Technology spillover effects and the evolution of inter-regional industrial structure in China

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【Abstract】 This paper focuses on the relationship between technology spillovers and the evolution of China's regional industrial structure. Based on a theoretical model which incorporates technology spillovers into the evolution of regional industrial structure, we empirically test technology spillovers for the period 1991-2007. The findings provide an important theoretical and practical basis for the government to formulate regional economic policies and industrial development plans.

Key words: *Regional economy; technology spillovers; industrial structure*; *China*

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1 Introduction

The Chinese government established a new pattern of regional economic development in 2007 and proposed an overall regional development strategy and this is to continue to boost the development of western and northeastern old industrial bases, promote the rise of the Central region and further develop the Eastern region. As one of largest emerging economies, China's resource endowment varies markedly from region to region. The level of economic development is obviously imbalanced from spatial and regional perspectives. Therefore, identifying the factors that affect the evolution of the industrial structure is important when formulating scientific industrial policies and regional development. In addition, upgrading the regional industrial structure is not only one element in the evolution of an economy, but also the main objective of the adjustment of the economic structure. In this context, it is important to study the effect of regional industrial structure evolution due to its crucial role in the adjustment and optimization of the industrial structure, and the overall and balanced development of regional economies. The findings will offer policy implications for policy makers in formulating regional development strategies.

The existing literature has examined the evolution of industrial structure and factors affecting industrial structures (Kirin Clark, 1940). Simon Kucinich (1985) studied the relationship between industrial structural change and economic development, and proposed that an increase in national per capita income level will cause a major shift in industrial structure, including changes in industrial output and employment. Moreover, Louise (1954) proposed the dual economic theory which stressed that economic development causes resource deployment to shift from low efficiency units to high efficiency units, thus realizing the transformation (evolution) of industrial structure and leading to growth of the local economy. Chenery (1968), using Kucinich statistical induction, has conducted more in-depth research on the general trend of industrial structural change. He treated GDP and population as exogenous variables, and then substituted them into a regression model of GDP market share. He proposed a standard industrial structure pattern based on empirical evidence.

Li (1983) applied a linkage analysis framework, namely relationships between industrial structural change and its direct linkage factors, such as technology advancement, social supplies, social demand and overseas supplies and demand. Shen (1998) stated that the basic reason of industrial vicissitude lay in the division of labor and the change of institutional arrangements. Some researchers have also conducted empirical studies on China's industrial structural change. For example, Guo (1994; 1999) has noted the relationships between Chinese economic growth and the industrial structural transformation and has examined the reason for unbalanced structure, which is probably attributable to insufficient total demand. Liu (1999) investigated the characteristic and the evolutionary rule of the industrial structure during the Chinese accelerated industrialization period. Zhou (1991) studied the relationship between the structural transformation and economic growth and proposed an analytical framework on the effect of industrial structural reform.

On the other hand, recent studies on technology spillovers have examined the impact of the market, the government and the configuration of organizations on technology spillovers (Sedaitis, 2000). Geroski (2000) stated that distance is a significant factor influencing technology spillovers. Bart (2002) showed that technology spillovers, with the elapse of time, exhibit a weak nature as distance increases. Abreu, Maria and Henri (2004) have studied spatial constraints on technology spillovers, and empirically examined localized technology spillovers. They suggest that high-tech enterprises should locate close to each other. MacGarvie (2005) used patent citations to measure international technological spillover and stated that if technology and resources are closely related, and language is interlinked, technology spillovers can be achieved. Robertson (2007) also highlighted that high-tech industries have a profound impact on technology spillovers. Healthy high-tech enterprises and industries largely depend on their firms' ability to sell their outputs to other industries and acquire external knowledge to enhance innovation. However, some Chinese experts mainly focus on the technology spillover effect of foreign direct investment (FDI) and its important role in promoting the economic development in China. Huang and Zhang (2004) modified Coe and Helpman (1995)'s (CH) trade spillover model by introducing merchandise trade and FDI into the model. Li and Zhu (2004) built an econometric model for technology spillovers of international trade. Examining regional technology spillovers, Li and Qian (2005) also extended and improved the CH model, and tested the technology spillover effect of imports and FDI in different regions during the period 1985-2003. Based on the location theory, Zeng and Lin (2006) have conducted spatial analysis on the factors influencing technology diffusion and applied their theoretical framework to the case of Zhangjiang High-tech Science Park. Li and Lu (2006) adopted the LP method, and analyzed the impact of imports on total factor productivity for the eastern, central and western regions.

These studies have shed light on technology spillovers; however, two aspects have been underexplored. Firstly, there is a lack of research on the effect of the evolution of industrial structure on technological progress. More specifically, empirical evidence is needed to help us to understand how the evaluation of industrial structure affects knowledge upgrading through knowledge spillovers. Secondly, most previous studies on knowledge spillovers have mainly focused on FDI as a major channel, but few of them have made the distinction between domestic and foreign technology spillover channels. This negligence may produce a biased result, given that China has invested in R&D substantially, and domestic technology spillovers are also important and should be taken into account when studying technology spillovers across regions. In addition, most studies tend to focus on particular industries. Hence, comprehensive analysis of regional economies, especially of the four main regions, namely the Eastern, Central, Western and Northeastern regions, has been largely overlooked.

