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

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First version: 21 March 2005
This version: 21 October 2008

Abstract
China’s patent surge, documented in this paper, 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 explores the factors that account for China’s rising patent activity. While the intensification of research and development in the Chinese economy tracks with patenting activity, it explains only a fraction of the patent explosion. The growth 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 patent boom. These results are robust to alternative estimation strategies that account for over-dispersion in the patent counts data and firm heterogeneity.

JEl classification: F2, L2, O3
Keywords: China, patent explosion, FDI, R&D

*We thank for their helpful comments Stuart Graham, Li Wei, Lim Kuanghui, Nannan Lundin and seminar and conference participants at Singapore Management University, Nanjing Workshop on Global R&D in China, May 28-29, 2005, Second Summer Industrial Organization Workshop, Tsinghua University, June 8-9, the University of Connecticut, Second ZEW Conference on the Empirical Economics of Innovation and Patenting, Mannheim, September 19-20, 2005, Globalization and Economic Growth, Shanghai, November 4-6, 2005, NBER China Workshop, September 30, 2005. Gordon Hanson (the editor) and two anonymous referees provided comments that have led to significant improvement of the paper. We also acknowledge support from the National University of Singapore Academic Research Fund(R-122-000-091-112), the National Science Foundation (Grant nos. 450823 and 400865) and the U.S. Department of Energy (contract no. DE-FG02-00ER63030).

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1 Introduction

Chinese patent applications have been growing at an annual rate of over 15 percent since 1986, the year after China passed its Patent Law. Not limited to patent applications from domestic Chinese inventors, the surge has also been driven by foreign patent applications, which since China first amended its Patent Law in 1992, have grown at an annual rate of 22 percent. Nor is the surge contained 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.

A 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 congruence of events that have accompanied China’s patent explosion may provide 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, thereby largely bringing 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.1

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

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1 On April 9, 2007, U.S. trade representative Susan Schwab commented that "piracy and counterfeiting in China remain unacceptably high" on the occasion of the United States filing two cases against China at the World Trade Organization over widespread piracy of American movies, music, books and software (International Herald Tribune, April 9, 2007).
Also during the past decade, foreign direct investment (FDI) that embodies rising technological sophistication has been expanding into more Chinese industries and regions, thus expanding opportunities for both innovation and imitation for both Chinese and foreign firms and therefore the opportunities for patenting. As foreign invested firms expand and deepen their manufacturing activities in China, the need to protect their intellectual property might also be expected to rise. 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 both the supply of patenting opportunities and the 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. Simultaneously, legislative changes that affirm private property rights 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.

Our investigation of these hypotheses is set 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. The incidence of patenting has grown rapidly worldwide as has the liter-
nature documenting and analyzing this growth. The patent explosion in the U.S. has particularly been well documented and analyzed.

Using aggregate patent data from the U.S. and international patent data, Kortum and Lerner (1999) 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. 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.

Studies that investigated the patent protection and innovation link outside the U.S. also reported mixed evidence. 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, both higher R&D spending and more patents should ensue, but, they found no evidence for either outcome. Lanjouw and Cockburn (2001) focused on the response of the global pharmaceutical industry to the trend of strengthening IPR, including in the developing economies that started with GATT negotiations in the mid 1980s. Their data showed that the research related to malaria that increased significantly from the mid-1980s ensued from the strengthening

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2The literature is built upon the intellectual foundation laid by Nordhaus' (Nordhaus, 1969) path-breaking 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.
of IPR.\footnote{Moser (2005) is a recent addition to this literature. Using a novel data set of innovations exhibited at 19th century World Fairs, she concluded that the adoption of patent laws had a significant effect on the direction of technological innovation by demonstrating that countries that did not have patent laws focused on a small set of industries where patents were less important.}

To estimate the candidate hypotheses explored above, we nest 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. To foreshadow the results of the paper, we find evidence of a strong link between stronger patent protection and innovation in Chinese industry. Our results also confirm that foreign direct investment and institutional changes induced by China’s transition to market economy have deeply impacted 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 describes China’s patent system and the government’s attempts to restructure it. Section three provides summary evidence on the patenting behavior of China’s large and medium-size enterprises. We discuss the specification and estimation of the patents production function in section four. In section five we draw inferences for the different hypotheses of China’s patent explosion based on the estimation results. Section six presents our conclusions and related discussion.

2 China’s patent system and the patent explosion

2.1 China’s patent system

China passed its first patent law in 1984 that helped to create a patent system that was similar to those used of Europe and Japan.\footnote{For example, the priority in granting patents is based on the principle of “first-to-file” rather than “first-to-invent”. The law also instituted a pre-grant opposition system under which parties can file a request with the patent office to object to the grant of a patent.} 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

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more incremental innovations and are not subject to examination for novelty and non-
obviousness.

