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Abstract

Innovation has widely been regarded as one of the main drivers of economic growth in the knowledge economy. This paper investigates the impact of foreign direct investment (FDI) on the development of regional innovation capabilities using a panel dataset from China. It finds that FDI has a significant positive impact on the overall regional innovation capacity. FDI intensity is also positively associated with innovation efficiency in the host region. The strength of this positive effect depends, however, on the availability of the absorptive capacity and the presence of innovation-complementary assets in the host region. The increased regional innovation and technological capabilities have contributed further to regional economic growth in China's coastal regions but not in the inland regions. It concludes that the type and quality of FDI inflows and the strength of local absorptive capacity and complementary assets in the host regions are crucial for FDI to serve as a driver of knowledge-based development. Policy implications are discussed.

I. Introduction

Technological capabilities are a key component of competitiveness at national, regional or firm levels. The development of regional innovation capabilities has been of crucial importance for competitiveness building in both developed and developing countries. In the past decade there has been increasing research on the regional innovation system. It is argued that there is something distinctive and systemic about innovation as a localized phenomenon which cannot be predicted by the more familiar national innovation systems frameworks (Braczyk, Cooke and Heidenreich, 1998, and Meltcalfe, 1997). Although knowledge is a non-rival public production asset, which can generate positive externalities or spillovers to others (Nelson, 1959; Arrow, 1962, Griliches, 1979), knowledge spillovers are geographically localized (Jaffe, Trajtenberg and Henderson, 1993; Austreche and Feldman, 1996; Audretsch, 1998; Anselin, Varga and Acs, 1997; and Almeida and Kogut, 1997). Knowledge and information may flow more easily among agents located with the same area because of social bonds that foster reciprocal trust and frequent face-to-face contacts (Breschi and Lissoni, 2001). Therefore, there may be geographic boundaries to information flows or knowledge spillovers among the firms in an industry (Marshall, 1920 and Krugman, 1991). These spacially bounded knowledge spillovers allow companies operating nearby important knowledge sources to introduce innovations at a faster rate than rival firms located elsewhere. This is particularly the case for those 'tacit' knowledge, ie. highly contextual and difficult to codify, and is therefore more easily transmitted through face-to-face contacts and personal relationships. Therefore, regional systems can much better capture the local nature of innovation than other wider eco-geographical systems.

One of the important players in the regional innovation system is the multinational enterprises (MNEs) and their affiliates. MNEs are a major force conducting cutting-edge research and innovation. Multinational companies are often regarded to possess certain advantages which enable them to succeed in the global market. Their advantage, their firm-specific assets, are often of a technological nature. More than 80% of royalty payments for international technology transfers were made by affiliates to their parent companies (UNCTAD, 1997 and 2005). Therefore, openness of local economy to multinational enterprises (MNEs) located in the region may have a significant impact on regional innovation performance. The strength of the effect of FDI on regional innovation capacity may, however, depend on the absorptive capacity of the host regions. Innovation is an evolutionary and accumulative process. Only with the necessary capability to identify, assimilate and development useful external knowledge can the host regions effectively benefit from the advanced technology embedded in FDI Although there has been some research on the role of absorptive capacity at the firm level, empirical studies of the role of absorptive capacity in the evolving regional innovation system in the developing countries have been rare.

In this paper, I will investigate the impact of FDI on regional innovation capabilities in China with special emphasis on the role of absorptive capacity and complementary assets in determining the strength of the assimilation and modification. This paper is organised as follows. Section II presents the theoretical framework for understanding relations between FDI, absorptive capacity and regional innovation performance. Section III discusses FDI and innovation in China and the innovation performance of foreign invested enterprises. Section IV presents empirical evidences. Section V concludes with some policy implications.

II. Foreign direct investment, absorptive capacity and regional innovation capabilities in developing countries: a theoretical framework

The development of technological capabilities is the outcome of a complex interaction of inventive structure with human resources, technology efforts and institutional factors. The incentive structure includes macroeconomic incentives, incentives from competition and factor markets; and the institutions includes market and non-market institutions such as legal framework, industrial institutions, and training and technology institutions. It is the interplay of all these factors in particular country settings that determines at the regional level, how well the regions employ the resources and develop their technological capabilities (Lall, 1992). In other words, it is the efforts of the agents in a region, ie. business, government and the universities, and the strength of the linkages between these agents that determine the performance of a regional innovation system (Braczyk, Cooke and Heidenreich, 1998; Fu et al., 2006a).

Foreign direct investment contributes to regional innovation in four ways. First, R&D and other forms of innovation generated by foreign firms and R&D labs of MNEs increases the innovation outputs in the region directly. Increasing FDI is found a factor causing the emergence of newer countries with the more sophisticated technology generation (Athreye and Cantwell, 2007). Globalisation of R&D activities by MNEs has been a major shift in international business in recent decades. There are three types of global R&D programmes of MNEs: support laboratories, locally integrated laboratories and internationally interdependent laboratories (Pearce, 1999). When the operations of MNEs in host countries move from cost-based towards the supply of higher-value parts, their R&D activities may eventually accede to locally integrated laboratory status. Increases in the internatinal spread of subsidiary research efforts in MNCs have tended on average to reinforce the position of established centres of higher grade technological activity (Athreye and Cantwell, 2007). Depending on the availability of low-cost but high-end skill human capital, MNEs may even establish international interdependent laboratories which oriented to basic research in one or more scientific disciplines. These independent laboratories have the potential to reinforce a country's developing strength in basic research which may provide technological inputs to radical innovation (Pearce, 2005).

Second, spillovers emanated from foreign innovation activities may affect the innovation performance in the region they locate. There are several channels for knowledge to spillover from foreign to local firms. These include knowledge transfers through the supply chain; skilled labour turnovers; and demonstration effects. Knowledge transfer via supply chain requires effective quality linkages between foreign firms and local suppliers and customers. When cross-regional labour mobility is low, it is likely that any benefits from MNEs will mainly go to local firms (Greenaway et al., 2002). Demonstration effects may also be local if firms only closely observe and imitate firms in the same region (Blomstrom and Kokko, 1998). There has been convincing evidence suggesting a productivity advantage of MNEs over domestic firms in developing countries and some industrialised countries (eg. Girma, Greenawy and Wakelin, 2001) Empirical evidences on the actual extent of spillovers from MNEs to domestic firms are, however, mixed (Blomstrom and Kokko, 1998; Gorg and Greenaway, 2004).

Third, FDI may affect regional innovation capacity through competition effect. Market competition may also be a two-edged sword on innovation. Geroski (1990) argues that lack of competition in a market will give rise to inefficiency and result in sluggish innovative activity. On the other hand, the traditional Schumpeterians claim that monopoly power makes it easier for firms to appropriate the returns from innovation and thereby provides the incentive to invest in innovation (Cohen and Levin, 1989; Symeonidis, 2001). Foreign R&D

activities may also crowd out domestic innovation activities as they attracted the most talent researchers and compete in the markets of innovation products which threatens local firms, SMEs in particular (Aghion et al., 2005; Fu, 2004a and 2007; UNCTAD, 2005b). In the Chinese electronics industry, Hu and Jefferson (2002) find significant productivity depression rather than positive spillover effects of FDI on domestic firms.