This paper aims to examine the impact of the evolution of regional industrial structure on technology upgrading. In particular, it focuses on seeking evidence of technology spillovers in the context of the evolution of industrial structure. It also compares different channels of technology spillovers - channels for international technology and domestic technology spillovers as well as their influence on regional technological progress during the evolution of industrial structure. The paper is organized as follows. The second section describes industrial structures in the four main regions, followed by a theoretical framework and empirical models. Section 5 discusses the empirical results and it concludes with policy implications in Section 6.

2. The evolution and status of China’s regional economic structure

In the past 30 years of economic reform and opening-up, China has experienced rapid economic development, but an imbalance in regional development is still very evident. From regional economy perspectives, the average annual GDP growth rate of the eastern part had reached 14.7% from 1997 to 2007, whereas, it was 13.36%, 12.39%, and 11.89% in the Western, Central and Northeastern regions, respectively. In terms of sectoral distribution, the secondary and tertiary industries have increased substantially in the eastern part, while primary industry accounts for a large share of regional economies in the Central and Western regions, and the tertiary industry has experienced a slow increase in the Northeastern region. With regard to the composition of GDP, the output share of primary industry has declined, but the output share of secondary and tertiary industries has increased in general, as shown in

Table 1 The ratio of industrial output values to GDP in the four regions Unit: %

Regions	1997			2007		
	Primary industry	Secondary industry	tertiary industry	Primary industry	Secondary industry	tertiary industry
Eastern	14.22	49.16	36.62	6.88	51.47	41.65
central	24.6	45.17	30.23	14.60	49.45	35.95
Western	26.66	41.06	32.27	15.97	46.32	37.70
Northwestern	17.51	49.29	33.20	12.12	51.44	36.44

Data sources: China statistical yearbooks (1998-2008)

As the strongest economic region, the total output value of the Eastern region accounts for 55.3% of total GDP, which is much higher than the total share of the Central, Western and Northeastern regions. In terms of the growth rate of value-added in different sectors, the ratio of the tertiary industry in the Eastern area is much higher than other areas. In contrast, the ratio of the primary and secondary industries of this region is lower than the other three areas. This implicitly shows that the eastern area accelerated the development of the tertiary industry and gradually slowed down the development of the primary and secondary industries.

The economic strength of the Central region is weaker than the Eastern region, accounting for 27.30% of the population, but only 18.88% of total GDP. The proportion of primary industry in GDP is 26.6%, whereas secondary industry accounted for 18.6%, and the share of tertiary industry was 17.21% in the central region. The primary industry in the central region is stronger than the secondary and tertiary industries, but GDP per capita is lower than the national average at 0.70 times less than the national level.

Although the overall economic strength of the Western region was also weaker than the Eastern region, economic growth of the Western region has taken off, and its growth rate is above the average national level perhaps due to the implementation of the western development strategy. GDP of the Western region in 2007 accounted for 17.37%; per capita GDP is 0.62 times lower than the national level. In 2007, primary and secondary industrial growth rates in the Western region were the highest among the four main regions. The growth rate of its tertiary industry is only lower that the eastern region. This shows that through the adjustment of its industrial structure, the western region has accelerated the pace of industrial development and economic growth.

At present, the Northeastern region is in an adjustment and transition period from a traditional industry base to modern industry. In 2007, the Northeastern region's GDP accounted for 8.5% of the country, and this percentage has continued to decline. The growth rate of its primary and secondary industries were above the average national level, while the growth rate of the tertiary industry is the lowest in the four regions. However, three provinces in Northeastern China used to be the base for heavy industry. Hence, the industrial foundations are solid in the region, and the level of regional economic development is relatively high. In 2007, the Northeastern region's per capita GDP was 1.02 times higher than the national level, ranking second after the Eastern region.

3 Model

3.1 A theoretical model on the effect of the regional industrial structure

evolution

Based on the Cobb-Douglas production function, we redefine the variables, and construct a function which considers the impact of industrial structural evolution. The Cobb-Douglas production function is well-known and is defined as

$$Y = AK^{\alpha}L^{\beta} \tag{1}$$

Where K is capital input, L is labor input, and A is total factor productivity. Assume that A is up to the level of technology which is represented by T. So A is a function of T, denoted by A=A(T), then the production function can be expressed as

$$Y = A(T)K^{\alpha}L^{\beta} \tag{2}$$

Before upgrading the industrial structure, the regional production function can be set as

$$Y_0 = A(T_0)K_0^{\alpha}L_0^{\beta} \tag{3}$$

Where $A\ (T_0)$ represents total factor productivity in the region before upgrading the industrial structure. In the same token, T_0 represents the average skill level of the region; K_0 represents the capital investment in the region. L_0 denotes the labor input; T_0 represents the average level of technology.

