The Determinants of Innovation:
Patent Laws, Foreign Direct Investment and Economic Growth in China

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Abstract: China's intellectual property rights regime provides formally for a measure of protection that is not always realised in practice. With the implementation of WTO-mandated measures in the coming years, China's intellectual property regime will come under increasing pressure. Intellectual property rights are one form of property rights which are thought to promote innovation by protecting the investment of the entrepreneur. Innovation is thought to be fundamental to economic growth. China has grown well without clearly defined property rights, although the IPR regime is better defined than most but not well-established in practice. This paper explores whether the patent law system has generated innovation in the Chinese economy during the reform period. Although imperfect, it appears that the IPR system has produced a stock of patents and innovation, which are closely associated with variations in per capita GDP among China's provinces. We also find that innovation can be explained by R&D expenditure, foreign direct investment, but not the number of science and technical personnel. R&D expenditure is found to be more important than foreign investment in generating innovation captured by patents, as is the level of human capital. We conclude that the patent laws in China have been associated with formally captured innovation that has accompanied economic growth despite the imperfections in the property rights system.

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

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

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I. Introduction

China has not had property rights conventionally defined and only recognised the existence of private property in March 2004, when the notion was included in the Constitution. Yet, China's phenomenal growth has taken place with residual claimant rights in its partially marketised economy, e.g., the Household Responsibility System implemented to great success in the rural economy in the late 1970s and early 1980s, and the Contract Responsibility System instigated in the mid 1980s so that state-owned enterprises can retain some portion of profits above the contracted amount to the state. This system of informal property rights extended to China's treatment of multinational corporations investing and establishing capacity in China. Interestingly, intellectual property (patents, copyright and trademarks) was given formal protection at a much earlier stage.

Moreover, since the "open door" policy of the mid 1980s and its take-off in the early 1990s, China has rapidly become nearly the world's top destination for foreign direct investment (FDI), holding a FDI stock that is third only to the U.S. and UK. Unlike most developing countries, China has exercised strict controls over the nature of inward investment. Until recently, the predominant form of FDI was joint ventures (JVs), where the Chinese and foreign partners set up either equity or cooperative joint ventures. Equity joint ventures partitioned returns on the basis of the invested capital in the JV while returns were contractually defined in cooperative joint ventures. Both forms of JV, however, were vested in essentially contractually-determined rights. The uncertainty that might have been generated by the lack of recognition of private property such as those held by JVs, though, did not seem to serve as a deterrent to Chinese attractiveness to FDI. Because of the lack of private property rights in the rest of the Chinese economy, the joint venture laws in some ways provided more protection to foreign-invested enterprises (FIEs) than accorded to Chinese non-state firms, such as *getihu* (sole prietorships) or small and medium sized enterprises (SMEs).

China thus successfully established a system of contracted-for rights spanning its institutional innovations, such as governing households, firms and even local governments, as well as with regard to FIEs. This system of legally defined but arguably informal property rights also seemed to stimulate China's impressive economic growth during the reform period despite an incomplete legal system. In a system of informal property rights, enforcement and definition would seemingly be of considerable significance, yet China's legal and regulatory systems lag behind its contractually defined obligations and growing body of laws.

This system has come under scrutiny with China's accession to the World Trade Organisation (WTO) in 2001. The WTO established a framework for international economic law that includes several provisions relating to the governance of trade-related intellectual property rights (TRIPs). Although China's first patent law was passed in the same year as urban reforms began in 1984, its intellectual property rights (IPR) system is far from established. Moreover, China's "open door" policy that had attracted a stock of FDI which included many agreements which either formally, e.g., technology transfer agreements, or informally, e.g., skills transfers through learning-by-doing, that transferred technology from the foreign to the Chinese partner. This transfer of technology, thought to be crucial to the "catching up" process well-known in the development literature, is increasingly subject to scrutiny, as the pace of investment has sped up and accordingly the demands for protection of intellectual property.

This paper will first examine the development of China's patent system and industrial policy aimed at improving its technological process in section 2. Section 3 will investigate the literature concerning the relationship among growth, FDI, and technological advancement, including studies of China. Section 4 gives the empirical findings regarding growth in China's provinces associated with formal IPR protection afforded to innovation such as patents. Section 5 presents the empirical model and the estimations of the factors that produce patents. The final section concludes.

II. China's Patent Laws and Policies

China's first patent law was enacted in 1984 and came into effect 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 revised a second time to eliminate the provisions that prevented state-owned enterprises (SOEs) from trading patents, among others in anticipation of accession to the World Trade Organisation (WTO) which occurred in 2001. Since the passage of the patent laws, there has 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 is further being 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 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 for Foreign Trade and Economic Cooperation (MOFTEC) also has a department that deals with trade-related intellectual property issues and the Chinese People's Court system also addresses enforcement.