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 pharmaceux-
tical 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. Administr-
ative procedure was also streamlined to expedite the patent application process. In
preparation for accession to the World Trade Organization (WTO), in particular to fulfill
member country obligations under TRIPS,\(^5\) 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 to compute statutory damages and
affirms that state and non-state enterprises enjoy equal treatment in obtaining patent
rights.\(^6\)

2.2 The patent explosion

Patent applications and grants in China began their surge 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. After 2000 the annual rate of growth of invention patent applications accelerated
to 23 percent, five percent more than the growth rate of overall patent applications.
The year 2000 was also a watershed for foreign patent applications, the growth of which

\(^5\) 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
the Patent Cooperation Treaty (PCT). Other treaties that China has joined include: Budapest Treaty

\(^6\) The amended law also 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.
jumped from 12 percent per annum prior to that year to 23 percent annually afterwards.

A major difference between the patenting behavior of domestic and foreign inventors is reflected in the composition of applications for 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 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 average 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 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.

3 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
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 LME share had risen to 38 percent. LMEs were also responsible for 4.7 percent of all domestic patent applications in 1995 and 8.5 percent in 2001. 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

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7Before 2003, to define large and medium-size enterprises, China’s NBS used 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. The Chinese NBS changed its classification system in 2003 and now apply the same criteria based on employment, sales and total asset to all industrial enterprises. See the web site of NBS (www.stats.gov.cn) for details.

8Each of the approximately 20,000 LMEs in the NBS survey self reports the number of patents applied for each year.
top ten patenting industries. Together these 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. The electronics and telecommunications equipment industry has seen its patent applications increasing by more than seven fold over the six-year span.

Table 1 also contrasts the patenting activities of domestic LMEs and foreign invested LMEs. Transportation equipment tops the domestic list of industries with 694 applications in 2001, or 11 percent of the domestic total. While all domestic industries but the pharmaceutical industry at least doubled their patent applications from 1995 to 2001, the foreign invested LMEs, starting from a negligible base, have seen much sharper increases. For example, foreign LMEs in the transportation equipment industry filed only two patent applications in 1995; the number increased to 197 in 2001.

The foreign patenting surge has taken place concurrent with the increasing foreign presence in Chinese industries. From 1995 to 2001, foreign invested firms increased their value added share in Chinese industry by an average annual rate of 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 lawsuits, use in negotiations, and enhancing reputation. All of these reasons might also be anticipated to motivate foreign firms to patent aggressively in China.

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9 Using patents to earn licensing revenue was reported to be the least important reason for applying for patents.
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</thead>
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<tr>
<td>Electron and Comm</td>
<td>121</td>
<td>1017</td>
<td>Transport equip.</td>
<td>189</td>
<td>694</td>
<td>Electron and Comm</td>
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<td>Transport equip.</td>
<td>191</td>
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<td>Electron and Comm</td>
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<td>612</td>
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<td>249</td>
<td>541</td>
<td>Food Manufacture</td>
<td>0</td>
<td>197</td>
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<td>Machine</td>
<td>205</td>
<td>537</td>
<td>Machine</td>
<td>204</td>
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<td>493</td>
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<td>224</td>
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<td>Chemical</td>
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<td>167</td>
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<tr>
<td>Pharmaceutical</td>
<td>242</td>
<td>394</td>
<td>Chemical</td>
<td>126</td>
<td>299</td>
<td>Metal products</td>
<td>1</td>
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<td>Beverage</td>
<td>60</td>
<td>350</td>
<td>Textile</td>
<td>96</td>
<td>294</td>
<td>Non-metal Mine</td>
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<td>86</td>
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<tr>
<td>Food Manufacture</td>
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<td>330</td>
<td>Beverage</td>
<td>56</td>
<td>265</td>
<td>Beverage</td>
<td>4</td>
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<tr>
<td>Textile</td>
<td>98</td>
<td>330</td>
<td>Other</td>
<td>14</td>
<td>248</td>
<td>Rubber</td>
<td>2</td>
<td>76</td>
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<tr>
<td>All industries</td>
<td>2400</td>
<td>8571</td>
<td>All industries</td>
<td>2286</td>
<td>6226</td>
<td>All industries</td>
<td>114</td>
<td>2173</td>
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Source: Authors’ own calculations
Table 2: Mean and standard deviations of key variables

