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

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Abstract

Patenting in China has been growing at an annual double-digit rate over the past 20 years with a marked acceleration 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 factors that account for China's patent boom. While the intensification of research and development (R&D) in the Chinese economy tracks with patenting activity, it explains only a fraction of the patent explosion. We find that a confluence of events and developments has been driving the patent explosion. The growing intensity of foreign direct investment in China is prompting Chinese firms to file for more patent applications. 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.

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1 Introduction

Chinese patent applications have been growing at an annual rate of over 15 percent since 1986, the year following the reinstitution of China's Patent Law. 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, patent applications filed by foreign inventors have grown at an 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. A number of authors have observed a world wide surge in patenting, particularly that in the U.S. since the mid-1980s, patenting has been growing at an annual rate of six percent. This compares modestly with the magnitude of the Chinese patent explosion. Another and perhaps more striking feature of the dramatic upsurge in patenting in China is that it has taken place in a legal environment where intellectual property rights protection continues to be weak and the rule of law not well established. These weaknesses in China's patent system presumably lead to weak incentives to patent, which make the causes of the surge particularly challenging to unravel.

A confluence of events that have accompanied China's patent explosion also provide candidate explanations. 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?

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 then continuing to climb to 1.35 percent in 2004. 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, 2008). One possible explanation of the surge 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 thereby leading to a higher propensity to patent.

Differences in the inter-industry incidence of patenting are often associated with "complex" and "discrete" product industries. The former industries develop new products or processes that consist of numerous separately patentable elements versus relatively few patentable elements in the discrete product industries. As a consequence, firms in complex product industries typically build up portfolios of intellectual property rights in order to gain a competitive edge in licensing negotiations. A structural shift of Chinese industry towards more complex industries would lead to a higher incidence of patenting.

Finally, the Chinese government accelerated ownership restructuring of the state-owned enterprises in the mid-1990s. Legislative changes that affirm private property rights and institutional changes such as the withdraw of local government from certain collectively owned enterprises have produced less ambiguous assignments of property rights in China's enterprise system. The increasing entry of non-state enterprises and the comparatively strong incentive of these enterprises to assert their property rights including those over intellectual property could also have contributed to China's patent

upsurge.

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.

This paper contributes to the literature that investigates how patent protection affects the rate and direction of technological change by providing evidence from the largest and fastest growing developing country against a backdrop of aggressive international harmonization of intellectual property rights protection that has been institutionalized through the Trade-related Aspects of Intellectual Property Rights (TRIPs) agreement. To foreshadow the results of the paper, we do not find evidence of a strong link between stronger patent protection and innovation in Chinese industry; instead, foreign direct investment and institutional changes induced by China's transition to market economy have had deep impact on the patenting decision of Chinese firms, thus enriching our understanding of the complexity of intellectual property protection in the process of economic development.

The remainder of the paper is organized as follows. The next section reviews the literature that investigates the causes of the U.S. patent explosion. Section three describes China's patent system and the government's attempts to restructure it. Section four 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 five. In section six we draw inferences for the different hypotheses of China's patent explosion based on the estimation results. Section seven presents our conclusions and related discussion.

2 Patent regime and patent explosion in the U.S. and beyond

The incidence of patenting has grown rapidly worldwide. This has often been concurrent with reform of patent laws that many countries have undertaken over the last

two decades. The proliferation of patent law reform has produced a fertile ground of empirical economic research, where economists take such incidences of change in patent regime as pseudo-natural experiments and investigate the question of how changes in the strength of patent protection affect the rate and direction of technological innovation. The literature is built upon the intellectual foundation laid by Nordhaus' (Nordhaus, 1969) pathbreaking work that showed a fundamental tradeoff between achieving dynamic efficiency through granting innovators strong patent rights and curbing the static inefficiency such monopoly power generates.

The patent explosion in the U.S. has particularly been well documented and analyzed. Studies have proposed and examined a plethora of hypotheses that potentially explain the patent upsurge. Kortum and Lerner (1999) investigated three alternative hypotheses: the friendly court hypothesis, the fertile technology hypothesis, and the regulatory capture hypothesis. The first of these refers to a series of pro-patent legislative developments that may have increased the propensity to patent. In contrast, the fertile technology hypothesis is predicated on three conditions: the expansion of technology opportunities, particularly in industries such as biotechnology and information technology and software, higher productivity of innovation due to the applications of information technology to R&D, and innovation in the management of R&D that is characterized by a shift towards applied R&D activities. The third hypothesis - the regulatory capture hypothesis - maintains the pro-patent legal developments were driven by the efforts of large U.S. firms to weaken the competitive edge of domestic and foreign entrants. Using aggregate patent data from the U.S. and international patent data, Kortum and Lerner through a process of elimination concluded that the U.S. patent explosion has been primarily driven by "changes in the management of innovation involving a shift to more applied activities."

Combining information from interviews and with firm-level economic data, Hall and Ziedonis (2001) examined the patenting behavior of 95 U.S. firms in the semiconductor industry, which had not traditionally relied on patents as a means to protect its intellectual property and yet had seen a sharp rise in patenting since the mid 1980s. They found evidence of "patent portfolio races" among these semiconductor firms following

the series of pro-patent legislative changes in the 1980s. Such races, they argued, were driven by the firms' incentive to enhance their bargaining position in the ensuing patenting licensing negotiations or patent litigations. In a recent synthesis, 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.

There is no consensus as to what is behind the U.S. patenting surge. Given the enormous inter-industry differences in technology opportunity and propensity to patent, it seems that there is room for both the fertile technology and the strategic patenting hypotheses in accounting for the patent explosion. Neither case supports a connection between changes in patent regime and innovation.

Studies that investigated the patent protection and innovation link outside the U.S. also reported mixed evidence. For example, Sakakibara and Branstetter (2001) examined the effects of a change in the Japanese patent system in 1988, which effectively expanded patent protection in Japan by increasing patent scope. They hypothesized that if the increase in patent scope had increased the return to innovation, this should be reflected in both higher R&D spending and more patents produced. They found no evidence for either potential outcome. Lanjouw and Cockburn (2001) focused on the response of the global pharmaceutical industry to the trend of strengthening IPR that started with GATT negotiations in the mid 1980s. Their approach was to identify potential shift of the research focus of the pharmaceutical industry as a result of the increasing strength of IPR protection in developing countries.Their data showed that research related to malaria increased significantly from the mid-1980s. Since there was no indication of any change in technology opportunity, the shift could only have come from the demand side, which the strengthening of IPR could have played a role.

3 China's patent system and the patent explosion

3.1 China's patent system

China passes its first patent law in 1984 that helped to create a patent system that was similar to those used of Europe and Japan.[1] 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.

