ISSN 1471-0498

DEPARTMENT OF ECONOMICS

DISCUSSION PAPER SERIES

PATENT LAWS AND INNOVATION IN CHINA

Linda Y. Yueh

Number 271

July 2006

Manor Road Building, Oxford OX1 3UQ

Patent Laws and Innovation in China

Linda Y. Yueh*

Pembroke College, University of Oxford

July 2006

Pembroke College
Oxford OX1 1DW
Tel: 01865 276444
E-mail: Linda.Yueh@economics.oxford.ac.uk

Abstract: This paper explores how the patent laws and intellectual property rights (IPR) system in China have affected innovation during the reform period. Subject to criticism due to imperfect enforcement, the patent law system has produced a stock of patents which has grown rapidly alongside economic growth. Despite significant regional disparities in income and the level of innovation, the success rates of patent applications are similar across the country. The application of the patent laws alone seems insufficient to explain these differences. We thus present a simple model of patent production in China derived from the patent law system. We find the main determinants of patents to be R&D expenditure and foreign direct investment (FDI), but not the number of researchers, though the level of human capital matters. We conclude that the policies governing FDI and R&D are the main determinants of patents, as the IPR system is fairly uniform across provinces.

Keywords: Intellectual property rights, patent laws, law and economics, innovation, economic growth, China.

JEL codes: O34, K29, O4, O53, K19

* This paper has benefited from comments from participants at seminars at the University of Nottingham, University of Oxford, the University of Sheffield, and the Conference on 'China and the World Economy' held by the Leverhulme Centre for Research on Globalisation and Economic Policy, University of Nottingham, and the Murphy Institute of Political Economy, Tulane University. Any errors are mine.

I. Introduction

Patent laws establish a system of intellectual property rights (IPR) that secure returns on an investment in innovation. Innovation is thought to be crucial to the long-run growth potential of an economy. For a developing and transition economy such as China, there is a further prospect of obtaining advanced technology from more developed countries through capital investment (foreign direct investment or FDI), which allows for "catching up" in growth. The lack of strong productivity gains in China throughout its otherwise remarkable period of growth during the post-1979 reform period underscores the importance of assessing the determinants of innovation in its economy (Borensztein and Ostry 1996).

China's first patent law was passed in the same year as urban reforms began in 1984. With accession to the World Trade Organisation (WTO) in 2001, China adopted the associated trade-related intellectual property rights (TRIPs) agreement and has harmonised its IPR system with the strictures of the international standards. However, ineffective enforcement has been an issue in China, and the patent laws are no exception. Despite the imperfect legal system, patents have increased rapidly in China.

In terms of foreign transfers of technology, China's particular "open door" policy has resulted in a notable stock of FDI which was increasingly technology-oriented in the 1990s. The restrictive nature of inward FDI into China situated in its Special Economic Zones (SEZs) and the explicit link to technology increase the prospect for FDI to be associated with innovation in China.

In this paper, we examine the effectiveness of the patent law system in China. The economic analysis of the patent laws in this instance relates as well to international aspects with China's adoption of TRIPs upon WTO accession. An assessment of the effectiveness of patent laws in producing innovation should also consider the determinants of patents. In other words, technology-oriented policies particularly in developing countries, such as China's FDI policy, are likely to affect the success rates of patents under any system. Further, given the size and importance of provincial authorities in China in governing FDI and industrial policies with differing levels of economic development and innovation, we first analyse whether the patent law system varies in its effectiveness across provinces. We then develop a patent production function for China which is similar to the ideas function in the endogenous growth literature. An innovation function in China would include an assessment of the role of researchers and the contribution of capital investment – either spending in the form of R&D expenditure or FDI – to innovation.

With its incomplete legal system characterised by weak enforcement, the effectiveness of patent laws in China is an interesting question, particularly as the number of patents have grown steadily over the past decade. As China emerges as a significant economy, the scope for comparing the drivers of its innovation with other OECD countries will also be of interest. With its successful record of attracting FDI, the contribution of foreign capital would be important to determine, particularly for other transition and developing economies. This paper will examine whether China's patent laws are effective in producing innovation and explore the contextual factors that generate innovation within such a system, e.g., FDI, R&D, and the number of researchers. We will look at patent success rates across provinces at different levels of development; ask whether FDI matters, following the focus of developing and transition economies in seeking foreign capital and technology transfers to help move them closer to the technology frontier; whether China's R&D spending has generated innovation captured in patents, akin to the OECD focus on increasing expenditure on research and development to foster productivity; and whether increasing research personnel will result in technological advancement, along the lines of the studies of the U.S. where innovation was found not to be clearly linked to the number of researchers.

The structure of this paper is as follows. We will first examine the development of China's patent laws and industrial policies aimed at achieving technological process in section 2. Section 3 will investigate the literature concerning the relationship among economic growth, FDI, and technology such as those embodied in patents, including studies of China. Section 4 gives the empirical findings regarding the effectiveness of patent laws in China. Section 5 presents the estimations of the determinants of patents. The final section concludes.

II. China's Patent Laws and Policies

A. Patent Laws

China's patent law was enacted in 1984 and was promulgated in 1985. In 1992, it was revised to extend the length of patent protection from 15 to 20 years for invention patents and from 5 to 10 years for process patents, *e.g.,* model and design patents. In 2000, it was further revised in anticipation of accession to the World Trade Organisation (WTO) which occurred in 2001. In 2001, China adopted TRIPs as part of its WTO obligations whereby its IPR standards were harmonised with international rules. Since the passage of the patent laws, there have been dozens of regulations and guidelines adopted to promote innovation. The patent law amendments also included conditions on the granting of compulsory licenses and prohibiting the unauthorized importation of products which infringe on the patents.

China's copyright law was promulgated in 1991 and has been amended several times since then and limits protection to works that do not harm China's "public interest." Enforcement of copyright laws was further strengthened to step up criminal prosecutions in 2004. Finally, China's trademark law was promulgated in 1983 with significant revisions in 1993, which permit registration and provide protection for service marks and also criminal sanctions for trademark infringement.

The set of regulatory agencies include the State Intellectual Property Office (SIPO) founded in 1980 as the Patent Office and renamed in 1998, the Trademark Office started in 1982 and the 1985 agency, National Copyright Administration. The Ministry of Commerce has a department that deals with trade-related intellectual property issues and the Chinese People's Court system addresses enforcement.

China's set of patent laws appears to largely meet the standards of international law. However, the adoption of laws does not necessarily imply effective enforcement, which will come under increasing scrutiny with the implementation of TRIPs. TRIPs should strengthen the IPR regime in China, particularly in terms of its enforcement provisions within the WTO. Approximately 20% of cases brought before the Dispute Settlement Mechanism of the WTO relate to the TRIPs provisions.

For China, however, TRIPs raises concerns about the development of its IPR system because the use of industrial policy to attract FDI into specific sectors is extensive and has been largely successful in propelling China to hold the third largest stock of FDI globally. The main criteria for permitting inward FDI is that the foreign investor has superior technology that can produce goods for export. Accordingly, technology transfer in some form accompanied the FDI, often not at the monopoly rates assured by strict IPR protection such as under TRIPs.

B. Industrial Policy

The establishment of Special Economic Zones (SEZs) at the beginning of the reform period in 1979 was designed to attract FDI into specifically designated export-oriented areas, such as in Shenzhen and Guangzhou. However, the Chinese authorities felt that there was insufficient technological progress in the SEZs and established Open Port Cities in 1984 which became Economic and Trade Development Zones (ETDZs) in 1985. These were more successful in attracting high technology foreign investment, particularly in the area of consumer electronics and computing. Free Trade Zones (FTZs) followed, which were established in 1992, which removed tariffs on numerous exports and imports. Then, China created High-Technology Development Zones (HTDZs) in 1995, which unlike the earlier zones, are widespread and located in nearly every province except for the western province of Qinghai and the Tibet and Ningxia Autonomous Regions. The HDTZs are focused on attracting technology in production as well as research centres, including industrial and science parks. The rapid growth of coastal regions which received FDI much earlier than the slower growing interior provinces prompted the government in the Ninth Five Year Plan (1996-2000) to try and move FDI westward into the interior.

C. Assessing Patent Laws and Industrial Policies

When considering the effectiveness of patent laws, it is not only the *de jure* law and the *de facto* enforcement that is of interest, but also the contextual factors which influence the rate of innovation. These would include industrial policies, such as China's creation of SEZs and therefore the impact of FDI, as well as its domestic factors, such as R&D spending and focus on scientific personnel.

