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GENERALIZED SPATIAL KNOWLEDGE SPILLOVERS MODEL ON REGIONAL SYNERGY

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Abstract. *Under the background of regional synergy development, the application of innovative knowledge spillover effects can not only promote the development of non-innovative region but also push forward the upgrading of active spillover area, which can enhance the development capacity of overall regional innovation-driven. We analyze the knowledge spillover dynamic mechanism of regional synergy from three angles: knowledge spillover sender, knowledge spillover receiver and the government. Based on the mechanism analysis, the traditional Caniëls spatial knowledge spillover model is modified by introducing knowledge spillover impedance function; and a generalized spatial knowledge spillover model is put forward under the background of regional synergy. Furthermore, the model is proved based on the principle of maximum entropy. Finally, knowledge spillover effects of Beijing, Tianjin and Hebei province are evaluated. The results show that the more developed the regions are, the more significantly the innovative knowledge spillover effects increase.*
Keywords: Generalized model, Knowledge spillover effects, Innovative knowledge spillovers, Regional synergy

1. **Introduction.** Increasing technological innovation supporting role for economic development by innovation-driven is not only the need of domestic economic and social development circumstances, but also the trend of global economic and technological competition [1]. Playing the exemplary role of innovation demonstration region is the realistic choice to solve the imbalance among region development and achieve region synergy development. During the development process of regional synergy, how to apply the principles of knowledge spillovers on guiding innovation demonstration area to play the leading role of radiation is the focus of management practice and theory.

As an economic impact factor, knowledge spillover effect has been involved in many theories such as new economic growth theory, industry cluster theory, and enterprise network theory [2]. At present, the great significance of knowledge spillovers for regional economic development has been recognized by academia and government administration. Knowledge spillovers play an increasingly important role in achieving rapid economic growth and shortening the gap between developed areas and backward regions, which has become one of the hot issues of endogenous growth theory and new economic geography theory [3]. The knowledge spillovers benefits are obvious for the developing areas; therefore, the spillover mechanism and effects from the perspective of knowledge spillover recipients have been discussed. However, under the background of regional synergy development, active knowledge spillovers based on the spillover senders are more meaningful for regional innovation and development, which can not only improve the knowledge spillover theory system but also can play a positive role in practice. Currently, there are little studies in the discussion of spillover mechanism and the measurement of spillover effects from the perspective of knowledge spillover senders. Therefore, it is a very valuable research area of further exploration. Under the background of regional synergy development, we need to re-examine and improve spatial knowledge spillover theory and modify knowledge spillover model to produce reasonable and realistic results. We analyze the dynamic mechanism of knowledge spillovers under the background of regional synergy development. By correcting Caniëls spatial knowledge spillover model, the generalized Caniëls spatial knowledge spillover model is proposed; and we get reasonable explanation by the maximum entropy principle. Empirical analysis of knowledge spillover effects of Beijing, Tianjin and Hebei province shows that the generalized model is reasonable.

The structure of this paper is organized as follows. Section 2 provides power mechanism of knowledge spillovers under the background of regional synergy. Section 3 presents the generalized spatial knowledge spillovers model. Section 4 shows the calculation of knowledge spillover effect. Finally, Section 5 discusses the conclusions of this paper.

2. **Power Mechanism of Knowledge Spillovers under the Background of Regional Synergy.** Under the background of regional economic synergy development, innovative knowledge spillover can be attributed to spillover senders, recipients and governments. These three parts will drive knowledge spillover to occur separately and also to work together to promote innovation and spillovers.

The spillover sender itself has such a requirement as using the recipient innovative resources to achieve the upgrading of knowledge and innovation, which constitutes the fundamental dynamic mechanism of knowledge spillovers. The purpose of the initiative knowledge spillover sender is to integrate the innovative resources such as talent, technology, capital, information and marketing in a wide scope by the possible low cost [4]. Cooperation with the recipient is for their own development and growth. Therefore, active knowledge spillovers by the sender not only promote the development of innovative knowledge itself, but also is conducive to the knowledge turnover and innovative output. The recipient has a strong demand and ability to absorb knowledge innovation, and the cooperation between the sender and the recipient will accelerate the process of innovation knowledge spillovers [5]. To break the market barriers and improve its status in the environment, the recipient has strong needs and wishes of absorption for knowledge spillovers. The government plays a supporting and promoting role in the process of innovative knowledge spillovers under regional synergy. The government will actively combat the negative role of the market environment for innovative knowledge holders and promote innovative knowledge spillovers to the development of large area.

