UNITED NATIONS
UNIVERSITY

UNU-WIDER
World Institute for Development
Economics Research

Research Paper No. 2008/96

# International and Intra-national Technology Spillovers and Technology Development Paths in Developing Countries

## The Case of China

Miao Fu,[1] Xiaolan Fu,[2] and Tieli Li[1]

October 2008

## Abstract

This paper analyses the paths of technology development among regions with heterogeneous economic and technological characteristics, focusing on the case of China. It finds that intra-national technology transfer, that is, the technology transfer from technologically advanced provinces to less advanced ones, is more important than that taking place through FDI in the backward regions. In technologically advanced areas, learning by doing, indigenous R&D and technology transfer from FDI all play a significant role in technical progress. The relationship between the strength of interprovincial technology transfer and technological distance is U-shaped, with the technology threshold falling outside the upper bound of technology distance. This suggests that technology transfer takes place more effectively when technological distance is small. The paper finds that learning by doing and R&D are important internal routes to technical progress. R&D plays a key role in the assimilation of foreign technologies, whereas learning by doing is relevant for the absorption of interprovincial technology transfers.

Keywords: FDI, technology spillovers, technology threshold

JEL classification: O14, O32

[1] Guangdong University of Foreign Studies, Guangdong, emails: cnfm@163.com (M. Fu), litlidd@163.com (T. Li); [2] (corresponding author) University of Oxford, Oxford, email: xiaolan.fu@qeh.ox.ac.uk

This study has been prepared within the UNU-WIDER project on the Southern Engines of Global Growth, co-directed by Amelia U. Santos-Paulino and Guanghua Wan.

UNU-WIDER gratefully acknowledges the financial contributions to the research programme by the governments of Denmark (Royal Ministry of Foreign Affairs), Finland (Ministry for Foreign Affairs), Norway (Royal Ministry of Foreign Affairs), Sweden (Swedish International Development Cooperation Agency—Sida) and the United Kingdom (Department for International Development).

ISSN 1810-2611 ISBN 978-92-9230-150-7

UNU World Institute for Development Economics Research (UNU-WIDER)
Katajanokanlaituri 6 B, 00160 Helsinki, Finland

Typescript prepared by Liisa Roponen at UNU-WIDER

## 1 Introduction

Technical progress is an important determinant of growth, and its significance is reflected in the extensive research that has been devoted to it. In the case of developing countries, what concerns policymakers and scholars the most is the question of whether these nations should rely on technological transfers from advanced countries or carry out independent innovation in order to advance technologically. Many studies have addressed the spillover effects of foreign direct investment (FDI), most of them arguing that FDI technology transferred from developed countries has positive effects on developing countries (Eden, Lecitas and Martinez 1997; Kokko, Tansini and Zejan, 1997).[1] However, for developing countries where economic and technical levels differ across regions, to solely rely foreign spillover effects is not enough, because technological distance also exists among diverse areas within these countries. New technologies can be transferred from domestic advanced regions to less advanced ones through competition, upstream or downstream association, flows of human resources and imitation of new products and management mechanisms. It is thus difficult to fully understand the technical progress path of developing countries without taking interregional technology spillovers into account. Therefore, for an integral explanation of technological progress, it is more realistic to consider both the international and intra-national technology spillovers together, that is, the ‘bi-channel technology spillovers’ from FDI and from native technologically advanced areas.

The existing literature related to bi-channel technology spillovers is mainly centred on developed countries. For instance, Brendstetter (2001) discovers that, in the case of the US and Japan, intra-national knowledge spillovers are more important as a source of technological progress than international spillovers. In turn, Mancusi (2004) notes that R&D in the European industrial countries can improve their absorptive capacity with regard to both international and intra-national knowledge spillovers. However, empirical studies on bi-channel technology spillovers that focus on developing countries are rare, as most works somewhat neglect technology spillovers among indigenous regions within these nations.

This paper argues that when considering technological progress paths for developing countries, more factors than those usually addressed by the literature should be taken into account. These factors can be separated into internal and external. To begin with, both technology spillovers from FDI and from native advanced regions represent external routes through which technological progress within a specific domestic region can take place. On the other hand, the internal channels for technological progress to occur are R&D and learning by doing. The actual choice of technology development path is mainly reflected in a combination of the four factors above.

Theoretically, where the technological progress of developing countries is dependent solely on technology spillovers from developed nations, the former would be stuck in the technological catch-up stage. In the long run, they would be unable to surpass the technical level of developed countries. Alternatively, developing countries can gain

---

[1] Eden, Lecitas and Martinez (1997) conclude that there are four ways in which technology spillovers from FDI to the host can occur: (i) domestic enterprises copy or imitate technology and management mechanisms of foreign enterprises, (ii) build up upstream or downstream associations with foreign firms, (iii) employ personnel that has been trained by the latter, or (iv) they compete with foreign enterprises in the market.

control of essential techniques through independent R&D, but this is undermined by the limited availability of resources. Given the need for high investment and the high risk of innovation involved, these countries are unable to complete the entire process of innovation independently. This has become a major dilemma for them (Erdilek 1984; Hoekman, Maskus and Saggi 2004).

In line with what has been outlined above, two opposite perspectives exist with regard to the choice of technology development paths for developing countries. One view understands that the technology spillover effects of FDI may be more important than the effects of domestic investments (Borensztein, Gregorio and Lee 1995), and Findlay (1978) finds that the technology diffusion capacity of FDI increases along with the increase in technological distance between the host and foreign countries.[2] The greater the technological distance, the more difficult it becomes for developing countries to build up independent innovation. Therefore, following this perspective, to rely totally on independent innovation is not as beneficial as taking advantage of foreign technology spillovers and creating independent innovative capabilities based upon them.

In contrast, a second outlook argues that the introduction of FDI will make the competing domestic firms worse-off (Aitken and Harrison 1999) and will reduce the R&D efforts of local firms (OECD 2002). Furthermore, according to this line of thought, the benefits of FDI technology spillovers are limited, because most techniques transferred from foreign-funded firms are usually mature—not core—techniques. Thus, as the working conditions and rewards offered by overseas-funded firms are better than those of native firms, knowledge diffusion caused by the turnover of local talented personnel usually takes place in one direction, from domestic firms to foreign-funded ones. Considering that technology progress has the characteristic of being path dependent, a country that depends on technology spillovers from FDI for a long period of time will later exhibit limited independent innovation. Consequently, according to this perspective, to strengthen R&D and enhance independent creative abilities should constitute the main path for the technological advancement of the developing countries.

In reality, most developing countries do not separate the internal and external routes for achieving technological progress. Research by Lall (2004) demonstrates that neither autonomous innovations nor FDI-reliant strategies can be used independently. Since R&D affects technological growth in two ways, through independent innovation and through absorptive capacity, these can be combined (Cohen and Levinthal 1989; Griffith, Stephen and Van Reenen 2004). Therefore, the internal and external channels through which technological advancement can occur are related. That is, when studying external ways of achieving such progress, absorptive capacity related to internal factors should also be considered.

In line with the above, Fu (2008) studies the impact of FDI on the innovation capabilities of a developing country, with special emphasis on the role of internal factors. The author represents absorptive capacity by taking into account the R&D spending-to-GDP ratio and the percentage of the population with 15 years of schooling. In addition, Fu measures complementary assets by considering the number of computers

---

[2] Some authors do not agree with this perspective. For instance, Kokko, Tansini and Zejan (1997) and Li, Liu and Parker (2001) find positive and significant spillover effects only when technology gap is moderate or small.

per thousand households, the share of value-added from high-technology industries and the transaction value in technological markets. Fu finds that internal factors, including absorptive capacity and complementary assets, are crucial vis-à-vis technology spillovers from FDI. Therefore, developing countries should rely not only on technology transfers from abroad, but should also improve their internal technological activities and technology capitals, both of which encourage local independent innovation and increase the capacity to assimilate external technology spillovers. This approach is also known as the 'multi-path' strategy.

The results presented by existing works reflect the complexity and multiplicity of the strategies with regard to technology progress paths for developing countries. The notions that both international and intra-national spillovers exist, that technology spillovers from abroad depend on internal factors, and that such dependence varies across regions are popular in reference to big developing countries. The reason underlying this is that economic and technical performance within these countries present different levels across their vast geographic areas. In this paper, we analyse these matters by focusing on China, one of the principal developing countries in the world that also embodies the above characteristics. In China, the stock of capital, techniques and knowledge as well as the structure and strength of R&D, industrial foundations and investment environments vary across provinces. FDI has diverse characteristics in different regions, as also does the degree of FDI technology spillovers (Li 2006). Therefore, China constitutes a suitable focus for the present study.

Zhang (2005) and He (2000) analyse technology spillovers with respect to such a country, but do not consider the interprovincial dimension. On the other hand, although Fu (2008) develops a detailed study of internal factors related to spillovers, and explains the differences between coastal and inland areas, she does not consider technology transfers from advanced coastal areas to backward inland regions.

At this point, it is relevant to note that investment and output have increased rapidly in the Chinese economy ever since it has followed the strategy to catch-up with, and surpass, advanced countries. During the past ten years, the growth rate of fixed-assets investment has amounted to more than 20 per cent per year, and the growth rate of GDP has been above 9 per cent per year. An important part of the achieved technical progress has been brought about by practicing and learning from experience gathered during this period of economic growth. This portion of technological advancement usually increases along with production and investment, so in the analysis of China's technical progress, we cannot neglect the effects of 'learning by doing'. In fact, the latter is recognized as the most important path for Chinese technological advancement in the past twenty years by scholars like Enos (1985), Bahk and Gort (1993) and by The Research Group of the Economic Institute of CASS (2006), among others.