Enforcement certainly matters, and the poor enforcement of laws in China is well known. However, China has managed growth with weak institutional bases, namely, the lack of well-defined property rights and an incomplete legal system with which to enforce rights, such as those granted by patents. Nevertheless, China has focused a great deal of effort in developing industrial policies to utilise the technology embodied in FDI and increasingly spend on R&D and accumulating researchers to foster innovation. Thus, the conclusions surrounding the economic impact of the patent laws are likely to be heavily linked to the determinants of patent production in China. An investigation of patent laws and innovation would need to encompass both the impact of the laws and the factors which influence their effectiveness.

Furthermore, the vast disparities in the levels of development among China's provinces and the autonomy that they have in terms of law and policy suggest that any study must also differentiate among provinces. The early opening of some coastal provinces is associated with faster growth, more FDI, and more innovation. However, the policy aimed at developing the interior in the past decade coincides with the focus on technological progress such that HTDZs are located throughout China. The implications for the effectiveness of patent laws in China must therefore further consider the particular context of the provinces and regions.

III. Literature Review: Patents, FDI, and Growth

A. IPRs and Growth

Technological innovation, such as those captured in formal intellectual property rights, holds significant implications for economic growth. The justification for IPRs such as patents generally relates to the need to protect the incentive to innovate weighed against the social cost of allowing monopoly profits to accrue and the loss to society of not having free access to the protected goods. As innovation generates technological advancement, it is the crucial driver of long-run economic growth. Nordhaus (1969), for instance, finds that the optimal patent policy equates the dynamic marginal benefit with the static marginal efficiency loss. Landes and Posner (1989) make similar arguments regarding the scope of protection, which they posit should be narrow in order to lower the cost of innovation. In the simplest case, the appropriate period of protection is that which allows the innovator to cover the risk-adjusted cost of innovative activity (see Besen and Raskind 1991). The breadth or scope of such protection will depend on the nature of the market (see Klemperer 1990). In a closed economy in which this framework is largely based, Arrow (1962) showed that the design of IPR protection poses a trade-off to a welfare-maximising government. However, in an open economy, Grossman and Lai (2004) argue that the trade-offs are less clear. Countries do not reap all the global benefits that come from protecting IPRs within its borders, and they will differ in their capacities for innovation due to differences in skill endowments and technical knowledge.

B. FDI and Growth

Another major area surrounds the potential for FDI to bring with it advance technologies to developing countries. The relationship between foreign direct investment and economic growth is an enduring question in development, and relates to the nature of technology transmission and possible positive spillover effects from multinational equity investments (Rodríguez-Clare 1996). FDI is thought to allow developing countries to "catch up" in the growth process by closing the technology gap through imitation and adoption of established technologies. The evidence, though, is limited (Rodrik 1999). The lack of convergence of the growth of rich and poor countries suggests that the process of capital and technology flows still needs to be better understood.

There are a number of studies which have examined possible spillover effects of inward FDI on host countries (see Bloomström and Kokko 1998 for a survey). Of the potential spillover effects from establishing foreign direct investment, there is only limited empirical evidence as to whether FDI improves the technological capability and productivity of local firms particularly in countries in the early stages of development (Javorcik 2004). Establishing and understanding this link would shed light on perhaps the key for developing countries to achieve longer term growth. In particular, the means through which technology is transferred between multinational corporations and the host countries is not well understood. The possible avenues include explicit transfers, such as contracts, and implicit transfers, including "learning by doing" and transmission of skills from foreign skilled labour to domestic employees working in the same factory.

C. Innovation in China

Despite the relatively well-defined IPR system, the attractiveness of China to FDI and the evidence of its impressive technological upgrading in manufactured goods over the past 15 years, there are few empirical studies related to innovation in China. A main reason is due to data limitations, although there are studies emerging at the firm level (see Hu *et al.* 2003). Cheung and Lim (2004), for instance, find a positive and significant effect of FDI on the number of patent applications. Using data from 1995 to 2000, provinces with more FDI are found to have more patent applications. They attribute this to a form of spillovers from foreign investment, namely, a demonstration effect on domestic enterprises. The difficulty with using patent applications filed rather than granted rests with filing as not being necessarily consistent with innovation. When we examine patents that have been granted, then the criteria for patents that usually include original and non-obvious innovation are more likely to have been met. A province which received substantial FDI could generate incentives to file patents, but does not necessarily capture innovation seen more readily through the amount of patents that are granted than by the number of applications. In this paper, we will focus on patents that have been granted and a richer set of determinants in a model of patent production generated from China's patent laws. Our estimation strategy will also utilise count models typically used for patents rather than OLS with its biases.

IV. Effectiveness of Patent Laws in China

A. China's Economic Development

China presents a good case for the study of the effects of the patent law system on innovation in an economy and the influence of foreign direct investment as well as R&D spending and researchers. China has an imperfect patent law system due to problems with enforcement, which is not uncommon among developing countries. However, it was established fairly early in the reform process and provides for a formal system of IPRs. Moreover, China has had a successful history of attracting FDI on its own terms and is at a low level of economic development, which makes FDI more likely to embody advanced technology that could be transferred to its benefit. In addition, the government's explicit policy targeting technology and creating science and industrial parks gives further evidence on which to judge the determinants of innovation similar to those which are found in more developed economies, notably R&D spending and scientific personnel. The combination of law and policy within a national framework that also exhibits regional variation allows for an exploration of the formal and contextual factors that determine innovation.

In terms of regional variation, China's development path has been skewed toward the coastal provinces. This can be seen in the regions that have been permitted to experiment with market-oriented reforms, which were primarily urban areas in the eastern region that have contributed to rapid GDP growth. China's "urban bias" and regional disparities are well documented (Knight and Song 1999). The resultant variation in regional and provincial growth is thus a product of government policy which has focused on the urban areas and coastal regions.

Its FDI policy follows a similar pattern where the "open door" policy only applied to Guangdong and Fujian initially in 1978, and the latter areas, still primarily coastal and for the most part eastern, did not receive foreign investment until less than a decade ago. Further, China's marketisation path is such that particularly with respect to FDI, the location of foreign investment and the clustering of economic activity would be highly conducive to agglomeration or network externalities, well-known in the new trade theory literature (Fujita et al. 1999). In particular, the HTDZs since 1995 have created "science parks" or "industrial parks" which aggregate economic activity in specified areas, such as the Haidan area of Beijing and the Pudong area of Shanghai. The HTDZs are geared at attracting more sophisticated technologies to China and given the rise in FDI and the increase in the technological components of Chinese manufactured exports in recent years, the initial evidence looks supportive (Lall and Albaladejo 2004).

The urban-rural and coastal-interior divides have been widening since the increase in FDI since the early 1990s. The introduction of foreign capital brings along a possibility of technology transfers that could further prompt the growth of the eastern and coastal regions, while contributing to the interior and western regions lagging behind.

B. FDI in China

Figure 1 shows that China has enjoyed a rapid rate of growth of inward FDI since the "open door" policy geared up in the mid 1980s. Figure 2 shows the corresponding number of FDI projects in China. These figures are particularly notable in contrast to the early part of the reform period. From 1979 to 1982, China received utilised FDI of only $1.17 billion and contracted FDI of $6.01 billion from just 922 FDI projects. The contrast with the period beginning in 1983 is remarkable. In 1984 alone, the number of FDI projects exceeded the prior period since 1979. Moreover, between 1991 and 1992, contracted FDI increased from $11.98 billion to $58.12 billion. The peak in 1992 can also be seen clearly in Figure 2. By 2003, China's utilised FDI was $53.50 billion and contracted FDI was an impressive $115.07 billion. China had become not only the leading destination for inward FDI among developing countries, but was one of the top three destinations for global FDI, often ranking just behind the U.S.

[FIGURE 1 HERE]

[FIGURE 2 HERE]

The other factor of note in Figure 1 is in the early 1990s when FDI began to pour into China primarily through the SEZs. During the early efforts to establish China's export capacity, the divergence between contracted and utilised FDI was significant. As China's technological capabilities in those areas of investment, namely, light industry and low technology products, increased, it was thought to be better able to use the agreed FDI and thus the gap between contracted and utilised FDI began to close. A similar pattern may be emerging corresponding to China's initiatives in the mid 1990s geared toward attracting more sophisticated technologies through ETDZs and HTDZs. There is again a trend of divergence between the amount of contracted for FDI and the amount that can be used. This interpretation is consistent with the evidence of the increasingly complex technological make-up of China's exports while China's domestic capacity lags somewhat behind.