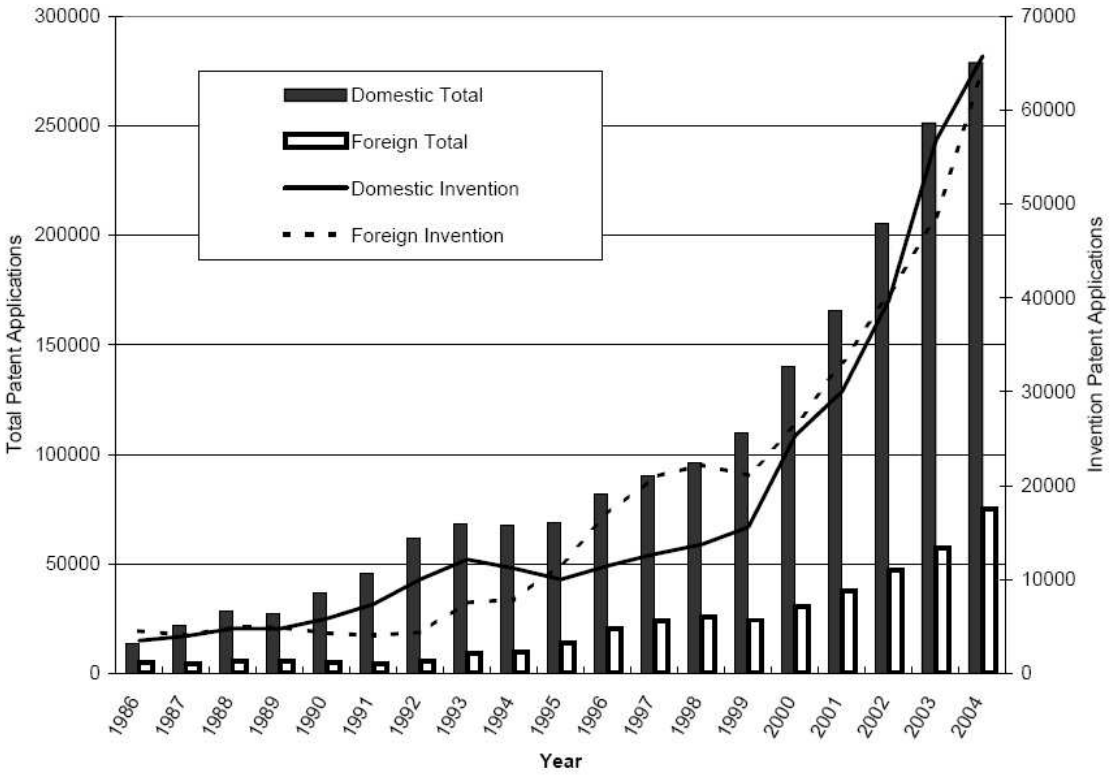
China's Patent Law was amended in 1992 to broaden the scope and extend the length of patent protection. For example, patent protection was extended to cover pharmaceutical products, food, beverages, flavorings, and substances obtained by means of chemical processes. The duration of invention patent protection was extended from 15 to 20 years, while that of utility model and design patents increased from 5 to 10 years. Administrative procedure was also streamlined to expedite process of patent application.

In preparation for accession to the World Trade Organization (WTO), in particular to fulfill member country's obligations under TRIPS,[2] China overhauled the Patent Law in 2000. In accordance with TRIPS requirements, the amendments provide patent holders with the right to obtain a preliminary injunction against the infringing party before filing a lawsuit. The new law also stipulates standards, not previously existing, to compute statutory damages. 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 had also served as the invalidation procedure.

[1] For example, 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.

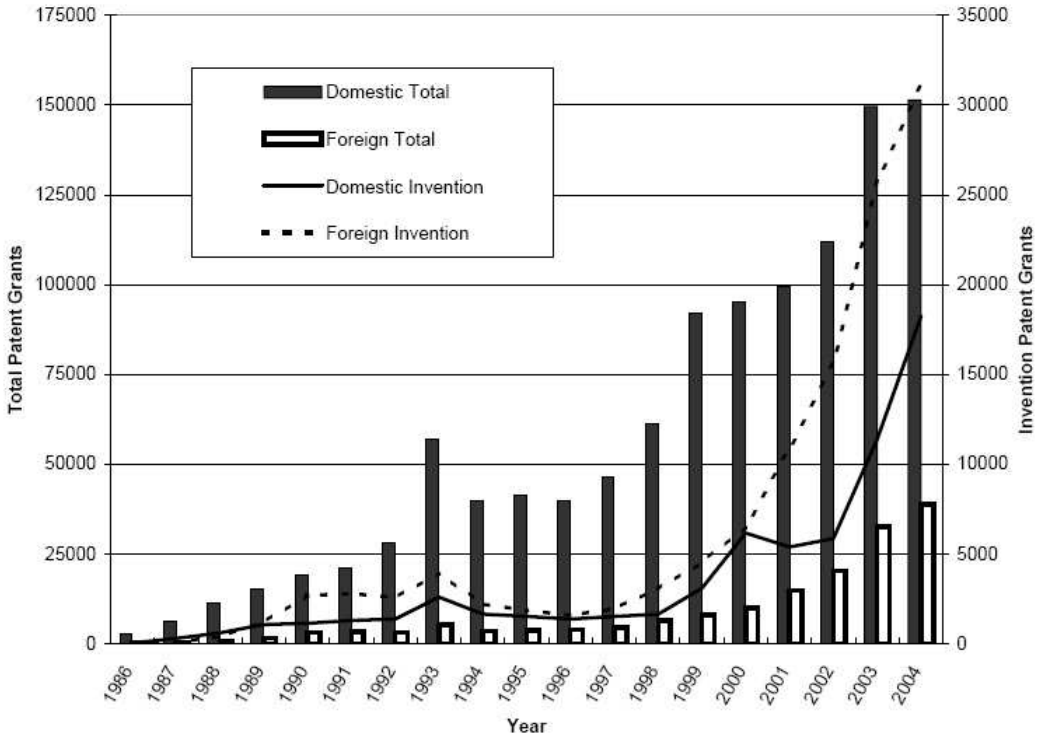
[2] Over the years China has also joined a number of international conventions for IP protection. In 1984, China became a signatory party to the Paris Convention on the Protection of Industrial Property and the Treaty on Intellectual Property in Respect of Integrated Circuits in 1990. In 1994, China 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).