We now incorporate the industrial upgrading into the production function which can be expressed as

$$Y_1 = A\ (T_1)K_1^{\alpha}L_1^{\beta} \tag{4}$$

Where $A\ (T_1)$ stands for total factor productivity (TFP) of the region after upgrading the industrial structure; T_1 indicates the average skill level of the region; K_1 is the capital investment of the region; L_1 represents the labour input in the region.

We make a number of assumptions as follows.

Assumption 1: $K_1 \geq K_0$. This implies that after upgrading the industrial structure, capital in the regional will increase. Hence, $K_1 \geq K_0$.

Assumption 2: $L_1 \geq L_0$. L_1 will increase with the upgrading of industries. In other words, the labor force of the region will scale up as a result of upgrading industries. Thus, we assume $L_1 \geq L_0$, and the region's labour input varies with the increases of the number of upgrades (defined as N), denoted by $L_1 = L_1(N)$.

The effect of upgrading the industrial structure of the region should be reflected in the final output, so we can preliminarily construct a function of the effect of industrial structure evolution according to the changes of the regional output.

$$Y = A\ (T_1)K_1^{\alpha}L_1^{\beta} - A(T_0)K_0^{\alpha}L_0^{\beta} - C \qquad (5)$$

where $A\ (T_1)K_1^{\alpha}L_1^{\beta}$ is the output of the region after the upgrading; $A(T_0)K_0^{\alpha}L_0^{\beta}$ is the output of the region before the upgrading; C is the cost incurred in the process of upgrading the industrial structure.

Equation (5) implies that the effects of industrial structure evolution are the net income which is equal to changes in the regional output minus the cost of upgrading.

After further derivation of the effect function, we can rearrange Equations (5) into (6).

$$U = A(t,N)K_1^{\alpha}(N)L_1^{\beta}(N) - A(T_0)K_0^{\alpha}L_0^{\beta} - C(N, P_d - P_f, t) \qquad (6)$$

where *U* is defined as the total effect of the evolution of the industrial structure.

The effects of the evolution of the industrial structure can be decomposed into sub-effects as follows.

$$
\begin{aligned}
U &= A\ (t,N)K_1^{\alpha}(N)L_1^{\beta}(N) - A(T_0)K_0^{\alpha}L_0^{\beta} - C(N,P_d-P_f,t) \\
&= d(AK^{\alpha}L^{\beta}) - C(N,P_d-P_f,t) \\
&= (Y_1-Y_0) - C(N,P_d-P_f,t) \\
&= dY - C(N,P_d-P_f,t) \\
&= K^{\alpha}L^{\beta}dA + \beta\cdot AK^{\alpha}L^{\beta-1}dL + \alpha\cdot AK^{\alpha-1}L^{\beta}dK - C(N,P_d-P_f,t) \\
&= \left[K^{\alpha}L^{\beta}dA - C(N,P_d-P_f,t)/3\right]_1 + \left[\alpha\cdot AK^{\alpha-1}L^{\beta}dK - C(N,P_d-P_f,t)/3\right]_2 \\
&\quad + \left[\beta\cdot AK^{\alpha}L^{\beta-1}dL - C(N,P_d-P_f,t)/3\right]_3 \\
&= U_1 + U_2 + U_3 \qquad (7)
\end{aligned}
$$

In Equation (7), U_1、U_2、U_3 are derived from U and are defined as sub-effects, and the direct effects of the evolution of industrial structure based on the variables, A, K and L. Specifically U_1 represents the technology spillover effect, mainly based on the effect that is caused by changes in the production technology level due to the evolution of the industrial structure. U_2 stands for industrial relations, which is based on changes in input of regional capital due to industrial upgrades. U_3 represents the employment effect which is induced by changes in labour input as a result of the evolution of the industrial structure. According to the analysis above, we can clearly depict a theoretical framework which explains the effect of the evolution of the industrial structure. This paper mainly focuses on measuring U_1, which captures the spillover effect on the evolution of technological structure.

3.2 Technology spillover effect Model

To study the regional technology spillover effect, we adopt a trade spillover model constructed by Coe & Helpman (1995). The Coe & Helpman (CH) model is based on innovation-driven growth theory proposed by Grossman & Helpman (1991). The innovation-driven growth theory aims to evaluate how technological advantages in foreign countries affect domestic output growth. More specifically, the theory evaluates the technology spillover effect from the import of goods and services on TFP growth. The basic hypothesis of the model is that technological knowledge is transmitted through trade. In other words, inventions in exporting countries will lead to the improvement of knowledge capital in importing countries through knowledge spillovers.

To examine regional technology spillovers, we extend the CH model and redefine the variables of the CH model in the following ways. First, we improve the variable of domestic R&D stock by introducing regional R&D expenditure, GDP per capita, and the number of technology-traded contracts into the model. Then we improve the variable of foreign R&D stock by introducing FDI as an additional channel for technology spillovers beside imports.