The types of investment forms and the rules governing foreign invested enterprises in China warrant further consideration. The vehicle for FDI in China has traditionally been Chinese-foreign joint ventures. Until recently, wholly foreign-owned enterprises were permitted only in select sectors and selectively so. For instance, wholly foreign-owned enterprises were prohibited to operate in many areas and joint ventures were only permitted if the Chinese partner held a controlling share. Those categories, though, often disguised further nuances. For instance, wholly foreign-owned enterprises were prohibited from operating in certain areas of the transportation sector, with respect to some raw materials and aspects of financial services, but encouraged to operate in others. As one example, construction and operation of local railways and bridges were prohibited, but investment in highway construction and rural railways were encouraged.

The result of China's strict control of the form of foreign invested enterprises (FIEs) can be seen in Figure 3 below. Figure 4 shows the rapid loosening of the vehicles for investment by 2003.[1]

[FIGURE 3 HERE]

[FIGURE 4 HERE]

In 2000, before China's accession to the World Trade Organisation, wholly foreign-owned enterprises constituted about 26% of all FDI investment forms. Joint ventures, both equity and cooperative, comprised around three-quarters of all FIEs, around 74%. In Figure 4, which shows the same chart of FDI investment vehicles for 2003, wholly foreign-owned enterprises now comprise nearly three-quarters of all

[1] With WTO accession, the three main laws governing FIEs, *Sino-foreign Equity Joint Venture Law, the PRC, Sino-foreign Cooperative Joint Venture Law* and *the PRC, Wholly Foreign-owned Enterprise Law* and its implementing rules, have been amended.

FIEs in China. Joint ventures account for just about 29%. This shift has implications for China's industrial policy regarding innovation.

Prior to WTO accession and further opening of its economy, China exerted significant control over the form and destination of inward FDI. For instance, joint ventures were not approved unless they met two criteria. First, the foreign partner must have superior technology that is of interest to China. In fact, many of the joint venture agreements included annexes designating explicit technology transfers. Second, the manufactured products must be suitable for export and demanded in global markets. These rules governing joint ventures meant that Chinese enterprises had more potential to benefit from both explicit and implicit technology transfers from the foreign partners and thus develop its domestic infrastructure in science and technology. For instance, Javorcik (2004) finds that there are productivity spillovers from FDI from shared ownership but not with fully foreign owned enterprises for Lithuania.

Moreover, joint ventures were usually nearly 50%-50% in ownership, reducing the threat of foreign capital taking over or dominating domestic sectors. It may also be that the shift in the vehicles of FDI means that China will be less able to direct the type of investment that comes into China, with FDI shifting away from manufacturing and into retail sales as has begun to happen. Manufacturing had been the main sector of inward FDI, comprising over 22% in 1999 of all foreign investment and rising to 30% in 2001. Real estate comprises a consistent share of about 5% of sectoral share of FDI, and this consistency characterises most of the sectoral shares. The sector of energy infrastructure, including electricity, power, gas and water, accounts for just over 2% over this period, making it the fourth most popular sector for investment. FDI in sales and catering services, interestingly, grew at the third fastest rate of over 21% during this period. This is expected with the increased liberalisation of China's domestic market and the loosening of controls over the vehicles of FDI.

This further suggests that China's intellectual property rights policy will come under increasing scrutiny as it is less able to control the form and nature of FDI, particularly as foreign investors since WTO accession will expect the extent of protection afforded under the TRIPs agreement.

C. Patents in China

Turning to patents, the data used in the empirical estimations is drawn from the China Statistical Yearbooks and the China Statistical Yearbooks of Science and Technology for several years. The data covers the years from 1991-2003 and 29 provinces, and all figures are in 1990 prices.[2]

[FIGURE 5 HERE]

[FIGURE 6 HERE]

Figure 5 plots GDP per capita and patents awarded in China, while Figure 6 presents the relationship between GDP per capita and patents by province. It is clear that there is strong growth in the number of patents over this period and wide provincial variation in levels of income. The Pearson correlation coefficient for a relationship between patents and GDP per capita is 0.813 while the non-parametric Spearman's correlation gives a coefficient of 0.889. Both are significant at the 1% level in a two-tailed test. The correlation coefficients confirm the impression from the data that there is a strong correlation between per capita GDP and patents granted among China's provinces.

[TABLE 1 HERE]

[2] Tibet has been omitted due to a lack of data on the relevant variables for patents.

Table 1 gives the number of patent filed and granted along with the GDP per capita data for each province. There is again evidence of wide variation among provinces both in terms of GDP and patents. In terms of total patents granted in 2002, Guangdong holds 111,874. It is also the richest province with a GDP per capita of 5876 RMB. By contrast, Ningxia, one of the poorest interior provinces of China, has a GDP of 164 RMB and 1879 patents granted. However, the rates of patent application to granted patents did not differ a great deal across provinces, suggesting that the reasons for the fewer patents in Ningxia is not necessarily the result of fewer applications.

[TABLE 2 HERE]

Table 2 gives the patent grant rate for selected years and the average success rate. The average rate of patents granted to patents filed is similar across provinces despite vastly different amounts of patents granted and levels of economic development. The lowest success rate is 52% in Hubei while the highest is Guangdong with 67%. Hubei is not the poorest province while Guangdong is not the most innovative. Zhejiang is typically viewed as the most driven by technological advancement and its rate of patent success lags behind that of Guangdong. When considering regions, the interior has the highest success rate of patent applications on average (61.04%) followed by the coast (60.51%) and the central region (57.28%). These figures are very close and given the low number of patents in the interior, they likely reflect insignificant differences in success rates.

Although not conclusive, the evidence suggests that there is not great variation in the patent law system across China. Success rate is one measure of the economic effect of IPR rules and any differences could indicate varying enforcement. As the applications are considered nationally, it seems that the impact of patent laws is fairly uniform across provinces despite different levels of development. Seeking variation in the patent law system will therefore not explain differences in innovation among regions in China. What the evidence does suggest is that the effectiveness of China's patent laws in producing innovation must be considered within the context of significant provincial differences, and the factors which produce patents will need to be analysed in a similar fashion.

V. Determinants of Innovation

Our investigation will analyse the determinants of patents under a national IPR regime, focusing on the relative contributions of FDI versus domestic policy and identifying other relevant factors such as the effect of the numbers of researchers in terms of generating innovation. We start with a simple model, followed by the estimation approach, and present the empirical results for the national sample and by region.

A. Model: Patent Production Function

The determinants of patents can be thought of as a production function that follows a Poisson process. As patents are not produced with certainty, a Poisson process that describes events that happen independently and randomly in time is suitable to estimate patent production functions (Hausman et al. 1984). This is a count model that is typically applied to estimate the production of patents (Hall et al. 1986). We are interested in the production of patents in aggregate for provinces in China, which have different amounts of investment and labour and varying growth rates but are subject to a uniform IPR regime. In fact, the success rate of patent applications is similar across provinces despite vast differences in the level of development. The provincial variation allows for comparisons to be made within a national patent law system.

This patent production function would equate to the ideas production function in an endogenous growth framework (Jones 1995). We are not, however, estimating the contribution of innovation to economic growth, but are interested in determining the parameters of the ideas/innovation production function for China. Moreover, we cannot comment on whether there would be more or fewer patents if there was a stronger or weaker IPR regime. We are simply estimating whether the current patent law system in China has produced innovation captured formally in patents and enquiring after the most important contributors to this innovation.

Adapting the standard patent count model to our enquiry, the Poisson probability specification is:

$$pr(p_{it}) = f(p_{it}) = \frac{e^{-\lambda_{it}} \lambda_{it}^{p_{it}}}{p_{it}!}, \qquad (1)$$

where p is the count of patents of province i in year t, λ_{it} is a deterministic function of X_{it}, and the randomness in the model comes from the Poisson specification for p_{it}. The p_{it} are assumed to be independent and have Poisson distributions with parameters λ_{it}, which depend on a set of explanatory variables, X_{it}. A knowledge production function is given by:

$$\lambda_{it} = \exp(X_{it}, \beta). \qquad (2)$$

The Poisson parameter is further designated in the usual form, $\log \lambda = X_{it}\beta$, where X is a vector of regressors that describe the characteristics of an observation in a given time period and β are the parameters to be estimated.

