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Typology and Knowledge Productivity of Regional Innovation System: Evidence from China

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Abstract: Through depicting a typology of regions, the study intends to capture the diversity of regional innovation systems across China. Based on the theories of Regional Innovation Systems (RIS), we select several variables related to the capabilities of a region regarding generate, to absorb, and to diffuse the knowledge generation, absorption, and diffusion, and its capacity about the commercialization of the R&D outcomes. The contribution of this paper is twofold. First of all, it provides the RIS typology for China's regions more completely using a large number of variables related to innovative indicators. Second, the conclusions obtained from the analysis may be used to lead policymakers' actions in the field of regional innovation policies from the evidence from China's regions with the industrial and technological perspective.

Key words: China; economic freedom; regional S&T reform; regional knowledge productivity
JEL code: O32

1. Introduction

It is well recognized that innovation activities and resources are not evenly distributed over space but tend to be clustered in certain regions (Enright, 2003; Feldman, 1994; Porter, 1998; Moreno, Paci & Usai, 2005). The spatial agglomeration of innovation resources and potential is not only in the global aspect but also in the regional dimension. Obviously, it can be one of main reasons that some locations have better advantages for innovative activity than others. In other words, based on the framework of regional innovation systems (RIS), these locational advantages stand out considerably with regard to their "innovative efficiency".

The RIS can be regarded as the institutional infrastructure supporting innovation within the production structure of a region (Asheim & Coenen, 2005, p. 1177). Region-specific conditions and partnerships between different actors underlie the regional innovation potentials. Regions are important bases of economic co-ordination at the meso-level (Asheim & Coenen, 2005; Cooke, 2001). The generation, diffusion and transfer of knowledge are all carried out within a certain boundary of a region due to the specific geographical conditions. This is because innovation is a social economic phenomenon, which cannot be done separately within one enterprise, but through the cooperation and interaction between enterprises and other organizations or individuals.

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Accordingly, geographical proximity and the specific institutional environment, including both formal and informal institutions, determine the cooperation and interaction across personnel and organizations especially because a portion of knowledge is tacit in nature and can only bear the best effect through face-to-face interaction between people. As emphasized in some regional economics literatures (Piore & Sabel, 1984; Stern, Porter, & Furmman, 2002), the role of small, innovative, firms embedded within regionally cooperative networks which facilitate innovation. By taking cases studied, Saxenian (1994) stressed a densely networked and flexible organization, and free information sharing among firms, research institutes and local government institutions to be critical for raising a regional advantage. The regional culture for encouraging individual initiative and independence also matters.

By employing a quantitative approach, some previous research has performed a systematic interregional comparison to look at the issue. Most of these works took the advanced world as a case study, but few studies know about the case from a developing high-profile economy, such China. Especially since the 1990s, China has restructured the science and technology system in order to bridge the divides across the science and industry sectors. Marking the S&T reform, the R&D by industry sector instead of public R&D institutes has taken the main players. As far as China as a high-profiled country is concerned, of note is the fact that China is featured by its substantial regional variations in economic development and innovation capacity (Guan et al., 2009; Li, 2009; Blue Book of China's Regional Development, 2007). As a result, it will be oversimplified to regard China as a homogenous whole in terms of the deployment of R&D facilities there.

The study therefore proposes to take into account the regional difference within China, in consistence with a well-established stream of literatures about the spatial dimension of technology. The hypothesis can be generated that the subsystem of an RIS can significantly determine the local innovation efficiencies. More specifically, the paper aims to explore various types of RIS in China and compare the efficiency difference across various RIS. More important, we examine the roles played by regional economic freedom, measured by degree of marketization, as well as the R&D investment made by the higher education system (universities), research institutes, and firms in determining the regional knowledge productivity.

This paper consists of four sections. Section 2 simply outlines some important factors related to RIS efficiency in China. Moreover, most research mainly uses patents and S&T papers as indicators for knowledge outputs. This may underestimate the results from basic research which can be patented but published by article or other ways (Fritsch & Slavtchev, 2005). In other words, we employ a cluster analysis briefly to outline various types of China's RIS, and further examine the factors in determining their knowledge productivity and efficiency in order to underlie the difference across China's regions. Drawing on the panel data of 30 provinces and municipal cities for 2001-2007 and taking a regional knowledge production function with patent and S&T articles as knowledge outputs, Sectors 4 and 5 mainly examines the effects of economic freedom, measured by the degree of marketization, as well as other factors on the typology of RIS and their knowledge productivity. Finally, Section 6 draws conclusions for further research.