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



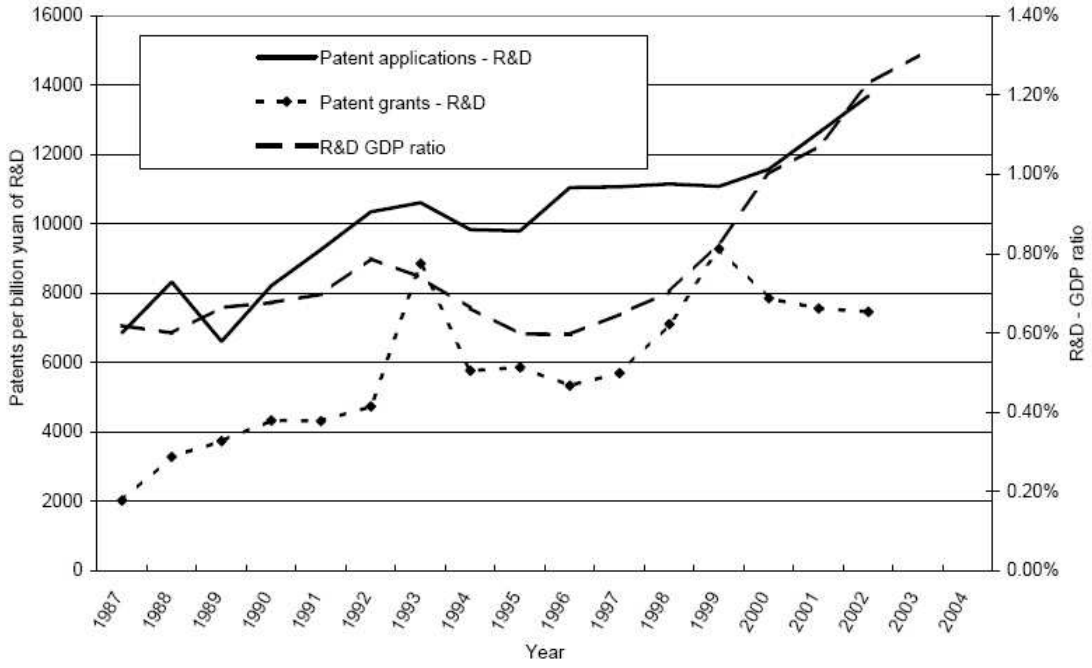
Source: web site of China's National Bureau of Statistics - www.stats.gov.cn.

3.2 The patent explosion

Patent applications and grants surged in 2000, although prior to that there was a small blip in 1993 after the first Patent Law Amendment. The take-off is particularly striking for invention patent applications that are plotted against the right hand axis in Figure 1. 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. More than 85 percent of foreign applications were for invention patents in 2004, while less than a quarter of domestic

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.

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 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.

The intensification of R&D in the Chinese economy, with the ratio of R&D expenditure to GDP more than doubling during 1996-2003, reaching a level of 1.3 percent in 2003, could potentially account for the patenting surge. 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.

4 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 Statistics (NBS) conducts annually. Jefferson, Hu, Guan and Yu (2003) provided a comprehensive description of this rich data set.[3] 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 most likely understate the technological capability of China's LMEs as it is reasonable to assume that relative to patents taken out by small enterprises and individual inventors, LMEs disproportionately focus on invention patents.

Table 1 tabulates the number of patent applications filed in 1995 and 2001 by the top ten patenting industries. Transportation equipment, electrical machinery and equipment, electronics and telecommunications equipment, ordinary machinery, special equipment, chemical, pharmaceutical, beverage, food manufacture and textile, together accounted for 70 percent of all LME patent applications in 2001 and the same share of the total increase in patent applications from 1995 to 2001. Electronics and telecommunications equipment industry has seen its patent applications increasing by more than seven fold over the six year span.

[3]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).

Table 1: Top patenting industries in 2001

All LMEs			Domestic LMEs			Foreign LMEs		
Industry	1995	2001	Industry	1995	2001	Industry	1995	2001
Electron and Comm	121	1017	Transport	189	694	Electron and Comm	12	391
Electric	332	985	Electric	298	687	Electric	34	266
Transport	191	897	Electron and Comm	109	623	Cultural	0	223
Special Machine	254	612	Special Machine	249	541	Food Manufacture	0	197
Machine	205	537	Machine	204	477	Transport	2	197
Chemical	132	493	Pharmaceutical	224	324	Chemical	6	167
Pharmaceutical	242	394	Chemical	126	299	Metal products	1	98
Beverage	60	350	Textile	96	294	Non-metal Mine	6	86
Food Manufacture	41	330	Beverage	56	265	Beverage	4	83
Textile	98	330	Other	14	248	Rubber	2	76
All industries	2400	8571	All industries	2286	6226	All industries	114	2173

Source: Authors' own calculation

Table 1 also contrasts the patenting activities of domestic LMEs and foreign invested LMEs. Transportation equipment tops domestic top patenting industries list with 694 applications in 2001, or 11 percent of the domestic total. While all domestic industries but pharmaceutical industry have at least doubled their patent applications from 1995 to 2001, the foreign invested LMEs, starting from a negligible base, have seen much sharper increase. For example, foreign LMEs in the transportation equipment industry had filed only two patent applications in 1995; the number increased to 197 in 2001. The composition of the top ten patenting industries also reveals noticeable difference between the domestic and foreign sub-samples. Machinery, special machinery and pharmaceutical, the fourth to the sixth largest domestic patent applicants respectively, fail to appear on the foreign top ten list. Likewise, cultural products, food, metal products, non-metal mining, and rubber from the foreign top ten list do not make the domestic list.

The foreign patenting surge has taken place concurrent to the increasing foreign presence in Chinese industries. From 1995 to 2001, the average increase in foreign invested firms' shares of Chinese industry 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.

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 was reported to be the least important reason for applying for patents.

Various authors have contrasted complex and discrete products industries in explaining inter-industry differences in patenting.[4] 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

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

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 negotiate for property rights over complementary technologies."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.

Table 2: Summary statistics

	Patent Applications	Real R&D	R&D-Value added	Industry FDI	Labor
Full sample; Year=1995; N=18215					
Mean	0.179	414.212	0.019	0.123	1442
Median	0.000	0.000	0.000	0.067	863
Std	1.593	3389.885	0.152	0.134	3347
Full sample; Year=2001; N=19146					
Mean	0.738	1279.329	0.019	0.302	1056
Median	0.000	0.000	0.000	0.268	533
Std	8.216	16574.502	0.078	0.205	2617
Full sample; All years; N=133444					
Mean	0.369	775.277	0.022	0.206	1267
Median	0.000	0.000	0.000	0.159	704
Std	5.384	8795.738	0.175	0.178	3086
Domestic; All years; N=111210					
Mean	0.365	733.674	0.023	0.183	1382
Median	5.669	8486.998	0.175	0.162	3332
Foreign; All years; N=19499					
Mean	0.386	1020.136	0.018	0.331	689
Median	3.441	9078.021	0.188	0.209	1090
Discrete industries; All years; N=36940					
Mean	0.212	476.342	0.017	0.147	1275
Std	2.513	2611.861	0.146	0.153	2003
Complex industries; All years; N=29525					
Mean	0.763	1751.779	0.040	0.258	1360
Std	10.063	17568.970	0.229	0.201	2957
Innovators; All years; N=22598					
Mean	2.013	2735.977	0.038	0.208	2595
Median	0.000	62.208	0.002	0.174	1096
Std	12.640	19230.251	0.209	0.181	6768