Thus, the log likelihood of a sample of N provinces over T time periods is given by

$$L(\beta) = \sum_{i=1}^{N} \sum_{t=1}^{T} \left[p_{it}! - e^{X_{it}\beta} + p_{it} X_{it} \beta_{it} \right], \qquad (3)$$

where X in this instance is a vector of independent variables which determines the production of patents, namely, capital expenditure (R&D spending, foreign direct investment) and labour (scientific and technical personnel).

The dependent patent variable, p_{it}, is related to (3) through the conditional mean of the Poisson model, with the property of equality between its first two conditional moments:

$$E(p_{it} | X_{it}, \beta) = V(p_{it} | X_{it} \beta) = \lambda_{it}. \qquad (4)$$

Given the diversity of provinces, we extend the Poisson model to include a province unobserved specific effect ε_t into λ_{it}. This province-specific effect is assumed to be time-invariant. The Poisson's parameters then become:

$$\tilde{\lambda}_{it} = \exp(X_{it}\beta + \varepsilon_i). \qquad (5)$$

The fixed effect Poisson model corrects for the bias that may result from omitted province-specific characteristics, as provinces in China differ greatly even after observable variables are introduced as control variables. These controls include per capita GDP, which relate to the level of economic development of a province, the degree of openness, which may affect the absorptive capacity of a province, and the level of human capital in a province, which reflects the level of the labour force. Year dummies are also entered to capture trends in the propensity to patent due to overall productivity changes. Finally, as the data is from a panel of provinces, the Huber/White/sandwich estimator of variance is used to produce robust estimates that correct for heteroskedasticity.

For patent data measured in panels, there is a further issue concerning 'overdispersion,' whereby the conditional variance exceeds the conditional mean.

This occurs when estimating a cross-section model such as Poisson. For instance, unobserved effects could exist, including the uncertainty inherent in undertaking R&D or patenting due to commercial risk. Such unobserved heterogeneity makes the Poisson model subject to concerns due to its property of equality between its first two moment conditions (Hausman et al. 1984; Cincer 1997). An alternative specification would be to estimate a fixed effect negative binomial model or a zero-inflated negative binomial model if there is also an "excess zero" problem. However, by using province-level measures, we do not encounter the "zero" problem often found in firm-level data where many firms do not patent at all, and thus avoid the bias in the estimates of the standard errors.

To deal with overdispersion, equation (4) is rewritten with the same conditional mean but a variance that is quadratic in the mean:

$$\begin{aligned} &E\left(p_{it} \middle| X_{it}, \beta\right), \\ &V\left(p_{it} \middle| X_{it}, \beta\right) = e^{\mathbf{x}_{it}'\beta} + \alpha e^{2\mathbf{x}_{it}'\beta}. \end{aligned} \tag{6}$$

The Poisson then becomes a special case of the negative binomial model where alpha is equal to zero (Blundell et al. 1995; Cameron and Trivedi 1998). Equation (6) provides the basis for our fixed effect negative binomial model.

B. Estimating the Model

To estimate the patent production function, we take the logarithmic form of the number of patents produced and also enter the production inputs (capital, labour) in logs which assume a proportional relationship between patents and the inputs of R&D expenditure, FDI, and scientific and technical personnel. The control variables are GDP per capita, degree of openness of the province and human capital). Year and province dummy variables are also included.

The input capital variables would include FDI, which can be associated with the transfer of more advanced foreign technologies to a developing country such as China. The high proportion of FIEs producing exports in high tech sectors would provide additional support for a positive effect from FDI (Lall and Albaladejo 2004). The second component of capital input is R&D spending, particularly given China's industrial policy aimed at creating science parks to fuel innovation. And, R&D expenditure in some form has been shown to increase innovation in OECD economies (Bloom et al. 2002).[3] The number of scientific and technical personnel would be a relevant determinant of innovation since individuals innovate and greater numbers of researchers could lead to more patents filed and granted. However, the relationship would depend on whether having more innovators increases or duplicates existing research (Jones 1995[4]). Labour is, therefore, an ambiguous input.

Considering the control variables, per capita GDP would indicate the level of economic development of the province. The variable for per capita GDP is deflated by the CPI so that the reported figures are in 1990 prices. The degree of openness is also included because a province that exports may be more affected by pro-competitive forces derived from international trade which can influence the propensity to innovate due to greater competition. Human capital in the usual form of educational enrolment of school-aged children is also entered as a control for the general level of education in the province, which can also increase the inclination to innovate by providing a skills base. The year dummies are entered to account for any

[3] The square of R&D expenditure was also entered to allow for non-linearity in the relationship between patents and R&D spending, but was collinear with R&D spending and therefore omitted from the estimation. Also, lags were not introduced for the R&D variable because the relationship between R&D and patents is generally found to be contemporaneous (see e.g., Hall et al. 1986; Hall and Ziedonis 2001).

[4] Jones (1995) finds that increasing the number of researchers does not increase the rate of innovation for the U.S.

overall trends in productivity during the period, 1991-2003. This chosen period coincides with the “open door” policy taking off in China and accession to the WTO. This is also the period of significant economic growth in China deriving from reform of the state sector and increased opening to the global economy, which makes it an appropriate period of study. Finally, as FDI can be realised with delay as seen in Figure 1, we include a lagged FDI variable. For instance, time is required to take over a factory in China and make it operational. However, there are minimal differences between the results which for FDI and lagged FDI, which suggests that the effect on innovation is largely contemporaneous as with R&D spending.

C. Empirical Results: National Estimates

[TABLE 3 HERE]

First, there is evidence of overdispersion in the data, seen in the significance of the alpha parameter reported in Table 3. Therefore, the fixed effect negative binomial model is suitable, though the fixed effect Poisson results are reported for comparison.

The results show that R&D expenditure and FDI significantly increase the number of patents and are significant at the 1% level. A comparison of the negative binomial model and the Poisson regression estimates confirms the closeness in magnitude of the effects of R&D spending and FDI on patents. The other variables are similarly robust. The negative binomial model is the appropriate specification and the coefficients are expected to differ from the Poisson due to the different underlying models, e.g., the negative binomial model allows for between subject heterogeneity.

Unlike the effect of R&D spending which is a fairly straightforward input into producing patents, the estimate for FDI likely reflects the more complex relationship of foreign investment to patents. FDI can contribute to patent production through capital investment with technology transfer which is a common form of joint venture for China, but the impact of FDI may also be attributed to pro-competitive effects such as a demonstration effect. This would imply that having more FDI in a province could stimulate innovation due to greater competition as well as having potential spillovers of knowledge from the more advanced technology embodied in the FDI. The positive and significant coefficient on the openness variable gives further support to this position. In fact, the control variables of per capita GDP of a province and the province dummies are significant alongside the measure for openness so that the export-to-GDP is capturing more than the level of development and is likely proxying competitive forces. Thus, the contribution of FDI is significantly positive.

The other form of direct input into patent production from our model is labour, comprising of researchers. Although the number of scientific and technical personnel has increased during this period alongside patents, there is no significant relationship between the number of researchers and patents obtained. Increasing the number of personnel does not increase the rate of innovation in China, which is a finding not dissimilar to the U.S. The "crowding out" or duplicative effect of innovation appears to be dominant in China, which is likely reflected in the large number of HTDZs which has created science or industrial parks in nearly every province by policy mandate. However, educational enrolment which captures the level of human capital in a province is significant and positive, suggesting that a general level of skill leads to more innovation.

Turning to other control variables, GDP per capita is significant, indicating different levels of development affect patent production. Significant province dummies further reflect the intrinsic differences among provinces in China while the insignificance of the time dummies suggest that there are no time-varying overall productivity trends that influence the rate of patent production.

A similar picture is seen when FDI is entered with an one year lag. All of the estimates for the other variables are similar. The coefficient on the lagged FDI term is slightly smaller than FDI (0.1958 versus 0.2692), though still significant at the 1% level. This suggests that the effect of FDI is significant in both contributing to patent production contemporaneously as well as with a time lag to account for investment time.

D. Empirical Results: Regional Estimates

[TABLE 4 HERE]

[TABLE 5 HERE]

Table 4 presents the fixed effect negative binomial model regression results by region, while Table 5 does the same with the Poisson specification again for comparison. Given the much earlier opening of China's coastal provinces and their accounting for the bulk of inward FDI, there could be regional differences that are obscured by the aggregate estimations. This table divides the provinces into the coastal region which includes relatively open provinces such as Guangdong, the central region with provinces such as Hunan, and the interior region that includes some of the least development provinces like Qinghai which does not have a High Technology Development Zone.