3. **Generalized Spatial Knowledge Spillovers Model.**

3.1. **Caniëls spatial knowledge spillovers model.** Caniëls model reflects factors of spatial knowledge spillover and relationships between the factors and knowledge spillovers effect. It provides a theoretical framework for further study of knowledge spillover effect. Caniëls knowledge spillovers honeycomb model is as follows [6].

$$S_{ij} = \frac{\delta_i}{\gamma_{ij}} e^{-\left(\frac{1}{\delta_i} G_{ij} - \mu_{ij}\right)^2}. \tag{1}$$

Here, S_{ij} indicates knowledge spillover effect of the region i accepted from the region j, δ_i is the learning ability of the region i , and γ_{ij} is the geographical distance from the region i to the region j. $G_{ij} = \ln(K_i/K_j)$ indicates the gaps of the stock of knowledge, which is the logarithm of quotient of the stock of knowledge between the two regions. μ_{ij} is called technological catch coefficient, which indicates the knowledge stock gap of the two regions in case of technology catch progress. The core elements of Caniëls knowledge spillovers honeycomb model are learning ability δ_i, geographical distance γ_{ij} and the stock gap of knowledge G_{ij}. Under the concept of regional synergy, measuring knowledge spillovers based on this model is neither reasonable nor feasible. Many of the core elements of the model will be transformative effect. For example, the learning ability will be strengthened in the ecological environment, and be weakened in economic growth according to the requirements for the regional synergy. Therefore, we propose the modified model to measure the knowledge spillovers effect under the background of regional synergy.

3.2. **Revised spatial knowledge spillover model.** In this paper, the knowledge spillover effect S_{ij} is seen as the sum of different kinds of knowledge spillovers under the background of regional synergy, which is the combined effect on all areas of ecology, economy, science and technology, environment, etc. The concept of knowledge spillover impedance is introduced in Equation (1) and we get the generalized spatial knowledge spillover model as follows.

$$S_{ij}^k = A_k \delta_i e^{-\left(\frac{1}{\delta_i} G_{ij} - \mu_{ij}\right)^2} f\left(\gamma_{ij}^k\right). \tag{2}$$

Here, S_{ij}^k indicates k categories of knowledge spillover effect of the region i accepted from the region j. A_k indicates the knowledge coefficient of the category k for the region i, which reflects the influence factors of spatial knowledge spillover except the aspects of learning and knowledge stocks. $f\left(\gamma_{ij}^k\right)$ indicates the k-th category of knowledge spillover impedance function for the region i and the region j, which represents the selective acceptance of knowledge spillovers for the recipient under the background of regional synergy. This means that the impedance function is the combination of all influencing factors.

3.3. **Model theoretical explanation based on maximum entropy principle.** To simplify the expression, we use G'_{ij} instead of $e^{-\left(\frac{1}{\delta_i} G_{ij} - \mu_{ij}\right)^2}$, which represents the characteristic function of knowledge stock. Therefore, Equation (2) can be rewritten as (3) as follows.

$$S_{ij}^k = A_k \delta_i G'_{ij} f\left(\gamma_{ij}^k\right). \tag{3}$$

S_i is the total of spatial knowledge spillovers for the region i. If there are m categories of knowledge and n spillover parties, then the number of knowledge spillovers is $m \times n$ in Table 1 as follows.