China's set of patent laws appears to largely meet the standards of international laws, notably the Paris and Berne Conventions. However, the adoption of laws does not necessarily imply effective enforcement of IPR protection, which will come under increasing scrutiny with the implementation of TRIPs, Annex C governing Trade-Related Aspects of Intellectual Property Rights (TRIPs) to the Marrakesh Agreements Establishing the World Trade Organisation in 1994. In the next decade, every member of the WTO including China will have adopted the guidelines of TRIPs, despite ongoing implementation problems in developing countries. In contrast to the previous framework concerning intellectual property based around territoriality and independence of the Paris and Berne Conventions, international economic law is premised on the norm that the harmony or uniformity of laws is the ideal for the free flow of goods and services globally. TRIPs, moreover, provides for longer periods of IPR protection and is closer to the duration and breadth of U.S. IPR laws, though China's duration is already the same length. The TRIPs framework reinforces the view that the justification for granting intellectual property rights is to present to the innovator some monopolistic return from an investment that will benefit society and which would otherwise not occur. 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. 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.

The establishment of Special Economic Zones (SEZs) at the beginning of the reform period in 1979 were designed to attract FDI into specifically designated export-oriented growth areas of urban areas, such as in Shenzhen and Guangzhou. However, the Chinese authorities felt that there was still 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 followed, which were established in 1992, which removed tariffs on 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 three inner provinces of Qinghai as well as 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 in contrast to the slower growing provinces, which have been closed to foreign investment, prompted the government in the Ninth Five Year Plan (1996-2000) to move FDI westward into the interior. The stimulation to economic growth from exports in particular is certainly true in China, but the question of whether targeted industrial policy and technological diffusion from FDI has benefited productivity advances in China is yet to be established.

III. Patents, FDI, 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.

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 investment decisions (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 literature). 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.

Despite 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). A recent article finds a positive and significant effect of FDI on the number of patent applications. Using data from 1995 to 2000, Cheung and Lim (2004) find that provinces with more FDI have more domestic patent applications. The strongest effects are found a minor category of patents, that of design patents. 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 to a domestic firm rather than by applications. In this paper, we will focus on patents that have been granted and seek to explain regional variation in terms of innovation. We will also look at the influence of FDI vis-à-vis successful patents and provincial growth. We will further contrast the contribution of FDI against R&D spending and scientific and technical personnel, among others.

Although this paper will not be able to shed light on the precise relationship between FDI and spillover, it will test the hypothesis that IPR protection, which is afforded to foreign investment, and domestic R&D spending, which is a product of China's industrial policy aimed at fostering innovation, have resulted in a growing number of patents granted in China. And, we will investigate the determinants of innovation through an empirical model that captures the major factors of input as well as account for differences among China's disparate provinces.

IV. Empirical evidence from China

China makes for a good case of study of the relationship between an IPR regime, the degree of innovation in an economy, the influence of foreign direct investment and per capita GDP. China has had a successful history of attracting FDI and is at a low level of economic development, which makes FDI more likely to embody advanced technology that could be transferred to the benefit of a developing country. China also exhibits variation at the province level, reflecting different degrees of openness and amounts of FDI which in turn allows for estimations of the relationship among per capita GDP, innovation and determinants of patents within an imperfect and not atypical IPR regime for a developing country. However, China is far more successful than most developing or transition economies in attracting foreign direct investment and its regional variation allows for an exploration of whether FDI is a significant determinant of patents, a form of formally captured innovation. 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, notably R&D spending and accumulation of scientific personnel.

China's development path has been skewed toward the coastal regions. This can be seen in the various regions which have been allowed to experiment with market-oriented reforms, which were primarily urban areas in the eastern region, which has contributed to rapid GDP growth in certain provinces. 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 coastal and for the most part eastern, did not receive foreign investment until less than 10 years 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.

China's "urban bias" and regional disparities are also 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. The urban-rural and indeed coastal and interior divide is widening and has been growing since the increase in FDI since the early to mid 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 the interior and western regions lag behind and could have played a role in their falling further behind. The role of FDI, though, in growth must centre on the diffusion of more advanced knowledge from developed economies. This knowledge can take the form of explicit transfers, *e.g.,* technology transfer agreements from the foreign to the Chinese firms, or implicit transfers, such as a demonstration effect or learning on the job that can generate positive external economies of scale for firms and increase the skills of the workers who then move within the labour market. Knowing the determinants of innovation and the relative contributions of FDI versus domestic R&D spending derived from China's industrial policy will be important in understanding the nature of economic growth through its effect on provincial development.

Figure 1 shows that China has enjoyed an explosive 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 (FIEs) in China warrant further consideration. The vehicle for FDI in China has traditionally been joint ventures, particularly equity 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 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, prior to 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

[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.

vehicles for 2003, wholly foreign-owned enterprises now comprise nearly three-quarters of all FIEs in China. Joint ventures account for just about 29%. This shift has implications for China's industrial policy toward 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, in a process akin to the "catching up" process noted earlier. 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, shifting the investment potential of FDI away from manufacturing and into retail sales as has been seen recently. Manufacturing has 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 consistent with the increased liberalisation of China's domestic market and opening to foreign invested enterprises in anticipation of WTO accession. This also suggests that China's intellectual property rights policy will be increasingly important 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.

