Article DOI: 10.22032/dbt.39352 Proceedings DOI: 10.22032/dbt.39296

Evaluation of Regional Patent Innovation efficiency and its Spatial Distribution from the Perspective of Spatial Spillover[1]

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Abstract
There is considerable interest among policy-makers and academics regarding other potential arrangements to encourage the innovative activities of firms. This study aims to investigate whether R&D investments promote or impede the enhancement of patent innovation efficiency in China, and also to reveal the spatial patterns of patent innovation and its regional interdependencies and evolution, as well as its role in determining the effects of local innovation in China. The spatial autoregressive model is used to examine the effects of patent innovation efficiency. Results show that geographical proximity matters in the interregional flow of knowledge and technology; moreover, innovation in a region depends on its own R&D efforts, its innovative tradition and its human capital endowments, and the regional innovative activities has demonstrated that policies enhancing regional R&D activities are probably to get a richer effectiveness on stimulating patent innovation.

Introduction
It is widely recognized that technological innovation is a source of economic growth. Consequently, there is considerable interest among policy-makers and academics regarding other potential arrangements to encourage or facilitate the innovative activity of firms. In this context, with a rapidly growing knowledge economy and increasing economic globalization, China has proposed the 13th Five-Year Plan (2016-2020) that stimulates the innovation of science and technology continuously, improves the ability of independent innovation, and also makes innovation a core position in the process of national economic development. Therefore, independent innovation seems to have become an inevitable means for many companies to achieve lasting survival and development and a lasting competitive edge.
Recent literature on the economics of innovation and technological process has a central issue that research and development (R&D), as a form of decision-making in enterprises, has endogenized the effects of technological innovations on economic growth. According to statistics, China has made huge R&D expenditures during the past decades; in 2017, the R&D expenditures reached approximately 1750 billion RMB (Chinese Yuan), with the eastern, central and western region each accounting for 69.95%, 17.58% and 12.47%. Besides R&D expenditures, patents may also be sensitive to its filing fees, which has received relative attention to the R&D input in China . As patents involve a lot of rich and timing information during innovative activities, which are widely regarded as indicators of innovative strength a sign of great development in China's innovative capacity, patent statistics are usually used to identify and measure innovations. While R&D expenditures are widely used as a proxy for

[1]This article is supported by the Youth Fund Project of the Ministry of Education (NO. 18YJC790083) , the Fundamental Research Funds for the Central Universities(NO. DUT17RC(3)107), National Natural Science Foundation of China (No.71774020/71473028) and Youth Fund Project of the Ministry of Education (NO. 16YJC790105)

innovation input, patent statistics could be applied to measure the output. This measure is also more easily obtainable than other proxies for outputs, such as total factor productivity (TFP) (Nagaoka, Motohashi, & Goto, 2010) . In view of the huge differences and heterogenicity across regions and provinces in China, a hypothesis could be assumed that there exists regional differentiation in patent innovation efficiency, which has important implications for policy makers to formulate the patent-related policies . However, the important question of how patents reasonably impact the continual innovation remains unsettled. Based on this background, we investigate the spatial spillover effect of technological innovations on regional economic growth, and make a further study of how patents impact the innovation incentives, and to what extent the amount of R&D input stimulates the improvement of patent innovation.

In this paper, we explore the influential relationship between patent innovation system and economic growth, and also analyses the spatial patterns of patent innovation, regional interdependencies and evolution, as well as its determinants in regional innovation in China. To have a better understanding, we studied patents usually relates to the need to protect the firms' incentive to innovate and maintain the monopoly profits to get their accumulative competitive edge under the condition of avoiding the loss of social welfare and not having free access to the protected goods. Thus the patent innovation system is getting a diverging trend among numerous patent innovation regions; the local patent innovation region is not only relevant to itself, but also relevant to the other patent innovation regions' spatial innovation spillovers. In this context, this paper analyses the spatial patterns of innovation and its spatial distribution via patent innovation efficiency, and also investigate the regional interdependencies and its evolution, so as to improve the effectiveness of patent innovation policies.