Not surprisingly, there are significant differences in the mean number of patents awarded in the regions. For the coast, the average number of patents during this period was 3492, while it was 1117 for the central region and 841 for the interior. However, we discussed earlier that the patent laws seem to be fairly uniform in China since the average success rate of patent applications is similar across regions. Indeed, the interior has a marginally higher rate of patents granted than the coast, which is slightly higher than the central region. Thus, there is no correlation between the number of patents held and the grant rate.

The findings for the coastal region are very similar to the aggregate results, except that researchers reduce the likelihood of patenting and the human capital variable is insignificant. This is a much stronger result indicating that increasing the number of scientific and technical personnel has a “crowding” effect on innovation. Given the proliferation of SEZs, it is likely there is much duplicative research. For the coast, the effect of R&D expenditure is also much greater than the sample as a whole. As a result, FDI is comparatively less important, though still significant. There are also no province-specific or year-specific effects in the coast. Thus, for the more developed coastal region, R&D spending and the numerous investments of FDI are the main drivers of innovation.

The evidence for the central region is somewhat different from the coast. For these provinces, FDI significantly increase the number of patents granted. However, R&D spending and the number of researchers do not matter. It seems that FDI brings with it the innovative capacity, while domestic spending on research and researchers do not generate innovation. The centre of China is still able to attract FDI, despite being poorer than the coast, as foreign capital moves inland, particularly to urban centres such as Chongqing. This could explain the innovation associated with spillover effects from FDI, while the domestic factors lag behind due to a significant underdevelopment in the central provinces.

Finally, the evidence for the interior provinces is again dissimilar to the coastal and central provinces. Interestingly, none of the direct inputs matter (R&D spending, FDI, number of researchers) while more human capital seems to increase the patent production rate for these provinces, suggesting that the provinces with a good education level tend to innovate more than those which do not in the interior. Given the low levels of R&D spending and FDI, this is a plausible finding for the interior provinces which are among the poorest in China. And, the province dummies are significant, suggesting that there are time-invariant, province-specific effects with respect to patent production.

VI. Conclusion

Innovation as captured by patents has been rising in China. The expectation of the implementation of TRIPs likely increases this incentive to patent, though the rate of successfully innovating is roughly the same as before WTO accession. Nevertheless, the amount of formally captured innovation in the form of patents is indeed growing in China despite an imperfect legal system. Moreover, in spite of vastly different levels of economic development, the rate of success of patent applications among provinces is similar, suggesting a fairly uniform effect of patent laws in China.

However, despite similar grant rates, there are still vast differences among provinces in terms of their level of innovation. The application of patent laws alone is insufficient to explain regional variation, which suggests that contextual factors and policies must play a role. We posit that innovation in China is also determined not only by the legal system but also by factors that affect the production of patents, such foreign direct investment, R&D spending and researchers.

We find that FDI and R&D are significant determinants of innovation, though the effects are predominantly found in the coastal region. We also find that having scientific and technical personnel does not increase innovation, though the general level of human capital does affect innovation in the coastal region and the interior. It appears that R&D spending as well as FDI are significant only where the province is at a sufficient level of development, perhaps when there is sufficient absorptive capacity and infrastructure to support innovation. In the poorer provinces of the central and interior regions of China, human capital tends to be the important factor.

Therefore, we find that R&D along with FDI are important contributors to innovation, while researchers are not. The lag in time of the effects of FDI also appears to be of negligible importance. R&D spending and FDI are found to be the most significant determinants of innovation for the better off provinces, and seen also in the national estimates. An interesting finding is that the number of scientific and technical personnel does not have a positive or even significant effect on innovation. There is likely to be a time element to the research undertaken by scientific personnel, but the impression would be broadly consistent with the evidence for the U.S. where increasing the number of researchers has a “crowding” effect on innovation, even though we are focused on innovation and not productivity estimates.

The determinants of innovation are difficult to assess for any country and patents are an under-measurement. But, China, despite an imperfect legal regime, has produced a stock of patents which has accompanied its economic growth. The very different estimates for the coastal, centre and interior regions of China confirm the supposition that an economic analysis of the impact of patent laws on producing innovation must also consider that the determinants of patents will vary according to the institutional context of the region. Although we find that China’s patent laws have produced innovation and are driven by FDI and R&D spending, much more work needs to be done to discover the relationship of patent laws to economic growth as well as the mechanisms for producing innovation.

References

Arrow, Kenneth A., 1962, "Economic Welfare and the Allocation of Resources for Invention," in *The Rate of Inventive Activity: Economic and Social Factors,* R. Nelson, ed., Princeton: Princeton University Press.

Besen, S.M. and Raskind, L.J., 1991, "An Introduction to the Law and Economics of Intellectual Property," *Journal of Economic Perspectives* 5, 3-27.

Blomström, Magnus and Kokko, Ari, 1998, "Multinational Corporations and Spillovers," *Journal of Economic Surveys*, 12(2), 1–31.

Bloom, Nicholas, Griffith, Rachel, Van Reenen, John, 2002, "Do R&D Tax Credits Work?" *Journal of Public Economics*, 85, 1-31

Blundell, Richard, Griffith, Rachel, and Van Reenen, John, 1995, "Dynamic Count Data Models of Technological Innovation," *Economic Journal* 105(429), 333-344.

Borensztein, Eduardo and Ostry, Jonathan D, 1996, "Accounting for China's Growth Performance," *American Economic Review*, 86(2), 224-28.

Cameron, A. Colin and Trivedi, Pravin K.,1998, *Regression Analysis of Count Data*, Cambridge: Cambridge University Press.

Cheung, Kui-yin and Lin, Ping, 2004, "Spillover Effects of FDI on Innovation in China: Evidence from Provincial Data," *China Economic Review* 15(1), 25-44.

Cincer, Michele, 1997, "Patents, R&D, and Technological Spillovers at the Firm Level: Some Evidence from Econometric Count Models for Panel Data," *Journal of Applied Econometrics*, 12(3), 265-280.

Fujita, Masa, Krugman, Paul, and Venables, Anthony J., 1999, *The Spatial Economy: Cities, Regions, and International Trade*, Cambridge: MIT Press.

Grossman, Gene and Lai, Edwin L.-C., 2004, "International Protection of Intellectual Property," *American Economic Review*, 94(5), 1635-1653.

Hall, Bronwyn H., Griliches, Zvi, Hausman, Jerry A., 1986, "Patents and R and D: Is There a Lag?" *International Economic Review*, 27(2), 265-283.

Hall, Bronwyn H. and Ziedonis, Rosemarie H., 2001, "The Patent Paradox Revisited: An Empirical Study of Patenting in the US Semiconductor Industry, 1979-95," *RAND Journal of Economics,* 32(1): 101-128.

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

Hu, Albert G.Z., Jefferson, Gary H., and Qian, Jinchang, "R&D and Technology Transfer: Firm-Level Evidence from Chinese Industry," *Review of Economics and Statistics, forthcoming*.

Javorcik, Beata Smarzynska, 2004, "Does Foreign Direct Investment Increase the Productivity of Domestic Firms? In Search of Spillovers through Backward Linkages," *American Economic Review,* 94(3), 605-627.

Jones, Charles I., 1995, "R&D-Based Models of Economic Growth," *Journal of Political Economy*, 103, 759–784.

Klemperer, Paul, 1990, "How Broad Should the Scope of Patent Protection Be?" *RAND Journal of Economics* 21, 13-130.

Knight, John, and Song, Lina, 1999, *The Rural-Urban Divide. Economic Disparities and Interactions in China,* Oxford: Oxford University Press.