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<td>All (1995)</td>
<td>0.179</td>
<td>414</td>
<td>0.019</td>
<td>0.123</td>
<td>1,442</td>
<td>18,215</td>
</tr>
<tr>
<td></td>
<td>(1.593)</td>
<td>(3,390)</td>
<td>(0.152)</td>
<td>(0.134)</td>
<td>(3,347)</td>
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<tr>
<td>All (2001)</td>
<td>0.738</td>
<td>1,279</td>
<td>0.019</td>
<td>0.302</td>
<td>1,056</td>
<td>19,146</td>
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<tr>
<td></td>
<td>(8.216)</td>
<td>(16,575)</td>
<td>(0.078)</td>
<td>(0.205)</td>
<td>(2,617)</td>
<td></td>
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<tr>
<td>All</td>
<td>0.369</td>
<td>775</td>
<td>0.022</td>
<td>0.206</td>
<td>1,267</td>
<td>133,444</td>
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<tr>
<td></td>
<td>(5.384)</td>
<td>(8,796)</td>
<td>(0.175)</td>
<td>(0.178)</td>
<td>(3,086)</td>
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<tr>
<td>Domestic</td>
<td>0.365</td>
<td>734</td>
<td>0.023</td>
<td>0.183</td>
<td>1,382</td>
<td>111,210</td>
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<tr>
<td></td>
<td>(5.669)</td>
<td>(8,487)</td>
<td>(0.175)</td>
<td>(0.162)</td>
<td>(3,332)</td>
<td></td>
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<tr>
<td>Foreign</td>
<td>0.386</td>
<td>1,020</td>
<td>0.018</td>
<td>0.331</td>
<td>689</td>
<td>19,499</td>
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<tr>
<td></td>
<td>(3.441)</td>
<td>(9,078)</td>
<td>(0.188)</td>
<td>(0.209)</td>
<td>(1,090)</td>
<td></td>
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<tr>
<td>Discrete</td>
<td>0.212</td>
<td>476</td>
<td>0.017</td>
<td>0.147</td>
<td>1,275</td>
<td>36,940</td>
</tr>
<tr>
<td></td>
<td>(2.513)</td>
<td>(2,612)</td>
<td>(0.146)</td>
<td>(0.153)</td>
<td>(2,003)</td>
<td></td>
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<tr>
<td>Complex</td>
<td>0.763</td>
<td>1,752</td>
<td>0.040</td>
<td>0.258</td>
<td>1,360</td>
<td>29,525</td>
</tr>
<tr>
<td></td>
<td>(10.063)</td>
<td>(17,569)</td>
<td>(0.229)</td>
<td>(0.201)</td>
<td>(2,957)</td>
<td></td>
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<tr>
<td>Innovators</td>
<td>2.013</td>
<td>2,736</td>
<td>0.038</td>
<td>0.208</td>
<td>2,595</td>
<td>22,598</td>
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<tr>
<td></td>
<td>(12.640)</td>
<td>(19,230)</td>
<td>(0.209)</td>
<td>(0.181)</td>
<td>(6,768)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Standard deviations are reported in parentheses. 
Source: Authors’ own calculations

Various authors have contrasted complex and discrete products industries to explain inter-industry differences in patenting.\(^{10}\) 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 difference is that firms in complex product industries usually do not control all of the patented technologies used in the manufacture of a product. Firms patent to build up a portfolio of intellectual property rights in order to gain a competitive edge in licensing negotiations. Hall (2004) suggests that “in complex product industries, firms are more likely to use patents to induce rivals to negotiate for property rights over complementary technologies.” We select beverage, textile, chemical,

\(^{10}\)See for example, Levin, Kleverick, Nelson and Winter (1987) and Merges and Nelson (1990).
and pharmaceuticals to represent the discrete product industries and special machinery, transport equipment, electric machinery, and electronics for complex product industries.

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,\(^\text{11}\) 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, while R&D’s coefficient of variation increased from 8 to 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. Foreign invested firms and domestic Chinese firms exhibit interesting differences. While foreign firms possess small advantage in patent applications, they are somewhat less R&D intensive than the domestic firms.

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

4 What is behind China’s patent explosion?

4.1 In search of an explanation: five hypotheses

We have identified five hypotheses with respect to China’s patent explosion:

1. The pro-patent amendments to the Patent Law in 1992 and 2000 may have raised the overall return to seeking patent protection.

2. The intensification of R&D in the Chinese economy has channeled more resources into innovation activities that may have led to patentable technologies.

3. International economic integration, particularly the vast inflow of foreign direct investment, has expanded the technological opportunity for domestic firms to innovate and imitate. In addition, the rising concentration of FDI has raised the stakes for protecting their intellectual property for foreign firms while potentially

\(^{11}\)Nominal R&D has been deflated using GDP deflator obtained from NBS website: www.stats.gov.cn.
motivating domestic Chinese firms to use patents as a strategic tool to counter competition from foreign-invested firms.