Table 1. The k-th category distribution of spatial knowledge spillovers

Category \ Party	1	2	...	n	$\sum_{j=1}^n S_{ij}^k$
1	S_{i1}^1	S_{i2}^1	...	S_{in}^1	$\sum_{j=1}^n S_{ij}^1$
2	S_{i1}^2	S_{i2}^2	...	S_{in}^2	$\sum_{j=1}^n S_{ij}^2$
⋮	⋮	⋮	⋮	⋮	⋮
m	S_{i1}^m	S_{i2}^m	...	S_{in}^m	$\sum_{j=1}^n S_{ij}^m$
$\sum_{k=1}^m S_{ij}^k$	$\sum_{k=1}^m S_{i1}^k$	$\sum_{k=1}^m S_{i2}^k$	...	$\sum_{k=1}^m S_{in}^k$	

The corresponding probability for knowledge spillovers distribution is as follows.

$$\left\{p_{ij}^k = S_{ij}^k / S_i : k = 1, \dots, m;\ j = 1, \dots, n\right\}. \tag{4}$$

And its entropy is

$$H = -\sum_{k,j} p_{ij}^k \ln\left(p_{ij}^k\right) = -\sum_{k,j}\left[\frac{S_{ij}^k}{S_i}\ln\left(\frac{S_{ij}^k}{S_i}\right)\right] = -\frac{1}{S_i}\sum_{k,j} S_{ij}^k\left[\ln S_{ij}^k - \ln S_i\right]. \tag{5}$$

For ease of discussion, the constant term can be omitted. Denote the k-th category of knowledge spillover impedance by γ_{ij}^k to simplify calculation. Therefore, the following model can be obtained by maximum entropy principle.

$$\begin{aligned} &\max_{S_{ij}^k} H = -\sum_{k,j} S_{ij}^k \left[\ln S_{ij}^k - \ln S_i\right] \\ &\text{s.t.} \left\{ \sum_{j,k} S_{ij}^k \ln\left(\gamma_{ij}^k\right) = R_i \right. . \end{aligned} \tag{6}$$

Here, R_i is the knowledge spillover total impedance for the region i. The Lagrange function of the programming is as follows.

$$L = H + \alpha \left(R_i - \sum_{j,k} S_{ij}^k \ln\left(\gamma_{ij}^k\right) \right). \tag{7}$$

Obtaining the partial derivative of S_{ij}^k, and order it to zero as

$$\frac{\partial L}{\partial S_{ij}^k} = -1 - \ln\left(S_{ij}^k\right) + \ln(S_i) - \alpha \ln\left(\gamma_{ij}^k\right) = 0. \tag{8}$$

The result is $S_{ij}^k = \frac{S_i}{e}\left(\gamma_{ij}^k\right)^{-\alpha}$. Order $A_k = \frac{S_i}{\delta_i e G'_{ij}}$. Then we obtain $S_{ij}^k = A_k \delta_i G'_{ij}\left(\gamma_{ij}^k\right)^{-\alpha}$.

The formula is the model with power-type function of the impedance function $f\left(\gamma_{ij}^k\right)$. Replace power-type function $\left(\gamma_{ij}^k\right)^{-\alpha}$ by general knowledge spillovers impedance function; and the above expression can be written as $S_{ij}^k = A_k \delta_i G'_{ij} f\left(\gamma_{ij}^k\right)$.

It is the Caniëls model $S_{ij} = \frac{\delta_i}{\gamma_{ij}} e^{-\left(\frac{1}{\delta_i} G_{ij} - \mu_{ij}\right)^2}$. When $\alpha = 1$ and $A_k = 1$, Caniëls model can be seen as the model of knowledge spillovers impedance function only related to the distance. The Caniëls model can be seen as a special case of generalized model as impedance function in the form of a power-type function. Through the generalized spatial knowledge spillover model, we can define knowledge spillover impedance function in the respective scenarios or specific conditions to obtain the appropriate knowledge spillover effect. For example, if considering changes in spatial knowledge spillover effect under the background of regional synergy, we can define the coordinate knowledge spillovers impedance function to calculate the spillover effects of new scenario. Therefore, the generalized spatial knowledge spillover model owns wide applicability.

4. Knowledge Spillovers Effect under Regional Synergy Background.

4.1. Measuring the gap of knowledge stock (G_{ij}).

Knowledge stock is the occupation amount of knowledge resources, which reflects the consolidation of knowledge production and technological innovation of the region. Knowledge stock is the key to improving the level of economic development and innovation and promoting coordinated development of the region. The idea of knowledge stock measurement is to establish the index system which can reflect the economic structure and social effects upon existing indirect measurement methods; and then obtain the value of regional knowledge stock through comprehensive calculation by statistical data. Index system can be divided into the following three parts.