Finally, in addition to greater R&D investments by MNEs and their affiliates, FDI may contribute to regional innovation capabilities by advanced practices and experiences in innovation management and thereby greater efficiency in innovation. Innovation is not a simple linear transformation with basic science and other inputs at one end of a chain and commercialisation at the other (Hughes, 2003). Successful innovation requires more than brilliant scientists. It involves from top management to employees in its R&D, finance, production and marketing divisions. It requires high-quality decision-making, long-range planning, motivation and management techniques, coordination, and efficient R&D, production and marketing. Therefore, innovation performance of a firm is determined not only by 'hard' factors such as R&D manpower and R&D investment, but also by certain 'soft' factors such as management practices and governance structures (Aghion and Tirole, 1994; Bessant et al., 1996; and Cosh, Fu and Hughes, 2004). MNEs are major participants in innovation and are more experienced in innovation management. They may contribute to local innovation system by transferring managerial know-how to local firms through spillover effects.

There are, however, two main conditions for significant spillovers from FDI: one is absorptive capacity of the local firms and organisations (Cohen and Levinthal, 1989; Girma, 2005); and second is the sufficient effective linkages generated between the foreign and domestic economic activities (Balasubramanayam, Salisu and Sapsford, 1996; Fu, 2004b). Absorptive capacity refers to the ability of an organisation or region to identify, assimilate and exploit knowledge from the environment (Cohen and Levinthal, 1989). Absorptive capacity is usually proxied by the technology gap between the foreign and the domestic firms, R&D intensities of the local firms, or human capital embodied in local firms. Studies using the first approach find that spillovers are present when the technology gaps fare moderate (Kokko et al, 1996); smaller plants or plants with a low share of skilled workers in the workforce lack the necessary absorptive capacity to benefit from FDI. R&D activities of organisations are regarded to have two faces (Aghion and Howitt, 1992 and 1998; and Griffith et al., 2003). One is the widely acknowledged knowledge creation function; another is its role in learning and promoting 'absorptive capacity' giving the fact that innovation is cumulative and path-dependent. It is argued that a certain level of R&D intensity is needed before firms benefit from FDI-generated externalities. The absorptive capacities of the local firms and organisations in turn determine the overall absorptive capacities of the host region, as they are the basic elements in a regional innovation system.

In addition to absorptive capacity, complementary assets (ingredients) may play an important role in forming the overall dynamic capabilities required to convert technological opportunities into innovative sales and competitive market advantage. (Teece, 1986; Teece, Pisano and Shuen, 1997; Brynjolfsson and Hitt, 2000; Cosh, Fu and Hughes, 2005; Hughes and Scott Morton, 2006; Cosh, Fu and Hughes, forthcoming). The introduction of substantially new or improved products requires parallel shifts in the strategy of organisations, the structure of organisations and practices in management. MNEs are also more likely to locate in regions with sound scientific and educational infrastructure, the potential for intro- and interindustry spillovers or locally embedded specialisation because they are seeking complementary assets to most effectively transfer and commercialise their technological advantage (Cantwell and Piscitello, 2002; Cantwell and Santangelo, 1999). Therefore, a region's acceptiveness to new idea, the strength of entrepreneurship, information and communication infrastructure as well as clusters of high-technology industries may all enhance a region's capability in assimilation of new idea and technology generated internally or transferred from external sources.

In summary, FDI impacts regional innovation capabilities in several ways. First, FDI may contribute to the overall regional innovation performance directly due to the greater innovation intensity in MNEs. Second, FDI may contribute to regional innovation performance through greater innovation efficiency in MNEs. Third, FDI may affect innovation capability of local indigenous firms through technological and managerial knowledge spillovers. The strength of the FDI effect on regional innovation capabilities depends upon the absorptive capacity of and the complementary assets in the domestic sector, the linkages between the foreign and the domestic sectors, and the technology content of the FDI.

III. FDI and innovation in China

- **FDI in China**

Since it launched the economic reforms and called for foreign capital participation in its economy in 1979, China has received a large part of international direct investment flows. China has become the second largest FDI recipient in the world, after the United States, and the largest host country among developing countries. The fastest growth of FDI inflows into China started from the Spring of 1992 after Deng Xiaoping circuited China's southern coastal areas and SEZs. Since then, China adopted a new approach, which turned away from special regimes toward more nation-wide implementation of open policies for FDI. The inflows of FDI into China reached the peak level of US$45 463 million in 1998. After a drop in 1999, mainly because of the impact of the Asian financial crisis and the rise of acquisition transactions in both OECD and non-OECD countries, FDI inflows into China picked up its fast growing trend and reached a historical peak of US60.63 billion in 2004 (Figure 1).

This huge inflow of FDI is, however, highly concentrated geographically in the coastal region. By the year 2005, total FDI stock into the coastal provinces accounted for 87% of total FDI stock in China (Figure 2). This uneven distribution of FDI in China has its economic, policy and geographic attributes and generates uneven impact on regional competitive performance in China. As a result, the average FDI intensity measured by foreign assets in total industrial assets was 28% in the coastal region, which was 3 times higher than that in the inland region at only 7%. In Guangdong, Fujian and Shanghai, nearly half of the net fixed industrial assets are foreign invested (Table 1).

The sources and entry modes of inward FDI in China has also evolved over time. While investment from overseas Chinese in Hong Kong, Macao and Taiwan was the major sources of inward FDI in the 1980s, the 1990s has seen increasing inward FDI from the major industrialised countries and other OECD countries. The entry modes of foreign firms have also evolved from joint-venture in 1980s to whole-foreign owned enterprises in 1990s which accounted for more than 70% of all FDI projects in the late 1990s. Some large MNEs has started to set up their global R&D centres in China, mostly in its coastal large cities such as Beijing and Shanghai. With the launch of Western Region Development Strategy by the Chinese government and the re-location of some foreign-invested enterprises into the inland regions has been increasing. They are, however, mostly in labour- or land-intensive industries.

- **Innovation**

As one of the important drivers of competitiveness, innovation effort and performance in China are not even across the regions. Again, there is a significant gap in innovation between the coastal and inland regions. In 2004, the coastal provinces accounted for 82 percent of China's total invention patent applications, 79 percent of the total sales of new products, and 73 percent of total industrial R&D expenditure. The innovation activity in the coastal provinces is further concentrated in several provinces including Guangdong, Shanghai, Jiangsu, Shangdong and Zhejiang (Figures 3, 4, 5). Expenditure on acquisition of technology from abroad by the coastal region accounted for 67% of China's total expenditure on foreign technology acquisition in 2004, which was about twice of that in the inland region (Table 2). Jiangsu, Shanghai, Beijing and Guangdong are the top four regions that spend most on foreign technology acquisition. While Shanghai and Beijing mainly acquire foreign technology; Jiangsu and Guangdong rely on both foreign and domestic technology. The inland regions, with the exception of Chongqin, spend much less than most of the coastal regions, with one third rely more on foreign and two-thirds of them acquire more domestic technology.