4. If there are inter-industry differences in the propensity to patent, shifts in industry composition toward industries with higher patent propensities will lead to higher overall levels of patenting.

5. 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.

4.2 The patents production function: specification and estimation issues

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. 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, $\lambda$:

$$E(Y_{it}) = \lambda_{it} = exp(X_i'\beta)$$ (1)

$$Prob(Y_{it} = y_{it}) = e^{-\lambda_{it}}\frac{\lambda_{it}^y}{y_{it}!}$$ (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 it is likely to be 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.

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 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 (2002) and Cameron and Trivedi (2005) 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. For this reason, we have decided to tackle the over-dispersion issue by adopting the PQML estimator. Cameron and Trivedi (2005, 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 errors.\footnote{We have estimated the model using the Negative Binomial estimator. The results are broadly consistent with those that we have obtained using the PQML estimator and are available upon request.}

The large number of zero observations for patent counts in our sample raises a second concern. 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:

\[
Pr(Y_{it} = y_{it}) = \begin{cases} 
p_{it} + (1 - p_{it})e^{-\lambda_{it}} & y_{it} = 0 \\
(1 - p_{it})e^{-\lambda_{it}} \frac{\lambda_{it}^y}{y_{it}!} & y_{it} = 1, 2, ...
\end{cases}
\]

(3)

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

\[
p_{it} = F(Z' \gamma) = \frac{1}{1 - \exp(-Z' \gamma)}
\]

(4)

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

\[
L(\gamma, \beta; y, X, Z) = \sum_{y_{it}=0} \ln\{F(Z_{it}' \gamma) + [1 - F(Z_{it}' \gamma)][-\exp(X_{it}')]\} \\
+ \sum_{y_{it}>0} \{\ln[1 - F(Z_{it}' \gamma)] - \exp(X_{it}') + nX_{it}' \beta - \ln(y_{it})\}
\]

(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 likelihood ratio 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.

4.3 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 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 this measure, since it is the appropriate measure of the share of industry GDP accounted for by foreign invested firms within each industry.\(^\text{13}\) 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

\(^{13}\text{As measures of the relative presence of foreign vs. domestic manufacturing activity, sales may be distorted by large variations in value added ratios while employment is subject to bias due to industry variations in capital-labor factor intensities.}\)
who are from Hong Kong, Macau, and Taiwan (HMT) (i.e. “overseas” firms) and those from other locations (i.e. “foreign” firms).

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. 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 create knowledge spillover for the firms in its vicinity. We are unable to separate analytically the effect of knowledge spillover and the strategic behavior inducing effect of FDI. Instead we try to gauge the relative importance of these effects in the context of patents production, where we control for other inputs to knowledge production, and by comparing the magnitudes of the effect with the estimates of knowledge spillover in the literature.

The technology of knowledge production may vary across industries. The interaction between foreign direct investment and patenting may also differ from industry to industry. In addition to estimating a patents production function for all the industries, we also estimate it for each of eight two-digit industries that have been most active in patenting.

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14In 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 taking out a patent ahead of their foreign competitors 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.

15Some authors have used patent applications to examine spillovers from FDI without making such a 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.
China’s enterprise restructuring in particular has given rise to a spectrum of ownership structures that include state ownership, local collective ownership, publicly-listed 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. The 1992 and 2000 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. 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 an even higher incidence of patenting.

5 Estimation results and discussion

5.1 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 3. 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 3 using patent grants. The results are consistent with the results in Table 3 using patent applications 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
Table 3: Patents production function estimation: Poisson