[FIGURE 5 HERE]

[FIGURE 6 HERE]

The data used below in the empirical estimation 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 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 a growth in patents and wide provincial variation. 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]

Table 1 gives the number of patent filed and granted along with the GDP per capita data for each province. There is expectedly wide variation among

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

provinces both in terms of GDP and patents held. In terms of total patents held as of 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. Interestingly, 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 successful applications. Although not conclusive, this also suggests that there is not great variation in the national IPR regime by province.

[FIGURE 7 HERE]

[FIGURE 8 HERE]

Figure 7 maps out the relationship among R&D spending, number of scientific and technical personnel and patents granted. There is also a positive trend of increasing R&D spending and growth of scientific personnel that has accompanied the increasing numbers of patents granted. Figure 8 shows a similar relationship for FDI and patents granted by province.

Therefore, our investigation will analyse the determinants of patents under this uniform IPR regime and seek out the relative contributions of FDI versus domestic policy, as well as identify other relevant factors such as the effect of the numbers of researchers in terms of innovation. Exogenous variation among provinces allows for investigation of these factors in China.

V. Empirical Investigation and Findings

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. We are interested in the production of patents in aggregate for different provinces in China each with different amounts of investment and labour but under a uniform IPR regime. 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.

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 is a vector of independent variables which determines the production of patents, such as capital expenditure (R&D spending, foreign direct investment that includes a component of technology transfer) and labour (scientific and technical personnel, human capital).

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:

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

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). In order to take this into account, an extension of the Poisson model would 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 also corrects for the bias that may result from omitted province-specific characteristics, which again makes this a suitable empirical model as provinces in China differ greatly even after observable variables are introduced as controls. These would include per capita GDP which relate to the level of economic development of a province and the degree of openness, which may affect the absorptive capacity of a province. Year dummies are also entered to capture trends in the propensity to patent due to overall productivity changes. Finally, by using province-level measures, we do not encounter the "zero" problem 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 estimate the Poisson maximum likelihood model, we take the logarithmic form of 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 same treatment is given to GDP per capita, while the variables of the degree of openness of the province and human capital are entered in levels, as no proportional relationship are assumed for these control variables. Year dummies are also included.

The next tables give our main empirical results. Spending on R&D would be an important factor in fuelling innovation, particularly given China's industrial policy aimed at creating science parks. And, R&D expenditure in some form has been shown to increase innovation in OECD economies (Bloom et al. 2002), so it is a crucial factor to consider for China.[3] Foreign direct investment can be associated with the transfer of more advanced foreign technologies to a developing country such as China. The statistics regarding the proportion of FIEs producing exports in high tech sectors would provide additional support. The expected effect of FDI is positive. 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 built up or duplicates existing research (Jones 1995[4]). Considering the control variables, per capita GDP would indicate the level of economic development of the province. The variable for per

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[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.

capita GDP is deflated by the CPI so that the reported figures are in 1990 prices. The degree of openness is also included as a province which 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 overall trends in productivity during the period, 1991-2003. This chosen period coincides with the "open door" policy taking off in China but before the adoption of the TRIPS agreement under WTO accession which may introduce an institutional change in the way that intellectual property rights are governed. 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. 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. As FDI can be realised with a lag, the second column in Table 2 shows the results with FDI lagged for one year. For instance, time is required to take over a factory in China and make it operational. However, the results in columns 1 and 2 in Table 2 are largely similar. Finally, the equality of moments conditions hold in the model as there is not evidence of "overdispersion" by examination of the conditional mean and conditional variance. The Poisson model is a good fit to the data.

[TABLE 2 HERE]

The Poisson results show that R&D expenditure and FDI significantly increase the number of patents in column 1 of Table 1. Both variables are significant at the 1% level. In terms of magnitude, the elasticity of R&D expenditure with respect to patent production is implied to be 4.92 while it is 3.63 for FDI. An 1% increase in R&D spending will increase the probability of innovation (grant of a patent) by 4.92%. The estimate for FDI, though smaller, is of a similar magnitude, the relationship of FDI to patents is more complex. 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 (Cheung and Lin 2004). 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 per capita GDP of a province and the province dummy variables are significant alongside the measure for openness so that the export-to-GDP is capturing more than just the level of development and is likely proxying competitive forces. The other direct input into patent production is labour. 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 that is similar for the U.S. (Jones 1995). 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 the GDP per capita variable, there is a negative relationship between the level of development and patent production. When the data is divided by region in the next table, it becomes clear that the negative relationship is driven by the coast while the interior and western provinces display a positive relationship between per capita GDP and the production of patents. The poorer interior and western regions are still catching up in terms of growth and thus their level of development is still accompanied by growing technical knowledge. For the coastal region, the less developed provinces may have fewer resources with which to invest in innovation as they are likely to be at a higher level of technical knowledge for which an easy correlation between income and technology is no longer sufficient to drive patent production. In the next table, we will see that the mean number of patents granted to the coastal areas is much greater than that awarded to the other regions. 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 with 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 in column 1 (0.0294 versus 0.0363), 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.

[TABLE 3 HERE]

Table 3 presents the Poisson regression results by region. 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 very open provinces such as Guangdong, the central region with provinces such as Hunan and the interior region, which has some of the least development provinces like Qinghai which does not have a High Technology Development Zone.