The remainder of this article is organized as follows. The paper first discusses the background and necessity to study patent innovation and spatial spillovers ; The section 2 provides the specific theoretical linkage and influential relationship of patent innovation and economic growth, where it is believed the patent innovation, instead of imitation, is definitely significant in driving long-run economic growth, in terms of patent innovation system and market institutions. The methodology for the further study underpin the logic is introduced in section 3, describing the process of data collection and variables used. In section 4, this paper makes an estimation of regional patent innovation efficiency in China by means of DEA tool, develops a spatial model to get the regional spillovers among regions, and also discusses the results of comprehensive analysis. Finally in section 5, this paper discusses the implications of overall findings for managing patent innovation policies and regional development of regional patent innovation in modern China.

Theoretical background

Current literation has a lot of discussion about the relationship between innovation and economic growth. According to the US Advisory committee, innovation is defined as follows: 'The design, invention, development and/or implementation of new or altered products, services, processes, systems, organizational structures or business models for the purpose of creating new value for customers and financial returns for the firms . In this context, patents are usually linked to the firms' inner desire of making a strategy to protect the firms' incentive, so as to invent new functional products and bring up new value for customers, and maintain the monopoly profits to get their accumulative competitive edge under the condition of avoiding the loss of social welfare and not having free access to the protected goods. Thus the technological advancement, which is generated from the patent innovation, is becoming the critical driver of long-run economic growth. Some economists have found the regular

rules between patent innovation and patent policies that the optimal patent policy equates the dynamic marginal benefit with the static marginal efficiency loss(Nordhaus, 1969) , while others find patents more effective in the high-tech area(Levin et al., 1987; Cohen et al., 2000) , particularly in the chemical and pharmaceutical areas where a precise chemical formula of a specific compound can be accurately described in a patent hence reducing the likelihood of dispute over property rights . In this context, China has proposed a the National Medium and Long Term Program for Science and Technology Development(2006–2020), putting its attention precisely on high-tech areas and probably supporting with favorable policies and financial incentives. Besides, according to Besen and Raskind's study, the appropriate period of patent protection is that allows the innovator to cover the risk-adjusted cost of innovative activity . Other scholars make a further discussion of the patent protection scope, and make a specific contrast under the condition of a closed economy and an open economy respectively; the results reveal that trade-offs are less clear and less it depends on the nature of the market , and a variety of innovation capacities will be demonstrated by their differences in skill endowments and technical knowledge .

Another body literature highlights the endogenous growth theory during the study of regional innovation capability, in which the investment in Research and Development (R&D) plays a significant role in the economic growth and sustainable innovation development of countries and regions. It not only emphasizes the effect of R&D effort and knowledge stock on innovation, but also recognizes that innovation depends to some degree on the level of a regions' technological capital and their absorptive capacities . A number of economists have taken R&D as a form of decision-making in enterprises and considered it as an effectiveness of technological innovations on economic growth. Hu and Jefferson (2009) estimate a patent production function for Chinese enterprises, finding significantly low patent-R&D elasticity and claim that foreign direct investment, institution change, and other factors are behind the patent surge . Other scholars also make studies into this area, taking adventure of R&D effects on innovation, and the results reveal that: both R&D and non-R&D innovation expenditures could positively promote the productivity, the point is to make the best practice to achieve an outward shift according to firms' production frontiers .