<table>
<thead>
<tr>
<th></th>
<th>Poisson</th>
<th>ZIP</th>
<th>ZIP</th>
<th>ZIP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ALL</td>
<td>ALL</td>
<td>Domestic</td>
<td>Foreign</td>
</tr>
<tr>
<td>log(R&amp;D)</td>
<td>0.143** (0.007)</td>
<td>0.066** (0.006)</td>
<td>0.073** (0.007)</td>
<td>0.017* (0.008)</td>
</tr>
<tr>
<td>log(R&amp;D)^2</td>
<td>0.018** (0.001)</td>
<td>0.018** (0.001)</td>
<td>0.019** (0.001)</td>
<td>0.006** (0.002)</td>
</tr>
<tr>
<td>log(labor)</td>
<td>0.644** (0.039)</td>
<td>0.329** (0.038)</td>
<td>0.334** (0.043)</td>
<td>0.285** (0.063)</td>
</tr>
<tr>
<td>industry FDI</td>
<td>1.762** (0.197)</td>
<td>1.528** (0.199)</td>
<td>1.677** (0.205)</td>
<td>1.077** (0.351)</td>
</tr>
<tr>
<td>Discrete</td>
<td>0.590** (0.148)</td>
<td>0.217* (0.177)</td>
<td>0.196* (0.188)</td>
<td>0.404 (0.476)</td>
</tr>
<tr>
<td>Complex</td>
<td>0.887** (0.137)</td>
<td>0.054** (0.160)</td>
<td>0.053** (0.169)</td>
<td>0.200 (0.472)</td>
</tr>
<tr>
<td>collective</td>
<td>1.114** (0.106)</td>
<td>1.000** (0.113)</td>
<td>0.969** (0.11)</td>
<td>1.114** (0.106)</td>
</tr>
<tr>
<td>private</td>
<td>1.386** (0.213)</td>
<td>0.947** (0.187)</td>
<td>0.951** (0.192)</td>
<td>1.386** (0.213)</td>
</tr>
<tr>
<td>limited</td>
<td>0.530** (0.086)</td>
<td>0.275** (0.086)</td>
<td>0.268** (0.087)</td>
<td>0.530** (0.086)</td>
</tr>
<tr>
<td>joint other</td>
<td>0.343 (0.304)</td>
<td>0.310 (0.331)</td>
<td>0.312 (0.334)</td>
<td>0.343 (0.304)</td>
</tr>
<tr>
<td>share</td>
<td>0.872** (0.100)</td>
<td>0.582** (0.100)</td>
<td>0.582** (0.102)</td>
<td>0.872** (0.100)</td>
</tr>
<tr>
<td>foreign</td>
<td>0.195 (0.109)</td>
<td>0.391** (0.103)</td>
<td>-0.081 (0.122)</td>
<td>0.195 (0.109)</td>
</tr>
<tr>
<td>HMT</td>
<td>0.71** (0.110)</td>
<td>0.517** (0.107)</td>
<td></td>
<td>0.71** (0.110)</td>
</tr>
<tr>
<td>1996</td>
<td>-0.078 (0.101)</td>
<td>-0.059 (0.108)</td>
<td>-0.089 (0.115)</td>
<td>0.241 (0.274)</td>
</tr>
<tr>
<td>1997</td>
<td>0.086 (0.133)</td>
<td>0.191 (0.143)</td>
<td>0.192 (0.152)</td>
<td>0.269 (0.281)</td>
</tr>
<tr>
<td>1998</td>
<td>0.138 (0.136)</td>
<td>0.272 (0.144)</td>
<td>0.265 (0.156)</td>
<td>0.391 (0.237)</td>
</tr>
<tr>
<td>1999</td>
<td>0.257** (0.108)</td>
<td>0.314** (0.113)</td>
<td>0.284* (0.123)</td>
<td>0.553* (0.221)</td>
</tr>
<tr>
<td>2000</td>
<td>0.520** (0.100)</td>
<td>0.463** (0.106)</td>
<td>0.361** (0.117)</td>
<td>0.986** (0.222)</td>
</tr>
<tr>
<td>2001</td>
<td>0.597** (0.098)</td>
<td>0.509** (0.106)</td>
<td>0.460** (0.118)</td>
<td>0.899** (0.226)</td>
</tr>
<tr>
<td>Obs.</td>
<td>130,751</td>
<td>130,435</td>
<td>111,035</td>
<td>19,400</td>
</tr>
<tr>
<td>Log Likelihood</td>
<td>-116,128</td>
<td>-72,088</td>
<td>-61,173</td>
<td>-9,548</td>
</tr>
<tr>
<td>Vuong test</td>
<td>26.93**</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses
* significant at the 5% level; ** significant at the 1% level
the association between R&D expenditure and patents production exists only at the contemporaneous level. Therefore contemporaneous 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, particularly for the fixed effects versions of our estimates. Therefore, as is frequently done in the related literature, we settle for using R&D expenditure as a determinant of patent counts.

The first two columns of Table 3 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 as the significant increase in log likelihood indicates. Explicitly modeling the data generating process of the zeros considerably changes the estimation of the patents - R&D elasticity. ZIP generates a much smaller elasticity estimate than Poisson does, but the elasticity estimate and the estimates of the coefficients of the other variables are broadly consistent with those obtained using the Poisson estimator. Therefore, we base our discussion and conclusion on the ZIP results.