2. Regional Innovation System and Efficiency

As well-documented, a cluster works on the essential elements of proximity and interdependence (Kim, 2005). The RIS is an adaptation of a national innovation system to a regional setting. In this system all the innovation actors in a regional setting are integrated in socio-cultural environments. Identified from the main body of the literatures, actors within an RIS are systematically engaged in interactive learning (Asheim & Coenen, 2005; Autio, 1998; Tödtling & Trippl, 2005). These actors consist of mainly of firms, public and private research laboratories, vocational training organizations, etc. An RIS, championed by Cooke (2001), is these interactions between partners, which may in some cases move beyond the business sphere and reach the public sphere of universities, research institutes, technology transfer and training agencies. As highlighted by Camagni (1991) notion of the "innovative milieu", the innovation heavily depends on the relationships between the firm and its local environment, and is also the outcome of the interplay between different actors, whose actions are in turn determined by their environment.

By analogy, this common regional culture—itself the product of commonly experienced institutional forces—shapes the way in which firms interact with one another in the regional economy. Since different RISs vary quite considerably from each other, firms need to identify the innovation region that best fits their R&D needs. Not only are the location choice, but also the local R&D linkages related to the compatibility between the RIS and the firm's innovation network.

Along with the advances in the market economy, the developments in science and technology are distributed in many different ways, including public and governmental departments, the private sector, universities, and enterprises. This leads to structural change occurring in the science and technology system, and enables some regions to successfully overcome the path-dependence problems in their existing regional learning system. The knowledge structure: the regions' knowledge potential in terms of the science and technology infrastructure, education and training system and research capacity. The learning system: the cluster structure of a region's industry, training system, institutions and organizations generating and transferring knowledge and the innovation support infrastructure (Cooke, 1999). Regional learning may become withdrawn especially where the innovation system "locks in" the functional and/or cognitive path dependence. As suggested by Grabher (1993), there are three types of lock-in problems: functional, cognitive, and political. A functional lock-in can become a hindrance to innovation by preventing access to diverse sources of experience and knowledge from various relationships with all partners within the innovation system such as universities, suppliers/customers, and professional associations. The functional path dependence further leads to a narrow world of uniform partnerships that set the barriers to the perception of new opportunities for innovation, the search for new technologies, and the development of new policies toward new and rapidly changing environments (cognitive path dependence).

To improve knowledge productivity in some developing countries, the advance of economic freedom and marketization not only redistributes S&T resources among more diverse agents, but also enhances the extent to which they are linked up. This can create efficient synergy inside a region through increasing interactions among various elements for learning, especially S&T resources redistributed to enterprise sectors. Furthermore, because learning can be regarded as one of the essential elements and prerequisites of RIS, firms within clusters can learn from other firms through production networks within which they operate, and by collaborating to offer products in the market. Outside innovation resources can be brought into the region to accelerate regional innovation capabilities. Accordingly, an industrial cluster is an important facilitator for such learning. Clusters form a "learning region" within which knowledge flows and is diffused amongst the firms residing there. The RIS also functions as a bridge between different learning regions in facilitating the effective transfer of knowledge. The efficiency of the RIS can be dependent on the quality of interaction and exchange between its different elements and the respective knowledge flows (spillovers). This quality interaction critically depends on the availability of potential partnership in the region. These partnerships may include firms working in the respective technological fields, public research institutes, and suppliers of innovative inputs. In addition to these various actors, the accessibility of the region, the technological, industrial and institutional infrastructure (e.g., the “networks”) may also play an important role (Fritsch & Slavtchev, 2007).

In short, with respect of regional knowledge productivity, the advance in economic freedom not only expands the size of knowledge networking by including various economic agents, but also enhances their being linked together. The improvement in economic freedom enables these economic agents to make use of local and outside S&T resources. The policy reform toward economic freedom essentially reshapes the regional innovation system into enterprise-centered ones, and demonstrates the structural changes taking place in their science and technology systems. These systems can then successfully overcome the path-dependence problems in their original learning systems.