Current literature has provided us a guidance in studying the drivers of patent innovation and its relationship with economic growth. In this context, a production–innovation system is employed to investigate the patent innovation efficiency and make a further analysis of the linkage between patent innovation and production systems. Nevertheless, considering innovation capacity in a specific area, literatures also contribute that spillovers of knowledge and information from external sources may have an inevitable impact on innovation processes and economic growth. In this context, the spatial dimension has become a critical aspect in determining how those spillovers occur and how those spillovers get interaction with each other in the local innovation process . A number of economists have investigated the spatial spillover effect of technological innovations on regional economic growth (Eaton and Kortum, 1996; Moreno et al., 2005). Some empirical findings also indicate that knowledge and information spillovers are tending to shape as clusters in spatial proximity from their respective source. Thus it can be assumed that knowledge and information spillovers could make an advantage in shaping the regional conditions for innovation activities. In this context, the framework of geographical space and spillovers lead us to get a further exploration into the question of how such spillovers become effective and what are the primary means for their diffusion . Cooperative relationships between regional actors may be an important vehicle for such spillovers. Consequently, a number of literatures demonstrate that policy could contribute to a wider and faster diffusion of knowledge and information spillovers by actively stimulating cooperative relationships (cf. Jorde and Teece, 1990) . With relevance to the importance of space for the diffusion of knowledge and information, geographic

proximity to innovation producers is likely to perform in two ways: in a close region, geographic proximity to other innovative regions seems to boost the local innovation; in a public region, geographic proximity to other innovative regions could almost promote knowledge and information spillovers across borders, and the importance of regional interaction for the flow of knowledge and information is positively enhanced. Consequently, we could not only study the R&D spillovers effects on innovation, but also discuss other key determinants spillovers and make proper innovation policy through speeding up the diffusion of knowledge and information . Our analysis will therefore concentrate on the role and characteristics of patent innovation and spatial spillovers among Chinese provincial regions that go beyond merely geographical aspects.

Research methods and data

A number of studies have investigated the innovation-productivity relationship with some empirical analysis reporting on the effectiveness of innovation on firms' productivity and efficiency, using the methodology of estimating Cobb–Douglas pro-duction functions. Given the aims of our analysis, a production–innovation system is employed to investigate the patent innovation efficiency and make a further analysis of the linkage between patent innovation and production systems.

Model used for the measurement of patent innovation efficiency

Data envelopment analysis (DEA) is a nonparametric method for the estimation of production frontiers to measure the productive efficiency of decision-making units, which aims to identify the most efficient units among a set of comparable entities. Basic DEA models include the Charnese Coopere Rhodes (CCR) model (Charnes et al., 1978) and the Bankere Charnese Cooper (BCC) model (Banker et al.,1984). These DEA models have been widely used to measure the technological and economic efficiency of units (Deilmann et al., 2016). Resources can be regarded as input variables together with capital and labor; patent applications and sales revenue of new products are chosen to approximate the innovative output potential in the region, because these two targets are almost probably relevant to the significant features of invention. Hence, we employ a traditional DEA model to evaluate the innovation performances of each provincial decision-making unit.

$$\min \theta$$
$$s.t.\begin{cases} \sum_{k=1}^{n} \lambda_k x_k + s^- = \theta X_t \\ \sum_{k=1}^{n} \lambda_k y_k - s^+ = Y_t \\ \sum_{k=1}^{n} \lambda_k = 1 \\ \lambda_k \geq 0, \quad k = 1,2,\cdots,n \\ s^+ \geq 0,\ s^- \geq 0 \end{cases} \tag{1}$$

Where the notation is as follows: n, number of *DMUs*; j, other *DMUs*; m, number of inputs consumed by DMU_j, x_{ik} (i = 1,2,⋯,m), amount of input i consumed by DMU_j; s, number of outputs produced by DMU_j; y_{rk}, amount of output r produced by DMU_j; s^-, vector of slack variables representing the amount of input i that, if reduced, shifts the projection of *DMU* from the weakly efficient frontier to the strongly efficient frontier; s^+, vector of slack variable

representing the amount of output *r* that, if increased, shifts the projection of *DMU* from the weakly efficient frontier to the strongly efficient frontier; λ_j, linear weights assigned to every single DMU_j to form a linear combination. Note that when the efficiency $\theta=1$ and the slacks summation is zero, the unit is considered strongly efficient. If $\theta=1$ but the slacks summation is not zero, the unit is considered weakly efficient. For any inefficient *DMU*, it is possible to find a composite *DMU* (linear combination of units) that can reduce its input level maintaining the same output level. In this study, the directional slacks-based model of inefficiency is employed to calculate regional patent innovation efficiency in China. By constructing the innovation production frontier, the term patent innovation efficiency is integrated as incorporating the extent of resources (such as capital and labor), with reliance on patent application, and sales revenue of new products involved in the creation of provinces.