5.1.1 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 patents - R&D elasticity estimate is not only small by OECD standards, it also suggests that R&D intensification is unlikely to be the primary driving force of China’s patenting boom. The ZIP estimation result in column(2) of Table 2 implies 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

---

16For example, see Pakes and Griliches (1984) and Hall and Ziedonis (2001)
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, while Hausman, Hall and Griliches (1984) and Pakes and Griliches (1984) obtained estimates of 0.87 and 0.61 respectively. 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 by the fact 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.

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.

5.1.2 Foreign direct investment and patenting

The impact of industry FDI on patenting is large. Column (2) of Table 3 indicates that a 10 percent increase in the foreign share of industry value added results in an increase in patent applications of approximately 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 the patent explosion by nearly as much as the 24 percent contribution that we estimate for R&D in the previous section.17

17Industry FDI may be correlated with time-varying industry shocks. In the absence of good instruments for industry FDI in our database, we address the issue by using the lag of FDI as a robustness check. Since all our regressions include industry fixed effects, the industry shocks are inter-temporal. We
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 3. 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. Furthermore, the surge in foreign patent applications in China may largely take the form of foreign firms seeking Chinese legal protection for innovations already patented 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, significantly more so than domestic Chinese firms. This is likely to be a result of 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.

have re-run the baseline model, i.e., column (2) of Table 3, using different lengths of the lag of industry FDI, up to a maximum allowable lag of five, in place of contemporaneous industry FDI. For all lengths of the lag, industry FDI remains statistically significant, and the magnitudes are similar. The regression results are available upon request.
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 explained 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 that for UK industry a 10 percent increase in FDI leads to a 0.5 percent increase in TFP. Keller and Yeaple (2003) showed that in the U.S. a 10 percent increase in industry FDI results in a 5 percent increase in TFP for domestic firms, and for Canada, the same 10 percent increase in industry FDI causes a 1 percent increase in TFP. Our estimate of the industry FDI coefficient is an order of magnitude larger than those cited here for the technology spillover effect alone. Clearly our results suggest a potentially large effect of industry FDI on the propensity to patent of domestic Chinese firms.
5.1.3 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 clearer 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.\(^\text{18}\)

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. From 1995 to 2001, 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 the place of China’s SOEs and COEs are most notably shareholding 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 have contributed 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 \(d_i\)

\(^{18}\)Statistics from pair-wise Wald test of the difference of the ownership fixed effects are available upon request.
denotes the ownership dummy estimates we obtain in column (2) of Table 3. The total effect works out to account for 7 percent of the total patent surge among LMEs from 1995 to 2001.

5.1.4 Patent law amendments in 2000

The economy-wide propensity to patent as measured by the year dummies in Table 3 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, but the structural break suggests a distinct strengthening in the propensity to patent beginning in 1999.

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.

5.1.5 Inter-industry differences in propensity to patent

We first select four complex industries and four discrete industries to examine whether there are inter-industry differences in propensity to patent. 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 compute the group specific propensity to patent, we use the industry dummies that were estimated, but not reported in Table 3, 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. But both groups of industries seem to have a higher propensity to patent than the other industries.

We compute the contribution of the interaction of inter-industry differences in propensity to patent and shifts in industry composition to the patenting surge using the same method we used in estimating the impact of ownership restructuring on the patenting surge in Section 5.1.3. While industries with higher propensity to patent, on average, expanded faster in terms of number of large- and medium-size firms, the changes in industry composition are so small that the overall effect is negligible. Thus, inter-industry differences in propensity to patent do not seem to be an important factor in explaining the patenting surge.

5.2 Robustness check

5.2.1 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 sub-sample leaves us with 4,514 firms and 22,598 observations. Summary statistics for this sub-sample are reported in the bottom panel of Table 2. Measured by employment, innovator firms are on average about twice as big as an average LME and nearly twice as R&D intensive. We first re-estimate the patents production function for the innovators using the same ZIP estimator specification as in column (2) of Table 2. The results, reported in the first column of Table 4, are very similar to what we obtained using the full sample.