- **Innovation by foreign firms**

Since late 1990s, with the increasing globalisation in innovation, R&D activities of foreign firms in China has been increasing, at a faster pace than that of the domestic firms. The average annual growth of R&D expenditure over the 1998 to 2004 period was 38 and 33 percent in foreign invested enterprises and Ethnic Chinese invested firms[1], respectively. This is much higher than that in indigenous firms at 25 percent over the same time period (Table 3).

In 2004, the number of foreign firms was about one third of China's total number of enterprises. Although the R&D expenditure and R&D staff of the foreign firms accounted for only 27 percent and 18 percent of China's total industrial R&D expenditure and R&D staff, innovation outputs by foreign firms in terms of percentage of total sales of new products and the percentage of invention patent application by foreign firms were both more than 40 percent. This suggests higher productivity in innovation and better innovation management in foreign firms than those in indigenous firms. The expenditure on acquisition of foreign technology[2] by foreign firms accounted for nearly half of China's total expenditure on foreign technology acquisition, suggesting greater effort by foreign firms in acquiring advanced technology (Figure 6).

IV. FDI and innovation capacity: empirical evidence

The econometric analysis of the impact of FDI on regional innovation capacity starts from a basic region's innovation production function as follows

$$Y_{i,t} = \alpha + \beta RDS_{i,t-1} + \lambda RDP_{i,t-1} + \gamma HC_{i,t-1} + \delta FDI_{i,t-1} + \varepsilon \qquad (1)$$

where Y is innovation output, RDS is R&D expenditure, RDP is the number of people involved in research and development activity, HC is human capital, FDI is FDI intensity measured by the ratio of net fixed assets of FIEs to total industrial net fixed assets in the

[1] Ethnic Chinese invested firms refers to foreign firms which have owners from Hong Kong, Macao and Taiwan.

[2] Expenditure on purchasing foreign technology, including expenses on product design, process design, blue-prints, prescription, patents and relevant key equipment, instruments and samples. Expenditure on absorption of foreign technology refers to expenditure on assimilation of foreign technology, this includes expenses on training, assimilation, imitation and development of foreign technology and relevant staff costs and equipment costs.

region. ε is the error term which has the normal property. All the variables are in logarithm. We use one year lagged values for all the explanatory variables. In other words, we assume that innovation production in a given year is reflected in the patents which are granted 1 year in the future. Another advantage in using one-year lag for the independent variables is that it removes the possible endogeneity between FDI and the dependent variable, number of patents, as FDI may choose to locate in regions that have high innovation capacity.

Here following Jaffe (1989) and Acs et al. (2002) we measure innovation output by number of patents granted to domestic applicants per 10 thousand population. Although patent number has its advantage, it also suffers from the low face validity problem that patents reflect little commercial success and value of new and renewed products (Acs and Audretsch, 1990; Kleintnecht, 1996). Investment in research and development (R&D) is often found to be a significant determinant of innovation performance. Regions that invest more in R&D are more likely to innovate because R&D directly creates new products and processes. Labour force skills, the availability of qualified scientists and engineers, particularly the qualified research staff directly involved in R&D activities, are another widely recognized critical factor that contribute to firm innovation performance (Hoffman et al., 1998; Porter and Stern, 1999).

In order to capture the effects of absorptive capacity and complementary assets, we expend the model by including the interaction terms of FDI and absorptive capacity (ABC) and FDI and complementary assets (CA) alternatively. According to the literature discussed earlier, absorptive capacity is measured in two ways alternatively : regional R&D intensity (RDS) measured by R&D spending to GDP ratio and labour force quality (HC) measured by percentage of population with 15 years schooling. They serve to enhance a region's capacity to recognise and absorb relevant external resources for innovation (Cohen and Levinthal, 1990). Complementary assets (CA) are also measured in three ways alternatively: (1) number of computers per thousand households (COMP) which may capture many innovative characteristics of a region, e.g. information infrastructure and acceptiveness to new idea; (2) the share of value-added from high-technology industry in regional total value added (HITECS), which indicating the industry and technology structure in a region and the industry infrastructure to assimilate and develop the R&D externalities from FDI; and (3) transaction value in technological markets[3] (TECHMKT) which measures the extensiveness and depth of technology linkages, flows and transactions in the regions and reflects the development level and activeness of the institutions that facilitate the transfer of technology within a region. Equation (1) is thus extended to the following:

$$Y_{i,t} = \alpha + \beta RDS_{i,t-1} + \lambda RDP_{i,t-1} + \gamma HC_{i,t-1} + \delta FDI_{i,t-1} + \theta ABC_{i,t-1} * FDI_{i,t-1} + CA_{i,t-1} * FDI_{i,t-1} + \varepsilon_{i,t} \qquad (2)$$

All the variables are in logarithm.

There are three types of patents, invention, utility model and external design. Invention is a new technical solution relate to a product, process or improvement thereof. Utility model refers to the practical and new technological proposals on the shape and structure of a product or the combination. External design involves a new design of shape, pattern, or combination or of color or aesthetic properties. Invention patents are regarded as major innovations. To obtain a patent for invention, an application must meet the requirements of "novelty, inventiveness and practical applicability". Usually, it takes about one to one and half years to process an invention patent application in China, but 6 months or even shorter for utility

[3] Technological transactions include technology transfer, technology consultation, technical service, technical training, technology-equity share exchange, technology intermediation and various research-production co-operations

model and design patents (Cheung and Lin, 2004). Given the different novelty and importance of the three different types of patents, we run regression (2) using these three types of patent as the dependent variable alternatively in order to examine the impact of FDI on innovations of different degrees of novelty.

The data used relates to a provincial level panel data set for the 31 provinces and municipality cities in China over the 1998-2004 period. The data are collected from the China Statistical Yearbook and the Ministry of Science and Technology of China (MOST) online database. This study differs from some existing studies in that it uses the data from MOST for R&D expenditure and R&D staff rather than using the data of 'investment in innovation' published in the China Statistical Yearbook. The MOST data is more precise on R&D expenditure because 'investment in innovation' includes in addition to spending on research and development, also expenditure on renewal of fixed assets, capital construction, new site construction, as well as expenditure on the corresponding supplementary projects for production or welfare facilities and the related activities[4]. The MOST measurement of R&D

[4] It includes: (1) projects listed in the innovation plan of the current year of the central government and the local governments at various levels as well as the projects, though not listed in the innovation plan of the current year, but continued to be constructed in this year, using the investment listed in the plan of innovation of previous years and carried forward to this year; (2) projects of technological innovation or renewal of the original facilities, arranged both in the plan of innovation and in the plan of capital construction; extension projects (main workshops or a branch of the factory) with the newly increased production capacity (or project efficiency) not up to the standard of a large and medium-sized project; and the projects of moving the whole factory to a new site so as to meet the requirements of urban environmental protection or safe production; (3) projects of reconstruction or technological innovation with the total investment of 500,000 RMB yuan and over by the state-owned units, though listed neither in the plan of capital construction nor in the plan of innovation; the projects in the state-owned units of moving the whole factory to a new site so as to meet the requirements of urban environmental protection or safe production.

is also better than using expenditure and staff on science and technology because, according to the definition given by MOST and SSB, science and technology includes the broad social science disciplines in addition to natural science and engineering disciplines.