Not surprisingly, there is a significant difference in the mean number of patents awarded for each of 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. The results for the coastal region are very similar to the aggregate results, except that the human capital variable is insignificant while having researchers reduces the likelihood of patenting. This is a stronger result confirming the hypothesis put forth that increasing the number of scientific and technical personnel has a "crowding" effect on innovation. For the coast, the effect of R&D expenditure is much greater than the sample as a whole. The coefficient on R&D implies that a 1% change in R&D spending will increase the probability of a patent by around 10%, which is substantially greater than the sample as a whole (with an elasticity of 0.0492). FDI is comparatively less important, though still significant. There are also no province-specific or year-specific effects in the coast.

The evidence for the central region is somewhat different from the coast. For these provinces, FDI along with per capita GDP significantly increase the number of patents granted. The level of development seems to be associated with greater innovation as well as having foreign direct investment. However, R&D spending and the number of researchers do not matter. Openness is also negatively correlated with patent production, which suggests that the export structure of these provinces is not associated with technical improvements, perhaps because low tech goods are produced there which do not generate innovation. Again, there are no province-specific effects.

Finally, the evidence for the interior provinces is again dissimilar to the coastal and central provinces in that the strongest explanatory variable is per capita GDP and not FDI. Interestingly, 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, consistent with the interpretation given to the per capita GDP variable, 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 quickly in China. Since WTO accession, the year 2002 registered a rise in 11% in patents granted, as compared with 4% for previous years. The expectation of the adoption of TRIPs likely increases this incentive to patent.

The evidence suggests that China's imperfect intellectual property rights regime has been successful in producing innovation in the form of patents. Although FDI is heavily biased toward coastal regions, innovation appears to be closely linked to per capita GDP and the rate of successful patent applications is similar across China's provinces. There is not strong evidence that some provinces, despite having vastly different amount of FDI, are more likely to be successful innovators. We also find that FDI is a slightly less important contributor to innovation than expenditure on research and development, particularly in the coastal provinces. The lag time for the effects of FDI also appears to be of negligible importance. R&D spending appears to be the most significant determinant of innovation for the better off provinces, and seen also in the national estimates. This would be consistent with the findings of other countries. An interesting finding is that the number of scientific and technical personnel does not have consistently significant effects on innovation. There is likely to be a time element to the innovative activity undertaken by scientific personnel, but the general interpretation would be broadly consistent with the evidence for the U.S. where increasing the number of researchers has a "crowding" effect, even though we are focused on innovation and not productivity estimates.

Although numerous reforms are still needed to strengthen the system of innovation, R&D spending, FDI and human capital are positively associated with more technological advancement captured in formal intellectual property in China. An analysis of the patent law system showed that the growth in patents is associated with economic growth generally, and this paper has uncovered the determinants of innovation but not the mechanisms of technological innovation. We conclude that innovation in China is driven by R&D spending and domestic industrial policy as well as by foreign direct investment, though the latter is only significant in coastal regions. We also find that having scientific and technical personnel does not increase innovation, though the general level of human capital does. 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, the general level of development and human capital are significantly positive factors. The determinants of innovation are difficult to assess for any country and patents are an under-measurement, but China, despite an imperfect IPR regime, has produced a stock of patents which have accompanied its economic growth. However, much more work needs to be done to discover the relationship of patent laws and IPRs to growth as well as the mechanisms for producing innovation.

References

Arellano, M. and S. Bond. 1991. "Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations," *The Review of Economic Studies* 58, 277-297.

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.

Bennett, David, Liu, Xiaming, Parker, David, Steward, Fred, Vaidya, Kirit, 2001, "Technology Transfer to China: A Study of Strategy in 20 EU Industrial Companies," *International Journal of Technology Management* 21(1/2), 151-182.

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 and Bond, Stephen, 2000, "GMM estimation with persistent panel data: An application to production functions," *Econometric Reviews* 19(3), 321-340

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, B.H. and Ziedonis, R.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.

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

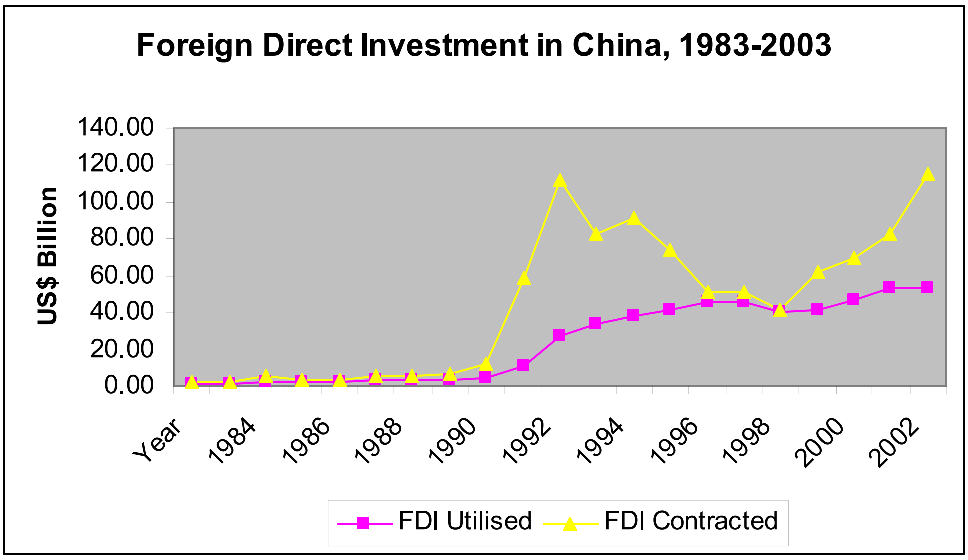
Lardy, Nicholas, 1991, *Foreign Trade and Economic Reform in China, 1978-1990*, Cambridge: Cambridge University Press.