To account for firm heterogeneity, we then estimate the patents production function
<table>
<thead>
<tr>
<th></th>
<th>ZIP</th>
<th>Fixed effect</th>
<th>Random effect</th>
<th>Fixed effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>All</td>
<td>All</td>
<td>Domestic</td>
</tr>
<tr>
<td>log(R&amp;D)</td>
<td>0.066**</td>
<td>0.035**</td>
<td>0.042**</td>
<td>0.043**</td>
</tr>
<tr>
<td></td>
<td>(0.0008)</td>
<td>(0.009)</td>
<td>(0.001)</td>
<td>(0.010)</td>
</tr>
<tr>
<td>log(R&amp;D)^2</td>
<td>0.017**</td>
<td>0.002</td>
<td>0.004**</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>(0.0002)</td>
<td>(0.002)</td>
<td>(0.0002)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>log(labor)</td>
<td>0.321**</td>
<td>0.561**</td>
<td>0.361**</td>
<td>0.604**</td>
</tr>
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<td></td>
<td>(0.005)</td>
<td>(0.092)</td>
<td>(0.012)</td>
<td>(0.099)</td>
</tr>
<tr>
<td>industry FDI</td>
<td>1.513**</td>
<td>0.566</td>
<td>1.081**</td>
<td>0.715*</td>
</tr>
<tr>
<td></td>
<td>(0.035)</td>
<td>(0.318)</td>
<td>(0.06)</td>
<td>(0.336)</td>
</tr>
<tr>
<td>1996</td>
<td>-0.054*</td>
<td>0.058</td>
<td>0.001</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td>(0.025)</td>
<td>(0.074)</td>
<td>(0.025)</td>
<td>(0.076)</td>
</tr>
<tr>
<td>1997</td>
<td>0.184**</td>
<td>0.161</td>
<td>0.117**</td>
<td>0.128</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.098)</td>
<td>(0.024)</td>
<td>(0.102)</td>
</tr>
<tr>
<td>1998</td>
<td>0.260**</td>
<td>0.129</td>
<td>0.074**</td>
<td>0.086</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.103)</td>
<td>(0.025)</td>
<td>(0.112)</td>
</tr>
<tr>
<td>1999</td>
<td>0.301**</td>
<td>0.302**</td>
<td>0.224**</td>
<td>0.227**</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.097)</td>
<td>(0.024)</td>
<td>(0.105)</td>
</tr>
<tr>
<td>2000</td>
<td>0.451**</td>
<td>0.748**</td>
<td>0.649**</td>
<td>0.527**</td>
</tr>
<tr>
<td></td>
<td>(0.023)</td>
<td>(0.114)</td>
<td>(0.024)</td>
<td>(0.126)</td>
</tr>
<tr>
<td>2001</td>
<td>0.496**</td>
<td>0.856**</td>
<td>0.759**</td>
<td>0.697**</td>
</tr>
<tr>
<td></td>
<td>(0.023)</td>
<td>(0.122)</td>
<td>(0.024)</td>
<td>(0.135)</td>
</tr>
<tr>
<td>Obs.</td>
<td>22708</td>
<td>22556</td>
<td>23192</td>
<td>19280</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-58933</td>
<td>-30959</td>
<td>-46926</td>
<td>-24680</td>
</tr>
<tr>
<td>Hausman test (χ²)</td>
<td>758.31**</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses
* significant at the 5% level; ** significant at the 1% level
using two panel estimators: Poisson fixed effects with robust standard errors\textsuperscript{19} and random effects. While the Hausman test unambiguously rejects the random effects model in favor of the fixed effects model, the two estimators generate similar estimates of the various determinants of patent production, including low patents-R&D elasticities, robust estimates of the positive effect of industry FDI on patent production, and pronounced increases in patent production after year 2000. There are differences too. The fixed effects estimates show larger scale effects in the form of a larger coefficients on the labor variable and larger year effects for 2000 and 2001.

The fixed effects estimator implemented using the innovators sub-sample produces smaller estimates of the patents - R&D elasticity than that for the average LME obtained using the ZIP estimator for the whole sample. The squared R&D variable exhibits 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 significant at only the 10 percent level.

We then estimate the patents production function for domestic and foreign firms separately using the Poisson fixed effects estimator. There is now an even sharper contrast between domestic and foreign firms than in Table 3. While the previous results found a weak link between R&D and patents among the foreign invested firms, for the innovators alone that link becomes non-existent. In the full sample estimation, both domestic and foreign firms increase their patenting in response to higher concentrations of industry FDI, with the latter’s reaction slightly smaller than that of 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 percent 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.

\textsuperscript{19}This estimator is implemented using the Stata program \texttt{xtpqml} created by Tim Simcoe.
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.

Finally, a comparison of the results in Tables 3 and 4 is instructive. Unbalanced sets of panel data, such as those used in this study, can potentially lead to selection bias. While we might use a Heckman two-stage procedure, that estimator is built on the premise that we are reasonably certain of the selection rule. To the extent that we are certain, it is likely that the firms whose IDs disappear from the panel are those that undergo a change in their formal ownership designation. Because the panel is limited to LMEs, it is unlikely that these firms are predominantly new entries or exits; they are simply reclassified and assigned new IDs. Because most of our regressions control for ownership, assuming that the change in ownership designation is the key selection rule that determines the disappearance of IDs, selection bias should not be a problem. Moreover, comparing the results shown in Tables 3(2) and 4(1) indicates highly stable estimates across the extremely unbalanced data used in Table 3 and the substantially more balanced data set used in Table 4, where the latter panel consists only of innovators with at least two observations in the sample and at least one registered patent over the seven years in our full data set.