Table 4 reports the estimation results of equation (2) on the impact of FDI on regional innovation capacity. The estimated coefficient of the FDI variable is positive and statistically significant at the 99 percent significance level. This fact suggests the significant contribution of FDI to regional innovation capacity. The magnitude for the estimated FDI coefficient in the base equation is 0.356 suggesting a one percent increase in FDI intensity increases regional patent output by 0.35 percent. These magnitudes are of the similar level of the R&D expenditure variable, some times even higher than that of the human capital variable.

The estimated coefficient of the two proxies of the absorptive capacity, RD intensity and labour force skills, bear the expected positive sign and are statistically significant at the 99 percent significance level as well. The estimated coefficients of the interaction terms between the absorptive variables and the FDI variable are positive and statistically significant as well. This evidence provides strong support to the proposition of the important role of absorptive capacity in assimilation of the knowledge spillovers from FDI.

We have three proxies to capture the complementary assets for innovation in the regions, number of computers per thousand household, the share of high-technology sector in regional total value-added, and the transaction value in technological market. The interaction terms between FDI and the first two complementary assets variables are positive and statistically significant as well[5]. These evidences suggest that better information and communication infrastructure, greater acceptiveness to new ideas and a better developed cluster of high-technology sector in the local economy will complement the advanced technology embodied in FDI, facilitate the innovation process and therefore lead to greater innovation capacity of the region. The estimated coefficient of the interaction variable between FDI and technological market transaction value bear the expected positive sign, but is not statistically significant. This maybe explained by the lack of foreign participation in the technological market as evidenced in a recent survey (Zhou, 2006), which we discussed in earlier section.

V. FDI and regional innovation efficiency

Statistical analysis to investigate the impact of FDI on regional innovation efficiency is in two steps. We first evaluate the innovation efficiency using the data envelopment analysis (DEA) which allows for multi-output and multi-input in the model. Second, we explore the role of foreign direct investment in the determination of regional innovation efficiency.

There are three main approaches to the measurement of efficiency: ratio analysis such as labour productivity and capital productivity, the normal econometric approach such as the Solow-type total factor productivity (TFP) index and the frontier approach, such as data envelopment analysis. Total factor productivity (TFP) provides a comprehensive guide to efficiency than partial productivity. It takes into account the contribution of factors, other than raw labour and capital, such as managerial skills and technical know-how. The conventional Solow-type total factor productivity defines TFP growth as the residual of output growth after the contribution of labour and capital inputs have been subtracted from

[5] The correlation coefficients between FDI intensity on one hand, and computer usage, share of high-technology industry and technological market transaction values are as high as 0.57, 0.54 and 0.40, respectively, and statistically significant at the 1% significance level. Inclusion of FDI and these complementary assets variables in the regression simultaneously raises significant multicolinearity problem. We, therefore, include FDI and the interaction terms only in the regress in addition to other variables of interest.

total output growth. This method, however, attributes all the deviations from the expected output to TFP without taking into account measurement error. It is subject to several well-known assumptions: (1) the form of production function is known; (2) there are constant returns to scale; (3) there is optimising behaviour on the part of firms; and (4) there is neutral technical change. If these assumptions do not hold, TFP measurements will be biased (Coelli et al., 1998; Arcelus and Arocena, 2000).

The frontier approach evaluates a firm's efficiency against a measure of the best practice. There are two main methods for the estimation. One is a non-parametric programming approach, the Data Envelopment Analysis (DEA); another is a parametric production function approach, the Stochastic Frontier Analysis (SFA). In the DEA approach, a best-practice function is built empirically from observed inputs and outputs. The efficiency measure of a firm's innovation activity is defined by its position relative to the frontier of best performance established mathematically by the ratio of the weighted sum of outputs to the weighted sum of inputs (Charnes et al., 1978). The strength of the programming approach lies not only in its lack of parameterisation, but also in that no assumptions are made about the form of the production function. In addition, the programming approach allows us to estimate efficiency with multi-output and multi-input. This technique has a main shortcoming in that there is no provision for statistical noise, or measurement error, in the model (Greene, 1997; Norman and Stoker, 1991).

Given the advantages and disadvantages of the different efficiency estimation approaches, we use the DEA approach in the estimation of the innovative efficiency because this method allows us to evaluate a firm's efficiency in innovation against best practice, and allows us to estimate efficiency with multi-output and multi-input.

In the DEA approach, for a sample of n firms, if X and Y are the observations on innovation inputs and outputs, assuming variable returns to scale, the firm's innovative efficiency score, θ, is the solution to the linear program problem,

$$
\begin{aligned}
& Max_{\theta,\lambda}\ \theta \\
\text{st.}\quad & -\theta y_i + Y\lambda \geq 0 \\
& x_i - X\lambda \geq 0 \\
& \lambda_i \geq 0 \\
& \sum \lambda_i = 1 \qquad i = 1,\ldots,n. \qquad (3)
\end{aligned}
$$

where θ is a scalar and λ is an nx1 vector of constants. The efficiency score ranges from 0 to 1. If θ_k = 1 and all slacks are zero, the kth firm is deemed to be technically efficient (Cooper et al., 2000).

In the analysis, since our major objective is to maximise innovation output, we concentrate on output-oriented efficiency, which reflects a firm's efficiency in producing maximum innovation output with given inputs, under constant returns to scale. Innovation output is measured by number of patents granted to each region. Given the differences in degrees of novelty across the three types of patents: invention, utility model and design, we include these three measures of innovation as outputs in our multi-output DEA model. Inputs in our models include the R&D expenditure to GDP ratio and the total number of R&D staff as a share of the total population. As invention patents are of higher degrees of novelty, we assume their importance is twice that of the utility models and design. Therefore, the weights restriction we use in the 3-outputs DEA model is as follows:

$$Q_{\text{invention}} = 2\ q_{\text{utilitymodel}} = 2\ q_{\text{design}}$$

The estimated regional innovation efficiency is then regressed on FDI intensity in each region. In the estimation of firm innovative efficiency, the efficiency scores have an upper bound of 1.0 and a lower bound of 0.0, the ordinary least squares estimates would be inconsistent. Therefore, the regression model for technical efficiency is specified in form of the Tobit model as follows (Tobin, 1958; Fu and Balasubramanyam, 2003).

$$IE = \begin{cases} \alpha + \beta X_i + \mu & \text{if } \alpha + \beta X_i + \mu < 1 \\ 1 & \text{otherwise} \end{cases} \qquad (4)$$

where IE = innovative efficiency, and X_i is a vector of explanatory and cc ariables including FDI intensity, labour force skills and industry structure in the region.

Figure 7 shows the distribution of the estimated regional innovation efficiency. Patterns revealed from this figure suggest that innovation efficiency of the Chinese regions has been increasing over time during the 2000 to 2005 period. Two observations form the regional innovation frontier. They are Shanghai in 2003 and 2004. Other regions close to the frontier are the several coastal provinces and municipalities including Tianjin, Beijing, Zhejiang and Guangdong.