4.1.1. *Investment in science and technology innovation.*

The investments include the expenditures on research and experimental development and the expenditures on science and technology activities, which reflect the strength of regional knowledge innovation and the ability of knowledge accumulation and innovation continuance. The main indicators of investment in science and technology innovation are represented by capital investment in terms of innovation activities.

4.1.2. *Environment of science and technology innovation.* This environment mainly refers to the full-time equivalent of R&D personnel and number of employees owning tertiary and higher education, which reflects the technology base and the environment during the process of innovative knowledge generation and application. The main indicator of environment of science and technology innovation is the total amount of scientific and technical personnel involved in innovation activities and their knowledge level.

4.1.3. *Output of science and technology innovation.* This part includes the number of patent applications and patents granted, the number of scientific papers published, sales of new products and technologies market turnover, which reflects the growth of regional knowledge stock. Overall, the output of science and technology innovation is reflected by measurable innovations.

4.2. **Measuring the learning ability (δ_i).** In order to stagger angle with the measure indicators of the knowledge stock gaps and considering the comprehensive ability of knowledge innovation and knowledge absorption, we select the R&D intensity, the relative extent of the patent application and the relative extent of scientific papers as measure indicators. Here, the R&D intensity equals R&D funding divided by GDP; the relative extent of the patent application equals the number of regional patent applications divided by patent applications; and the relative extent of scientific papers equals the number of regional scientific papers divided by scientific papers. These relative indicators can not only better reflect the absorption capacity and learning ability but also stagger angle with the measure indicators of the knowledge stock gaps. Using the relative indicators to measure learning ability is more appropriate at a region with higher level of economic development, because the higher the level of economic development is, the greater R&D funding is and the higher intensity of R&D investment is, the greater the attractiveness of R&D personnel is, the greater the full-time equivalent of R&D personnel is and the stronger the ability is to absorb knowledge and learning.

4.3. **Measuring the knowledge factor (A_k).** Recognizing the contribution of knowledge to the economy is equivalent to affirming that gross regional product that will certainly reflect the knowledge factor. Thus, the substance result of knowledge is reflected by the GDP ultimately and knowledge factor can be expressed by per capita GDP. In addition to the stock of knowledge and learning ability, other factors affecting knowledge spillovers related with knowledge can be classified to the knowledge factor. From the perspective of relative indicators to measure the knowledge, the knowledge factor can be calculated as a ratio of GDP per capita regional and national GDP per capita.

4.4. **Measuring the knowledge spillover impedance ($f(\gamma_{ij}^k)$).** In the circumstance of regional synergy development, knowledge spillovers from developed regions to the less developed regions have changed. Less developed regions are no longer one-sided pursuit of economic growth while ignoring other aspects such as the impact of environment, technology and society. In the process of industrial gradient transfer, the less developed regions gradually set a higher threshold for the high pollution, high energy consumption industries; never passively accept the industries transfer to economic growth as in the past; and the less developed regions re-examine the way in order to avoid the negative effects arising in development. In regional synergy development circumstance, relevant economic and social activities have taken place different from the previous. The selective acceptance appears in the process of the knowledge spillovers, which is similar to the filter acts. We use impedance to represent the selective acceptance of knowledge spillovers The corresponding function is called the impedance function, which involves six dimensions of regional synergy development: environment, resource use, economic level, social development, science and technology, and capacity development.

4.5. **Calculation of spatial knowledge spillover effect.** In the circumstance of regional synergy development, each region has a strong will to catch up with technology; and then let $\mu = 0.8$ and $\gamma = 1$ in power type impedance function in Equation (2). These parameters are strongly influenced by the regional policy. Although the size of the parameter has a strong influence on the numerical size of knowledge spillovers, the law of spatial knowledge spillover effect under regional synergy development has little effect by the parameters. For example in Beijing, Tianjin and Hebei province, the gap of knowledge stock (G_{ij}), the learning ability (δ_i), the knowledge factor (A_k) and the impedance (γ_{ij}) are listed in Table 2; and the raw data are from statistical yearbook [7].