3. Landscape of RIS in China

As far as China as a host country is concerned, of note is the fact that China is featured by its substantial regional variations in economic development and innovation capacity (Guan et al., 2009; Li, 2009; Blue Book of China’s Regional Development, 2007). Prior to economic reform, the highly centralized system of innovation featured China’s research capabilities concentrated within government institutions. Pursuing the sustainability of broad-based productivity growth and living standard improving, China exhibited a rapid shift in S&T system by sourcing innovation resources that increasingly lie outside the state sector and developing a broad-based set of research capabilities during the reform period. Reform of S&T system toward market-oriented is performed rapidly.

During the socialist-era, invention in China’s science and technology (S&T) system was treated as a public good. It was unnecessary for developing requisite institutions, including patent laws, royalties, and courts, for the creation and protection of intellectual property rights. The reform of the China’s S&T system can be traced back to the broader agenda of economic reforms in the mid-1980s. In the 1990s, the Chinese S&T system was accelerated by the maturing of by some socio-economic conditions, including on-going international opportunities (e.g., accession to WTO in 2001 and cross-border technology cooperation), improvement of corporate governance, as well as further reforms of the university and public research sectors and legal system for the protection of intellectual property rights.

Historically, the significant policy reform of China’s S&T system toward commercialization has been performed after 1999 (Zhong & Yang, 2007). Before 1999, the universities and public research institutes were granted greater autonomy in conducting research. They were not only encouraged to establish various forms of linkages with enterprises, but were also encouraged to spin-off high-tech enterprises. After 1999, strengthening the NIS and accelerating the commercialization of S&T outputs has been the primary focus. With the acceleration of ownership restructuring in the latter half of the 1990s, these conditions either changed dramatically or were on the path toward fundamental change. One typical and critical measure was that where the government has aggressively transformed government-owned applied research institutes into high-tech enterprises or technical service enterprises. The majority of enterprise-funded R&D has been conducted outside the state-owned R&D institutes since the ownership restructuring took place, and the state-owned research institutes have been converted into high-tech enterprises and non-profit research institutes. As a result, the enterprise sector plays the major role in innovation.

The role played by the science sector in China’s economic development has changed quite dramatically, especially since the late 1990s. STRs have been restructured and intensified. With the acceleration of ownership restructuring in China the later half of the 1990s, these conditions had either changed dramatically or were on the path toward fundamental change by 2000. The majority of enterprise-funded R&D has been performed outside the state-owned R&D institutes since the ownership restructuring. The stated-owned research institutes have been converted to non-government S&T enterprises and non-profit research institutes. As a result, the enterprise sector acts the major role of innovation. Over 60 percent of the country's R&D spending has been funded and performed by the enterprise sector since 2000, marking China's S&T policy reform. Like other developed countries, the enterprise sector in China has since then taken the central position in the innovation system (Gao & Jefferson, 2007).

Market-based channels, such as patenting and contract research, play an increasingly important role but some institutional features specific to China, notably the importance of business affiliates of universities and to a lesser extent research institutes and the role and nature of intermediaries in the "technology market", continue to strongly influence STRs' patterns. S&T industrial parks, university science parks and technology business incubators act as new infrastructures to encourage industry-science relationships, and spin-offs from public research organizations (PROs) have started to fill the gaps within the national innovation system. Especially, in pursuit of its membership to the WTO, China has reformed patent laws to be in line with the institutions of intellect properties in the western world. The economic in some regions facilitates technology-trading in some regions, such as Beijing, Shanghai, and other cities.

The landscape of regional innovation capacities in China demonstrates a ladder-like tendency from the east to the west. The gap of the regional innovation capacity between the eastern and the middle/western regions is quite large. While the middle regions and the western regions are generally on the same level. The innovation capacity of coastal areas in eastern China is superior to that of provinces in the middle areas and the western inland area. Enterprises in coastal areas have established a more flexible innovation system, and the market economy operates well, making enterprises the main body of technology innovation.

The S&T mechanism in some regions, such as technology markets, IP rights exchanges, S&T personnel flows, S&T venture capitals, S&T evaluation institutions, were formed quickly. Moreover, there are two forms of industrial clusters in China: government-driven industrial clusters and market-driven industrial clusters. The government-driven industrial clusters mainly include economy and technology development zones and high-tech parks. The hi-tech Industrial clusters represented by the high-tech parks are going up rapidly. The market-driven industrial clusters, such as Wenzhou in Zhejiang province and Dongguan in Guangdong province, cannot be ignored in developing learning regions. The regional multi-S&T investments, financing systems, and SMEs are developing rapidly (Wilsdon & Keeley, 2007).