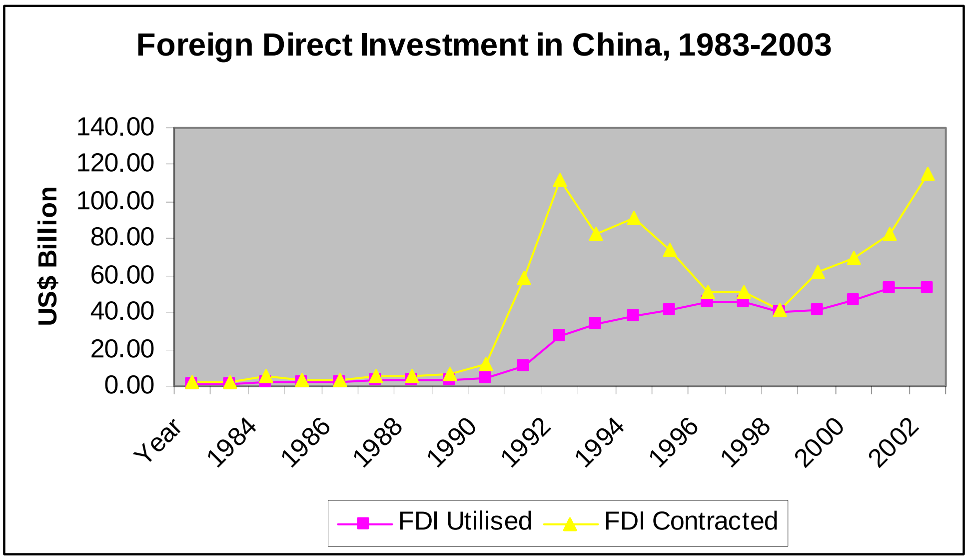
Lall, Sanjaya and Albaladejo, Manuel, 2004, "China's Competitive Performance: A Threat to East Asian Manufactured Exports?," *World Development*, 32(9), 1441-1466.

Landes, W.M. and Posner, Richard A., 1989, "An Economic Analysis of Copyright Law," *Journal of Legal Studies* 18, 325-363.

Nordhaus, William D., 1969, *Invention, Growth and Welfare: A Theoretical Treatment of Technological Change*, Cambridge, Massachusetts: The M.I.T. Press.

Rodríguez-Clare, Andrés, 1996, "Multinationals, Linkages, and Economic Development," *American Economic Review*, 86(4), 852–73.

Rodrik, Dani, 1999, "The New Global Economy and Developing Countries: Making Openness Work," Overseas Development Council (Baltimore, MD) Policy Essay No. 24.



Source: All figures are based on data from China Statistical Yearbook and China Statistical Yearbook of Science and Technology, various years.