Naughton, Barry, 1996, *Growing Out of the Plan: Chinese Economic Reform, 1978-1993,* Cambridge: Cambridge University Press.

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 Yearbooks of Science and Technology, various years.

Figure 1

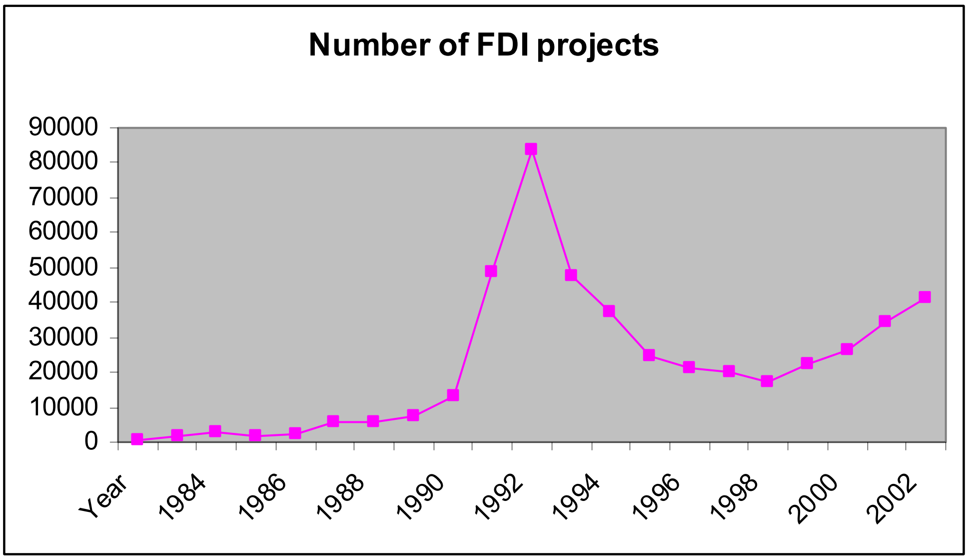