Based on the previously outlined premise that it is necessary to understand the complexity and multiple routes in achieving Chinese technological progress, this paper analyses international and intra-national technology spillovers, taking into consideration R&D, learning by doing, and the absorptive capacity of internal factors with regard to technology spillover from abroad. The analysis is organized as follows: section 2 presents a theoretical framework for the study of technology spillovers in considering the above factors. Section 3, in turn, calculates the total factor productivity (TFP) series for the provincial panel data, providing values for the dependent variable and identifying the technological frontier. Next, section 4 presents the empirical results and their discussion. In so doing, it attempts to address the following questions: Do interprovincial technology spillovers exist? What are their characteristics? Does a technology threshold exist for interregional technology spillovers? Is FDI technology spillover a major technological progress driver for the developing countries? Do the effects of FDI and interprovincial spillovers take place independently, or with the help of local absorptive capacity? What roles do internal factors play in the technological progress? Do any differences exist between the east and the middle-west areas? Finally, section 5 presents the conclusions of the study and elaborates on their policy implications, discussing progress paths for countries and regions at different stages.

## 2 Theoretical framework

This section sets out the theoretical framework for the study of inter- and intra-national spillovers, taking into account internal factors of an economy that are not usually considered in most of the literature. Following Cameron, Proudman and Redding (1998), we start from a production function presented in Equation (1), where the region is denoted by $i$ and time by $t$. We use $Y_{i,t}$ to represent the value added output of region $i$ in period $t$, produced with labour $L_{i,t}$ and capital stock $K_{i,t}$. Further, $A_{i,t}$ stands for technical progress and technical efficiency, or total factor productivity. Assume that the $A_{i,t}$ of different regions and time is a variable.

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta} \tag{1}$$

In Equation (1), suppose that technical progress $A_{i,t}$ can be acquired through four routes: learning by doing, R&D, technology spillovers from FDI and technology spillovers from other regions. The first two routes are highlighted by the perspective that supports an independent path for technical progress, while the last two constitute the core of dependent paths that require technologies to be transferred from external sources, which can be external to the region but within the country and/or from broad. The basis for grouping together learning by doing and R&D is the theory developed by Young (1993), who argues that these routes are inseparable. According to this understanding, scientific studies help invent new goods, and the learning-by-doing strategy results in the progress of such new goods developing to mature products. Without scientific research, learning by doing seldom brings about innovation, given that the economy keeps producing the same goods. Alternatively, without learning by doing, the newly invented goods are not improved through practice, and therefore remain in the initial deficient stages, unable to replace old mature products. This leads to the failure of new goods in the markets, and causes shrinkages in subsequent R&D.

With respect to technology spillovers between domestic provinces, and following convergence theories (Barro and Sala-i-Martin 1995) and technology gap theories (Findlay 1978; Fagerberg 1994), we assume that technology spillovers are related to technological distance. Inspired by the technology spillover term of Caniëls and Verspagen (1999), we represent the relationship between technology spillovers and interregional technological distance as in Equation (2). Caniëls and Verspagen (1999) regard $\rho$ and $\mu$ as parameters that are related to intrinsic learning capability, while assuming $\rho < 0$ and without considering the effects of technology thresholds. Here we view $\mu$ as the threshold value or the turning point of the relationship, and $\rho$ as the test coefficient for interregional technology spillovers. The value of $\rho$ can be smaller, greater or equal to zero.

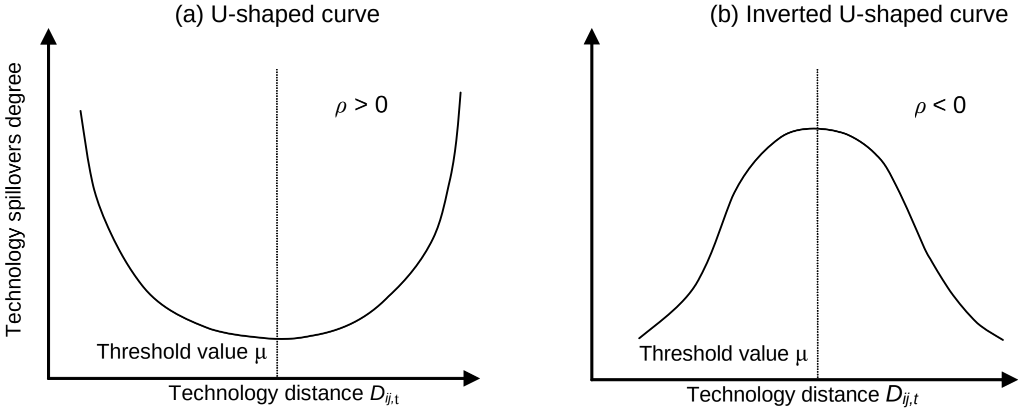
$$\phi_{ij,t} = \lambda_i e^{\rho(D_{ij,t}-\mu)^2} \tag{2}$$

where $\phi_{ij,t}$ represents the degree of technology spillover existing between regions $i$ and $j$ in period $t$, and $\lambda_i$ stands for endowed initial technological absorptive capacity which is constant in region $i$, while $D_{ij,t}$ denotes the technological distance between regions $i$ and $j$. Following the method used by Cameron, Proudman and Redding (1998), and by Griffith, Redding and Van Reenen (2004), we utilize the logarithm of the ratio produced by the technological frontier's TFP divided by the technologically backward area's TFP, so that $D_{ij,t}$ is greater than zero. When $\rho < 0$ and $D_{ij,t}$ is less than the threshold value, the degree of technology spillover increases along with technological distance. Alternatively, if $D_{ij,t}$ is greater than the threshold value, then the degree of technology spillover diminishes as technological distance rises.

Some authors (Girma 2005) find that there is a discontinuous change in the spillover effects of FDI around the threshold value. That is, when technological distance surpasses such a level, technology spillovers will change from insignificant to significant, or from positive to negative externalities. In our study, Equation (2) is used to measure interprovincial technology spillovers. The technological gap between provinces is not wide enough to bring about discontinuous effects such as a sudden stop in technology transfer, nor cause the splitting of the sample. Therefore, we assume that there is no discontinuous change around the threshold value, and that the technology spillover curve continues, although there is a change in trend after the threshold value. In other words, the threshold is the turning point of the curve, not the splitting point of the sample in our case. When $\rho > 0$ and the value of $D_{ij,t}$ is lower than the turning point, the smaller the technological distance, the greater is the technology spillover. However, if $D_{ij,t}$ is higher than the turning point, an increase in technological distance corresponds to a rise in technology spillovers. The relationship between technology spillovers and technology distance is depicted in Figure 1.

We assume that learning by doing influences TFP concurrently, but that the influence of R&D upon TFP lags for one year. Similarly, we also assume that the technology

Figure 1
Degree of technology spillover and technology distance relationship curve



Source: Compiled by authors based on Equation (2), inspired by Caniëls and Verspagen (1999).

spillover of local FDI occurs in the current period, yet interregional technology spillover experiences a one-year lag. This lag is based on the results of Mansfield (1985), who finds that 70 per cent of new innovations 'leak out' within one year. According to the above analysis, we represent $A$ in production function form as the product of the input factors of learning by doing, R&D, technology spillover from FDI and technology spillover from other regions. In line with the results from Fu (2005) showing that exports do not have significant impact on the TFP of Chinese manufacturing industries, we exclude exports from the model's explanatory variables:

$$A_{i,t} = B_i K_{i,t}^{\alpha} G_{i,t-1}^{\beta} F_{i,t}^{\gamma} \lambda_i e^{\rho(\ln\frac{A_{j,t-1}}{A_{i,t-1}} - \mu)^2} \tag{3}$$

In Equation (3), the left-hand side stands for TFP, representing technological progress and technological efficiency of region $i$ in period $t$. In turn, $K_{i,t}$ is the capital stock, used as representing the technological progress effects induced by learning by doing. Following the thoughts of Arrow (1962), capital stock is representative of learning by doing, and a rise in knowledge is a function of an increase in capital. Therefore, the stock of knowledge is a function of the stock of capital. Another body of work regards GDP as the measurement of learning by doing (Caniëls and Verspagen 1999). Yet comparing the two variables, GDP measures only the current year's output, while capital stock records the contributions of cumulative historic capital output. For this reason, we use capital stock instead of GDP to represent cumulative experience. In addition, we take $\alpha$ to denote the output elasticity of learning by doing.