Moreover, the performance of RIS can be demonstrated in the knowledge outputs, especially patents. In general, Bohai Rim, Yangtze River Delta, and Pearl River Delta share all China's patents by 65-70%. This indicates that these three regions contribute a lion's share of China's knowledge outputs. However, the amount of patenting may not be equivalent to knowledge outputs. In some way, an indicator for patent outputs per R&D worker may stand for knowledge productivity.

4. China's RIS and Estimation of Knowledge Productivity

This subsection seeks to highlight the RIS in China in terms of their local knowledge productivity and output efficiency. Different from previous studies focusing on regional innovation diffusion and adoption or on diversity of RIS (such as Aguado et al., 2008), this study intends to depicts various patterns of knowledge progress of China's RIS.

Based on the framework of a knowledge production function initiated by Griliches (1990), various research confirms that a regional supportive infrastructure or knowledge generation subsystem consists of research laboratories, vocational training organizations, etc. (Asheim & Coenen, 2005; Grasjo, 2005; Fritsch & Slavtchev, 2007). At regional level, the contribution of university knowledge R&D on knowledge outputs may also be marked (Acs, Audretsch & Feldman, 1992; Jaffe, 1989). The innovation activities can be served as a production process of knowledge. We model the knowledge production function as follows:

$$KI_{i,t} = F(RDP_{i,t-1}, RDKS_{i,t-1}) \quad (1)$$

where *i* and *t* refer to region *i* and year *t*, respectively. *F* is the knowledge production function; *KI, RDE,* and *RDKS* denote to knowledge output, number of R&D workers, and R&D capital stock, respectively. We consider one year as the time lag of R&D inputs and outputs. *KI* can be the mix index of the amount of granted patents and published S&T papers for China's regions over the period of years 2001-2007.

Since China had been an under planned economy for quite a long time, the assessment of social or economic development was conducted in each administrative area. In other words, the policy implementation and political achievement assessment were all done within each administrative area and seldom across the areas. Simply speaking, China's RIS can be regarded as provinces, municipal cities or autonomous regions.

Taking the advantage of panel data, we employ the nonparametric approach of Data envelopment analysis for the estimation of regional knowledge production efficiency and the change in regional knowledge production frontiers. It is a powerful method to estimate total factor productivity (TFP) and its components, based on panel data. Conceptually, DEA is an indicator referring to regional knowledge efficiency. The indicator, TCH, denotes each region's capability in resource reallocation for capturing the opportunity of technological progress.

Table 1 Characters of Four Patterns of China's RIS

	Indicators	Mean	Std. Dev.	# of Obs
High Efficiency Group 1 (TGP1)	DEA	0.783	0.157	95
	TCH	1.046	0.114	
Fast Progress Group 2 (TGP2)	DEA	0.512	0.170	23
	TCH	1.195	0.385	
Moderate Group 3 (TGP3)	DEA	0.467	0.103	41
	TCH	1.125	0.125	
Lag-behind Group 4 (TGP4)	DEA	0.405	0.100	51
	TCH	0.942	0.155	

Source: the study.

Furthermore, using a hierarchy-cluster analysis with Ward-linkage, we use both indexes of DEA and TCH for clustering 30 regions of seven years into four groups. The estimation outcome can be summarized in Table 1. The first group of 95 observations is named "High Efficiency Group" due to their highest DEA indexes; the second group of 23 observations is named "Fast Progress Group" due to their highest TCH indicators; the third group of 41 observations, named "Moderate Group" is characterized by two fair DEA and TCH indexes. Finally, the fourth group of 51 observations is "Lag-behind Group" because of their lower DEA and TEC indicators.