Table 5 reports the estimated results on the impact of FDI on regional innovation efficiency. The estimated coefficients of the FDI variable are positive and statistically significant at the 5% significance level. The results are robust across different specifications, suggesting the significant positive impact of FDI on regional innovation efficiency. Regions with higher FDI intensity are more efficient in innovation. Human capital, measured by percentage of population with university degree has the largest impact on regional innovation efficiency. The estimated coefficient of the high-technology share variable bears an unexpected negative sign. This may be explained by the fact of heavy investment in R&D and large R&D personnel number in the domestic high-technology sector which have not been used efficiently.

VI. Innovation and regional economic growth

Finally, we include the innovation output variable in a growth function in the light of the new growth theory, and estimate the impact of innovation on regional economic growth.

$$y_{it} = \alpha + \varphi t_{it} + \beta l_{it} + \gamma k_{it} + \lambda x_{it} + \nu_{it} \qquad (5)$$

where i and t denote regions and time, respectively. The disturbance term, $v_{it,}$ varies across regions and time and has the usual properties. The dependent variable, y_{it}, is the real growth rate of GDP; the explanatory variables are the number of patents granted, $t_{it,}$ the growth rate of labor, $l_{it,}$ the growth rate of the capital stock, k_{it}, real growth rate of exports, x_{it}, and y_{it-1}, which is the one year lag of y_{it}. Lower case denotes logarithm. We introduce exports into the production function explicitly for three reasons. First, the incentives associated with export orientation are likely to lead to higher total factor productivity because of economies of scale and competition effects. Second, exports are likely to alleviate serious foreign exchange constraints and thereby enable the country to import more advanced machinery and materials. Third, exports are likely to result in a higher rate of technological innovation and dynamic learning from abroad although the direction of causality is debatable (Balasubramanyam *et al.,* 1996).

We estimate equation (5) for all the regions in the country and for the coastal and inland region sub-groups separately. To examine the FDI-innovation-growth link in the two different regional groups, we also estimate equation (2) for the coastal and inland region sub-sample separately. The estimated results are reported in Table 6. In the coastal region, FDI has been a significant contributor to regional innovation performance; and innovation again contributes significantly to output growth. The story in the inland region is, however, not the same. In the inland region, the estimated coefficient of the FDI variable though bearing the expected positive sign in the innovation function, it is not statistically significant. Again, the estimated coefficient of the innovation variable is not statistically significant although the sign is positive as expected. These facts suggest that FDI is not a significant driver of innovation capability in the inland region, nor does innovation lead to regional economic growth. The estimated coefficients of the exports and innovation variables show the expected positive sign and are statistically significant when they enter the regressions alternatively. However, the estimated coefficient of innovation marginally lost its significance when it enters the regression together with exports. This is likely due to the fact that the two variables are correlated because greater innovation enhances competitiveness and hence more exports; and greater openness by exporting may contribute to more innovation.

VII. Conclusions

This paper has investigated the impact of FDI on regional innovation capabilities and efficiency in a fast growing developing country that received phenomenal amount of foreign direct investment. We find that FDI can contribute significantly to the overall regional innovation capacity. The strength of this positive effect depends, however, on the availability of the absorptive capacity and the presence of innovation-complementary assets in the host region. In the coastal region of China, which possesses a pool of intelligent educated R&D staff and skilled labor and hosts most of China's R&D activities and top universities and research institutes and where inward FDI has evolved from labour-intensive processing activities to more strategic asset-seeking type FDI by major MNEs, FDI has played a significant role in promoting regional innovation capacity as well as regional innovation efficiency over the 2000-2004 period. This increased regional innovation and technological capability contribute further to the fast regional economic growth in this region. However, in the inland provinces, they have not experienced such innovation-growth-promotion effect of FDI. The type and quality of FDI they attracted and the lack of absorptive capacity and complementary assets may all be blamed for this failure in the inland region. FDI into the inland regions of China are mainly in labour-, land- or resource-intensive production activities. The newly increased re-located FDI may also be motivated by tax holidays provided by local government and low labour- and land-costs in the inland region. The technology content of these FDI is low and spillovers are limited. The lack of absorptive capacity and complementary assets may become another bottleneck that hinders the upgrading of the local economy towards higher end of value chain and the transition of local economy to a knowledge-based economy.

Our attention to innovation has long been mistakenly placed on focusing on R&D expenditure. R&D spending is, however, only one of the important inputs of innovation. In many cases, huge R&D spending has been input into innovation activities but does not generate sufficient innovation output as we have expected. The productivity of innovation and the management of innovation are of crucial importance, especially for the developing countries whose resources for innovation are limited. This research indicatess that FDI contributes not only to the outputs of regional innovation system, but also to the productivity of innovation in the developing countries.

The sample period under study anchors in the era with increasing globalization of R&D activities. Findings from this study have important policy implications. First, globalization of R&D may provide an opportunity for the developing countries to catch up on the technology frontier. MNEs can become an embedded driver of knowledge-based development. However, the quality and type of FDI are important for the significant innovation promotion effect of FDI. Technology-intensive, R&D-related FDI may play an important role in this process. FDI into the coastal regions of China in the 21-century with greater participation of global leading MNEs has been much different from the labour-intensity, export-oriented FDI in the early stage. Second, enhancement of local absorptive capacity has been crucial to the effective assimilation of the knowledge and technology spillovers from FDI. Finally the development of complementary assets in the local innovation system has also been crucial for greater success in assimilation and development of external knowledge. Therefore, there is a role remains for government policies in promoting these necessary conditions for a successful FDI-assisted technological advancement.

Evidences from current study, however, provide little information on whether FDI has promoted the indigenous innovation capability of the developing countries. According to a recent report by Zhou (2006), most of the foreign R&D labs in China are independent wholly foreign owned for better protection of intellectual property rights. More than 90 percent of these MNE's labs do not apply for patents to avoid disclosure of the technology know-how. About 80 percent of the foreign firms do not have any plan to collaborate with indigenous labs or firms or universities. Moreover, these foreign owned R&D labs are again unevenly distributed geographically, with Beijing, Shanghai and Shenzhen accounted for nearly 84 percent of total foreign R&D labs in China. A study by Fu et al. (2006b) based on 12 British enterprises operating in East Asia reveals that firms intend to use technology superior to local level rather than world class technology in their subsidiary or joint ventures in China. One of the main reasons is their concern about the poor intellectual property rights protection in China. All this raised concerns that these R&D active foreign firms may remain as isolated innovation poles in the developing economy. Though they have increased the overall innovation inputs and outputs in the developing economy, their benefits to the technological capability building of the indigenous sector remain to be small. This may also give rise to another form of brain drain, which intelligent research staff has been lost from the domestic sector to the foreign sector though physically they stay in the country. Evidences from this study also suggest that the lack of effective protection to IPR has been a significant barrier preventing MNEs from introducing more advanced technology into China and investing more in innovation. Another important step for the governments of the developing countries is to strengthen the protection to intellectual property rights to attract more technology-intensive FDI and to encourage innovation.