In our model, $G_{i,t\text{-}1}$ is the R&D capital stock of region $i$ in period $t$-1, and is used to represent the impact of R&D on technical progress. Also, $F_{i,t}$ stands for FDI received by region $i$ in period $t$, and we utilize it to estimate the technology spillover effects of FDI. The last term of technological distance is equivalent to Equation (2), which denotes the degree of interregional transfer of techniques. While $A_{j,t\text{-}1}$ is the TFP of the technological frontier, $A_{i,t\text{-}1}$ is the TFP of the area that is currently under study. As repeated developments of knowledge products are not meaningful, and since the latter can be broadcasted and copied at low cost, we do not limit the output elasticity of each input factor, nor assume constant returns to scale. Merging $\lambda_{\text{i}}$ into $B_{\text{i}}$ and taking logarithms on both sides of Equation (3), we get:

$$\begin{gathered} \ln(A_{i,t}) = \ln(B_i\lambda_i) + \alpha\ln(K_{i,t}) + \beta\ln(G_{i,t}) + \gamma\ln(F_{i,t}) + \rho[\ln(\frac{A_{j,t-1}}{A_{i,t-1}}) - \mu]^2 \\ \text{where}\ldots\rho[\ln(\frac{A_{j,t-1}}{A_{i,t-1}}) - \mu]^2 = \rho\ln^2(\frac{A_{j,t-1}}{A_{i,t-1}}) - 2\rho\mu\ln(\frac{A_{j,t-1}}{A_{i,t-1}}) + \rho\mu^2 \end{gathered} \tag{4}$$

In Equation (4), the technological distance term and its square, that is, $\ln(A_{j,t\text{-}1}/A_{i,t\text{-}1})$ and $\ln^2(A_{j,t\text{-}1}/A_{i,t\text{-}1})$, are used to measure the contribution of interprovincial technology spillover. In empirical studies by Cameron, Proudman and Redding (1998) and Griffith, Redding and Van Reenen (2004), technology spillovers are measured by the linear or interaction term of $\ln(A_{j,t\text{-}1}/A_{i,t\text{-}1})$. In addition to the linear term, we include its quadratic term to estimate the non-linear relationship between technological distance and technology transfer. If $\rho = 0$, it means that interregional technology spillover is nonexistent. Alternatively, if $\rho < 0$ and $\mu > 0$, it means that there exists a technical turning point and that its value is $\mu$. The technology spillover effects rise on the left side of the turning point and decline on the right side. On the other hand, if $\rho > 0$ and $\mu < 0$, in the valid domain of technological distance, the relation curve is monotonously and exponentially rising, so the negative value of $\mu$ makes the turning point invalid. Finally, if $\rho > 0$ and $\mu > 0$, the technology spillover effects decline on the left side of the turning point and rise on the right side.

A small variety in $\ln(G_{i,t\text{-}1})$ is approximately equal to $\Delta G_{i,t\text{-}1}/G_{i,t\text{-}1}$. According to the works of Kinoshita (2001) and Griffith, Redding and Van Reenen (2004), and under the assumption of a very low depreciation rate of R&D capital stock, $\Delta G_{i,t\text{-}1}/G_{i,t\text{-}1}$ can be represented as the linear function of $R_{i,t\text{-}1}/Y_{i,t\text{-}1}$.[3] We use $R_{i,t\text{-}1}$ to denote the R&D capital investment of region $i$ in period $t$-1, and $Y_{i,t\text{-}1}$ to represent the GDP of region $i$ in period $t$-1. In their empirical studies, Griffith, Redding and Van Reenen (2004) and Kinoshita (2001) use $R/Y$ instead of $\ln(R)$, the difference between them being that while $\ln(R)$ measures the increase in R&D, $R/Y$ stands for the investment ratio of R&D to GDP. We find that using $R/Y$, rather than $\ln(R)$, is much better for our model. Thus, we substitute $\ln(G_{i,t\text{-}1})$ in Equation (4) with the linear function of $R_{i,t\text{-}1}/Y_{i,t\text{-}1}$. Merging the constants together, and using a random variable $\varepsilon$ to represent the detrimental factors that are not included in the model, we get the econometric form of Equation (4).

$$\ln(A_{i,t}) = C_i + \alpha \ln(K_{i,t}) + \eta \frac{R_{i,t-1}}{Y_{i,t-1}} + \gamma \ln(F_{i,t}) + \rho \ln^2(\frac{A_{j,t-1}}{A_{i,t-1}}) + \varphi \ln(\frac{A_{j,t-1}}{A_{i,t-1}}) + \varepsilon_{it} \tag{5}$$

The estimated value of $\varphi$ can be used to calculate the threshold value $\mu$ with the formulation $\mu = \varphi/(-2\rho)$. In turn, $\eta$ is used to measure the impact of R&D on independent innovation. In the consideration of innovative and imitative aspects of R&D activities, the R&D efforts of region $i$ not only improve its technical creative ability directly and increase TFP, but also indirectly raise the area's absorptive abilities vis-à-vis advanced technology transferred from other regions or through FDI. In other words, besides the direct effects of the spillovers from FDI and from technologically advanced areas, the absorptive capacity of a region has to be taken into account, since exterior factors need the help of internal ones—such as local R&D level—before they can produce any positive results. Therefore, we use interaction terms relative to both exterior and internal factors to represent the composite effects. These terms include the interaction term of R&D and technological distance, which represents the absorptive capacity of R&D with regard to interregional technology transfers, as well as the interaction term of R&D and FDI, which stands for the absorptive capacity of R&D in relation to FDI technology transfers. The corresponding econometric specification is represented by Equation (6).

---

[3] Following Griliches (1980), Nadiri (1980) and Kinoshita (2001), R&D capital stock over time can be calculated as $G_{i,t} = R_{i,t} + (1-\delta)G_{i,t-1}$, where $R_{i,t}$ is the R&D expenditure of region $i$ in period $t$; $\delta$ is the depreciation rate of R&D capital stock. The existing literature usually estimates $\delta$ by patent data, or assumes it is small enough. Because we cannot get the patent renewal data, we take the latter and assume that $\delta$ is equal to 0, as we already assume that $G$ lags for one year in Equation (3). Therefore, we understand that $\Delta G_{i,t} = R_{i,t}$, and we get the following equation:

$$\frac{\Delta G_{i,t-1}}{G_{i,t-1}} = \frac{R_{i,t-1}}{G_{i,t-1}} = \frac{Y_{i,t-1}}{G_{i,t-1}} \frac{R_{i,t-1}}{Y_{i,t-1}} = (1/\kappa)\varsigma \frac{R_{i,t-1}}{Y_{i,t-1}}$$
$$\text{where}\ldots \kappa = (\partial Y_{i,t-1} / \partial G_{i,t-1})(G_{i,t-1} / Y_{i,t-1}), \varsigma = \partial Y_{i,t-1} / \partial G_{i,t-1}$$

In this equation, $\kappa$ is the elasticity of GDP with respect to R&D capital stock.

$$\ln(A_{i,t}) = C_i + \alpha\ln(K_{i,t}) + \eta\frac{R_{i,t-1}}{Y_{i,t-1}} + \gamma\ln(F_{i,t}) + \rho\ln^2(\frac{A_{j,t-1}}{A_{i,t-1}}) + \\ \varphi\ln(\frac{A_{j,t-1}}{A_{i,t-1}}) + \theta_1\ln(F_{i,t})\frac{R_{i,t-1}}{Y_{i,t-1}} + \theta_2\ln(\frac{A_{j,t-1}}{A_{i,t-1}})\frac{R_{i,t-1}}{Y_{i,t-1}} + \varepsilon_{it} \tag{6}$$

In the equation above, $\theta_1$ measures the absorptive ability of R&D in relation to FDI technology spillovers, and $\theta_2$ measures its capacity to absorb technology spillovers from the native technological frontier. In addition, $\varphi$ denotes technology spillover effects exerted through channels other than R&D; these include competition, exchange of personnel and industrial connections.

Learning by doing comprises the ability to absorb exterior technology other than R&D. In this paper, we use the interaction term of the logarithm of learning-by-doing capital stock and technological distance to represent learning-by-doing capacities to absorb interregional technology spillover. Further, we utilize the interaction term of the logarithm of learning by doing capital stock and FDI to represent learning by doing abilities to assimilate FDI technology spillovers. The econometric specification is shown in Equation (7).

$$\ln(A_{i,t}) = C_i + \alpha\ln(K_{i,t}) + \eta\frac{R_{i,t-1}}{Y_{i,t-1}} + \gamma\ln(F_{i,t}) + \rho\ln^2(\frac{A_{j,t-1}}{A_{i,t-1}}) + \\ \varphi\ln(\frac{A_{j,t-1}}{A_{i,t-1}}) + \theta_3\ln(F_{i,t})\ln(K_{i,t}) + \theta_4\ln(\frac{A_{j,t-1}}{A_{i,t-1}})\ln(K_{i,t}) + \varepsilon_{it} \tag{7}$$

In Equation (7), $\theta_3$ denotes the contribution of learning by doing to the absorption of advanced technology spillovers originating from FDI, while $\theta_4$ measures the contribution of learning by doing to the assimilation of spillovers from region *j*. To avoid including the contents of two other explanatory variables, we subtract FDI and R&D from the calculation of $K_{it}$, so that $K_{it}$ represents the pure effects of learning by doing.

As has been repeatedly stated, industries in technologically backward areas receive technology spillovers not only from local FDI, but also from technologically advanced native regions. This, in our paper, is referred to as 'bi-channel technology spillovers', and the crux of our analysis consists of determining which of these channels is more important, what characteristics these two routes have, and whether the transferred technologies are absorbed through R&D or through learning by doing. Following the model outlined above, we present the following hypotheses:

> *H1.* Learning by doing has positive effects on technical progress; represented by the coefficient $\alpha$ in Equations (5), (6), and (7), which is thus positive.
>
> *H2.* The independently innovative abilities of R&D contribute positively to the TFP of a region, represented by the coefficient $\eta$ in Equations (5), (6), and (7), which is therefore positive.
>
> *H3.* When the distance from the technological frontier and the level of FDI increase, the technologically lagging areas will take more advantage of 'bi-channel technology spillovers' from FDI and technologically advanced

regions. This is represented by the positive coefficients $\gamma$ and $\varphi$ in Equations (5), (6), and (7).

We assume that $\rho < 0$. Since $\varphi$ is assumed to be positive, the assumption that $\rho < 0$ implies that $\mu > 0$. This is because while the technology levels of two regions are close, the opportunity for study and imitation decreases (Fagerberg 1994; Caniëls and Verspagen 1999). Thus, with an increase in the technology gap, the possibility of technology spillovers also initially rises. However, the technological gap should not be too wide either. According to technology gap theories, if such a distance is too great, then the backward region—even if the space for study and imitation grows—is unable to absorb the transferred technologies, owing to the lack of knowledge stock and qualified human resources. Therefore, after technological distance surpasses a specific threshold value, the possibility of technology spillovers occurring decreases. Hence we have the following hypothesis:

> *H4.* Both the interregional technology spillovers and the threshold of interregional technology spillovers exist. The technology spillover effect first rises, but declines once it surpasses the threshold value.