Figure 2

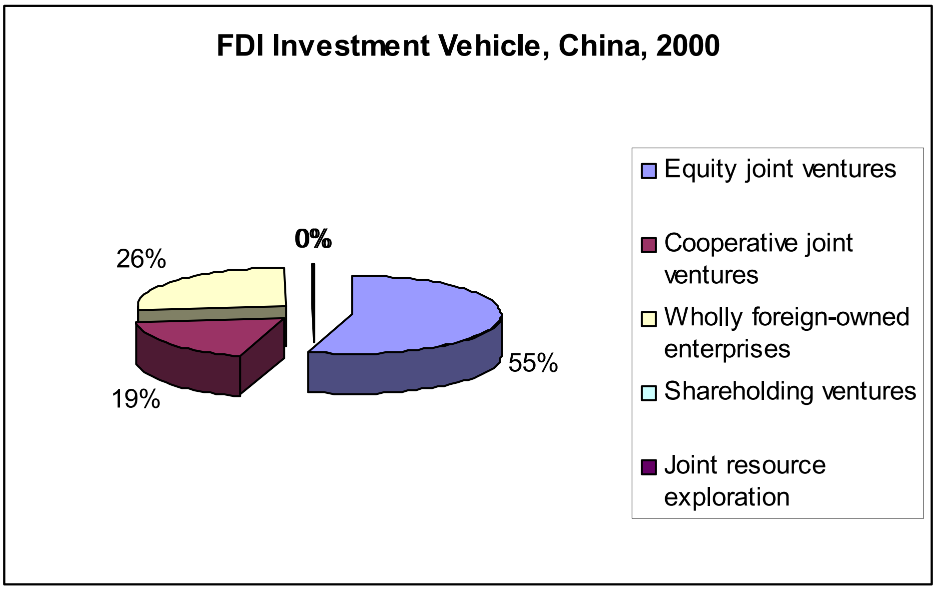


Figure 3

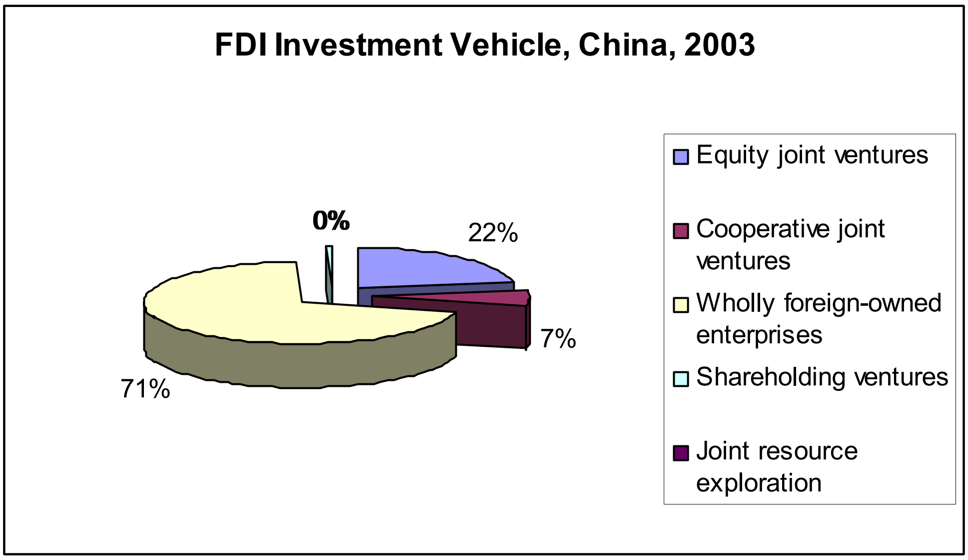


Figure 4

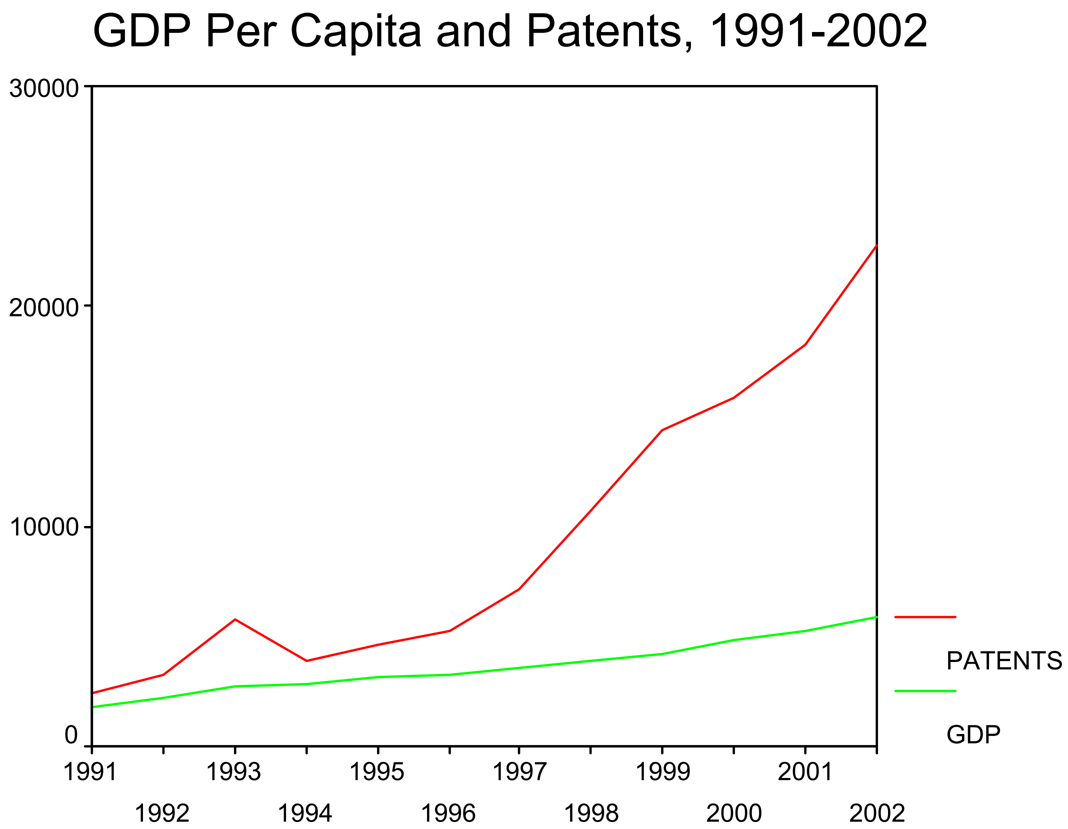

GDP Per Capita and Patents, 1991-2002
30000
20000
10000
0
1991
1993
1995
1997
1999
2001
1992
1994
1996
1998
2000
2002
PATENTS
GDP