Figure 1

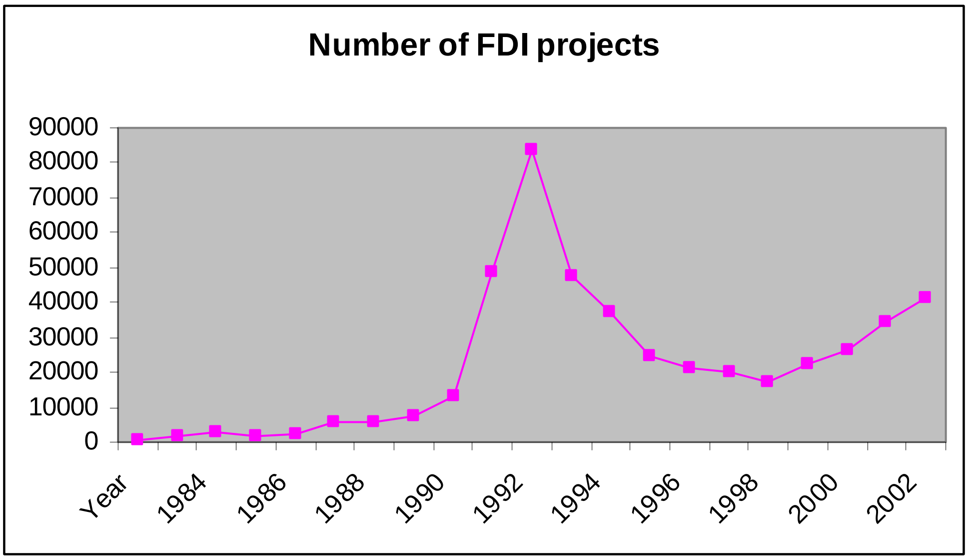


Figure 2

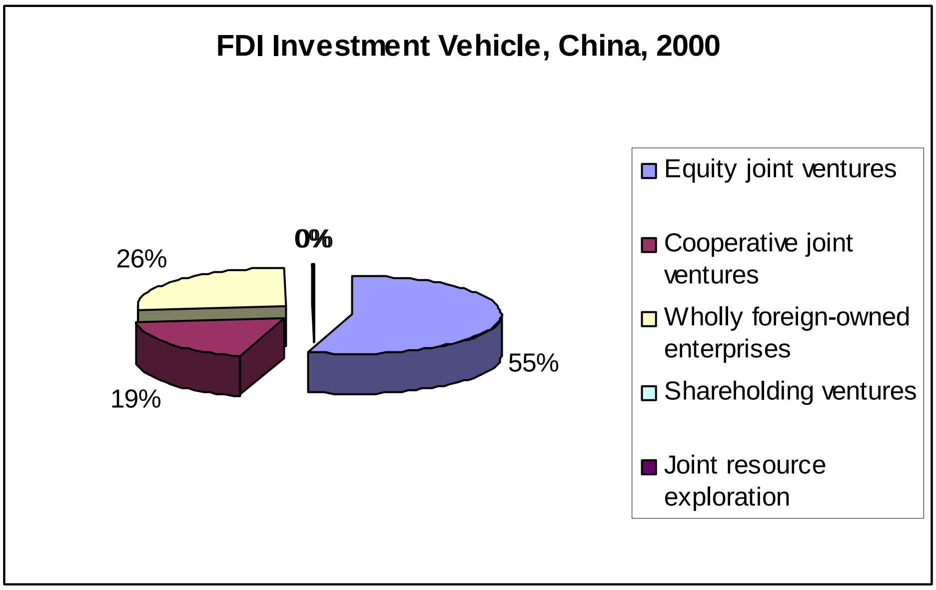


Figure 3

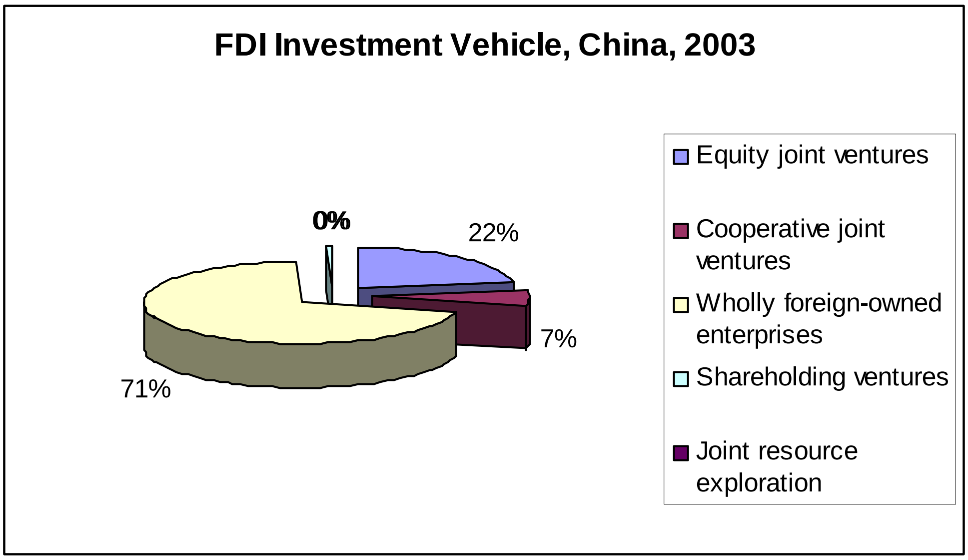


Figure 4

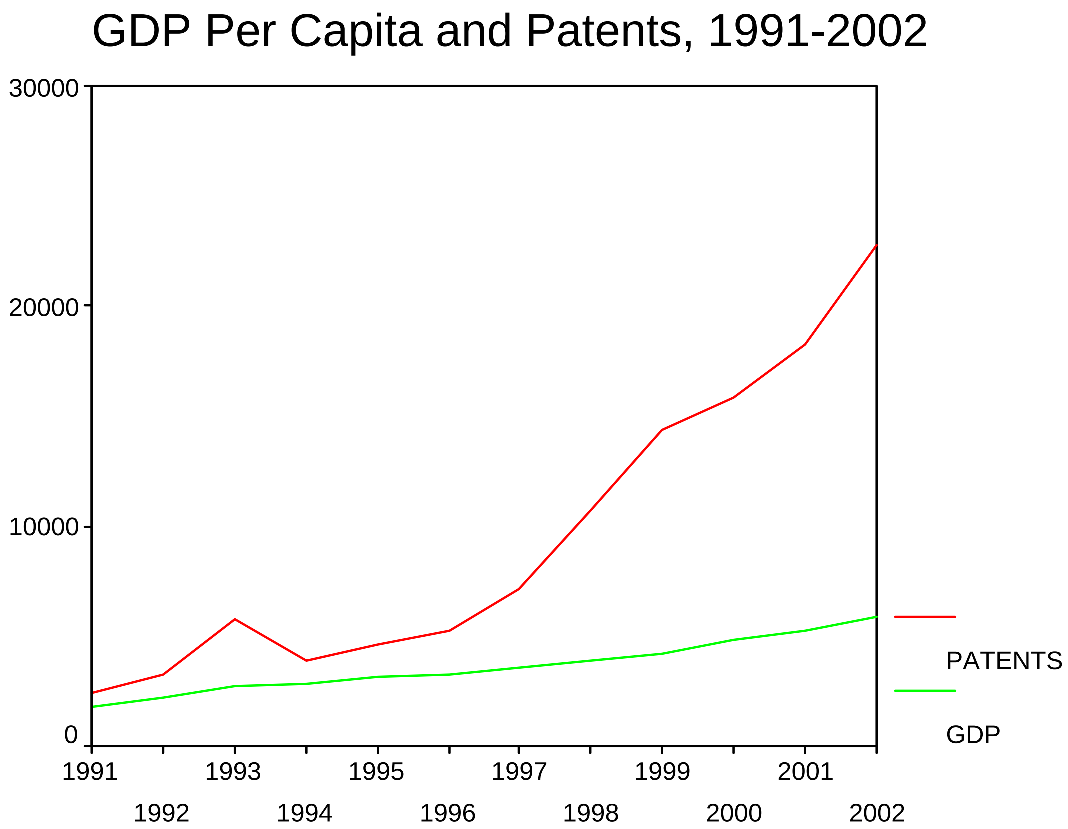
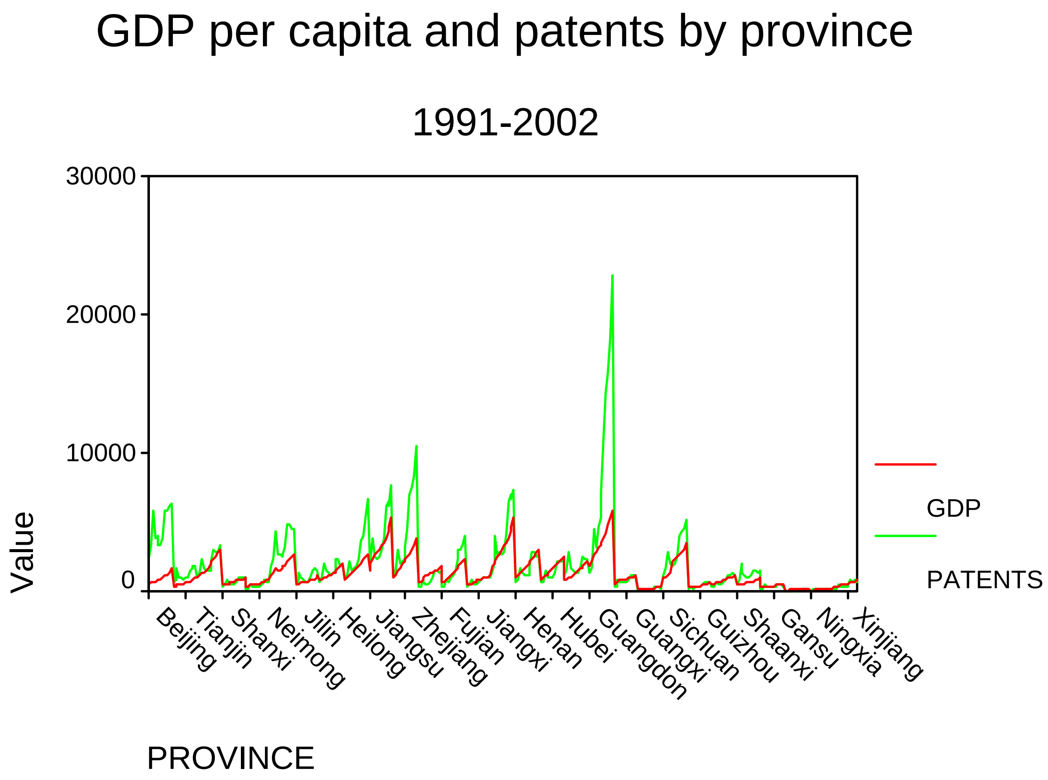

GDP Per Capita and Patents, 1991-2002
30000
20000
10000
0
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
PATENTS
GDP

Figure 5



Source: China Statistical Yearbook and S&T Yearbook, various years

Figure 6

Table 1
Patents and GDP per capita by Province, 2002

Province	Patents Filed	Patents Granted	Success Rate (Granted/Filed)	GDP per capita (RMB)
Beijing	111065	60826	54.77%	1604
Tianjin	30758	16951	55.11%	1024
Hebei	44434	26750	60.20%	3056
Shanxi	16012	9308	58.13%	1007
Inner Mongolia	11031	6152	55.77%	865
Liaoning	80134	45965	57.36%	2725
Jilin	27594	14672	53.17%	1121
Heilongjiang	39194	20986	53.54%	1938
Shanghai	76986	36474	47.38%	2700
Jiangsu	84880	51960	61.22%	5308
Zhejiang	91119	56119	61.59%	3892
Anhui	18599	11229	60.37%	1782
Fujian	36523	22150	60.65%	2337
Jiangxi	17645	9382	53.17%	1223
Shandong	93836	54088	57.64%	5268
Henan	39953	22367	55.98%	3080
Hubei	37148	19221	51.74%	2484
Hunan	49366	26336	53.35%	2167
Guangdong	168363	111874	66.45%	5876
Guangxi	19183	10581	55.16%	1225
Hainan	3860	2037	52.77%	301
Sichuan	62911	36918	58.68%	3418
Guizhou	10038	5239	52.19%	591
Yunnan	16035	10275	64.08%	1114
Shaanxi	27775	16397	59.04%	1016
Gansu	8612	4724	54.85%	579
Qinghai	1988	1067	53.67%	170
Ningxia	3344	1879	56.19%	164
Xinjiang	10459	5917	56.57%	798

Source: China Statistical Yearbook, various years; China Statistical Yearbook for Science and Technology, various years. All data for the following tables use these sources unless otherwise denoted.

Notes: GDP per capita has been deflated where 1990 is the base year.

Table 2
Patent Grant Rate by Province, Selected Years

Province	**1995**	**1998**	**2001**	**Average grant rate, 1995-2003**
Beijing	63.27%	60.12%	51.31%	**57.02%**
Tianjin	62.74%	70.17%	59.36%	**58.82%**
Hebei	58.37%	63.43%	59.45%	**63.08%**
Shanxi	62.05%	60.19%	71.08%	**63.07%**
Inner Mongolia	64.14%	66.62%	68.35%	**59.29%**
Liaoning	61.70%	56.03%	59.20%	**58.06%**
Jilin	59.32%	53.62%	54.93%	**53.62%**
Heilongjiang	54.61%	56.29%	50.95%	**57.31%**
Shanghai	58.47%	68.27%	42.04%	**57.50%**
Jiangsu	59.17%	64.97%	59.49%	**63.39%**
Zhejiang	52.72%	63.19%	64.80%	**62.87%**
Anhui	55.95%	62.87%	62.49%	**61.49%**
Fujian	47.15%	68.32%	66.30%	**63.50%**
Jiangxi	50.50%	60.76%	56.19%	**55.69%**
Shandong	61.87%	54.32%	60.21%	**58.28%**
Henan	47.99%	57.00%	63.08%	**57.78%**
Hubei	50.75%	48.12%	50.99%	**52.70%**
Hunan	57.65%	50.33%	55.94%	**54.63%**
Guangdong	59.66%	79.47%	66.17%	**67.59%**
Guangxi	54.02%	64.77%	59.79%	**59.49%**
Hainan	59.02%	51.07%	77.69%	**59.67%**
Sichuan	63.37%	58.15%	86.86%	**63.81%**
Guizhou	48.75%	52.25%	67.58%	**56.22%**
Yunnan	59.33%	73.24%	75.13%	**67.65%**
Shaanxi	63.04%	65.53%	58.21%	**62.16%**
Gansu	47.07%	58.36%	69.75%	**59.00%**
Qinghai	65.00%	45.26%	62.35%	**56.45%**
Ningxia	65.68%	53.63%	56.07%	**59.45%**
Xinjiang	51.23%	47.24%	69.52%	**59.00%**

Source: China Statistical Yearbook, various years; China Statistical Yearbook for Science and Technology, various years.