We also need to take into account that R&D affects technological growth in two ways (Griffith, Redding and Reenen 2004), and accordingly we have:

> *H5a.* When the R&D budget of a certain area increases, for the same technological distance, the absorptive capacity rises both in respect to interregional and FDI technology transfers. This implies that the coefficients $\theta_1$ and $\theta_2$ in Equation (6) are positive.
>
> *H5b.* Learning by doing also affects technological growth in two ways, so the coefficients $\theta_3$ and $\theta_4$ in Equation (7) are also positive.

## 3 Estimation of provincial TFP and identification of the technological frontier

We use provincial data for the years 1990 to 2005 to estimate the model. Data resources are the *China Statistical Yearbooks,* 1991-2006, and *China Statistical Yearbooks on Science and Technology*, 1991-2006 from the National Bureau of Statistics (NBS). All currency variables have been adjusted to constant 1990 prices.

The capital stock of each province is calculated using the perpetual inventory method: $K_{it} = I_{i,t} + (1\text{-}9.6\%)K_{i,t\text{-}1}$, where 9.6 per cent is the depreciation rate of capital stock and $I_{i,t}$ is the gross capital formation of region $i$ in period $t$. In order to avoid including the contents of THE other two explanatory variables, FDI and R&D are deducted from $I_{i,t}$ before the latter is added to $K_{it}$. The capital stock of the initial year is taken from the data used in Zhang, Wu and Zhang (2004). To represent R&D we use provincial expenditure allocated to scientific and technological funds, while for FDI data we utilize the provincial yearbook of 1991-2000.

In our model, TFP is the dependent variable, and the lagged TFP ratio of two regions is used to measure technological distance, the explanatory variable. TFP is generally taken to represent technology and, indeed, we can understand the former as an extensive definition of the latter. TFP includes not only science and technology in their strict definition, but also management efficiency internal or external to the firm, comprising, for example, efficient operating mechanisms within the company, qualified public services, a perfect taxation system, and the protection of property rights. Thus, we understand TFP to include two elements: technological progress and technological efficiency.

Before continuing with our discussion of technology transfers, we should solve two problems. The first one is the calculation of the provincial TFP time-series, without which we would have no knowledge of the current state and the history of the technical level in each province. Second, there is the issue of identifying the technological frontier. The TFP of the technological frontier is used to calculate the technological distance which is utilized, in turn, to measure the effects of interregional technology transfers. The latter are important for areas where FDI is absent or where the ability to absorb FDI is not sufficient.

The technological frontier is represented by the province with the highest TFP, yet difficulties exist in the estimation of the latter. These include decisions related to capital stock, labour and their output elasticities, since various choices with respect to these may cause notable differences in the estimation results. Zhang and Shi (2003), for instance, calculate Chinese TFP from 1952 to 1998 based on time-series data for the country, and their estimation approach and results are widely accepted within Chinese academic circles. For precise results, we estimate provincial TFP based on their method. As we calculate ‘total’ factor productivity, we do not deduct FDI and R&D from capital stock here, and we select the number of employed persons at the end of the year to represent labour.

Given that Zhang and Shi calculate TFP based on country data while we, in contrast, base our analysis on provincial panel data, the suitability of these authors’ output elasticities for provincial data still constitutes a problem. Thus, to assure that the output elasticities and our data match, and to test the results of Zhang and Shi, we estimate the output elasticities for capital stock and labour independently from provincial panel data. The elasticity estimation model is shown in Equation (9). The Hausman test statistics suggest that the fixed-effects model is preferable to the random-effects model. We therefore choose the former for our estimation. The results are given in Table 1.

$$\ln Y_{it} = C_i + \lambda t + \alpha \ln K_{it} + \beta \ln L_{it} + \varepsilon_{it} \qquad (9)$$

The adjusted $A^2$ and the F statistic show that the model fits the data very well. All coefficients are significant at the 1 per cent level. By normalizing the coefficients of capital stock and labour, we calculate the output elasticities of capital stock and labour: $\alpha = 0.303691 / (0.202083 + 0.303691) = 0.600448$, $\beta = 1 - \alpha = 0.399520$.[4] These contrast with the results reported by Zhang and Shi (2003), where $\alpha = 0.609$ and $\beta = 0.391$. We find that even if we use different data, the outcomes are very similar. These demonstrate that Zhang and Shi’s output elasticities are suitable for provincial panel data. Taking the output elasticities calculated above and equation (10), we

---

[4] We assume that $\alpha + \beta = 1$. This is according to constant returns to scale and definition of TFP, which is generated by dividing outputs with total factors. As there are two input factors, total factors mean that weighted averages of the two factors. Thus $\alpha + \beta = 1$ is to assure that the denominator of Equation (10) is an average operation, like geometric mean, $a^{1/2}b^{1/2}$, where 1/2 + 1/2 = 1. Otherwise, estimates of TFP may be out of traditional range and this makes different estimates incomparable. The same normalization procedure of $\alpha$ and $\beta$ is applied by Zhang and Shi (2003).

construct the provincial TFP time-series. The top four provinces by TFP are shown in Table 2.

$$A_{i,t} = \frac{Y_{i,t}}{K_{i,t}^{\alpha} L_{i,t}^{1-\alpha}} \tag{10}$$

In Table 2, we can observe that the technologically advanced provinces are located the coastal area. Guangdong is on the frontier of Chinese reform and opening-up, and its TFP is the highest for the research period. As mentioned above, TFP embodies an extensive definition of technology. The highest TFP value of Guangdong does not mean that the province has the strongest innovation abilities in China, but instead that it has the best capacity for applying technologies. Invention and application are two different concepts, and only applied technology can be observed in TFP. Therefore, a province that allocates a significant proportion of its budget for scientific research does not necessarily exhibit a high level of TFP. Furthermore, thanks to contact with foreign enterprises and self-endeavour, Guangdong has achieved an efficient public management system, a good business culture, and a relatively strict protection of property rights. Owing to the accumulation of devices, human resources and continuous reforms in recent years, some traditional industrial areas have also developed high TFP.

Table 1
Estimation results of the model for capital and labour output elasticity

| | C | Ln(K) | Ln(L) | t | Adjusted $A^2$ | F test |
|---|---|---|---|---|---|---|
| Coefficient | -103.1404*** | 0.3037*** | 0.2021*** | 0.0532*** | 0.9927 | 2030.631 |
| t statistic | -13.1464 | 9.5982 | 2.8241 | 13.0699 | | |

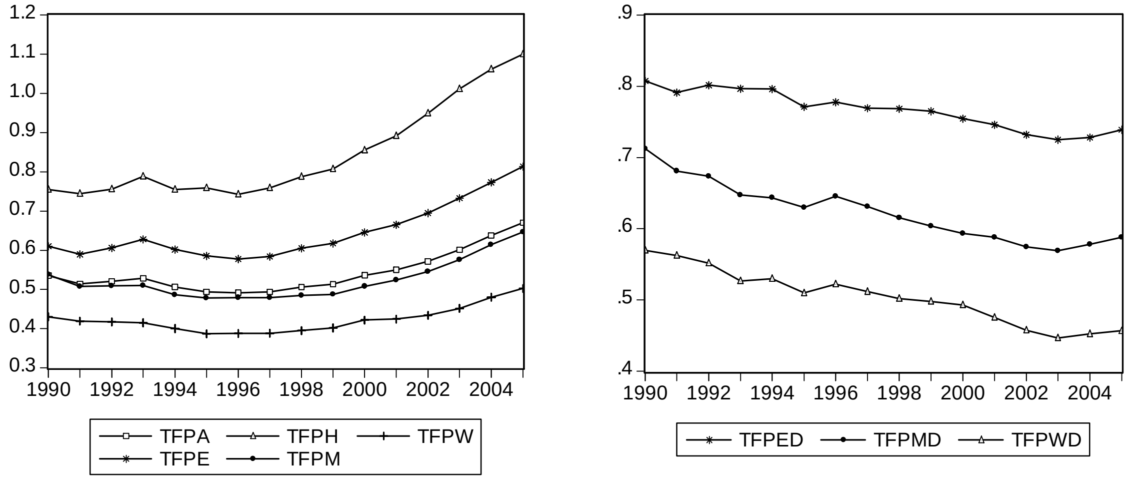
Note: Dependent variable is Ln(*Y*). *** Significant at 1% level.