The expanded CH model can be expressed as

$$\ln TEP_{it} = U_1 = \alpha + \alpha_1 \ln S_t^{rd} + \alpha_2 \ln S_{it}^{pgdp} + \alpha_3 \ln S_{it}^{cnt} + \alpha_4 \ln S_{it}^{f\_imp} + \alpha_5 \ln S_{it}^{f-fdi} + \varepsilon_{it} \quad (8)$$

Where, TFP_{it} is total factor productivity in province (city or district) i in a given year t in China, measuring generalized technological progress; S_t^{rd} is R&D expenditure in year t. It is assumed that domestic R&D stock is transmitted among provinces (cities, districts) through R&D investment, so we use a regression model which includes domestic R&D expenditure and TFP in each province (city or district).

S_{it}^{pgdp} is GDP per capita in province i (city or district) in a given year t. We choose this variable for two main reasons. First, GDP per capita reflects the diversity of economic development in different regions, which can affect the improvement of regional TFP. Second, GDP per capita is able to capture knowledge stock in a certain region because GDP in a specific year represents an economy's overall knowledge accumulation and, in fact, the regional GDP gap is always in accordance with the regional knowledge gap.

S_{it}^{cnt} is the number of technology transactions which include technology transfer, technological development, and/or technology consulting and technical services. As an important channel for regional technology spillovers, technology transactions play a promoting role in the improvement of regional innovation, and are a direct way of transferring technology among regions. Hence, technical transactions are regarded as one of the main factors promoting regional technology improvement in China.

S_{it}^{f-imp} is imports in province i (city or district) in a given year t in China.

S_{it}^{f-fdi} is FDI in province i (city or district) in a given year t in China.

α_{0i} is intercept.

α_{1i} 、α_{2i} 、α_{3i} 、α_{4i} 、α_{5i} are the coefficients to be estimated, and represent R&D expenditure, GDP per capita, number of technology transactions, imports, FDI elasticity of TFP, respectively. ε_{it} is an error term.

4 Data and variable estimation

The data used in the study covered the period 1990-2007 and were taken from China Statistical Yearbooks, China Statistical Yearbooks of Foreign Trade and Economics, and Provincial Statistical Yearbooks. The variables are converted into constant prices in the base year, 1990. For the variables of TFP, domestic R&D stock and R&D expenditure, the data were calculated using different methods based on previous studies. The specific procedures are as follows:

TFP

By employing the Cobb-Douglas production function, we assume the production function is subject to constant returns to scale i.e. the total elasticity of capital and labour is equal to 1, so we have:

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} \qquad (9)$$

The logged form of Equation (8) is:

$$\ln Y_t = \ln A_t + \alpha \ln K_t + \beta \ln L_t \qquad (10)$$

We define TFP as:

$$TFP_t = \frac{Y_t}{K_t^{\alpha} L_t^{\beta}} \qquad (11)$$

Hence, we can obtain the elasticity of capital and labor, α and β by estimating Eq. (11).

In order to maintain accuracy and consistency, we calculated real GDP in the base year, 1990. We used the number of provincial employees at year-end to represent labor input, L_{it}. We adopted the perpetual inventory method proposed by Goldsmith (1951) to estimate capital input.

$$K_{it} = K_{i,t-1}(1-\delta) + I_{it} \qquad (12)$$

where I_{it} represents the amount of fixed capital formation in each province (city/district), and is converted at constant prices in the base year, 1990.

In order to compute the elasticity of capital output, α and the elasticity of labour output, β, the OLS method is generally employed based on the following regression equation:

$$\ln Y_{it} = \ln A_{it} + \alpha \ln K_{it} + \beta \ln L_{it} + \varepsilon_{it} \qquad (13)$$

We employ the panel data of 29 provinces in China to carry out the regression estimation for the period of 1990-2007. The results show that $\alpha = 1.020852$, and $\beta = 0.191679$ which means the significant level of the coefficients is very high. However, we have found that the variables of capital and labour suffer from multicollinearity. In order to eliminate multicollinearity in the model, we assume that $\alpha + \beta = 1$ i.e. production is subject to constant returns to scale. The regression equation is changed to:

$$\ln (Y_{it} / L_{it}) = \ln A_0 + \alpha \ln K_{it} + \varepsilon_{it} \qquad (14)$$

The results of the second regression produced better goodness of fit, but indicated the existence of autocorrelation in the model. In order to eliminate the autocorrelation, we use the generalised least squares method, so the autocorrelation between panel data can be automatically corrected. After the regression model is amended, the capital-output elasticity is 0.53, and the elasticity of labour is 0.47. Accordingly, under the above definition, TFP is calculated as:

$$TEP_{it} = \frac{Y_{it}}{K_{it}^{0.53} L_{it}^{0.47}} \qquad (15)$$

Domestic R&D stock and R&D expenditure

Using the perpetual inventory method, the stock of domestic R&D from 1991 to 2007 is estimated as

$$S_t^{rd} = (1-\delta)S_{t-1}^{rd} + RD_t \qquad (16)$$

where, S_t^{rd} is the stock of domestic R&D in a given year t; similarly, S_{t-1}^{rd} is the stock of domestic R&D in a given year t-1. RD_t is R&D expenditure in a given year t; δ stands for the depreciation rate of R&D expenditure, which is assumed to be 5% according to Coe & Helpman (1995).