The econometric model used for spatial regression

To have a better understanding of the inner heterogenicity of regional patent innovation efficiency, an econometric model is adopted to detect the geographical characteristics and its spatial interdependencies in the distribution of innovation activities. The degree of spatial dependence can be explained by Moran's I-statistic which is defined as:

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_{ij} w_{ij}(X_i - \bar{X})(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2} \quad if\ i \neq j \qquad (2)$$

where X_i and X_j are the observations for regions *i* and *j* of the variable of interest, $\bar{X}$ represents the regional average, *N* represents the number of observations and w_{ij} represents a row-standardized *W* matrix of weights. There is a hypothesis based on geographical contiguity that the proximity between regions could be defined as w_{ij}, the innovative contiguity between productive sectors; if the intensity of their innovative activities are highly bonded than the average, the innovative contiguity w_{ij} could almost equal to 1. Thus the bilateral weights w_{ij} could be used to approximate the intensity of regional interdependences of patent innovation efficiency in China.

In fact, the activities of patent innovation in a region does not only have a dependency on local capacity for innovation and local economy scale, but also have a tendency of being influenced by the nearby regions, which could be explained as regional spillovers. In this study, a spatial econometric methodology is provided to discuss this problem further, and the model could be obtained according to Eq.(3)-(4)

SLM model: $I_{it} = \alpha + \rho W I_{it} + \beta_1 RDL_{it} + \beta_2 RDE_{it} + \beta_3 S_{it} + \beta_4 TD_{it} + \varepsilon_{it}$ (3)

SEM model: $I_{it} = \alpha + \beta_1 RDL_{it} + \beta_2 RDE_{it} + \beta_3 S_{it} + \beta_4 TD_{it} + \varepsilon_{it},\ \varepsilon_{it} = \lambda W \varepsilon + u_{it}$ (4)

where *I* is innovative output, *W* is the weight matrix defining the proximity of regions and the regional spillover variable, *RDE* denotes local R&D investment efforts and *RDL* is human capital endowments. Additionally, the innovative performance could also be influenced by the regional structural characteristics, such as industrial structure and external trade, and by its innovative tradition. The regional spillover term is the weighted sum of innovation efforts in nearby regions. Thus the consideration of regional spillovers will promote a richer analysis from taking different sources of public innovative efforts and its economic implications into account.

Data and determinants

In the process of making comprehensive estimation of regional patent innovation efficiency, this paper uses 2005-2015 data from *China Statistical Yearbook* and *China Statistical Yearbook of Science and Technology*. By constructing the innovation production frontier, the

term patent innovation efficiency is integrated as incorporating the extent of resources including capital and labor devoted in R&D activities, with reliance on patent application, and sales revenue of new products involved in the creation of provinces.

In the process of spatial estimation, several determinants are used to detect the proximity of regions and the regional spillover, where I represents the patent innovation efficiency, *RDE* denotes local R&D investment efforts and *RDL* is human capital endowments; *S* and *TD* represent industrial structure and external trade respectively. The original innovation database is integrated by *China Statistical Yearbook* and *China Statistical Yearbook of Science and Technology* during 2005-2015, which is classified according to the major three traditional areas in China.

Results and analysis

By using patent innovation production function, this paper first make an comprehensive evaluation including the heterogeneity in innovative capacity of different regions in China and get the basic features of the variation tendency.