Table 2
Top four provinces in total factor productivity, 1990-2005

| | First | | Second | | Third | | Fourth | |
|---|---|---|---|---|---|---|---|---|
| Year | Province | TFP | Province | TFP | Province | TFP | Province | TFP |
| 1990 | Guangdong | 0.7551 | Liaoning | 0.7264 | Hubei | 0.7189 | Peking | 0.6819 |
| 1991 | -”- | 0.7447 | -”- | 0.6759 | -”- | 0.6466 | Shanghai | 0.6398 |
| 1992 | -”- | 0.7555 | -”- | 0.6987 | Shanghai | 0.6740 | Hubei | 0.6223 |
| 1993 | -”- | 0.7880 | -”- | 0.7483 | -”- | 0.7142 | Fukien | 0.6641 |
| 1994 | -”- | 0.7551 | Fukien | 0.6805 | Liaoning | 0.6759 | Shanghai | 0.6671 |
| 1995 | -”- | 0.7589 | -”- | 0.6576 | Shanghai | 0.6209 | Liaoning | 0.6204 |
| 1996 | -”- | 0.7425 | -”- | 0.6506 | Liaoning | 0.6195 | Shanghai | 0.5994 |
| 1997 | -”- | 0.7586 | -”- | 0.6627 | -”- | 0.6479 | -”- | 0.6145 |
| 1998 | -”- | 0.7872 | Liaoning | 0.7106 | Shanghai | 0.6658 | Fukien | 0.6599 |
| 1999 | -”- | 0.8070 | -”- | 0.7464 | -”- | 0.6778 | -”- | 0.6587 |
| 2000 | -”- | 0.8553 | -”- | 0.7947 | -”- | 0.7111 | Jilin | 0.6679 |
| 2001 | -”- | 0.8916 | -”- | 0.8121 | -”- | 0.7252 | -”- | 0.6854 |
| 2002 | -”- | 0.9491 | -”- | 0.8433 | -”- | 0.7321 | Tienjin | 0.7153 |
| 2003 | -”- | 1.0109 | Liaoning | 0.8496 | -”- | 0.7886 | -”- | 0.7724 |
| 2004 | -”- | 1.0617 | Shanghai | 0.8521 | Tienjin | 0.8367 | Liaoning | 0.8229 |
| 2005 | -”- | 1.1001 | Tienjin | 0.8951 | Liaoning | 0.8818 | Shanghai | 0.8776 |

Figure 2
Comparison of the total factor productivity of China's east, middle and west areas

Panel A Panel B



Source: Generated by authors, based on own estimations.

According to our hypothesis H3, one of the premises for technology spillovers is the existence of technological distance among countries or regions. Since the technologically advanced provinces are mostly located in the coastal areas, we divide the different regions of China into east, middle and west areas. We then calculate the average TFP for each, which we show in Pane A of Figure 2 under the labels TFPE, TFPM, TFPW, corresponding to the east, middle and west areas, respectively. In turn, TFPH represents the highest TFP level in China, which is that of Guangdong. Finally, TFPA is the average TFP for the whole country.

If we now focus on Panel B of Figure 2, it shows the ratios of east, middle and west TFP to TFPH, which are identified as TFPED, TFPMD and TFPWD. TFP in Figure 2(B) is measured so that the value of the TFP of Guangdong is set to 1. From these graphs, we can observe that, TFP increases gradually from west to east, and that the TFP of the middle area is almost equal to the TFPA. Although the average TFP of each of the three areas is increasing, gaps among them remain. That is, as the western regions go through technological progress, the eastern regions also advance. Therefore, with regard to technological progress, our research finds no convergence in the review of present TFP. This does not, nevertheless, preclude further possibilities of convergence. This is addressed in the following sections. In fact, it is the existence of technological distance between the regions that makes our discussion of technology spillovers realistic and practical.

## 4 Econometric estimation results

Equations (5), (6), and (7) represent, respectively, the basic model, the R&D interaction model, and the learning-by-doing interaction model. We adopt the panel data model and use the model specification F test in Equation (8) to decide whether to reject the constant intercept model.

$$F = \frac{(S_3 - S_1)/[(N-1)(k+1)]}{S_1/(NT - Nk - N)} \; F[(N-1)(k+1), NT - Nk - N] \tag{8}$$

$S_3$ is the residual sum of squares for the constant intercept model and $S_1$ is the residual sum of squares for the unrestricted model. $T$ is the number of periods, $N$ is the number of cross-sections, and $k$ denotes the number of explanatory variable. For a given significance level $\alpha$, if $F > F_\alpha[(N-1)(k+1), NT - Nk - N]$, then we reject the null hypothesis of the constant intercept model, which implies that the variable intercept model is correct. For the variable intercept model, the Hausman test is used to choose between fixed or random effects.

The model specification $F$ test shows that the $F$ statistic is significant at the 1 per cent level, so we reject the null hypothesis of the constant intercept model, and the variable intercept model is selected. Then, through the Hausman test, we employ fixed-effects models for the three basic models of Equations (5), (6), and (7). The estimation results of the three models are given in Table 3.

The basic model does not include interaction terms, and it measures the independent impact of each of the four routes to technological progress. The R&D interaction model includes—in addition to the independent factors of the four routes to technological advancement—the interaction items of R&D and technological distance, and of R&D and FDI. After adding the interaction items, the impact of R&D is differentiated into independent innovation effects and absorptive capacity effects.

The learning-by-doing interaction model considers the independent impacts of the four routes, the interactive impact of learning by doing and technology distance, and the interactive impact of learning by doing and FDI. As the share of learning-by-doing capital stock is determined by subtracting from one the share of R&D and FDI in total

Table 3
Estimation results for the technology spillovers models

| | Basic model | | R&D interaction model | | Learning-by-doing interaction model | |
|---|---|---|---|---|---|---|
| | Coefficient | t-statistic | Coefficient | t-statistic | Coefficient | t-statistic |
| C | -1.9184*** | -29.4992 | -1.8178*** | -25.8052 | -1.2086*** | -7.2052 |
| $Ln(K_{i,t})$ | 0.2214*** | 20.4268 | 0.2146*** | 19.3925 | 0.1243*** | 5.1967 |
| $RD_{i,t-1}/Y_{i,t-1}$ | 6.4609*** | 7.4928 | 3.8217*** | 3.3372 | 6.3770*** | 7.4118 |
| $Ln(FDI_{i,t})$ | -0.0182*** | -4.1282 | -0.0292*** | -5.2449 | -0.0269 | -1.5391 |
| $RD_{i,t-1}/Y_{i,t-1} \bullet Ln(FDI_{i,t})$ | | | 0.7505*** | 3.0396 | | |
| $Ln(K_{i,t}) \bullet Ln(FDI_{i,t})$ | | | | | 0.0019 | 0.7268 |
| $Ln(A_{j,t-1}/A_{i,t-1})$ | -1.2334*** | -10.8864 | -1.3318*** | -10.9357 | -2.6293*** | -9.6500 |
| $Ln^2(A_{j,t-1}/A_{i,t-1})$ | 0.4231*** | 4.0794 | 0.5215*** | 4.9097 | 0.2562** | 2.1712 |
| $RD_{i,t-1}/Y_{i,t-1} \bullet Ln(A_{j,t-1}/A_{i,t-1})$ | | | 0.8382 | 0.3844 | | |
| $Ln(K_{i,t}) \bullet Ln(A_{j,t-1}/A_{i,t-1})$ | | | | | 0.2031*** | 5.6889 |
| Adjusted A2 | 0.9112 | | 0.9135 | | 0.9175 | |
| F statistic | 135.0664 | | 131.0799 | | 138.0042 | |

Note: Dependent variable is Ln(Ai, t). * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Table 4
Estimation results for the technology spillovers models
(Separated into the east and middle-west areas of China)

| ‘ | R&D interaction model (east) | | Learning-by-doing interaction model (east) | | R&D interaction model (middle & west) | | Learning-by-doing interaction model (middle & west) | |
|---|---|---|---|---|---|---|---|---|
| | coefficient | t statistic | Coefficient | t statistic | coefficient | t statistic | coefficient | t statistic |
| C | -1.6510*** | -14.0218 | -1.2686*** | -3.2677 | -2.0158*** | -24.2177 | -1.0695*** | -4.5571 |
| $Ln(K_{i,t})$ | 0.1882*** | 9.7168 | 0.1250** | 2.4720 | 0.2414*** | 17.9773 | 0.1189*** | 3.4426 |
| $RD_{i,t-1}/Y_{i,t-1}$ | 0.7450 | 0.4696 | 4.9101*** | 3.8937 | 19.6731*** | 5.7950 | 9.4997*** | 6.4444 |
| $Ln(FDI_{i,t})$ | -0.0599*** | -4.3511 | -0.0909 | -1.3817 | -0.0362*** | -5.1665 | -0.0299 | -1.4556 |
| $RD_{i,t-1}/Y_{i,t-1}\bullet Ln(FDI_{i,t})$ | 1.6420*** | 4.0801 | | | 1.7847*** | 4.0386 | | |
| $Ln(K_{i,t})\bullet Ln(FDI_{i,t})$ | | | 0.0084 | 0.9679 | | | 0.0032 | 1.0170 |
| $Ln(A_{j,t-1}/A_{i,t-1})$ | -0.7479** | -2.5004 | -1.7712*** | -2.8047 | -1.4047*** | -10.0073 | -2.9717*** | -8.2917 |
| $Ln^2(A_{j,t-1}/A_{i,t-1})$ | 0.1435 | 0.3573 | -0.0508 | -0.1248 | 0.6567*** | 5.6829 | 0.4023*** | 2.9611 |
| $RD_{i,t-1}/Y_{i,t-1}\bullet Ln(A_{j,t-1}/A_{i,t-1})$ | -5.9890 | -1.6082 | | | -21.0352*** | -3.9974 | | |
| $Ln(K_{i,t})\bullet Ln(A_{j,t-1}/A_{i,t-1})$ | | | 0.1355* | 1.8995 | | | 0.2133*** | 4.0113 |
| Adjusted $A^2$ | 0.8547 | | 0.8408 | | 0.8849 | | 0.8819 | |
| F-statistic | 57.7542 | | 51.9444 | | 86.1975 | | 83.7873 | |

Note: Dependent variable is Ln(Ai, t). * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

capital stock, a model that includes the interaction terms both of learning by doing and R&D will cause a multi-collinearity problem. In Table 3, $K_{i,t}$ denotes the capital stock that does not include FDI and R&D, $A_{j,t-1}$ represents the TFP of technological frontier, and $A_{i,t-1}$ stands for the TFP of the region currently under study. The meaning of the rest of the other variables is explained in Equations (5), (6), and (7).

Table 4 shows the estimation results of the R&D interaction model and the learning-by doing interaction model, according to regions to correspond to the east and middle-west areas of China. Since the east part of the country is technologically advanced, the table also give separated estimation results for the technologically advanced regions and the backward ones.