5 Empirical results and analysis

The panel data include cross-sectional and time series dimensions and the accuracy of the empirical model affects the validity of parameter estimates. Therefore, we must test whether the model parameters have the same constant in all cross-sectional and time sample points. Because the sample data were collected for 29 provinces and cities, there is no problem of random sampling. Therefore, we study the individual fixed effect changes of parameters on all cross-sectional sample points.

We tested whether the mixed regression model or individual fixed effect model should be used. The results presented in the Appendix show that the individual fixed effect model fits well with the Eastern region, the Central region and Western region, whereas the mixed regression model is appropriate for the Northeastern region. The results for the four regions based on panel data estimations are presented in Table 2.

Table 2: The results of technical diffusion based on panel data regressions in four regions

Region	Eastern region α_d	Central Region α_z	Western Region α_x	Northeastern Region
α	-3.678890 -7.002909*	-3.896513 -9.517933*	-2.392499 -8.010444*	-3.450999 -6.116020*

α_1	0.039371	-0.005990	0.128728	0.159924
	1.334239	-0.197165	5.409034*	3.784729*
α_2	0.371428	0.432757	0.146782	0.228493
	6.321487*	7.107842*	3.909141*	3.067998**
α_3	0.006274	0.006877	-0.000177	0.034665
	0.673359	0.671686	-0.027877	1.521686
α_4	0.002862	0.006877	-0.010179	0.010972
	0.607686	-0.176108	-2.647901*	0.821903
α_5	0.014652	0.011318	0.004899	0.010874
	1.451680	1.425046	1.278494	0.824411
$AR(1)$	0.858942	0.824974	0.862344	0.768947
	20.90718*	15.14070*	21.86935*	7.195926*
$AR(2)$				
R^2	0.988896	0.987080	0.984132	0.985121
$Ajust-R^2$	0.987814	0.985501	0.982587	0.983091
F	914.3075	625.1074	636.7578	485.5151
$D.W$	1.722276	1.775261	1.820822	2.245501
SSE	0.306165	0.108989	0.233771	0.085267

Notes：1． *, ** and *** represent significance at the 1%, 5% and 10% levels, respectively.

2. The individual fixed effect regression model was used for the Eastern, Central and Western regions, whereas the mixed regression model was used for the Northeastern region.

The findings show that the elasticity of domestic R&D stock on TFP is negative for the central region, whereas the coefficients of domestic R&D expenditure and per capita GDP variables are positive, exceeding the elasticity of imports, FDI and a number of technology transactions on TFP. This indicates that domestic R&D expenditure and technology innovation play a dominant role in regional TFP growth and also shows that China's technological progress mainly depends on the improvement of economic development, R&D investment and domestic technological innovation.

For the Eastern region, the elasticity of per capita GDP and domestic R&D stock on TFP are positive and statistically significant, indicating that technical progress in the Eastern region mainly depends on the improvement of local innovation capabilities. The elasticity of FDI spillovers on TFP is 0.015, suggesting that FDI has played a certain role in promoting TFP of the region. The coefficients of the variables of imports and technology transactions are 0.003 and 0.006, which are much lower than those of the other three factors.

For the Central region, the variables of per capita GDP and FDI are positive and statistically significant, indicating that the effect of domestic technology and FDI on technological progress in the central region has played a large role in enhancing TFP. The impact of domestic technology is even greater than that of international technology spillovers. Technology contracts and imports are hypothesized to promote the technological progress of the Central region, but the evidence shows that there is no significant effect on TFP. The coefficient of the variable of domestic R&D expenditure on technological advancement in the central region is 0.006, indicating that its role in promoting technological progress is limited.

In terms of the Western region, the coefficients of the variables of domestic R&D stock, per capita GDP and FDI are all positive, whereas the variables of imports and the number of technology contracts are negative. The coefficients of domestic R&D expenditure and per capita GDP variables in the Western region are significant and positive, whereas the variable of imports is significant though negative. The results show that per capita GDP and domestic R&D investment have played a significant role in promoting technical progress in the Western region. However, imports seem to have a negative impact on technological progress. In addition, technology transactions have a positive association with the improvement of TFP of the Western region

For the Northeastern region, per capita GDP, domestic R&D stock and expenditure, and technology transactions have a positive association with TFP. The results suggest the technological progress in the northeast relies mainly on raising the level of domestic technological innovation. It is evident that FDI and imports also play an important role in this region.

We can also compare differences and similarities in factors affecting TFP across these four regions. Domestic R&D stock in the Northeastern and Western regions is able to promote technological progress significantly. This is mainly due to a lack of R&D investment in the past in these regions. This has led the regions to lag behind economic development and technological innovation. Hence, the impact of initial R&D investment can show up in a relatively short period. However, with the rise of Eastern and Western regional economies, such a catalytic role may gradually become smaller.