Source: Authors' own calculation

Table 2 summarizes the basic characteristics of the sample firms. The top two panels show that the average real R&D expenditure by LMEs tripled from 1995 to 2001, while

the average number of patent applications filed more than quadrupled. But innovation activity and output are highly varied and skewed among China's LMEs. For both years, the median R&D expenditure is zero and the variation coefficient of R&D increased from 8 to almost 13 over the six year period. Measured by the R&D to value added ratio, R&D intensity did not change from 1995 to 2001. On the other hand, the Chinese LMEs have become leaner as average employment declined from 1442 to 1056 workers. As a result of the rapid expansion of FDI the share of industry valued added accounted for by foreign firms has on average increased by 18 percent.

Foreign invested firms and domestic Chinese firms are quite similar in innovation activity. They file similar numbers of patent applications and invest similar fractions of value added in R&D. However foreign firms apparently are much less labor intensive than domestic firms.

Firms from complex industries are twice as R&D intensive as those from discrete industries. They file for more three times as many patent applications and appear to be more capital intensive. Their industries also attract more foreign investment.

5 What is behind China's patent explosion?

5.1 In search of an explanation: five hypotheses

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 differences in the incidence of patenting between complex and discrete product industries, and changing industrial structure may also raise the overall incidence of patenting. Economic reform, which has strengthened

private property rights and accelerated the exit of inefficient state-owned firms and entry of non-state enterprises, has produced more non-state enterprises that are seeking patent protection more aggressively than before.

5.2 The patents production function: specification and estimation issues

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

$$E(Y_{it}) = \lambda_{it} = exp(X'_{it}\beta) \tag{1}$$

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

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 most critical assumption for the asymptotically efficiency of the Poisson estimator is its assumption that the conditional mean ($E(Y|X)$) is equal to the conditional variance ($Var(Y|X)$). This is usually violated in applications, as is the case with our sample of patent counts. Most often, the violation takes the form of the conditional variance being much larger than the conditional mean, leading to the situation of over-dispersion. A consequence of this is that the standard errors will be under-estimated resulting in inflated statistical significance. Nevertheless the Poisson estimates will still be asymptotically consistent.[5]

One solution to the over-dispersion bias is to adopt a parametric specification that allows for the conditional variance to be different from the conditional mean. One such estimator is the Negative Binomial estimator, which assumes that the conditional mean

[5]See, for example, Wooldridge (2002) and Cameron and Trivedi (2005) for clear exposition.

is the product of a deterministic term and an error term that follows the gamma distribution. Another solution is the Poisson Quasi Maximum Likelihood (PQML) estimator. Wooldridge and Cameron and Trivedi have shown that the PQML estimator is asymptotically consistent under the weaker assumption of the correct specification of the conditional mean and no restriction on the functional form of the conditional variance. If the Negative Binomial functional assumption is correct, then it will be more efficient than the PQML estimator; otherwise, it will be inconsistent. We have decided to tackle the over-dispersion issue by adopting the PQML estimator. Cameron and Trivedi (p. 683) further indicated that the PQML estimator can be obtained by estimating a normal Poisson model and replacing the standard error with recomputed robust standard error. But we report for comparison the Negative Binomial results in the appendix.

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 large 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 requires 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 fixed effect Poisson model developed by Hausman, Hall and Griliches (1984). This model corrects for the bias that may be introduced to the patents production function estimates by the omitted firm-specific characteristics.

5.3 Exploring the five hypotheses

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 U.S. firms allows us to gauge the innovative efficiency of Chinese firms. We also include the square of the log of R&D to account for possible non-linearity in the relationship between R&D and patents production.

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 that are not involved in R&D activities 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. 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 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 (HMT) (i.e. "overseas" firms) and those from other locations (i.e. "foreign" firms).

The surge of FDI in China has multiple implications for the patenting behavior of both domestic Chinese firms and foreign firms operating in China. As foreign firms deepen and expand their activity in China, the need to protect their existing intellectual property against domestic Chinese firms will rise as well as the need to compete with other foreign firms in China by introducing more sophisticated products and technologies. The aggressive enforcement of patent rights by foreign invested firms may demonstrate for domestic Chinese firms the strategic value of holding patents. Anecdotal evidence

suggests that Chinese firms are taking advantage of loopholes in the Chinese patent system in order to use patents to preempt competition from foreign firms. [6] 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.

On the other hand, by embodying more sophisticated technology than domestic firms, increasingly establishing R&D operations in China, and through various channels of diffusion such as personnel turnover and demonstration effect, FDI could effect knowledge spillover to the firms in its vicinity. We are unable to separate analytically the effect of knowledge spillover and the strategic behavior inducing effect of FDI.[7] Instead we try to gauge the relative importance of these effects in the context of patents production, where we control of other inputs to knowledge production, and by comparing the magnitudes of the effect with the estimates of knowledge spillover in the literature.

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 enterprise restructuring in particular has given rise to a spectrum of ownership structures that include state ownership, local collective ownership, publicly-listed

[6] 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.

[7] 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.

firms with majority of equity controlled by the state, private enterprises, foreign wholly owned and joint ventures. This 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 the entitlement to intellectual property by non-state enterprises. We therefore expect the propensity to patent to vary across ownership types. As in the case of FDI, there is also a potential efficiency effect on knowledge production from ownership reform. Non-state firms may enjoy an increase in the efficiency of knowledge production due to the incentive structure in these firms. 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 legislative changes as well as the efficiency effect.

That state-owned enterprise restructuring have accelerated the exit of inefficient state-owned enterprises and the entry of non-state enterprises produces yet another implication for the patent surge. To the extent that non-state firms are more assertive of their patent rights, the changing ownership structure of Chinese industry must have led to even higher incidence of patenting.