## 4.1 Identification of the technological threshold and interregional technology transfers

We begin by identifying the interregional technology spillovers threshold. The coefficients of $Ln(A_{j,t-1}/A_{i,t-1})$ and its square are all significant at the 1 per cent or 5 per cent level in the three models, as shown in Table 3. The fact that $\rho$ is significantly different from zero in these three models supports the notion that interregional technology transfers exist. Since $\varphi$ is negative in the three models, $\mu$ is positive. The estimated coefficients are similar in the basic model and the R&D interaction model.

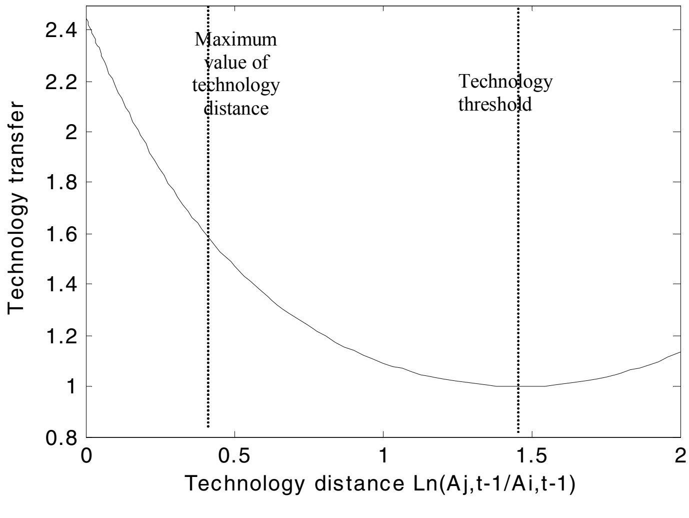
Given that the basic model does not include interaction items, it is of a more general nature than the special models that do contain this type of term. Therefore, we calculate the threshold value $\mu$ based on the estimation results of the basic model: $\mu$ = φ / (-2ρ) = -1.2334/(-2*0.4231) = 1.4577. The range of Ln($A_{j,t\text{-}1}/A_{i,t\text{-}1}$) in our observations is [0, 0.4557], which means that the threshold value is out of the range of the technological distance and is greater than the maximum value of the latter. Thus, so far the threshold value does not affect interregional technology transfer. Since $\rho > 0$, such empirical result contradicts hypothesis H4. When we draw the technological distance and technology spillover relationship curve based on the estimated coefficients, we get Figure 3. The figure depicts the relevant section of the curve, in consideration of the range of Ln($A_{j,t\text{-}1}/A_{i,t\text{-}1}$) and the threshold value. The function related to Figure 3 is shown in Equation (11):

$$\phi_{ij,t} = e^{0.4231(\ln \frac{A_{j,t-1}}{A_{j,t-1}} - 1.4577)^2} \tag{11}$$

The analytical results for the threshold value show that the curve representing the relationship between technology spillovers and technological distance for China is U-shaped curve, thus different from the standard inverted curve. This means that when technological distance is on the left side of the threshold, the effect of technology spillovers declines as technological distance increases. Interregional technology spillovers occur mostly between provinces that are at a similar stage of technological progress. With regard to right side of the threshold, since the threshold is outside the range of estimated technological distance based on our provincial samples, it is impossible to observe the turning trend on the right side of the threshold. That is, the connection that technology spillovers increase as technological distance rises on the right side of the threshold is not applicable here.

To sum up, our empirical outcomes reject the hypothesis of $\rho < 0$, accept $\rho > 0$ but discard the right side of the curve because of the range of estimated technological distances. Hence, we only accept the left side of the curve which means that technology spillovers increase as technological distance become smaller, indicating that the best

Figure 3
Estimated curve of technology spillovers and technology distance



Source: Figure computed by authors based on Equation (11).

way to strengthen interregional technology transfers is to reduce the technological distance or to build transitional areas between the technologically advanced and backward areas, instead of expanding their technological distance.

Observing the area-specific results in Table 4, we find that $\rho$ is significant for the mid-west area, but not for the eastern region. It can therefore be deduced that interregional technology spillover effects are more relevant in the case of the former than in the latter. Hence, it can be argued that interregional technology spillovers take place from advanced areas to backward ones, and that these transfers are faster in regions that are technologically similar.

The reason underlying the U-shaped relationship may be the counteracting effects of positive spillovers and negative crowding-out effects. We can illustrate this point if we move from right to left along the X axis in Figure 1(A), noting that when the technological distance between regions is large, a major part of the interprovincial technology transfer effects are spillovers effects. As the technologically backward areas catch up and technological distances become smaller, products of the advanced and backward regions become similar, and competition among them intensifies. Furthermore, firms in advanced areas will pay more attention to preventing their technologies from leaking-out to rivals. Competition then causes crowding-out effects that slow down technology transfer. However, a turning point exists where this trend changes. When technologies keep improving in the less-advanced areas, they build up a technological foundation which helps them to overcome the negative crowding-out effects. Their absorptive capacities improve and the technological protection of advanced regions becomes less efficient. Our empirical results show that among the less-advanced provinces, most have already surpassed the turning point and are no longer negatively affected by interprovincial crowding-out effects. Therefore, a major portion of the impact of interprovincial technology transfer is again constituted by spillover effects.

## 4.2 The effects of independent routes to achieve technological progress

In Table 3, the coefficients of capital stock and R&D are significant and positive for the three models, which shows that R&D and learning by doing have a beneficial impact on China’s technological progress. Since learning by doing is a function of output or capital stock, the positive and significant results are due to the increase in Chinese GDP and capital stock during the research period. Furthermore, since learning by doing is the technological progress route that is based on the accumulation of production experiences, it usually becomes a mechanism of ‘imitation and arbitrage’ and contributes little to independent innovation (CASS 2006). Thus, learning by doing does not represent the independent innovative abilities of native industries. In fact, the estimation results of learning by doing presented in this study testify to similar conclusions reached by research related to our work (EGFI 2003; Liu 2005).

The coefficients of learning by doing, capital stock, and R&D are significant in almost all seven models in Tables 3 and 4. This outcome illustrates that even though exterior technology spillovers exist, domestic factors still play an important part in the technological progress of the country or region. While comparing the results of the east and mid-west regions in Table 4, we find that the coefficients of R&D for the middle-west region are greater than those for the east area, which means that for the same input of R&D, the technologically backward provinces get higher returns. Technological catch-up through domestic factors appears to be possible for backward areas, a result which implies the possibility of $\beta$ convergence among Chinese regions.

### 4.3 FDI technology spillovers

In the five results observed in Tables 3 and 4, the coefficients of FDI are all negative, which shows that an increment in FDI does not cause technological progress *per se*. This estimation result contradicts an important assumption about FDI and demonstrates that its direct impact is through the crowding-out effects. There can be several explanations for this outcome. First, the absorption of FDI technology may need a certain technological foundation, including the R&D and learning-by-doing abilities cultivated by former practices. Therefore, the positive impacts of FDI are mainly reflected in the interaction items of FDI and domestic factors.

Second, it should also be pointed out that the most important beneficial aspect of FDI has to do with its existence, rather than with its quantity. For example, a small amount of FDI products can inspire innovation by local companies, while too much FDI may lead to a monopoly and can have crowding-out effects. Along this line, Zhao and Zhang (2006), for instance, conclude that the reason for the decreasing and vanishing FDI technology spillover effects is, in fact, excessive FDI.

### 4.4 The capacity of R&D and learning by doing to absorb FDI and interregional technology transfers

As has been already noted, the analysis above resulted in negative coefficients for FDI. However, the coefficients of the interaction terms of FDI and R&D are significantly positive and large in the three R&D interaction models showed in Tables 3 and 4. In relation to such estimations, we argue that the influence of R&D can be separated into independent innovative effects and absorptive abilities. The significant coefficients of R&D itself and of its interaction terms demonstrate the existence of these two aspects. Thus, we can conclude that R&D is the foundation for FDI technology transfer because technology spillovers of FDI usually occur through intensive competition in native markets and upstream or downstream association. No core technology is transferred directly through these channels. Consequently, in order to acquire core technologies, it is imperative for a country to carry out independent R&D activities.

Compared to the capacity of R&D to absorb FDI technological transfer, its absorptive capacity vis-à-vis intra-national technology transfers does not perform well. The R&D interaction model in Table 3 shows that the coefficient for the interaction term of R&D and technology distance is not significant. The reason for this is that in China most R&D projects sponsored by governments or big state-owned firms focus on foreign advanced technologies (Yao and Zhang 2001). When technologies have already been absorbed by other native regions, repeated research is usually restricted by the government, or avoided by the rational choice of firms. In sum, R&D research promotes the absorption of foreign technologies.

Furthermore, R&D-intensive areas normally are technologically advanced, while technologically backward regions also fall behind in terms of R&D investments.

However, the mainstream of the technology flow takes place from the advanced areas to the backward ones. That is, the areas with low R&D investment absorb more intra-national technology transfers than those with high levels of R&D investment. This also limits the empirical significance of the coefficient corresponding to the R&D and interprovincial technology transfer interaction term. Further, if we compare the east and middle-west areas, the interaction term of R&D and interregional technological distance for the east area is not significant either, while the interaction item for the middle-west area is significant but negative. This means that when the technological distance is wide, an increase in R&D will intensify competition between the backward and advanced regions, and this will cause negative crowding-out effects.