5.2.2 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 re-estimating column(2) of Table 3 and including the interactions between the ownership fixed effects and the year fixed effects.\footnote{We thank an anonymous referee for suggesting this exercise.} The data do not have sufficient variation to identify a full set of interactions 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 2000 and 2001, and zero otherwise. The cut-off year of 2000 is chosen to also reflect China’s reform of its patent law in that year and thus a potential change in the patent regime. The coefficients on the R&D, labor and FDI variables are
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 propensity to patent during the first period from 1995 to 1999. There is also an across-the-board increase in the average propensity to patent between the two periods. The collective and private enterprises increased their propensity to patent more than the other groups. The foreign-invested, Hong Kong, Macau and Taiwan-invested and shareholding companies have also seen their propensity to patent increasing more than that of state, limited liability and jointly-owned companies. Comparing the inter-ownership group differences in propensity to patent between the two periods, it is clear that overall patterns have not changed except that state-owned, other jointly-owned and limited liability firms have lagged further behind firms from the other ownership groups.\textsuperscript{21}

\textsuperscript{21}These differences are statistically significant; the test statistics are available upon request.
5.2.3 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 5. 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. Although our results in Table 3 show highly robust results for the full sample, at the industry level, the electric machinery industry is in some sense the only “perfect” industry that encapsulates all the driving forces we have identified. In the other seven industries, one factor or another stands out as the dominant explanation of the patenting surge.

6 Concluding remarks

China’s patent explosion has taken place in an institutional environment that is not known for the rule of law and rigorous protection of intellectual property rights. Such
institutional deficiencies should have substantially weakened the incentives for inventors to apply for patents. And yet in recent years, we observe a surge in patent applications. 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, along with 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 surge by estimating a patents production function. ZIP and Poisson fixed effects 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.

One robust result is the rather small estimate of the elasticity 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, while significant, China’s recent R&D intensification is unlikely to be the primary force behind the patent explosion.

We have found that foreign direct investment is also significantly contributing to the rising incidence of patenting 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 the 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.
Table 5: Patents production function estimation by industry: ZIP

<table>
<thead>
<tr>
<th></th>
<th>Discrete industries</th>
<th>Complex industries</th>
<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beverage Textile</td>
<td>Chemical Pharma</td>
<td>Special</td>
<td>Transport</td>
<td>Electric</td>
<td>Electronics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>log(R&amp;D)</td>
<td>-0.017 (0.019)</td>
<td>0.058 (0.033)</td>
<td>0.036 (0.025)</td>
<td>0.028 (0.021)</td>
<td>0.066** (0.014)</td>
<td>0.038 (0.036)</td>
<td>0.052** (0.01)</td>
<td>0.069** (0.011)</td>
</tr>
<tr>
<td>log(R&amp;D)$^2$</td>
<td>-0.005 (0.004)</td>
<td>0.022** (0.005)</td>
<td>0.013* (0.005)</td>
<td>0.001 (0.004)</td>
<td>0.012** (0.003)</td>
<td>0.009* (0.004)</td>
<td>0.017** (0.002)</td>
<td>0.020** (0.002)</td>
</tr>
<tr>
<td>log(labor)</td>
<td>0.638** (0.124)</td>
<td>-0.249 (0.154)</td>
<td>0.287 (0.169)</td>
<td>0.377** (0.077)</td>
<td>-0.014 (0.085)</td>
<td>0.195 (0.205)</td>
<td>0.717** (0.088)</td>
<td>0.489** (0.084)</td>
</tr>
<tr>
<td>industry FDI</td>
<td>0.859 (0.475)</td>
<td>-0.866 (1.732)</td>
<td>2.451** (0.402)</td>
<td>-0.507 (0.775)</td>
<td>-0.062 (0.631)</td>
<td>1.339** (0.43)</td>
<td>2.924** (0.721)</td>
<td>1.967 (1.018)</td>
</tr>
<tr>
<td>Obs.</td>
<td>5084 14945 11531</td>
<td>4589 7802 7903</td>
<td>11531 7506 5701</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-2177 -2575 -3989</td>
<td>-3685 -6091 -5605</td>
<td>-3989 -6091 -5605</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses
* significant at the 5% level; ** significant at the 1% level
Labor excludes R&D personnel.
References