Table 3
Determinants of Patents in China, 1991-2003:
Fixed Effect Poisson Regression and Fixed Effect Negative Binomial Model
(z-statistics in parentheses)

	Poisson Model (1)	Poisson Model with lagged FDI (2)	Negative Binomial Model (3)	Negative Binomial Model with lagged FDI (4)
Constant	-7.4895	-6.2759	-75.3366	-58.8431
	(-1.10)	(-0.82)	(-2.19)**	(-1.58)
Explanatory Variables:				
Log of R&D Expenditure	0.0492	0.0489	0.2562	0.2692
	(3.07)***	(2.87)***	(4.02)***	(4.01)***
Log of Foreign Direct Investment	0.0363	---	0.2558	---
	(6.77)***		(6.30)***	
Log of Foreign Direct Investment (one year lag)	---	0.0294	---	0.1958
		(5.74)***		(4.69)***
Log of Scientific and Technical Personnel	-0.0135	-0.0108	-0.0444	-0.0337
	(-0.77)	(-0.59)	(-0.58)	(-0.42)
Controls:				
Log of per capita GDP	-0.0598	-0.0572	-0.2294	-0.2456
	(-3.26)***	(-3.09)***	(-1.97)**	(-1.96)**
Exports to GDP ratio	0.0007	0.0009	0.0063	0.0091
	(1.68)*	(2.30)**	(2.15)**	(2.94)***
Educational enrolment	0.0184	0.0208	0.0721	0.0911
	(4.76)***	(4.43)***	(3.48)***	(3.94)***
Province dummies	-0.0042	-0.0043	-0.0222	-0.0262
	(-3.45)***	(-3.35)***	(-3.13)***	(-3.48)***
Year dummies	0.0037	0.0030	0.0363	0.0274
	(1.09)	(0.79)	(2.08)**	(1.45)
Overdispersion parameter			0.2445	0.1955
			(10.40)***	(7.19)***
Wald Chi $X^2(8)$	932.76***	646.73***		
X^2 (8)			345.29***	310.16***
Pseudo R^2	0.0467	0.0432	0.0971	0.0905
N	203	195	203	195

Source: China Statistical Yearbook on Science and Technology, China Statistical Yearbook, various years.

Notes:
1. Dependent variable: log of number of patents granted. Mean is 6.9929.
2. Independent variables: log of foreign direct investment, log expenditure on research and development, log of number of science and technology personnel, exports-to-GDP ratio is recorded times 10 to create a comparable scale to the other explanatory variables, the educational enrolment of school-aged children, and log of per capita GDP. Dummy variables for province and year are also included to control for time-invariant and time-varying effects.
3. The overdispersion parameter is a t-test of the alpha variable specified in the negative binomial model (equation 6).
4. Coefficients are followed by z-statistics, where *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 4
Determinants of Patents in China by Region, 1991-2003:
Fixed Effect Negative Binomial Model
(z-statistics in parentheses)

	(1) Coast	(2) Central	(3) Interior
Constant	**-10.5435**	**-74.7784**	**225.1165**
	(-0.17)	**(-0.99)**	**(3.06)*****
Explanatory Variables:			
Log of R&D Expenditure	**0.7917**	**-0.0703**	**0.0881**
	(6.41)***	**(-1.02)**	**(0.54)**
Log of Foreign Direct Investment	**0.1925**	**0.1087**	**-0.0786**
	(2.73)***	**(1.73)***	**(-1.13)**
Log of Scientific and Technical Personnel	**-0.3972**	**0.0592**	**0.3329**
	(-3.25)***	**(0.57)**	**(1.40)**
Controls:			
Exports to GDP ratio	**0.0078**	**-0.1274**	**0.0086**
	(2.14)**	**(-4.38)*****	**(0.33)**
Log of per capita GDP	**-1.0332**	**0.7024**	**2.3354**
	(-5.41)***	**(1.99)****	**(6.32)*****
Educational enrolment	**0.2343**	**-0.0253**	**0.1487**
	(2.06)**	**(-0.55)**	**(6.55)*****
Province dummies	**-0.0369**	**0.0283**	**-0.3441**
	(-3.03)***	**(1.68)***	**(-5.46)*****
Year dummies	**-0.0015**	**0.0391**	**-0.1232**
	(-0.05)	**(1.01)**	**(-3.31)****
Overdispersion parameter	**0.1955**	**0.0530**	**0.1177**
	(7.20)***	**(4.86)*****	**(5.23)*****
X^2(8)	**128.37*****	**78.57*****	**154.49*****
Pseudo R^2	**0.0715**	**0.1047**	**0.1748**
N	**98**	**48**	**57**

Source: China Statistical Yearbook on Science and Technology, China Statistical Yearbook, various years.

Notes:
1. Dependent variable: log of number of patents granted. For equation (1), the mean is 7.6255. For equation (2), the mean is 6.8767. For equation (3), the mean is 6.0810.
2. Independent variables: log of foreign direct investment, log expenditure on research and development, log of number of science and technology personnel, exports-to-GDP ratio is recorded times 10 to create a comparable scale to the other explanatory variables, the educational enrolment of school-aged children, and log of per capita GDP. Dummy variables for province and year are also included to control for time-invariant and time-varying effects.
3. Coastal region includes Beijing, Tianjin, Hebei, Liaoning, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan. Central region includes Shanxi, Inner Mongolia, Jilin, Anhui, Jiangxi, Henan, Hubei, and Hunan. Interior region includes Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.
4. The overdispersion parameter is a t-test of the alpha variable in the negative binomial model (equation 6).
5. Coefficients are followed by z-statistics, where *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 5
Determinants of Patents in China by Region, 1991-2003:
Fixed Effect Poisson Regression
(z-statistics in parentheses)

	(1) Coast	(2) Central	(3) Interior
Constant	**5.2155**	**-8.6940**	**25.5784**
	(0.65)	**(-0.73)**	**(1.90)***
Explanatory Variables:			
Log of R&D Expenditure	**0.1086**	**-0.0096**	**0.0101**
	(7.91)***	**(-1.01)**	**(0.35)**
Log of Foreign Direct Investment	**0.0304**	**0.0165**	**-0.0191**
	(3.47)***	**(1.39)**	**(-1.38)**
Log of Scientific and Technical Personnel	**-0.0540**	**0.0073**	**0.0727**
	(-3.83)***	**(0.617)**	**(1.50)**
Controls:			
Log of per capita GDP	**-0.1385**	**0.1066**	**0.3134**
	(-5.46)***	**(1.90)***	**(6.12)*****
Exports to GDP ratio	**0.0008**	**-0.0174**	**0.0024**
	(1.93)*	**(-4.54)*****	**(0.65)**
Educational enrolment	**0.0221**	**-0.0024**	**0.0299**
	(1.56)	**(-0.33)**	**(5.54)*****
Province dummies	**-0.0051**	**0.0040**	**-0.0463**
	(-2.62)***	**(1.67)***	**(-6.74)*****
Year dummies	**-0.0026**	**0.0050**	**-0.0143**
	(-0.70)	**(0.81)**	**(-2.12)****
Wald Chi X^2(8)	**269.70*****	**230.60*****	**750.30*****
Pseudo R^2	**0.0171**	**0.0087**	**0.0666**
N	**98**	**48**	**57**

Source: China Statistical Yearbook on Science and Technology, China Statistical Yearbook, various years.

Notes:
1. Dependent variable: log of number of patents granted. For equation (1), the mean is 7.6255. For equation (2), the mean is 6.8767. For equation (3), the mean is 6.0810.
2. Independent variables: log of foreign direct investment, log expenditure on research and development, log of number of science and technology personnel, exports-to-GDP ratio is recorded times 10 to create a comparable scale to the other explanatory variables, the educational enrolment of school-aged children, and log of per capita GDP. Dummy variables for province and year are also included to control for time-invariant and time-varying effects.
3. Coastal region includes Beijing, Tianjin, Hebei, Liaoning, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan. Central region includes Shanxi, Inner Mongolia, Jilin, Anhui, Jiangxi, Henan, Hubei, and Hunan. Interior region includes Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.
4. Coefficients are followed by z-statistics, where *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.