The effect of domestic R&D stock on TFP in the Central region is negative. When merely testing the relationship between TFP and domestic R&D stock, there is a positive correlation between the two factors. However, putting together a regression analysis of various factors, the coefficient of the domestic R&D stock variable becomes negative. This indicates that other factors played a more important role in TFP growth in the Central region.

Per capita GDP has played a significant role in promoting TFP, and its effect in the Eastern, Central and Northeastern regions is statistically significant. This suggests that domestic technological innovation capability is crucial to technological progress. The impact of technical transactions on TFP is significant for all the regions except the Western region. In particular, technical transactions are found to play a bigger role in the Northeastern region. Taken together, the results show that China relies mainly on enhancing domestic technological innovation capability to promote technology progress. Domestic enterprise innovation is still the driving force of regional economic development.

The impact of imports on TFP varies from region to region. It is positive and significant for the Northeast region, whereas the impact of imports is not significant for the Eastern and Central regions, though the coefficient is positive. The result is even negatively significant for the Western region. This shows that importing has helped to improve technical progress in the Northeastern region, but has been less important in the Eastern and Central regions. This finding is consistent with that of Li (2007).

Considering the impact of FDI on TFP in the four regions, the results show that the effect is positive, especially in the Eastern, Central and Northeastern regions. FDI spillovers of foreign R&D stock on technological progress has the largest positive effect in the Eastern region, which may suggest that the economic development of the Eastern region has reached the critical ‘threshold’, whereas in the Western region, due to relatively weak economic foundations, economic development has not crossed the critical ‘threshold’. Hence, there is no evidence of technology spillovers from FDI in the Western region.

Furthermore, our empirical findings are different from those of He (2000) who found that FDI generates substantial technology spillovers. Even if in Eastern and Central regions, where there is a significant spillover effect of FDI, the magnitude of FDI spillovers was only 0.015 and 0.011. The contribution of FDI spillovers to technological progress is only 0.005 in the Western region. This may be mainly due to the rapid development of the Chinese economy, which has gradually narrowed the gap with developed countries. China's science and technology development is also catching up with developed countries. Foreign invested enterprises in China began to use technological monopoly, intellectual property protection, independent research and other means to control its core technology. Therefore, the scope of learning from foreign firms may be limited. This implies that China may have received limited technological spillovers from developed countries through FDI and imports.

6. Conclusions

Using panel data analysis, the paper examines the impact of technology spillovers in the four main regions of China in the context of the evolution of the industrial structure. We find that domestic R&D stock plays a more important role than foreign R&D stock, especially in the Northeastern region. The results show that domestic technology innovation is the major source of technological progress in the four main regions. This indicates that investment in Northeastern traditional industry has generated a remarkable improvement in technology. Along with the increasing investment, technological progress in the four regions will gradually shift to mainly depending on independent technological innovation. Nevertheless, the impact of international technology spillovers on technological progress in China cannot be ignored. FDI is still an important source of technological progress in the four regions. In particular, imports help to promote technological progress in the Northeastern region

We have found that different channels for technology spillovers have different contributions to technological progress in the four regions. Among the three domestic technology spillovers channels, R&D spillovers have played a significant role in technological advances in Eastern, Western and Northeastern regions, whereas the stock of per capita GDP has had a significant impact on technical progress in all the four regions. Technology transactions have had a significant impact on the Eastern, Central and Northeastern regions. International technology spillovers have played a role in promoting technological progress in these regions through FDI spillovers. However, importing has only affected the Northeastern region.

It is noted that the stock of per capita GDP has had a greater impact on technological progress than other channels, which indicates that China's technological progress mainly depends on domestic technological innovation. In addition, the threshold effect exists in terms of FDI spillovers. At present，the Eastern，Central and Northeastern regions have reached above the threshold. Hence, the impact of FDI spillovers is significant. However，the Western region has not crossed the threshold, and FDI has not had a significant effect. This may be one of the reasons why the Western region is unable to obtain technology spillovers from FDI. Furthermore, technology transactions have positively affected the technological progress of the Eastern, Central and Northeastern regions, but not the Western region. Importing has played a certain role in promoting technological progress in the Eastern, Central and Northeastern regions. However, the Western region has failed to absorb technology spillovers through importing perhaps due to its weak technical capacity. Finally, domestic R&D has played a certain role in promoting technological advancement in the Eastern, Western and Northeastern regions, but its effect on TFP in the Northeastern region was the most important. Domestic R&D has not enhanced technological progress in the Central region.

The findings have important policy implications. The government should adopt a combined strategy to develop domestic technological capability and continue investing in R&D. At the same time, local firms should be encouraged to engage in building links with foreign firms to gain external technology spillovers.