4.1 Economic Freedom (MKT)

This study aims to underlie the institutional change toward more economic freedom as the critical role in determining regional knowledge efficiency and the change in production frontiers. In the regional framework, the economic freedom can be the innovative complementary assets for improving the availability of absorptive capabilities and strengthening their innovation capacities. Due to offer secure property rights and voluntary exchange, the advances in economic freedom will not only encourage the pouring of more resources into innovation activities, but also accelerate to redistribute these resources among more diverse agents or innovators and enhance the extent to which they are linked up. This can create efficient synergy inside a region through increasing interactions among various elements for learning, especially S&T resources redistributed to enterprise sectors in the process of economic freedom. In addition, the advances in economic freedom in some regions facilitate technology-trading in other regions. Knowledge creation can be encouraged because such regions with well-defined economic freedom can make knowledge fair priced (Gassmann & Han, 2004).

In the empirical study, the variable *MKT* denotes the degree of regional economic freedom. We thus expect that the coefficient of *MKT* will be positive, implying that the advances in regional economic freedom will increase the knowledge productivity. The economic freedom index of China's provinces that are sourced from Fan et al. (2007) is used to measure the development of economic freedom among regions. Such the index is calculated to follow the methodology of economic freedom index published by the Fraser Institute, and used to measure the extent of market-oriented institutional reforms at provincial-level. The index is derived from 5 major clusters of data, namely: (1) the degree of intervention and handling by the government in the regional economy, (2) the development of the non-state sector and the advances in the reform of the corporate governance of the state enterprises, (3) the magnitude of inter-regional trade liberalization in product markets, (4) the liberalization of factor markets and factor mobility, and (5) the formation of market mediators, the rule of law, and legal frameworks. Although the covered terms in a way in which Fan et al. (2000; 2002; 2004; 2006) are considering slightly differ from the case for the index of economic freedom proposed by Fraser Institute, the central theme of both indexes emphasizes the views of market liberalization including reducing government intervention and economic regulation, secure property rights, giving greater autonomy and control over prices.

4.2 Share of R&D Expenditure by Large Scale Firms (Rdfmr)

The variable *Rdfmr* denotes the share of R&D investment conducted by state-owned enterprises. Taking the Spanish experience, Sánchez (2008) focuses on the role of state-owned enterprises in the context of a weak national innovation system. She suggests that SOEs make more effort to innovate than privately-owned enterprises. SOEs can significantly contribute to innovation in one of two ways: through the direct carrying out of a substantial part of the business and total R&D, and through their role in the promotion of new activities. As the main reasons, certain characteristics inherent in public ownership, such as no short-term profit determination, the capacity to invest a great amount of capital, less risk adversity, easy access to financial resources, as well as the ability to plan long-term objectives, can positively affect innovation strategies. The enterprise's advantage in the sector and the size of state-owned firms are beneficial to carrying out R&D activities. However, when set against the above argument, Nee and Opper (2007) suggest that state-owned firms have lower innovation levels than their privately-owned counterparts.

In general, the firms in a planned economy have the propensity to engage in *ex ante* screening, thus inducing a less effective ability to involve the coordination of innovation activities with industrial sectors associated with high uncertainty and select promising innovation projects. In addition, in a way that is different from private firms having strong profit incentives in pursuing accelerating innovation processes for surviving, state-owned enterprises that are operating under soft budget constraints and multiple public goals often fail to detect and realize new market opportunities through innovation (Cosh et al., 2007).

4.3 Share of R&D Expenditure by Research Institutions (Rdfmr) and Higher Education Units (Rdher)

In parallel to the ongoing economic institution transformed toward a market economy, China's market-based science and technology policy reform intends to bridge both science and industrial sector and enterprises. The public R&D institutes have no more acted as the only primary locus of innovation systems (Motohashi & Yun, 2007; Li, 2009). Both institutions' and universities' funding from external sources occur predominantly due to certain competitive procedures and are, therefore, largely dependent upon the quality of the research conducted. In particular, the funds from firms are well suited for indicating the relevance of academic research to commercial applications as well as the intensity of university-industry linkages, which may be characterized by pronounced knowledge spillovers (Fritsch & Slavtchev, 2011). Universities and public research institutes are popular counterparts for outsourcing. One of the factors behind this trend is the ongoing reform of the science system that is intended to encourage ties between industry and science. Within the market economy regime, the contribution of both universities' (Acs et al., 1992; Jaffe, 1989) and research institutes' knowledge R&D to patenting and other knowledge outputs should be marked. According to the above arguments, we presume the coefficients of Rdisr and Rdher in the equations of TCH to be positive.