6 Estimation results and discussion

6.1 Accounting for the patent explosion

We try to unravel China's patent surge paradox by analyzing the results from estimating the patents production function that are presented in Table 2. The number of patent applications measures the output of patents production. Our discussion below is based on the results using patent applications because patent grants data are missing for the last two of the seven years covered by the sample. However, 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 au-

Table 3: Patents production function estimation: Poisson

	Poisson	ZIP	ZIP	ZIP
	ALL	ALL	Domestic	Foreign
log(R&D)	0.143**	0.066**	0.073**	0.017*
	(0.007)	(0.006)	(0.007)	(0.008)
log(R&D)^2	0.018**	0.018**	0.019**	0.006**
	(0.001)	(0.001)	(0.001)	(0.002)
log(labor)	0.644**	0.329**	0.334**	0.285**
	(0.039)	(0.038)	(0.043)	(0.063)
industry FDI	1.762**	1.528**	1.677**	1.077**
	(0.197)	(0.199)	(0.205)	(0.351)
Discrete	0.590**	0.217*	0.196*	0.404
	(0.148)	(0.177)	(0.188)	(0.476)
Complex	0.887**	0.054**	0.053**	0.200
	(0.137)	(0.160)	(0.169)	(0.472)
collective	1.114**	1.000**	0.969**	
	(0.106)	(0.113)	(0.11)	
private	1.386**	0.947**	0.951**	
	(0.213)	(0.187)	(0.192)	
limited	0.53**	0.275**	0.268**	
	(0.086)	(0.086)	(0.087)	
joint other	0.343	0.31	0.312	
	(0.304)	(0.331)	(0.334)	
public	0.872**	0.582**	0.582**	
	(0.1)	(0.1)	(0.102)	
foreign	0.195	0.391**		-.081
	(0.109)	(0.103)		(0.122)
HMT	0.71**	0.517**		
	(0.11)	(0.107)		
1996	-.078	-.059	-.089	0.241
	(0.101)	(0.108)	(0.115)	(0.274)
1997	0.086	0.191	0.192	0.269
	(0.133)	(0.143)	(0.152)	(0.281)
1998	0.138	0.272	0.265	0.391
	(0.136)	(0.144)	(0.156)	(0.237)
1999	0.257*	0.314**	0.284*	0.553*
	(0.108)	(0.113)	(0.123)	(0.221)
2000	0.52**	0.463**	0.361**	0.986**
	(0.1)	(0.106)	(0.117)	(0.222)
2001	0.597**	0.509**	0.46**	0.899**
	(0.098)	(0.106)	(0.118)	(0.226)
Obs.	130751	130435	111035	19400
Log Likelihood	-116128	-72088	-61173	-9548
Vuong test		26.93**		

Robust standard errors in brackets

* - significant at 5% level; ** - significant at 1% level

thors 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.[8] 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.

The first two columns of Table 2 include the results from estimating the patents production function using both normal Poisson and the ZIP estimators. The *Vuong* test statistics indicate that the normal Poisson model is rejected in favor of the ZIP model. The ZIP model also fits the data much better than the Poisson model - the log likelihood has increased by more than one third. 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 Poisson panel estimation, which controls for firm heterogeneity and estimating the patents production function at individual industry level. We will return to these alternative estimates in the section of robustness check. Therefore, we base our discussion and conclusion on the ZIP results.

6.1.1 Has the patent upsurge been driven by R&D?

The R&D intensification of the Chinese economy together with the increasing patents-R&D ratio makes innovation a prime candidate explanation for the patent explosion. However the the patents - R&D elasticity estimate is not only small by OECD standard; also suggests that R&D intensification is unlikely to be the primary driving force of the China's patenting boom. The ZIP estimation result in column(2) of Table 2 implies

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

a patents-R&D elasticity of 0.066 when evaluated at the sample median level of real R&D expenditure, which is zero. The patents-R&D elasticity will be 0.3 if we evaluate the elasticity at the sample mean of the real R&D expenditure. This larger magnitude no longer represents the "typical" firm's patents-R&D elasticity since the distribution of R&D activity is highly skewed in our sample and is likely to be driven by the few extremely innovative firms - an issue we will return to below. Even this most optimistic estimate of patents-R&D elasticity 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. Given the increases in patent applications and real R&D expenditure from 1995 to 2001, a patents-R&D elasticity of 0.3 would imply that R&D intensification had contributed to 24 percent of the patenting increase, leaving the bulk of the patent explosion unexplained.

6.1.2 Foreign direct investment and patenting

The impact of industry FDI on patenting is large. Column (2) of Table 2 indicates a 10 percent increase in the foreign share of industry value added results in an increase in patent applications of nearly 15 percent. This elasticity translates into an increase of patent applications of 27 percent from 1995 to 2001, or 20 percent of the total increase. In other words, FDI explains just slightly less of the patent explosion than R&D.

We then estimate the patents production function separately for domestic and foreign invested firms to examine whether the patenting behavior of foreign and domestic firms reacts differently to industry FDI. The results are reported in columns(3) and (4) of Table 2. Although the effect of industry FDI on patenting also extends to foreign invested firms, domestic firms react more aggressively to the presence of FDI in their industry. This

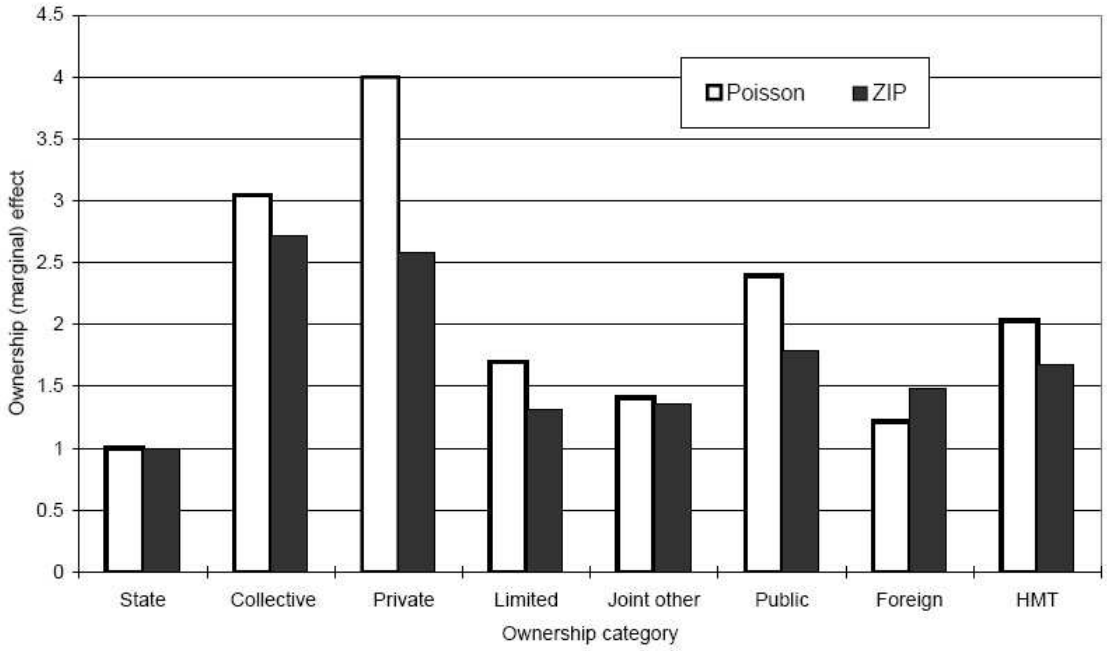
result together with the weak patents-R&D link are consistent with the hypothesized opportunistic patenting behavior of Chinese firms. That foreign firms also patent more in FDI intensive industries suggests that the intensification of FDI is correlated with the escalation of technological intensity of a Chinese industry.