Although learning by doing is one of the major routes for gaining new technology, it is completely different from R&D with regard to the assimilation of external technology transfers. This is because learning by doing appears to perform better in absorbing interregional technology spillovers than FDI technology spillovers. As can be observed from our results, all the interaction terms of learning by doing and technological distance are significant, while all the interaction terms of learning by doing and FDI are not. This implies that learning by doing contributes little to the absorption of FDI technology, yet plays an important role in absorbing interprovincial transferred technology. Learning by doing has such a small impact on the absorption of FDI technology, as compared to R&D, because its main function is to help new technology to mature. This mechanism is not favourable for FDI technology spillovers, given the fact that FDI core technologies are complex. However, the situation is different in the case of interprovincial technology transfers, because technological distance among regions is not as significant and the technologies of the advanced areas are appropriate for those that fall behind.

Hence, technologically backward areas, by strengthening R&D activities and learning by doing, can benefit from the effects associated with the ‘two aspects of R&D and learning by doing’ and ‘bi-channel technology spillovers’. In other words, R&D can help the less-advanced regions improve their independent innovative abilities and capacity to absorb FDI. In the case of learning by doing, it also improves independent innovative abilities, and increases the capacity to absorb interregionally transferred technologies.

In conclusion, technologies acquired via FDI and spillovers from advanced areas can both be absorbed by backward provinces. For the technologically advanced areas, learning by doing, R&D, and FDI technology absorbed via R&D all contribute significantly to technological progress. This shows that R&D activities enhance the absorptive capacity for FDI technology, and that learning by doing plays a key role in the practical application of new knowledge in these areas.

### 4.5 The importance of the channels

Bi-channel technology spillovers exist for both the technologically backward and advanced areas, i.e., advanced technology is transferred via FDI and from other provinces. In Tables 3 and 4, the coefficients of the interaction terms of R&D and interregional technological distance are negative or not significant, but the coefficients of the interaction terms of R&D and FDI are positive. This implies that from the point of view of the absorptive capacity of R&D, FDI is more important than interregional transfers. Nevertheless, interregional spillovers in many other aspects contribute more to technological growth than the spillover effect from FDI.

In considering the absorptive capacity of learning by doing, the coefficients of the interaction terms of learning by doing and interregional distance are all significantly positive, while this is not the case with the interaction terms of learning by doing and FDI. Furthermore, for all areas, the coefficients for FDI considered separately from the interaction term are significantly negative. That is, apart from the interaction item, FDI does not impact directly on technology progress. Compared to this, the coefficients of the interregional technological distance term and its square considered separately from the interaction term are all significant in Table 3. This means that interregional technology spillovers have a direct impact, and become stronger when technological distance decreases. These empirical results point to the fact that interregional technology spillovers contribute more to the technological development of different regions in China than FDI technology transfers.

There can be several reasons for the interregional technology spillovers to be the strongest among the bi-channel technology spillovers. First, absorptive abilities of domestic areas are suitable for technology transferred from other advanced native areas, but may not at times match FDI technology, which can be too complex. Second, transferred technology should fit the local factor endowment. According to the appropriate technology theory (Bash and Weil 1998; Lin and Zhang 2005), some technology developed in the advanced countries is suitable only for the factor endowment structure of such nations. Therefore, in order to achieve valid transfers, in adapting these technologies, developing countries should pay attention to technology that is adequate for their own factor endowment. In this respect, and compared to foreign technology, transfers from the technologically advanced domestic areas may be more appropriate for the local factor endowment.

Third, the exchange of human resources is more frequent and the connection based on intermediate products is closer among native companies than that established with foreign enterprises. An investigation carried out by Wu (1995) shows that only 29.4 per cent foreign-funded firms in China presented technology spillover effects. This result is similar to the crowding-out effects of our no-interaction FDI term. Also, research by Yao and Zhang (2001) finds that within a specific industry, state-owned enterprises have significant technology spillover effects, but foreign-funded enterprises do not. In relation to this, and considering that human capital flows can be divided into physical and logical (Li 1999), physical flows from foreign enterprises to technologically backward firms are rare; 90 per cent of the job-hopping by the employees of foreign companies takes place among these firms only (Liu 1998). Consequently, logical flows, such as interpersonal contacts or informal networks of friends and parttime employees, are more important for technologically backward areas or firms. These logical flows usually occur within native sectors. These close relationships between domestic enterprises within the same industry make the interregional element more important.

## 5 Conclusions and policy implications

This paper analysed the effects of international and intra-national technology spillovers on technological progress in the developing countries, by taking into account internal factors. These include learning by doing and independent R&D, factors that induce technological progress, and the absorptive capacity of these with regard to technology spillovers from abroad. The results show that intra-national technology spillovers are more relevant than international ones, and that the internal routes represent the more stable channel for technological progress.

Among the several internal factors studied, R&D plays a crucial role in the absorption of international technology spillovers, whereas the absorptive capacity of learning by doing is important vis-à-vis the absorption of intra-national technology spillovers. Comparing international technology spillovers that occur via FDI with interprovincial ones, the impact of FDI depends on the absorptive capacity of indigenous R&D. Without interaction with indigenous R&D, the coefficient estimated for FDI is negative, suggesting that it causes crowing-out effects when it functions alone, without sufficient absorptive capacity. By contrast, interprovincial technology spillover, represented by the technological distance between the technology frontier and the technologically backward areas and its square, can occur even without interaction with R&D or learning by doing.

The empirical analysis testifies to the existence of interregional technological transfer, as well as its technology threshold. In China, the relationship between technology spillovers and technological distance is a U-shaped curve, contrary to the standard inverted U-shaped curve. This means that as interregional technological distance decreases, crowding-out effects first intensify due to competition, but are subsequently overcome by the technological advancement of the backward areas. In our sample, the technology threshold for interregional technology spillovers is greater than the maximum value of technological distance, suggesting that most provinces in China have surpassed the turning point and the interregional crowding-out effects. In addition, the U-shaped relationship also means that the closer the technological distance is, the easier it becomes for technology spillovers to be effective.

Our study shows that interregional technology spillovers in the middle-west area are stronger than those in the eastern one. This suggests that for the backward regions, it is mainly the interregional transfers from domestic technologically-advanced regions that play an important role. For the middle-west area, the coefficient of the interaction term of learning by doing and interregional technological distance is much larger than that of the east area. Also for the middle-west region, the test coefficient for interregional technology spillovers is significant, while this is not the case for the east region. For the latter, the coefficient of the interaction term of R&D and FDI is significant, while the coefficient of the interaction term of R&D and technology distance is not. Therefore, we can conclude that FDI technology spillovers are important for the east area. Also, learning by doing and R&D are shown to have a more profound effect on production for the east and middle-west areas. Further, bi-channel technology spillovers do exist: the spillovers from FDI are based on the interaction with R&D, and the spillover from technologically-advanced regions act directly or through the interaction with learning by doing.

For achieving technological progress, the independent routes among the four channels, namely, learning by doing and R&D, represent important and stable paths. This is empirically supported by our research, given that the coefficients corresponding to these two approaches turn out to be significant in almost all models. In this respect, the coefficients of R&D and the interaction term of learning by doing and technological distance are much higher in the middle-west region than that in the eastern one. This suggests the possibility of technological catch-up effects for the backward areas should they have the same access to, and the capacity to absorb, technological spillovers of the more advanced provinces. In sum, for the technologically backward regions, learning by doing, R&D and interregional technology transfers are relevant. Furthermore, for areas that have already acquired an advanced level of domestic technology, learning by doing, R&D, and FDI technology spillovers based on R&D also have a positive impact on local technological progress.

The findings of this paper have important policy implications. First, learning by doing, R&D, technology transfer via FDI and from other regions are all indispensable for regional technology upgrading. While R&D helps to produce innovative goods and increases the capacity to absorb and maximize the advantages of technology spillovers from FDI, learning by doing improves the innovative products and is important for interregional technology transfers. In the absence of these two independent routes, the host-country would face problems in absorbing technology transfers. Since technological level is distributed unevenly across China's geographical locations, FDI techniques should be introduced in those domestic areas where they are more appropriate. Subsequently, steps should be taken to narrow the technological distance between neighbouring regions in order to accelerate and facilitate interregional technology spillovers—taking into account that the interregional relationship of technology transfer and technological distance is U-shaped. In this way, advanced foreign technique could reach certain domestic regions via FDI, to be later transferred to others on the basis of learning by doing.

Second, strategies to achieve technological progress should be differentiated across regions. Foreign technology and independent innovations should be given priority in the technologically-advanced areas. In view of both these aspects, R&D is important, and since it has scale effects and cluster characteristics (Dosi 1988; Buettner 2003; Rodriguez-Pose 2001), it is more efficient in these areas. For developing countries with limited budget, it is economically efficient to support R&D in advanced areas. Moreover, these regions normally attract substantial amounts of FDI. Thus, government policies against the monopolies that can be brought about by FDI are important, since they can reduce the related crowding-out effects. The level of FDI should be such that it is sustainable for domestic firms to compete, and appropriate for the absorptive capacity existing within the region. The latter can be enhanced in the local economy through R&D and learning by doing.

Finally, it is important for the regions that are technologically less-advanced to keep close economic and social linkages with the advanced ones. As has been stated elsewhere, intra-national technology spillovers are more relevant than international spillovers for the backward areas, where the techniques related to FDI might not be suitable, and the irrational creation of high-tech special zones risky. Moreover, the marginal output effect of R&D is higher in these regions than in the advanced areas. Backward regions, with their advantage in terms of low labour and land costs, can thus introduce industries that would lose their advantage in the advanced regions. Advanced indigenous technology is more suitable for the less-advanced regions, and technology transfer less restrictive. Finally, for these backward areas, it is of crucial importance to enhance their capacity to absorb international or domestic technology spillovers through fiscal, industrial, and technological policies.