4.4 Time Trend and R&D capital-stock

In this paper, we will examine the effects of time trend on regional knowledge production efficiency and regional knowledge resource allocation. Traditionally, time trend may refer to the effect of "learning by doing". In the way, we may presume the coefficients of variable "Time" in both DEA and TCH equations to be positive. By contrast, the negative coefficients of variable "Time" in both DEA and TCH equations can reflect the convergence in terms of regional knowledge productivity. In short, the sign of coefficient of "Time" are not sure.

In terms of the empirical setting, this simplification is based on the assumption that the variables *MKT*, *Rdfmr*, *Rdisr*, *Rdher*, and time enter Equations *DEA* (2) and TCH (3). Thus we rewrite both equations as follows:

$$DEA = \alpha_0 + \alpha_1 MKT + \alpha_2 Lrdstock + \alpha_3 Rdfmr + \alpha_4 Time + v \quad (2)$$

$$TCH = \beta_0 + \beta_1 MKT + \beta_2 Rdisr + \beta_3 Rdher + \beta_4 Time + \beta_5 Dealag + u \quad (3)$$

5. Efficiency of RIS in China

The empirical results are presented in Table 2. The discussion regarding the empirical results can be summarized as follows:

First of all, in columns (1) and (3), the coefficients of MKT are statistically positive and significant. The empirical results are in line with the above presumption. Some regions with higher economic freedom are able to enjoy comparatively higher knowledge production efficiency, and they can also have higher capability to reallocate their R&D resources to capture the technological progress in knowledge production. Moreover, taking group dummy variable (*Tgp1*, *Tgp3*, and *Tgp4*) into account, the coefficients of MKT in Equations (2) and (4) remain statistically positive and significant. These empirical results can be of high robustness and meet the theoretical expectation.

Second, the coefficients of *Rdisr* and *Rdher* in Equation (3) are statistically positive and significant. The empirical results also consist with our presumption. That is, the empirical results confirm the regions with higher share of R&D investment by research institutes and higher education units have the comparative advantage in determining or capturing the regional knowledge production frontier shift, *TCH*. However, the statistical significance of both coefficients turns to weak after taking group dummy variables into Equation (3). The empirical results may indicate that the comparatively higher shares of R&D investment performed by the research institutes and the higher education units are able to characterize the typology of China's RIS.

Third, the coefficient of *Lrdstock* is statistically negative and significant in Equation (1) but insignificant in Equation (2). To some extents, this indicates that more plenty of accumulated R&D capital stock usually set barriers to regions in reducing their knowledge production efficiency. This is because the capital is characterized to be indivisible and inflexible in their natures. The regions with higher R&D capital stock have disadvantage in pursuing higher knowledge production efficiency. More important, the coefficients of *Tgp1* and *Tgp4* are positive and negative, respectively, and both are statistically significant. However, we can find the significance of *Lrdstock* to become weaker after taking group dummy variables in the equation setting. This may indicate R&D capital stock cannot be ignored for characterizing the typology of China's RIS.

Table 2 Efficiency and Technology Progress of Knowledge Production

	(1) DEA	(2) DEA	(3) TCH	(4) TCH
Tgp1		0.150***		-0.348***
		(5.52)		(-6.32)
Tgp3		-0.020		-0.403***
		(-0.73)		(-7.48)
Tgp4		-0.095***		-0.583***
		(-3.38)		(-10.76)
Mkt	0.113***	0.069***	0.016*	0.017**
	(5.17)	(4.32)	(2.10)	(2.92)
Rdisr			0.184*	0.060
			(2.29)	(1.00)
Rdher			0.552**	0.265
			(2.68)	(1.73)
Lrdstock	-0.064*	-0.025		
	(-2.08)	(-1.15)		
Rdfmr	-0.302*	-0.216*		
	(-2.39)	(-2.31)		
Time	-0.015	-0.011	-0.006	-0.007
	(-1.65)	(-1.67)	(-0.91)	(-1.43)
DEAlag			-0.286***	-0.493***
			(-4.63)	(-7.36)
_cons	0.987**	0.635**	1.046***	1.640***
	(2.90)	(2.65)	(19.31)	(23.97)
σ_u	0.158***	0.106***	7.62e-19	0.017
	(6.24)	(5.87)	(0.00)	(0.96)
σ_e	0.118***	0.093***	0.146***	0.100***
	(17.86)	(17.83)	(18.97)	(16.81)
# of observation	210	210	180	180

Note: *t* statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The fourth, no matter of taking group dummy into the DEA equation or not, we can find the coefficients of Rdfmr remain statistically negative and significant. In this paper, we consider the published S&T papers to be important elements of knowledge outputs. However, the published S&T papers don't matter to most of firms but matter to higher education units and research institutes. Therefore, the empirical results can meet our presumption. In addition, the existences of group dummy don't influence the significance of *Rdfmr* in the model, indicating the variable may not significantly determine the typology of China's RIS.