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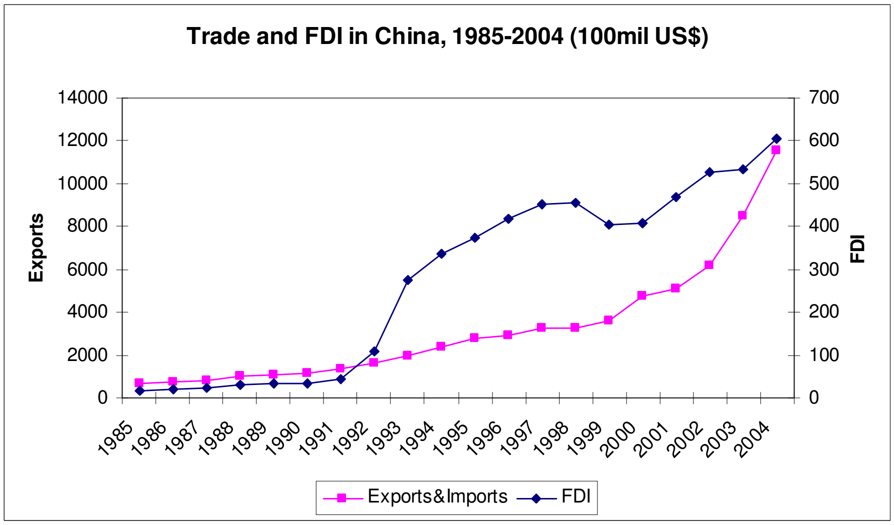
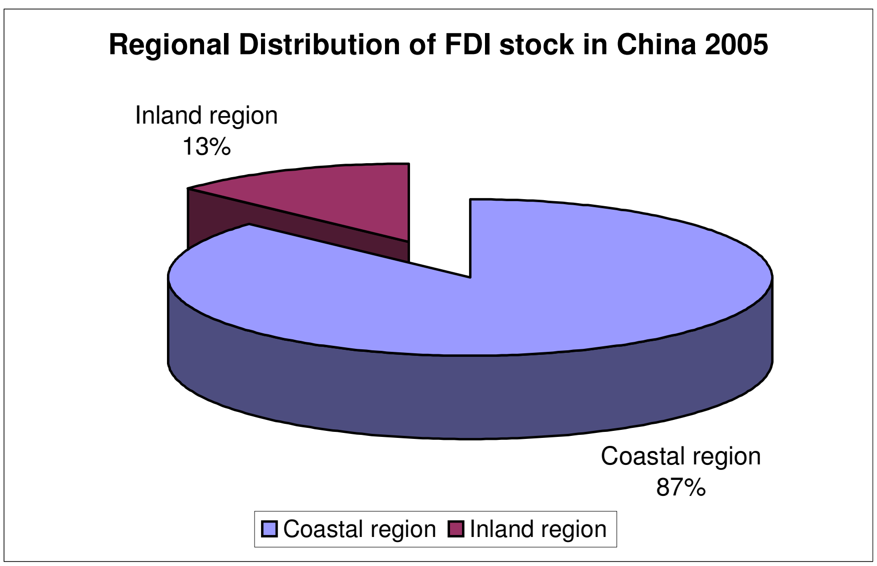
Figure 1.



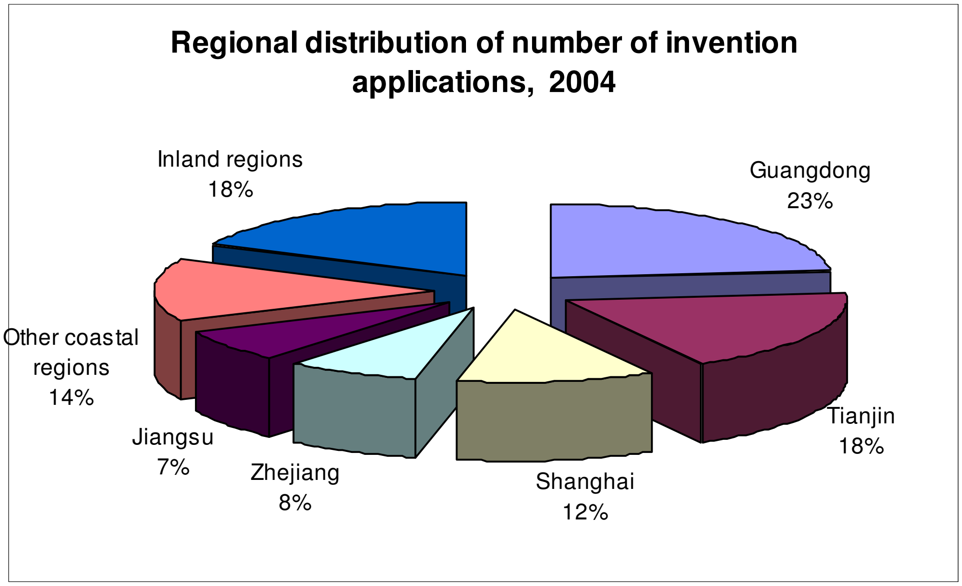
Source: Statistical Yearbook of China

Figure 2.



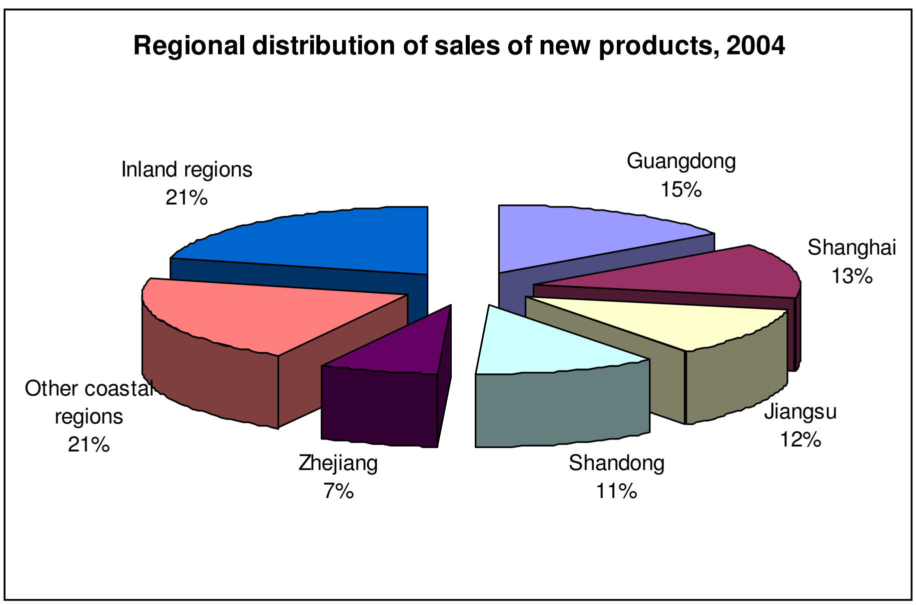
Source: http://www.fdi.gov.cn/

Figure 3.