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Appendix

Estimation Model selections

1 Technology diffusion model for the Eastern region

① Mixed regression model

We get the regression results using Eviews 5.0. It can be expressed as:

$$\ln TEP_{it} = -4.015121 + 0.179659 \ln S_t^{rd} + 0.260656 \ln S_{it}^{pgdp} + 0.018731 \ln S_{it}^{cnt}$$

(-32.01100) (10.70254) (10.88289) (3.126762)

$$-0.007564 \ln S_{it}^{f-imp} + 0.075446 \ln S_{it}^{f-fdi} + \varepsilon_{it}$$

（-0.810560） (7.569947) （1）

$$R^2 = 0.932246 \qquad SSE_r = 2.247321$$

② Individual fixed effect model

We get the regression results using Eviews 5.0 to estimate the OLS. It can be expressed as:

$$\ln TEP_{it} = -0.237482 + 0.013051 D_2 + \cdots + 0.079179 D_{10} + 0.065330 S_t^{rd} + 0.444629 \ln S_{it}^{pgdp}$$

(1.765036) (6.482717)

$$+0.010965 \ln S_i^{cnt} + 0.015751 \ln S_i^{f-imp} - 0.030999 \ln S_{it}^{f-fdi} + \varepsilon_{it}$$

（2.575582） (1.891347) (2.309572) （2）

$$R^2 = 0.965378 \qquad SSE_u = 1.148380$$

Where, the dummy variables D_1, D_2, $\cdots$, D_{10} are defined as:

$$D_i = \begin{cases} 1, \ if\ it\ belongsto\ the\ individual\ \ i, \ i = 1,2,\cdots,10 \\ 0, \qquad other\ cases \end{cases}$$

③ Sig.-F for the two models

Now we adopt F-statistic to test which regression model should be established for the Eastern region. Null hypothesis and alternative hypothesis are as follows:

$H_0: \alpha_i = \alpha$, which means that intercepts are the same for different individuals in the model (The model should be set as a mixed regression model.)

H_1: intercepts are different for different individuals in the model (The model should be set as an individual fixed effect model.)

F-statistic is defined as:

$$F=\frac{(SSE_r-SSE_u)/[(NT-K-1)-(NT-N-K)]}{SSE_u/(NT-N-K)}$$

$$=\frac{(SSE_r-SSE_u)/(N-1)}{SSE_u/(NT-N-K)} \qquad (3)$$

where, SSE_r is the Residual Sum of Squares of the constrained model, i.e., mixed model; SSE_u is he Residual Sum of Squares of the non-binding model, i.e., individual fixed effect model. Non-binding model has one more parameter to be estimated than the constrained model.

It is known that, $SSE_r = 2.247321$, $SSE_u = 1.148380$, $N = 10$, $NT = 180$ and $K = 5$. Calculated from the equation above, we get $F = 17.54$; from the table, we know that, $F_{0.05(9,165)} = 2.50$.

Because $F = 17.54 > F_{0.05(9,165)} = 2.50$, we reject the null hypothesis and set up an individual fixed effect model instead.

(2) Technology diffusion model for the Central region

① Mixed regression model

By adopting a mixed regression model, the regression result for the Central region is obtained.

$$\ln TEP_{it} = -3.617755 + 0.034875\ln S_t^{rd} + 0.363756\ln S_{it}^{pgdp} - 0.011569\ln S_{it}^{cnt}$$

$$(-12.77863) \quad (1.171337) \quad (6.793563) \quad (-1.670914)$$

$$+0.008325\ln S_{it}^{f-imp} + 0.0341811\ln S_{it}^{f-fdi} + \varepsilon_{it}$$

$$（0.382558） \quad (5.495327) \qquad （4）$$

$$R^2 = 0.942989 \qquad SSE_r = 0.583031$$

② Individual fixed effect model

By adopting an individual fixed effect model, the regression result for the Central region is obtained.

The model can be expressed as:

$$\ln TEP_{it} = -0.074273 + 0.011038D_2 + \cdots + 0.027004D_6 - 0.083887\ln S_t^{rd} + 0.598190\ln S_{it}^{pgdp}$$

(-2.246028) (8.528793)

$$-0.017373\ln S_i^{cnt}+0.013102\ln S_i^{f-imp}+0.0226841\ln S_{it}^{f-fdi}+\varepsilon_{it}$$

（-1.500354） (1.678843) (2.393347) (5)

$$R^2=0.957448 \qquad SSE_u=0.435165$$

where, the dummy variables D_1, D_2, $\cdots$, D_{10} are defined as:

$$D_i=\begin{cases}1, \textit{ if it belongsto the individual } i, \ i=1,2,\cdots,10\\ 0, \qquad \textit{otherwise}\end{cases}$$

③ Sig.-F for the two models

Now we adopt F-statistic to test which regression model should be established for the Eastern region, mixed regression model or individual fixed effect model. Null hypothesis and alternative hypothesis are as follows:

$H_0:\alpha_i=\alpha$, which means that intercepts are the same for different individuals in the model (The model should be set as a mixed regression model.)

H_1: intercepts are different for different individuals in the model (The model should be set as an individual fixed effect model.)

F-statistic is also calculated from equation (16). It is known that that $SSE_r=0.459369$, $SSE_u=0.242097$, $N=6$, $NT=108$ and $K=5$. Calculated from the equation above, we get $F=6.59$; from the table, we know that $F_{0.05(5,97)}=2.81$.

Because $F=6.59>F_{0.05(5,97)}=2.81$, we reject the null hypothesis and set up an individual fixed effect model instead.