Table 1. Results of comprehensive evaluation of regional patent innovation efficiency during 2005-2015 in China

	2005	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Beijing	0.983	0.944	0.975	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	1.000	1.000	1.000	1.000	1.000	1.000	0.892	0.851	0.945	1.000	0.808
Hebei	0.648	0.694	0.654	0.647	0.663	0.643	0.646	0.701	0.703	0.796	0.772
Shanxi	0.763	0.588	0.694	0.555	0.463	0.530	0.413	0.423	0.467	0.426	0.478
Inner Mongolia	0.731	0.735	0.552	0.457	0.476	0.341	0.379	0.289	0.372	0.321	0.354
Liaoning	0.692	0.690	0.619	0.657	0.625	0.769	0.790	0.851	0.857	0.921	0.849
Jilin	0.810	0.772	0.875	0.846	0.730	0.776	0.790	0.757	0.785	0.827	0.836
Heilongjiang	0.775	0.831	0.737	0.769	0.808	0.881	0.849	0.879	0.912	0.886	0.855
Shanghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.990	1.000	1.000	0.980
Jiangsu	0.766	0.791	0.733	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.913
Zhejiang	1.000	1.000	1.000	1.000	1.000	1.000	0.835	0.937	1.000	1.000	0.987
Anhui	0.843	1.000	0.903	0.950	0.804	0.822	1.000	0.859	0.855	0.831	0.821
Fujian	0.812	0.790	0.626	0.655	0.645	0.642	0.647	0.689	0.755	0.641	0.782
Jiangxi	0.455	0.422	0.366	0.432	0.423	0.405	0.437	0.500	0.640	0.710	0.653
Shandong	0.728	0.722	0.733	0.762	0.784	0.902	0.700	0.658	0.964	0.921	0.824
Henan	0.568	0.616	0.589	0.612	0.601	0.604	0.506	0.528	0.525	0.752	0.710
Hubei	0.975	0.952	0.964	0.997	0.677	1.000	0.970	0.842	0.748	0.799	0.744
Hunan	1.000	1.000	1.000	1.000	0.705	0.977	0.913	0.857	0.863	0.872	0.844
Guangdong	1.000	1.000	1.000	0.956	0.970	0.986	0.981	0.976	0.964	0.980	0.954
Guangxi	0.661	0.755	0.599	0.791	0.730	0.720	0.672	0.686	0.808	0.847	0.848
Hainan	1.000	0.831	1.000	1.000	0.975	0.814	0.647	0.681	0.722	0.774	0.728
Chongqing	0.996	0.982	0.891	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sichuan	0.418	0.499	0.526	0.608	0.712	0.820	0.796	0.859	0.831	0.831	0.826
Guizhou	0.576	0.561	0.627	0.588	0.503	0.552	0.510	0.691	0.700	0.779	0.781
Yunnan	0.690	0.542	0.565	0.601	0.550	0.606	0.640	0.648	0.634	0.695	0.777
Shan'xi	0.629	0.651	0.724	0.808	0.885	0.919	0.966	1.000	1.000	1.000	0.873
Gansu	0.649	0.681	0.734	0.748	0.773	0.644	0.658	0.687	0.734	0.756	0.763
Qinghai	0.159	0.222	0.331	0.349	0.411	0.349	0.267	0.241	0.222	0.272	0.376
Ningxia	0.466	0.452	0.520	0.478	0.498	0.522	0.321	0.367	0.593	0.738	0.495
Xinjiang	0.773	0.834	0.996	0.819	0.635	0.653	0.549	0.569	0.642	0.633	0.690

Given the availability of data and current national policy, we select 11 units in the eastern area, 8 units in the central area, 11 units in the western area and focus our attention on the

time period from 2005 to 2015 to calculate the regional patent innovation efficiency of 30 provincial districts using DEA method. We discover that the regional patent innovation efficiency in southeastern coastal areas are generally higher than those of districts in central and western areas. Among regional clusters, the regional patent innovation efficiency of the Yangtze River Delta is the highest, followed by the Pearl River Delta and the Jing-Jin-Ji area. This is because the economy of the Yangtze River Delta is highly developed and its industrial structure is dominated by light industry, which results in lower innovation efficiency. The Jing-Jin-Ji area, in particular in Hebei Province, has a large number of steel-smelting and leather-processing enterprises, which are typically energy-and-emission intensive and put less attention on the innovation activities. The eastern districts have high levels of economic development, and the central districts have substantial resource and environmental carrying capacities. Therefore, districts in these two regions have got considerable patent innovation efficiency.