## References

Aitken, B. J., and A. E. Harrison (1999). 'Do Domestic Firms Benefit from Direct Foreign Investment? Evidence from Venezuela'. *American Economic Review*, 89 (3): 605-18.

Arrow, K. J. (1962). 'The Economic Implications of Learning by Doing'. *The Review of Economic Studies*, 29 (2): 155-73.

Bahk, B.-H., and M. Gort (1993). 'Decomposing Learning by Doing in New Plants'. *Journal of Political Economy*, 101 (4): 561-83.

Barro, R., and X Sala-i-Martin (1995). *Economic Growth*. New York: McGraw Hill, 186-94.

Bash, S., and D. Weil (1998). 'Appropriate Technology and Growth'. *The Quarterly Journal of Economics*, 113 (4): 1025-54.

Borensztein, E., J. D. Gregorio, and J. W. Lee (1995). 'How Does Foreign Direct Investment Affect Economic Growth?'. NBER Working Paper 5057. Cambridge, MA: National Bureau of Economic Research.

Brendstetter, L. G. (2001). 'Are Knowledge Spillovers Are International or Intra-national in Scope? Microeconometric Evidence from the US and Japan'. *Journal of International Economics*, 53 (1): 53-79.

Buettner, T. (2003). 'R&D and the Dynamics of Productivity'. Working Paper. London: London School of Economics.

Cameron, G., J. Proudman, and S. Redding (1998). 'Productivity Convergence and International Openness'. In J. Proudman and S. Redding (eds), *Openness and Growth*. London: Bank of England.

Caniëls, M. C. J., and B. Verspagen (1999). 'The Effects of Economic Integration on Regional Growth: an Evolutionary Model'. ESRA conference papers, ersa99pa219. Liverpool: European Regional Science Association.

Cass (2006). 'Learning by Doing, Low Cost Competition and Conversion of Economic Growth Pattern'. (China) *Economic Research Journal*, 4: 4-14.

Coe, D. T., and E. Helpman (1995). 'International R&D Spillovers'. *European Economic Review*, 39 (5): 859-71.

Cohen, W., and D. Levinthal (1989). 'Innovation and Learning: Two Faces of R&D'. *Economic Journal*, (99): 569-96.

Dosi, G. (1988). *Technical Change and Economic Theory*. London: Pinter.

EGFI (Economic Growth Frontier Issues Project Group) (2003). 'Economic Growth, Accumulative Effects of Structural Adjustment and Capital Formation'. (China) *Economic Research Journal*, 8: 3-12.

Eden, L., E. Lecitas, and R. J. Martinez (1997). 'The Production, Transfer and Spillover of Technology: Comparing Large and Small Multinationals as Technology Producers'. *Small Business Economics*, 9 (1): 53-66.

EGFI (Economic Growth Frontier Issues Project Group) (2003). ‘Economic Growth, Accumulative Effects of Structural Adjustment and Capital Formation’. (China) *Economic Research Journal,* 8: 3-12.

Enos, J. (1985). ‘A Measure of the Rate of Technological Progress in the Petroleum Refining Industry’. *Journal of Industrial Economics*, 6 (3): 180-97.

Erdilek, A. (1984). ‘International Technology Spillovers in the Middle East and North Africa’. *Management Decision*, 22 (2): 45-9.

Fagerberg, J. (1994). ‘Technology and International Differences in Growth Rates’. *Journal of Economic Literature*, 32: 1147-75.

Findlay , R. (1978). ‘Relative Backwardness, Direct Foreign Investment and the Transfer of Technology: A Simple Dynamic Model’, *Quarterly Journal of Economics*, 92 (1): 1-16.

Fu, X. (2005). ‘Exports, Technical Progress and Productivity Growth in Chinese Manufacturing Industries’. *Applied Economics*, 37 (7): 725-39.

Fu, X. (2008). ‘Foreign Direct Investment, Absorptive Capacity and Regional Innovation Capabilities: Evidence from China’. *Oxford Development Studies*, 36 (1): 89-110.

Girma, S. (2005). ‘Absorptive Capacity and Productivity Spillovers from FDI: A Threshold Regression Analysis’. *Oxford Bulletin of Economics and Statistics*, 67 (3): 281-306.

Griffith, R., S. Redding, and J .V. Reenen (2004). ‘Mapping the two Faces of R&D: Productivity Growth in a Panel of OECD Industries’. *The Review of Economics and Statistics*, 86 (4): 883-95.

Griliches, Z. (1980). ‘R&D and Productivity Slowdown’. *American Economic Review*, 70 (2): 343-8.

Grossman, G. M., and E. Helpman (1991). *Innovation and Growth in the Global Economy*. Cambridge, MA: MIT Press.

He, J. (2000). ‘The Further Precise Quantification of FDI’s Spillover Effects on Chinese Industrial Sectors’. (China) *World Economy*, 12: 29-36.

Hoekman, B. M., K. E, Maskus, and K. Saggi (2004). ‘Transfer of Technology to Developing Countries: Unilateral and Multilateral Policy Options. WB Policy Research Working Paper 3332. Washington, DC: World Bank.

Kinoshita, Y. (2001). ‘R&D and Technology Spillovers through FDI: Innovation and Absorptive Capacity’. CEPR Discussion Paper 2775. London: Centre for Economic Policy Research.

Kokko, A., R. Tansini, and M. Zejan (1996). ‘Local Technological Capability and Productivity Spillovers from FDI in the Uruguayan Manufacturing Sector’. *Journal of Development Studies*, 32 (4): 602-11.

Kokko, A., R. Tansini, and M. Zejan (1997). ‘Trade Regimes and Spillover Effects of FDI: Evidence from Uruguay’. Stockholm: Stockholm School of Economics. Unpublished manuscript.

Lall, S. (2004). ‘Industrial Success and Failure in a Globalizing World’. *Journal of Technology Management and Sustainable Development*, 3 (3): 189-213.

Li, P. (1999). ‘Analysis of Spillover Effects in Technology Diffusions’. *Nankai Journal*, 2: 28-33.

Li, T. (2006). ‘The Positive Analysis of the Differentiation of Foreign Direct Investment Technology Spillover Effects’. (China) *Finance & Trade Economics*, 4: 13-18.

Li, X., X. Liu, and D. Parker (2001).’ Foreign Direct Investment and Productivity Spillovers in the Chinese Manufacturing Sector’. *Economic Systems*, 25: 305-21.

Lin, Y., and P. Zhang (2005). ‘Appropriate Technology, Technical Selection and the Economic Growth of Developing County’s Techniques’. CCER Working Paper, 2005-004. Beijing: China Center for Economic Research, Peking University.

Liu, E. (1998). ‘Industry Driving Effects of Foreign Direct Investment’. (China) *Science of Contemporary Economics*, 4: 52-7.

Liu, S. (2005). ‘The Pressure of Growth Pattern Transition and Strategy Selection’. (China) *Economic Perspectives*, 9.

MacDougall, G. D. (1960). ‘The Benefits and Costs of Private Investment from Abroad: A Theoretical Approach’. *Economic Record*, 37: 13-35.

Mancusi, M. L. (2004). ‘International Spillovers and Absorptive Capacity: A cross-country Cross-Sector Analysis Based on European Patents and Citations’. Working Paper: Milan: Istituto di Economia Politica, Università Bocconi.

Mansfield, E. (1985). ‘How Rapidly Does New Industrial Technology Leak Out?’. *Journal of Industrial Economics*, 34 (2): 217-23.

Nadiri, M. I. (1980). ‘Contributions and Developments of Research and Development Expenditures in the US manufacturing Industries’. In G. M. Furstenburg (ed.), *Capital, Efficiency, and Growth*. Cambridge, MA: Ballinger.

NBS (National Bureau of Statistics) (various issues). *China Statistical Yearbooks*. Beijing: Statistical Press.

NBS (various issues). *China Statistical Yearbooks on Science and Technology*. Beijing: Statistical Press.

OECD (Organization for Economic Cooperation and Development) (2002). *Science and Technology Industry Outlook*. Paris: OECD.

CASS (Research Group of the Economic Institute of CASS) (2006). ‘Learning by Doing, Low Cost Competition and Conversion of Economic Growth Patterns’. (China) *Economic Research Journal*, 4: 4-14.

Rodriguez-Pose, A. (2001). ‘Is R&D Investment in Lagging Areas of Europe Worthwhile?’. *Regional Science*, 80 (3): 275-95.

Romer, P. M. (1990). ‘Endogenous Technological Change’. *Journal of Political Economy*, 98 (October): S71-S102.

Wu, N. (1995). *Performance Analysis of Guangdong Overseas Chinese, Joint Ventures and Foreign Enterprises*. Guangzhou: Sun Yat-sen University Press.

Yao, Y., and Q. Zhang (2001). ‘An Analysis of Technological Efficiency of Chinese Industrial Firms’. *China Economic Research*, 10: 13-28

Young, A. (1993). ‘Invention and Bounded Learning by Doing’. *The Journal of Political Economy*, 101 (3): 443-72.

Zhang, H. (2005). ‘The R&D Absorptive Abilities of Chinese Industry Sections and Technology Transfer of Foreign Investment’. (China) *Management World*, (6): 82-8.

Zhang, J., and S. Shi (2003). ‘Change of Total Factor Productivity in the Chinese Economy: 1952-1998’. (China) *World Economic Forum*, 2: 17-24.

Zhang, J., G. Wu, and J. Zhang (2004). ‘The Estimation of China’s Provincial Capital Stock: 1952 -2000’. *China Economic Research*, 10: 35-44.

Zhao, Q., and C. Zhang (2006). ‘Economy Growth and Technology Spillover Effects of FDI: the Case of Jingjinji Area’. (China) *Journal of Quantitative & Technical Economics*, (3): 11-20.