A noticeable difference between foreign and domestic firms is in the patents - R&D elasticity estimate. While foreign firms' Chinese patents are only loosely related to their R&D activity in China, R&D makes a significant contribution to patenting production among Chinese firms. This result affirms the general perception that the R&D of foreign firms in China has more to do with local customization than with generating new technologies and that the surge in foreign patent applications in China may largely take the form of seeking Chinese legal protection for foreign firms' existing patents invented elsewhere. Another possibility is that the Chinese subsidiaries of multinationals may file for Chinese patent applications on behalf of their parent companies. In the meantime 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 may be assigned to parent companies.

Finally, column(4) shows that patenting by foreign invested firms assumed greater urgency after 2000, more so than domestic Chinese firms. This is likely to be a result, that is the combined effect of foreign firms' anticipating China's entry to the WTO and the amendment to the patent law in 2000 that sharpened the teeth of patent rights enforcement in preparation for signing the TRIPS treaty.

As we have noted earlier, we are unable to differentiate the propensity to patent and the knowledge spillover effect of FDI. However, an examination of the findings of the literature on knowledge spillover of FDI indicates that the magnitude we obtain for the effect of FDI is simply too large to be rationalized by the spillover effect. Aitken and Harrison (1999), for example, found a negative impact of industry FDI on domestic firms' productivity. Two more recent studies on OECD countries obtained modest estimates of the spillover effect of FDI. Haskel et al. (2002) reported for UK industry a 0.5% increase in TFP for 10% increase in industry FDI. Keller and Yeaple (2003) showed that in the U.S. a 10% increase in industry FDI leads to a 5% increase in TFP for domestic firms;

Figure 4: Enterprise Ownership and Propensity to Patent



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

and for Canada, 1% increase in TFP for 10% increase in industry FDI. Our estimate of the industry FDI coefficient is an order of magnitude larger than those cited here. Clearly our results suggest a potentially large role for the strategic behavior interpretation of the effect on Chinese domestic firms' patenting of industry FDI.

6.1.3 Non-state enterprises vs. state-owned enterprises

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 4. 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 thereby confirming our conjecture that ownership reform and pro-patent legislative changes have resulted in more clear property rights assignments, which have led 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.

Since the mid 1990s enterprise restructuring has picked up speed, so that both exit of state-owned enterprises and entry of non-state enterprises have accelerated. This evolution of the structure of the ownership of Chinese industry is depicted in Figure 9. Over the 1995 to 2001 period, the proportion of state-owned enterprises among the population of large and medium size enterprises has declined from 69 percent to 30 percent. The share of collective-owned enterprises in the LME population has also fallen by more than half. Taking place of China's SOEs and COEs are most notably individual and private large and medium size enterprises that were non-existent in 1995 but whose combined share rose to a quarter of all LMEs over the following six years. This changing industry ownership structure together with the more assertiveness of the non-state enterprises in patenting can be expected to contribute substantially to the patent explosion. We quantify the effect as:

$$\sum_{i=1}^{8}(s_{i,2001} - s_{i,1995})d_i$$

where $s_{i,t}$ refers to ownership group i's share of total units of LMEs in year t and d_i denotes the ownership dummy estimates we obtain in column (2) of Table 2. The total effect works out to account for 7 percent of the total patent surge among LMEs from 1995 to 2001.

6.1.4 Patent law amendments in 2000

The economy-wide propensity to patent as measured by the year dummies in Table 2 shows a clear and consistent pattern. Although the incidence of patenting increased somewhat in 1999, year 2000 exhibited the most robust increase in the propensity to patent. This structural shift was reaffirmed in 2001. The data panel is perhaps too short for us to extrapolate far into the future years, but the conspicuous upward trend warrants careful scrutiny. As far as patenting is concerned, year 2000 is a watershed in the

Chinese economy. Although the amendments to China's patent law and the conclusion of China's WTO negotiations with the U.S. have both increased the real or expected returns to patenting in China, it is probably reasonable to attribute most of the effect to the patent law amendments given that the trend started somewhat in 1999 and that China's WTO negotiations were only completed towards the end of 2000. The combined year effects of 2000 and 2001 explain almost 70 percent of the increase in patenting from 1995 to 2001. Naturally we cannot attribute all of this to the amendments of China's patent law.

Another interesting observation that we commented on briefly before is the noticeable differences between the year effects for domestic and foreign firms. To the extent that foreign firms have stronger R&D capabilities and larger stocks of intellectual property, they stand to benefit more from stronger patent rights. Therefore the differences in the year effects indirectly corroborate the proposition that the propensity to patent has increased as a result of stronger patent rights.

6.1.5 Complex vs. discrete industries

We select four complex industries and four discrete industries to examine how inter-industry differences may have contributed to the patent explosion. The complex industries are special machinery, transport equipment, electric machinery, and electronics; the discrete group consists of the beverage, textile, chemical, and pharmaceutical industries. To gauge the group specific propensity to patent, we compute the mean and standard error of the average of the four industry dummies from each group and report them as complex and discrete in Table 2. That is, after estimating the industry dummies, which we did not report in column (2), we use them to construct the mean and standard error of the average of the dummies for the four industries from each group.

Other than in the normal Poisson estimation, where standard errors are biased, we cannot find any difference in the propensity to patent between the complex and discrete industries. However, this does not mean that the complex-discrete distinction is inconsequential. As we will see in the industry level regressions, there is a stronger patents-R&D link in the Chinese complex industries, which are also more R&D intensive. To the ex-

tent that complex industries might grow faster than discrete industries, the changing composition of industrial structure would lead to a higher incidence of patenting. But such an effect would have been absorbed in the patents-R&D link.

Finally, we also find a quite robust firm scale effect, represented by the labor variable, on patenting. The scale elasticity hovers around 0.3, which is slightly lower than the typical finding in the OECD literature. Large firms take out more patents because there are economies of scale from preparing patent applications and potential scale economies in conducting R&D.