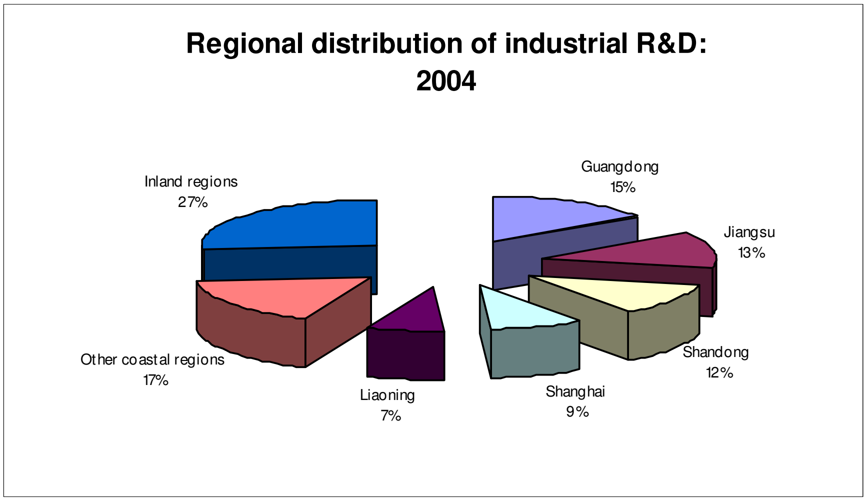
Source: First Economic Census of China, 2004.

Figure 4.



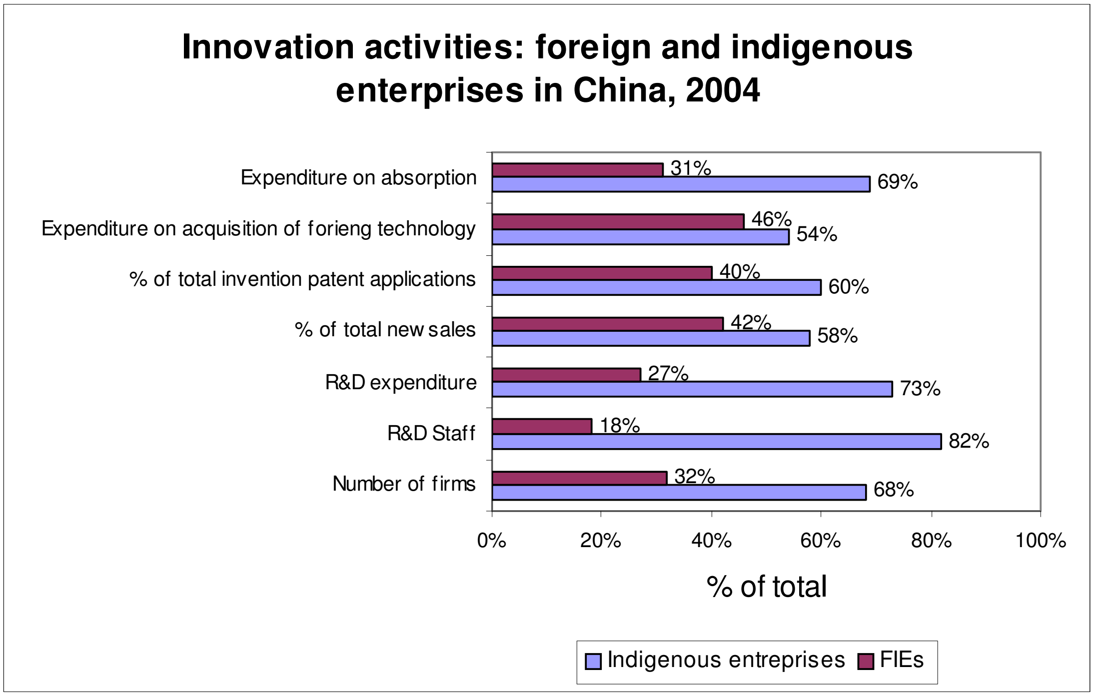
Source: First Economic Census of China, 2004.

Figure 5.



Source: First Economic Census of China, 2004.

Figure 6.



Source: First Economic Census of China, 2004.

Figure 7.

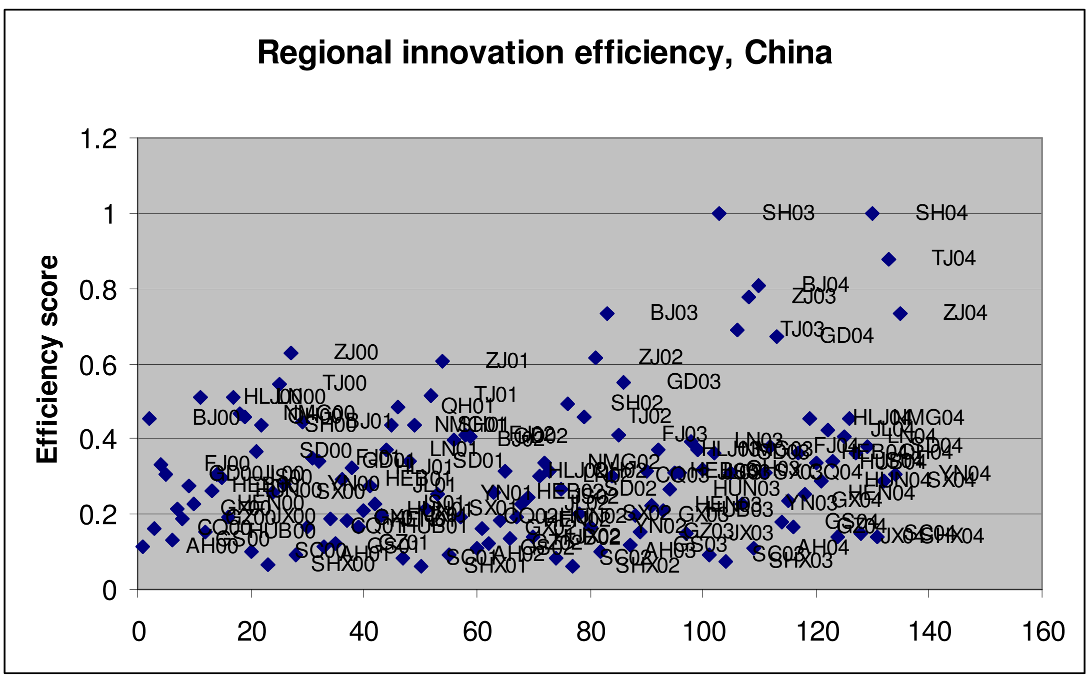


Table 1. FDI intensity: share of foreign assets in total industrial assets

	1999	2004	1999-2004 average
Guangdong	50%	51%	51%
Fujian	48%	50%	50%
Shanghai	40%	49%	44%
Jiangsu	28%	37%	32%
Tianjin	28%	28%	27%
Beijing	19%	22%	20%
Zhejiang	19%	22%	19%
Liaoning	16%	16%	15%
Hainan	19%	14%	15%
Shandong	13%	16%	14%
Guangxi	9%	14%	13%
Hebei	12%	12%	12%
Coastal average	**25%**	**28%**	**26%**
Chongqing	13%	16%	16%
Anhui	9%	12%	12%
Jilin	11%	12%	11%
Hubei	11%	9%	10%
Jiangxi	6%	9%	7%
Henan	8%	7%	7%
Hunan	4%	8%	6%
Shaanxi	6%	4%	6%
Yunnan	6%	5%	6%
Sichuan	4%	6%	5%
Shanxi	2%	7%	5%
Ningxia	4%	8%	5%
Heilongjiang	6%	5%	5%
Inner Mongolia	3%	4%	4%
Gansu	3%	2%	2%
Guizhou	2%	3%	2%
Xinjiang	2%	1%	1%
Qinghai	1%	1%	1%
Tibet	1%	NA	1%
Inland average	**5%**	**7%**	**6%**