Figure 5

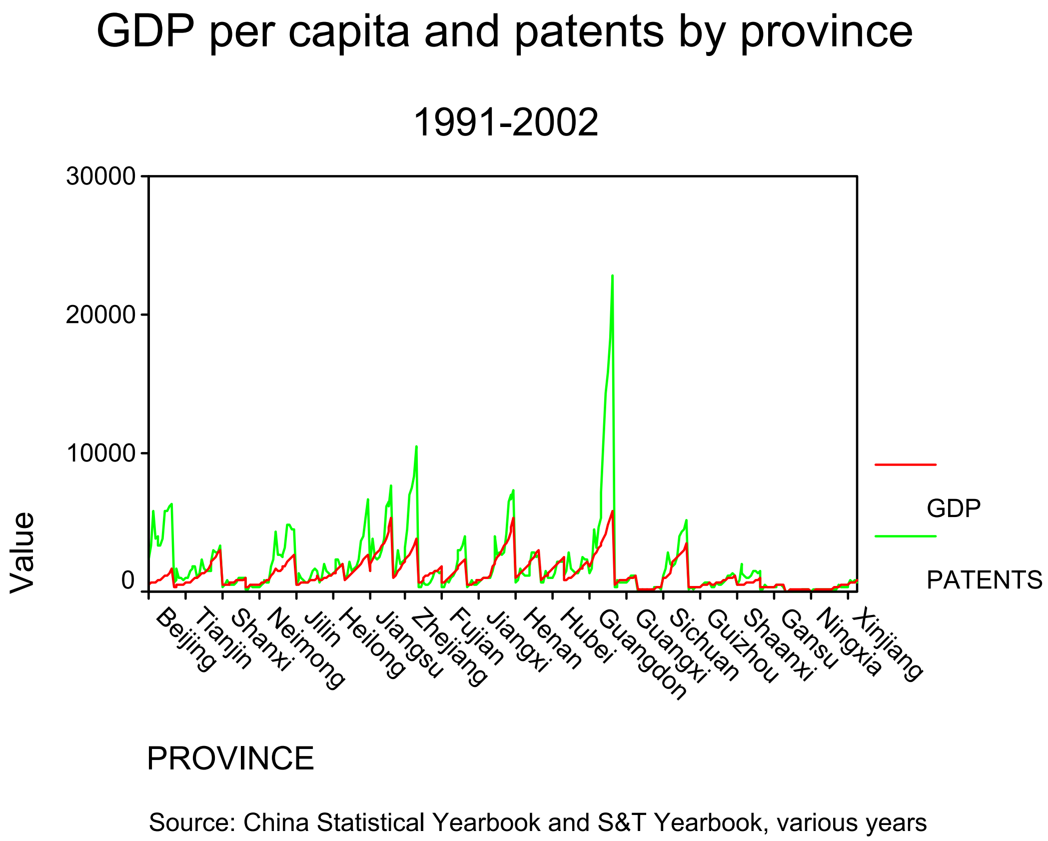

GDP per capita and patents by province
1991-2002
30000
20000
10000
0
Value
GDP
PATENTS
Beijing
Tianjin
Shanxi
Neimong
Jilin
Heilong
Jiangsu
Zhejiang
Fujian
Jiangxi
Henan
Hubei
Guangdon
Guangxi
Sichuan
Guizhou
Shaanxi
Gansu
Ningxia
Xinjiang
PROVINCE
Source: China Statistical Yearbook and S&T Yearbook, various years

Figure 6

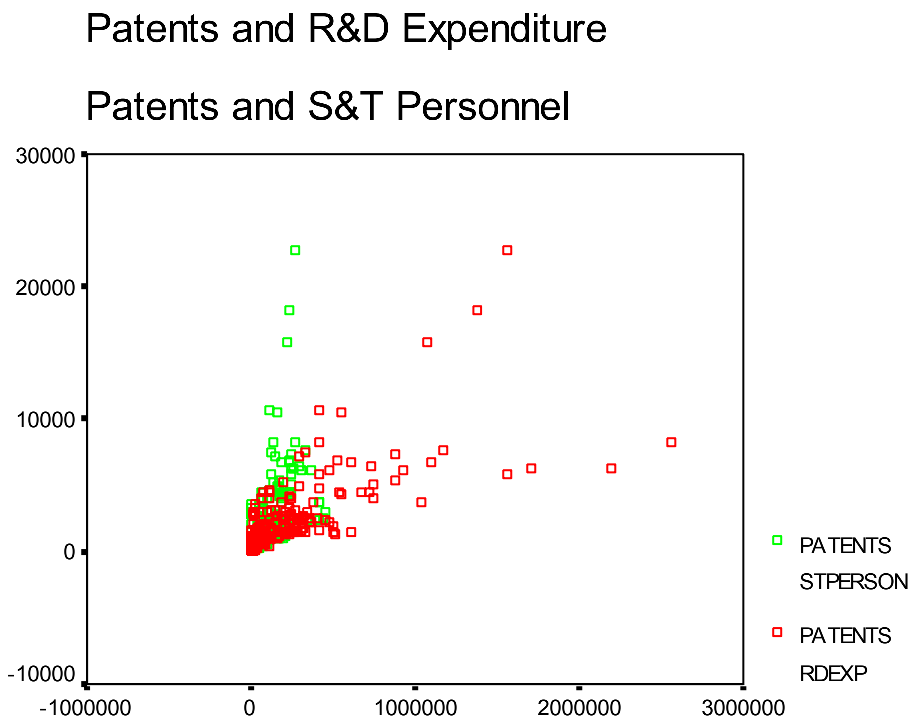

Patents and R&D Expenditure
Patents and S&T Personnel
30000
20000
10000
0
-10000
-1000000
0
1000000
2000000
3000000
PATENTS
STPERSON
PATENTS
RDEXP