Table 4: Patents production function estimation: innovators

	ZIP	Fixed effect	Random effect	Fixed effect	
	All	All	All	Domestic	Foreign
log(R&D)	0.066**	0.035**	0.042**	0.043**	0.002
	(0.0008)	(0.009)	(0.001)	(0.010)	(0.017)
log(R&D)^2	0.017**	0.002	0.004**	0.004	-.003
	(0.0002)	(0.002)	(0.0002)	(0.002)	(0.003)
log(labor)	0.321**	0.561**	0.361**	0.604**	0.125
	(0.005)	(0.092)	(0.012)	(0.099)	(0.160)
industry FDI	1.513**	0.566	1.081**	0.715*	-.195
	(0.035)	(0.318)	(0.06)	(0.336)	(0.674)
1996	-.054*	0.058	0.001	0.009	0.429
	(0.025)	(0.074)	(0.025)	(0.076)	(0.273)
1997	0.184**	0.161	0.117**	0.128	0.512
	(0.024)	(0.098)	(0.024)	(0.102)	(0.307)
1998	0.26**	0.129	0.074**	0.086	0.68**
	(0.024)	(0.103)	(0.025)	(0.112)	(0.271)
1999	0.301**	0.302**	0.224**	0.227*	0.972**
	(0.024)	(0.097)	(0.024)	(0.105)	(0.295)
2000	0.451**	0.748**	0.649**	0.527**	1.917**
	(0.023)	(0.114)	(0.024)	(0.126)	(0.284)
2001	0.496**	0.856**	0.759**	0.697**	1.875**
	(0.023)	(0.122)	(0.024)	(0.135)	(0.304)
Obs.	22708	22556	23192	19280	2431
Log likelihood	-58933	-30959	-46926	-24680	-4478
Hausman test (χ^2)		758.31**			

Robust standard errors in brackets

* - significant at 5% level; ** - significant at 1% level

6.2 Robustness check

6.2.1 The innovators

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 innovators subs-ample leaves us with 4514 firms and 22598 observations. Summary statistics for this sub-sample are reported in the lower panels of Table 2. Innovator firms are on average about twice as big as an average LME and nearly twice as R&D intensive with the intensity measured by the real R&D to value added ratio. We first re-estimate the patents production function for the innovators using the ZIP estimator and report the results in the first column of Table 4. They are very similar to what we obtained using the full sample.

To account for firm heterogeneity, we then re-estimate the patents production function using two panel estimators: Poisson fixed effect with robust standard error[9] and random effect. While the Hausman test unambiguously rejects the random effect model in favor of the fixed effect model, the two estimators generate similar broad patterns of the various determinants of patent production, such as low patents-R&D elasticity, positive effect of industry FDI on patent production, and pronounced increase in patent production after year 2000. There are differences too. The fixed effect estimates show a larger scale effect in the form of a larger coefficient on size that is measured by labor and larger year specific effects for 2000 and 2001.

The fixed effect estimator implemented using the innovators sub-sample have produced smaller estimates of the patents - R&D elasticity than that for the average LMEs obtained using the ZIP estimator for the whole sample. The squared R&D variable has seen the biggest reduction in magnitude reflecting the much smaller variation in the scale of R&D operation among the innovators. The effect of industry FDI, at one third of its previous magnitude, is only significant at 10 percent level.

We then estimate the patents production function for domestic and foreign firms separately using the Poisson fixed effect estimator. There is now an even sharper contrast

[9]This estimator is implemented using the Stata program *xtpqml* created by Tim Simcoe.

between domestic and foreign firms than in Table 3. The previously found weak link between R&D and patents has become non-existent among the foreign invested firms. In the full sample estimation, both domestic and foreign firms increase their patenting in response to a higher concentration of FDI in their industry with the latter's reaction slightly smaller than the former. However, Table 4 shows that foreign innovators do not respond to industry FDI at all, while domestic innovators' patent applications remain strongly correlated with industry FDI intensity at the 5% significance level.

Table 4 also reaffirms the much higher rate of patenting by foreign firms and domestic firms over time and the dramatic structural shift in 2000. The growth rates of foreign patenting have exceeded those of domestic patenting. Taken together with the non-existence of a patents-R&D link, this shows that foreign firms' patenting in China largely takes the form of patenting existing intellectual property that they created elsewhere. The rapid increase of such patenting is likely to be driven by both the change in the legal environment of patent protection in China and the lure of the Chinese market at a time when China further liberalized its economy and integrated more closely with the global economy.

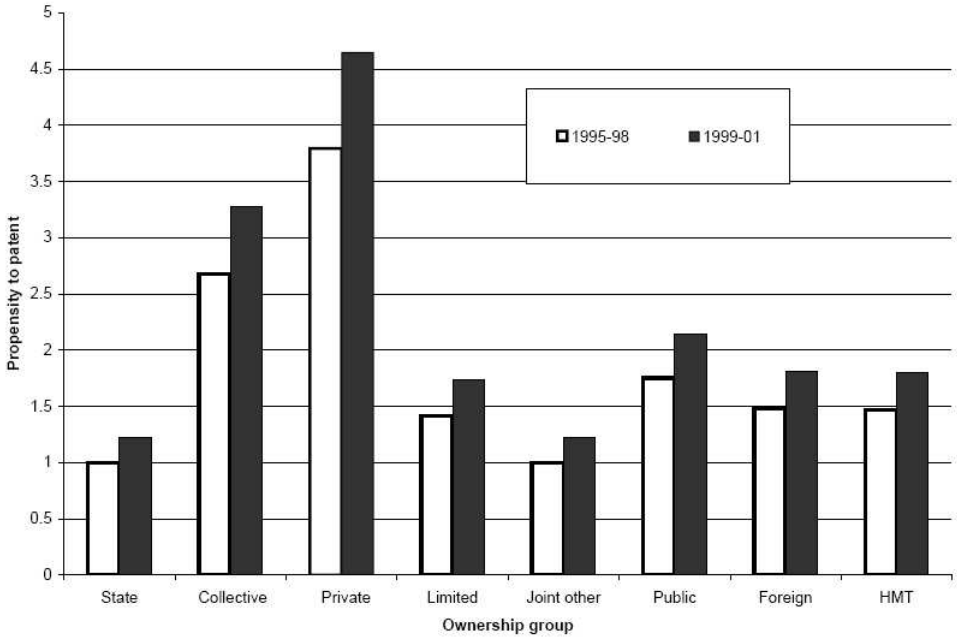
6.2.2 Ownership and changes in propensity to patent over time

We examine whether and how the ownership induced differences in propensity to patent might have changed over time by interacting the ownership fixed effects with the year fixed effects in re-estimating column(2) of Table 3.[10] The data do not have sufficient variation to identify a full set of interaction of the ownership and year fixed effects. Instead, we interact the ownership fixed effects with a dummy variable that takes the value of 1 for 1999, 2000 and 2001, and zero otherwise. The coefficients on the R&D, labor and FDI variables are similar to those in column (2) of Table 3, which we do not report here and available upon request. Instead we compute the implied ownership effects for the two periods and plot them in Figure 5.