Based on the estimation of regional patent innovation efficiency, we are particularly interested to investigate the geographic features and regional spatial dependence using the tool of spatial econometric approaches including spatial lag model and spatial error model, with the selecting controlled variables of industrial structure and external trade. The two forms of spatial autocorrelation that are most relevant in applied empirical work are so-called substantive dependence, or dependence in the form of a spatially lagged dependent variable, and nuisance dependence, or dependence in the regression error term.

Table2. Results of spatial econometric regression

index	*OLS*	*SEM*	*SAR*
Constant	-0.152*	-0.155**	-0.241***
Iit	0.125**	0.117***	0.146***
RDLit	0.205	0.284**	0.223***
RDEit	0.365**	0.386***	0.374***
Sit	0.012	0.028**	0.019**
TDit	-0.002	-0.005	-0.004
ρ		0.241**	--
λ		--	0.307**
R-squared	0.560	0.629	0.694
Breusch-Pagan test	6.554**	11.245***	8.395**

Dependent variable: I_{it}. Note: significance indicated as ** for 5%. Period 2005–2015.

The econometric results within groups estimations are presented in Table 2. Both the human capital and R&D expenditure efforts positively determine innovation in a region. Moreover, with these controlling factors, the composition of industrial structure also plays a determinant role in the innovation in the region. These results point to the presence of a positive correlation between specialization and innovation is found in regional areas. According to other scholars' findings, we have also performed a robustness check of the main econometric results after imposing different R&D structures.

Nevertheless, from a deeper analysis of the residuals of the estimation, we detect the existence of spatial autocorrelation, which could be explained as the functions of the volume of imports between two regions and implies that the higher the volume of imports from a region, the higher the volume of innovation that is accessible for the importing region, and thus the higher the intensity of spillovers. Consequently this matrix widens the assumption largely

supported by the literature (see Karlsson and Manduchi, 2001, for an empirical survey) that geographical proximity matters in the interregional flow of knowledge and technology.
Moreover, both the spatial error model and spatial lag model tests reject the null hypothesis of the absence of spatial autocorrelation in the innovative activity at a 1%level of significance, which points to the necessity of revising the model specification. In this study, the SEM test has a higher value than the SLM test, pointing to a specification of the spatial dependence by means of a spatial error model. Thus, the model changes as:

$$I_{it} = \alpha + \beta_1 RDL_{it} + \beta_2 RDE_{it} + \beta_3 S_{it} + \beta_4 TD_{it} + \varepsilon_{it,}\ \varepsilon_{it} = \lambda W\varepsilon + u_{it}$$

Given that regions trade mainly with geographically neighboring regions, interregional knowledge spillovers have significant and positive effects on local innovation. Moreover, the regional innovative activities of R&D performed by regional trade partners has demonstrated that policies enhancing regional R&D activities are probably to get a richer effectiveness on stimulating innovation.

Conclusion

The regional patent innovation efficiency in China shows a decline tendency from eastern area to western area, with three major clusters of Yangtze River Delta, Pearl River Delta and Jing-Jin-Ji area. This is because the economy of the Yangtze River Delta is highly developed and its industrial structure is dominated by light industry, which results in lower innovation efficiency. Nevertheless, this paper also detect the effect of interregional externalities on patent innovation from a temporal and spatial perspective, by means of the spatial econometric techniques. Results show that innovation in a region depends on its own R&D efforts, its innovative tradition and its human capital endowments. Moreover, the composition of industrial structure also has a positive effect on innovation. Moreover, the regional innovative activities of R&D performed by regional partners has demonstrated that policies enhancing regional R&D activities are probably to get a richer effectiveness on stimulating patent innovation.

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