006]	(0.007)	(0.008)
$[Log(R\&D)]^2$	0.018**	0.019**	0.006**
	(0.001)	(0.001)	(0.002)
Log(labor)	0.329**	0.333*	0.283**
	(0.038)	(0.043)	(0.063)
Industry FDI	1.496**	1.601**	1.253**
	(0.199)	(0.207)	(0.363
Ownership dummies	yes	yes	yes
Industry dummies	yes	yes	yes
1996	-0.038	-0.066	0.273
	(0.109)	(0.115)	(0.276)
1997	0.200	0.201	0.270
	(0.143)	(0.153)	(0.279)
1998	0.295*	0.292	0.419
	(0.145)	(0.157)	(0.238)
1999	0.338**	0.314**	0.564*
	(0115)	(0.125)	(0.223)
2000	0.447**	0.376**	1.003**
	(0.105)	(0.116)	(0.225)
2001	0.519*	0.474**	0.889**
	(0.106)	(0.118)	(0.227)
Observations	130287	110888	19,399
Log likelihood	-30960.86	-61207.21	-9515.25

Robust standard errors in brackets: * significant at 5%; ** significant at 1%

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