Figure 7

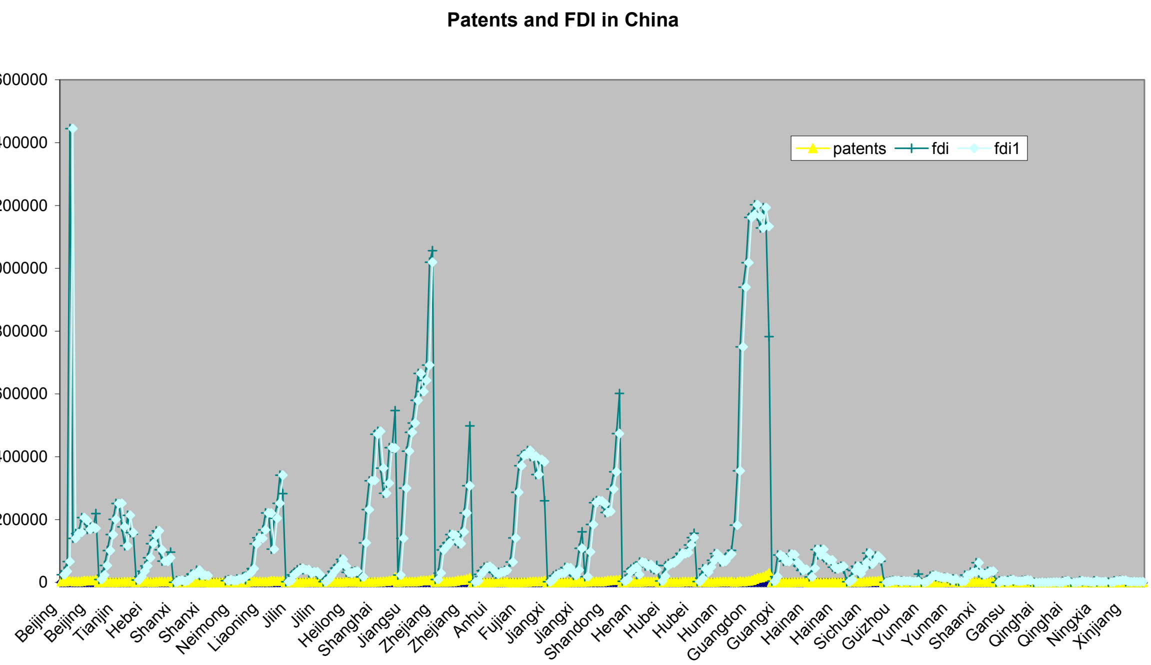

Patents and FDI in China
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
patents
fdi
fdi1
Beijing
Beijing
Tianjin
Hebei
Shanxi
Shanxi
Neimong
Liaoning
Jilin
Jilin
Heilong
Shanghai
Jiangsu
Zhejiang
Zhejiang
Anhui
Fujian
Jiangxi
Jiangxi
Shandong
Henan
Hubei
Hubei
Hunan
Guangdon
Guangxi
Hainan
Hainan
Sichuan
Guizhou
Yunnan
Yunnan
Shaanxi
Gansu
Qinghai
Qinghai
Ningxia
Xinjiang

Figure 8

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 (1990=100).

Table 2
Determinants of Patents in China, 1991-2003:
Poisson Regression
(z-statistics in parentheses)

	(1)	(2)
Constant	-7.4895	-6.2759
	(-1.10)	(-0.82)
Log of per capita GDP	-0.0598	-0.0572
	(-3.26)***	(-3.09)***
Log of R&D Expenditure	0.0492	0.0489
	(3.07)***	(2.87)***
Log of Foreign Direct Investment	0.0363	---
	(6.77)***	
Log of Foreign Direct Investment (one year lag)	---	0.0294
		(5.74)***
Log of Scientific and Technical Personnel	-0.0135	-0.0108
	(-0.77)	(-0.59)
Exports to GDP ratio	0.0007	0.0009
	(1.68)*	(2.30)**
Educational enrolment	0.0184	0.0208
	(4.76)***	(4.43)***
Province dummies	-0.0042	-0.0043
	(-3.45)***	(-3.35)***
Year dummies	0.0037	0.0030
	(1.09)	(0.79)
Wald Chi X^2(8)	932.76***	646.73***
Pseudo R^2	0.0467	0.0432
N	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 per capita GDP, 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, and the educational enrolment of school-aged children. Dummy variables for province and year are also included to control for time-invariant and time-varying effects.
3. Coefficients are followed by t-statistics, where *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 3
Determinants of Patents in China by Region, 1991-2003:
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)***
Log of per capita GDP	**-0.1385**	**0.1066**	**0.3134**
	(-5.46)***	**(1.90)***	**(6.12)*****
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)**
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 per capita GDP, 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, and the educational enrolment of school-aged children. 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 t-statistics, where *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.