As in Figure 4, the plotted magnitudes are marginal effects implied by the coefficient estimates. There are significant differences across different ownership groups in their

[10] We thank an anonymous referee for suggesting this exercise.

Figure 5: Enterprise Ownership and Propensity to Patent



Source: authors' own tabulation.

propensity to patent during the first period from 1995 to 1998. There is also an across-the-board increase in the average propensity to patent between the two periods, but the difference in the increase is not significant between ownership groups. The implication is that while firms of all ownership types have increased their propensity to patent over time, the differences between them have not shrunk.

6.2.3 Patents production at the industry level

Given the inter-industry heterogeneity in technology opportunity and the relative importance of the means to protect intellectual property, we estimate the patents production function separately for the eight complex and discrete industries and report the results in Table 4. This set of estimates allows for a more careful examination of the differences between complex and discrete industries.

The weak patents-R&D linkage carries through to the industry level with marked differences along the complex-discrete line. The R&D coefficient is insignificantly different from zero in all four discrete industries; the R&D square term is significant in textiles and only marginally significant in chemicals. In stark contrast, all the complex

industries demonstrate a statistically robust patents-R&D link with the only exception being transport equipment.

We do not find any systematic differences with respect to the other estimates. The finding of higher patenting rates in FDI intensive industries applies to three industries: chemicals, transport, and electric machinery. The effect of FDI intensity in the chemicals and electric machinery industries is particularly prominent with magnitudes that are larger than the coefficient we obtained using the full sample. The scale effect is most pronounced in the beverage, pharmaceutical, electric machinery, and electronics industries.

In sum, the results in Table 5 show that the driving force behind the patent surge varies from industry to industry. The electric machinery industry is in some sense a "perfect" industry that encapsulates all the driving forces we have identified. In the other industries, one factor or another stands out as the dominant explanation of the patenting surge.

7 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 substantially weakened the incentives for inventors to apply for 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 in 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.

Table 5: Patents production function estimation by industry: ZIP

	Discrete industries				Complex industries			
	Beverage	Textile	Chemical	Pharma	Special Machine	Transport Equipment	Electric Machine	Electronics
log(R&D)	-.017	0.058	0.036	0.028	0.066**	0.038	0.052**	0.069**
	(0.019)	(0.033)	(0.025)	(0.021)	(0.014)	(0.036)	(0.01)	(0.011)
log(R&D)^2	-.005	0.022**	0.013*	0.001	0.012**	0.009*	0.017**	0.02**
	(0.004)	(0.005)	(0.005)	(0.004)	(0.003)	(0.004)	(0.002)	(0.002)
log(labor)	0.638**	-.249	0.287	0.377**	-.014	0.195	0.717**	0.489**
	(0.124)	(0.154)	(0.169)	(0.077)	(0.085)	(0.205)	(0.088)	(0.084)
industry FDI	0.859	-.866	2.451**	-.507	-.062	1.339**	2.924**	1.967
	(0.475)	(1.732)	(0.402)	(0.775)	(0.631)	(0.43)	(0.721)	(1.018)
Obs.	5084	14945	11531	4589	7802	7903	7506	5701
Log likelihood	-2177	-2575	-3989	-3685	-6091	-5605	-7779	-4458

Robust standard errors in brackets

* - significant at 5% level; ** - significant at 1% level

Labor excludes R&D personnel.

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 surge by estimating a patents 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, at least by OECD standards. The patents - R&D link is particularly weak among foreign invested firms. The phenomenon of increasing R&D intensity explains less than a quarter of the patent upsurge in our sample. This result leads us to conclude that China's recent R&D intensification is unlikely to be the primary force behind the patent explosion.

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, and chemical industries.

Differences in the propensity to patent across ownership groups are consistent with our conjecture that the clarification of enterprise property rights had led to the more aggressive assertion of patent rights. The changing ownership structure of Chinese industry - the accelerated exit of state-owned enterprises and entry of non-state enterprises - has produced a 10 percent increase in patent applications of the LMEs in our sample from 1995 to 2001.

The largest impact on patenting comes from the year effects of 2000 and 2001. To the extent that we can associate at least some of surge in the incidence of patenting in 2000 with China's pro-patent legislation, a more patent-friendly legal environment emerges as an important explanation of China's patenting boom.

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 address is differences 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.

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Table 6: Patents production function estimation: Negative Binomial

	Neg. Binomial	ZINB	ZINB	ZINB
	All	All	Domestic	Foreign
log(R&D)	0.13**	0.071**	0.076**	0.032**
	(0.005)	(0.006)	(0.006)	(0.012)
log(R&D)^2	0.011**	0.016**	0.016**	0.009**
	(0.0009)	(0.001)	(0.001)	(0.003)
log(labor)	0.621**	0.31**	0.318**	0.158
	(0.03)	(0.034)	(0.036)	(0.081)
industry FDI	1.619**	1.487**	1.388**	1.248**
	(0.204)	(0.159)	(0.167)	(0.299)
Discrete	0.677**	0.367*	0.388*	0.136
	(0.164)	(0.163)	(0.171)	(0.169)
Complex	1.012**	0.555**	0.642**	0.017
	(0.156)	(0.158)	(0.166)	(0.136)
collective	0.541**	0.685**	0.684**	
	(0.071)	(0.063)	(0.063)	
private	1.148**	1.235**	1.280**	
	(0.207)	(0.166)	(0.168)	
limited	0.861**	0.692**	0.727**	
	(0.102)	(0.094)	(0.095)	
joint other	0.234	0.303	0.262	
	(0.208)	(0.196)	(0.191)	
public	1.231**	0.99**	1.010**	
	(0.2)	(0.12)	(0.118)	
foreign	0.498**	0.551**		
	(0.113)	(0.105)		
HMT	0.906**	0.928**		0.331**
	(0.107)	(0.088)		(0.126)
1996	-.117	-.155*	-.198*	0.408
	(0.089)	(0.078)	(0.082)	(0.301)
1997	-.140	-.136	-.149	0.031
	(0.137)	(0.107)	(0.114)	(0.276)
1998	-.244**	-.098	-.152	0.298
	(0.091)	(0.08)	(0.085)	(0.247)
1999	-.183*	-.027	-.064	0.414
	(0.089)	(0.078)	(0.084)	(0.237)
2000	0.247*	0.266**	0.125	1.055**
	(0.099)	(0.083)	(0.089)	(0.225)
2001	0.255*	0.38**	0.298**	1.030**
	(0.103)	(0.088)	(0.096)	(0.246)
Obs.	130605	130289	110889	19400
Log Likelihood	-48046	-46053	-39860	-6194
Vuong test		20.64**		

Robust standard errors in brackets

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