The fifth, the time trend variable (*Time*) seems to have weak effects in the *DEA* and *TCH* equations. The coefficients of Time are negative but statistically insignificant. They may indicate that the R&D experience may not significantly improve the knowledge production efficiency or effectively capture the technology transition.

Finally, the coefficients of *Dealag* are negative and statistically significant in columns (3) and (4). The empirical evidence may indicate that the region with higher knowledge efficiency usually adhere on their own technology trajectory and mostly fail to reallocate their R&D resources to cope with the shift in the regional knowledge production.

6. Conclusions

Against the background of China's science and technology system reform since the 1990s, private sectors, instead of public R&D institutes, act as the main body in performing innovation. In some way, economic freedom matters in innovation capabilities. However, less effort is made to examine the role of economic freedom on RIS efficiency more systematically. Taking China as a case study, the research intends to enrich literature on the regional innovation capabilities by underlying the role played by the advancement in economic freedom. Employing a knowledge production function and data of 30 provinces and cities for 2001-2007, the study aims quantitatively to examine the important factors of China's RIS in terms of their knowledge production efficiency (*DEA*) and their capability to reallocate R&D resources for coping with the shift on regional knowledge production technology.

Within the framework of RIS, R&D employment and R&D capital stock are considered as the knowledge inputs and numbers of granted patents and published S&T papers are measured as knowledge outputs. Taking the advantage of data envelope analysis (*DEA*) approach and the available data for China's 30 provinces and cities of 2001-2007, this study uses Malmquist index method to estimate regional knowledge productivity. Based on regional knowledge production efficiency index (*DEA*) and production frontier shift index (*TCH*) of China's 30 provinces, municipal cities or autonomous regions for 2001-2007, we primarily explore four types of China's RIS. Moreover, we consider the relevant variables for examining the typology of China's RIS. The share of R&D investments related to the higher education units, research institutes, the private sector, and the scale of R&D stock in a region are considered. The Tobit regression models are employed to examine these variables.

The important conclusion can be summarized as follows. First of all, regional economic freedom can improve the efficiency and enhance the advancement of regional knowledge productivity in China. Regional economic development in China is significantly associated with the degree of economic freedom advancement. That is, the enhancement in regional economic freedom will be able to shorten the gap between the science and industrial sectors. The well-defined technology market is helpful for innovation diffusion and exploitation due to proper intelligent protection. In addition, the improvement in the market mechanism also intensifies market competition. The market competition pressure forces firms to innovate more. In general, the advance in economic freedom not only improves regional knowledge production efficiency, but also upward shifts the knowledge production frontier.

Second, the RIS characterized with high portion of R&D investment made by the industrial sector has lower efficiency of knowledge production in China. This result may occur since we measure knowledge outputs in the paper by both using patenting and S&T publications. The empirical results are robust no matter with RIS grouping.

Third, according to regional *DEA* and *TCH*, we can assort all China's RIS into four types: the high efficiency group (*TGP1*), the fast progress group (*TGP2*), the moderate group (*TPG3*), and the Lag-behind group (*Tgp4*). More importantly, the empirical results highlight some variables, which are significantly related to the typology of China's RIS. *TGP2* are characterized by comparatively higher Rdisr and Rdher. TGP1 enjoy the higher *DEA* than *TGP2*; *TGP2* and *TGP3* share the similar the degree of *DEA*, but *TGP4* has lower *DEA*. *TGP1* and *TGP4* are featured with lower and higher R&D capital stock, respectively.

Finally, regions with higher knowledge production efficiency tend to have a barrier effectively to reallocate their R&D resources to cope with the knowledge production technology shifts. This may demonstrate a kind of path-dependency or lock-in problem.

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