(3) Technology diffusion model for the Western region

① Mixed regression model

By adopting a mixed regression model, the regression result for the west region is obtained.

The model can be expressed as:

$$\ln TEP_{it}=-3.907137-0.001550\ln S_t^{rd}+0.407726\ln S_{it}^{pgdp}-0.006919\ln S_{it}^{cnt}$$

(-28.16559) (-0.082157) (14.15838) (-1.044922)

$$+0.045797\ln S_{it}^{f-imp}+0.011324\ln S_{it}^{f-fdi}+\varepsilon_{it}$$

（6.695787） (2.113749) (6)

$$R^2=0.900190 \qquad SSE_r=1.672953$$

② Individual fixed effect model

By adopting an individual fixed effect model, the regression result for the west region is obtained, as exhibited in Tab. 5.20.

The model can be expressed as:

$$\ln TEP_{it} = 0.113797 + 0.085880 D_2 + \cdots - 0.031838 D_{10} + 0.017750 \ln S_t^{rd} + 0.425766 \ln S_{it}^{pgdp}$$

(0.650258)　　(8.855530)

$$+0.007782 \ln S_i^{cnt} + 0.019460 \ln S_i^{f-imp} + 0.008474 \ln S_{it}^{f-fdi} + \varepsilon_{it}$$

（0.915589）　　(2.829852)　　(1.565821)　　(7)

$$R^2 = 0.951797 \qquad SSE_u = 0.807944$$

where, the dummy variables D_1, D_2, $\cdots$, D_{10} are defined as:

$$D_i = \begin{cases} 1, & if\ it\ belongsto\ \ the\ individual\ \ i,\ i = 1,2,\cdots,10 \\ 0, & otherwise \end{cases}$$

③ F-statistic test of two models

Now we use F-statistic to test which regression model should be selected for the Western region. Null hypothesis and alternative hypothesis are as follows:

H_0: $\alpha_i = \alpha$. It means that different individuals' intercepts are the same for different individuals in the model (The model should be set as a mixed regression model.)

H_1: Different individuals' intercept α_i in the model are different (The model is an individual fixed effect model)

F-statistic is still calculated from equation (16) expression. It is known that $SSE_r = 1.667891$, $SSE_u = 0.579530$, $N = 10$, $NT = 180$. $K = 5$ Then we substitute those to the expression, and obtain $F = 19.63$.

Look-up table: $F_{0.05(9,165)} = 2.50$

Because $F = 19.63 > F_{0.05(9,165)} = 2.50$, we reject the null hypothesis, and set up a fixed effect model.

(4) The selection of Technical Diffusion Model for the Northeastern region

①The regression results if using a mixed regression model

The regression results calculated from a mixed regression model for the Northeast are shown below.

$$\ln TEP_{it} = -3.688036 + 0.218874 \ln S_t^{rd} + 0.208304 \ln S_{it}^{pgdp} + 0.027601 \ln S_{it}^{cnt}$$

(-8.143614)　(4.373186)　　(2.146296)　　(1.179995)

$$+0.010423\ln S_{it}^{f-imp}+0.031790\ln S_{it}^{f-fdi}+\varepsilon_{it}$$

$$(0.6137)\qquad(2.128092)\qquad\qquad(8)$$

$$R^2=0.964664\qquad SSE_r=0.216676$$

②The regression results if using a fixed effect model

The regression results for Northeast calculated from a fixed effect model are presented as the following equation.

$$\ln TEP_{it}=-0.085213+0.056922D_2+0.028291D_3+0.155997\ln S_t^{rd}+0.328845\ln S_{it}^{pgdp}$$

$$(2.913844)\qquad(3.191105)$$

$$+0.053536\ln S_i^{cnt}+0.016557\ln S_i^{f-imp}+0.014321\ln S_{it}^{f-fdi}+\varepsilon_{it}$$

$$(2.450011)\qquad(1.382294)\qquad(2.207644)\qquad\qquad(9)$$

$$R^2=0.972916\qquad SSE_u=0.183374$$

The dummy variables D_1, D_2, $\cdots$, D_{10} are defined as:

$$D_i=\begin{cases}1, \textit{if it is the first individual } i, & i=1,2,\cdots,10\\ 0, & \textit{otherwise}\end{cases}$$

③ F test of two models

Now we use F statistics to test which regression model should be established for the Western region. Null hypothesis and alternative hypothesis are as follows:

H_0: $\alpha_i=\alpha$, It means that different individuals' intercept are the same in the model (The model is a mixed regression model)

H_1: Different individuals' intercept α_i in the model are different (The model is a fixed effect model)

F-statistic still adopts equation (16) expression. It is known that $SSE_r=0.227683$ $SSE_u=0.206308$, $N=3$, $NT=54$. Then we substitute $K=5$ to the expression, and obtain $F=4.17$.

Look-up table: $F_{0.05(2,46)}=4.38$

Because $F=4.17<F_{0.05(2,46)}=4.38$, we accept the null hypothesis, and set up a mixed regression model.