Source: Statistical Yearbook of China

Table 2. Expenditure on technology acquisition, 2004

(¥10th)

Provinces	Expenditure on acquisition of technology from abroad	Expenditure on acquisition of technology from domestic sources	Expenditure on acquisition of technology from abroad %	Expenditure on acquisition of technology from domestic sources %
Whole	3679496	699192	100.0%	100.0%
Jiangsu	549744	90289	14.9%	12.9%
Shanghai	540190	33743	14.7%	4.8%
Beijing	314287	2865	8.5%	0.4%
Guangdong	258259	61465	7.0%	8.8%
Liaoning	210968	14075	5.7%	2.0%
Tianjin	163259	6578	4.4%	0.9%
Zhejiang	151700	40682	4.1%	5.8%
Shandong	138257	80177	3.8%	11.5%
Fujian	64123	25842	1.7%	3.7%
Guangxi	33388	11368	0.9%	1.6%
Hainan	486	1108	0.0%	0.2%
Coastal region total			65.9%	52.7%
Chongqin	253162	36568	6.9%	5.2%
Hubei	154054	38464	4.2%	5.5%
Hebei	137388	29658	3.7%	4.2%
Henan	127227	27226	3.5%	3.9%
Anhui	85003	10095	2.3%	1.4%
Jilin	84493	2695	2.3%	0.4%
Heilongjian	74177	29977	2.0%	4.3%
Hunan	66696	7769	1.8%	1.1%
Shaanxi	60553	27010	1.6%	3.9%
Shanxi	54788	18144	1.5%	2.6%
Jiangxi	48822	24384	1.3%	3.5%
Sichuan	47248	41492	1.3%	5.9%
Inner Mongolia	20988	6157	0.6%	0.9%
Gansu	16013	5579	0.4%	0.8%
Yunnan	9627	15479	0.3%	2.2%
Ningxia	9012	1850	0.2%	0.3%
Guizhou	3966	4525	0.1%	0.6%
Xinjiang	1529	3925	0.0%	0.6%
Qinghai	90	4	0.0%	0.0%
Tibet	na	na		
Inland region total			34.1%	47.3%

Source: First Economic Census of China, 2004.

Notes: Expenditure on technology acquisition refers to expenditure on purchasing technology, including expenses on product design, process design, blue-prints, prescription, patents and relevant key equipment, instruments and samples from foreign or domestic sources.

Table 3.
Growth rate of R&D expenditure

	1998	*1999*	*2000*	*2001*	*2002*	*2003*	*average annual change (1998-2003)*
Indigenous enterprises	18%	44%	19%	18%	22%	32%	25%
FIEs by HK, M & T	50%	23%	12%	25%	27%	59%	33%
FIEs	7%	73%	19%	25%	53%	49%	38%

Source: First Economic Census of China, 2004.

Table 4. Impact of FDI on regional innovation capacity

	Dependent variable: log (patents per thousand population)											
	Coef	*p-value*	*Coef*	*p-value*	*Coef*	*p-value*	*Coef*	*p-value*	*Coef*	*p-value*	*Coef*	*p-value*
C	1.309***	0.000	1.506***	0.000	2.591***	0.000	1.383***	0.000	1.265***	0.000	1.321***	0.000
LOG(RDGDP?(-1))	0.354***	0.002	0.690***	0.000	0.243**	0.043	0.392***	0.001	0.403***	0.001	0.411***	0.000
LOG(RDSTAF?(-1))	0.149*	0.058	0.147**	0.041	0.173**	0.025	0.157**	0.047	0.148*	0.061	0.118	0.132
LOG(HC?(-1))	0.316***	0.000	0.304***	0.001	0.724***	0.000	0.337***	0.000	0.287***	0.001	0.334***	0.000
LOG(FDIS?(-1))	0.357***	0.000	0.474***	0.000	0.816***	0.000	0.310***	0.000	0.299***	0.000	0.302***	0.000
LOG(FDIS?(-1))*LOG(RDGDP?(-1))			0.138***	0.008								
LOG(FDIS?(-1))*LOG(HC?(-1))					0.134**	0.018						
LOG(FDIS?(-1))*LOG(COMP?(-1))							0.020*	0.086				
LOG(FDIS?(-1))*LOG(HITECS?(-1))									0.041***	0.007		
LOG(FDIS?(-1))*LOG(TECHMKT?(-1))											0.010	0.291
LM	258.21***		175.27***		247.74***		212.76**		250.77**		268.82	
Hausman	0.07		2.18		7.74		6.53		7.85		32.18***	
Model	RE		RE		RE		RE		RE		FE	

Notes: ***Significance at 99% level; ** significance at 95% level; * significance at 90% significance level.

Table 5. Impact of FDI on regional innovation efficiency

Dependent Variable: *LOG(IE)*				
Variable	Coefficient	Prob.	Coefficient	Prob.
C	-0.963***	0.000	1.481***	0.001
LOG(FDIS?(-1))	0.157**	0.044	0.192**	0.021
LOG(HC?(-1))			0.596***	0.000
LOG(HITECS?(-1))			-0.263**	0.012
Random Effects				
Hausman statistics	0.16		0.05	
Adjusted R-squared	0.14		0.50	

Notes: ***Significance at 99% level; ** significance at 95% level; * significance at 90% significance level.

Table 6. The FDI-innovation-growth linkage in the coastal and inland regions

	Log(rgdp)						Log(patent)		
Coastal									
	Coef	p-value	Coef	p-value	Coef	p-value		Coef	p-value
LGL	-0.085	0.481	-0.075	0.537	-0.087	0.467	FDIS	2.834**	0.018
LKY	0.072***	0.004	0.095***	0.000	0.077***	0.002	RDGDP	0.513**	0.023
LGREX	0.097***	0.003			0.072**	0.045	HC	6.176**	0.010
LPATENT			0.010***	0.008	0.006	0.119			
Constant	0.166***	0.000	0.128***	0.002	0.125***	0.002	Constant	6.648***	0.000
LM	0.02		0.48		0		LM	85.93	
Hausman	5.9		1.49		5.01		Hausman	6.54	
	C		C		C			C	
Inland									
	Log(rgdp)						Log(patent)		
	Coef	p-value	Coef	p-value	Coef	p-value		Coef	p-value
LGL	-0.465*	0.050	-0.468**	0.036	-0.469**	0.037	FDIS	2.694	0.143
LKY	0.055***	0.001	0.077***	0.000	0.078***	0.000	RDGDP	0.199	0.129
LGREX	0.006	0.714			-0.001	0.949	HC	4.231*	0.069
LPATENT			0.006	0.154	0.006	0.155			
Constant	0.138***	0.000	0.116***	0.000	0.116***	0.000	Constant	6.268***	0.000
LM	4.55		5.71**		5.71**		LM	133.36	
Hausman	1.86		3.08		3.08		Hausman	6.3	
	C		RE		RE			C	

Notes: ***Significance at 99% level; ** significance at 95% level; * significance at 90% significance level.