According to Equation (2), the knowledge spillover effects from 2011 to 2014 are shown in Figure 1.

As can be seen from Figure 1, with the advance of regional synergy development, the more developed the regions are, the more obvious the initiative spillover effects are, such as Beijing and Tianjin. Innovative knowledge spillover effects of both regions show an increasing trend; and the upward trend is more pronounced in Beijing. However, as a relatively backward region, innovative knowledge spillover effect in Hebei province shows a downward trend, which is consistent with the actual situation. National innovation demonstration zone such as Zhongguancun encourages enterprises to actively carry out innovation cooperation with other regions in the current conditions of scarcity of resources such as space, land, human resources and marketing. In promoting innovation and knowledge spillovers at the same time, enterprises also make full use of each other's resources, which achieves mutual benefits and win-win situation.

Table 2. The calculation data of Beijing, Tianjin and Hebei province

		2011	2012	2013	2014			2011	2012	2013	2014
G_{ij}	Beijing	0.1618	0.1607	0.1579	0.1493	A_i	Beijing	2.7202	2.6140	2.4606	2.3211
	Tianjin	0.0306	0.0286	0.0280	0.0292		Tianjin	2.3398	2.4435	2.4319	2.4221
	Hebei	0.0160	0.0156	0.0150	0.0145		Hebei	0.9802	0.9599	0.9551	0.9655
δ_i	Beijing	0.1272	0.1179	0.1106	0.1047	γ_{ij}	Beijing	0.1406	0.1403	0.1314	0.1039
	Tianjin	0.0337	0.0291	0.0299	0.0304		Tianjin	0.0441	0.0420	0.0419	0.0400
	Hebei	0.0132	0.0132	0.0124	0.0127		Hebei	0.0233	0.0231	0.0244	0.0276

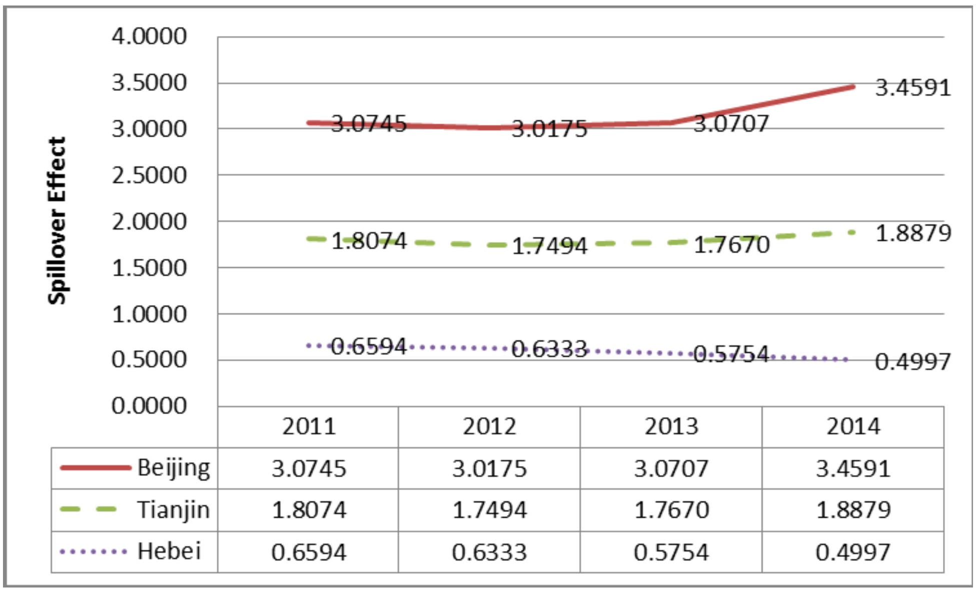

Figure 1. Knowledge spillover effects of Beijing, Tianjin and Hebei province

5. **Conclusions.** In the circumstance of regional synergy development, we regard the innovative knowledge spillover sender as the main research object. On the one hand, the dynamic mechanism of knowledge spillovers under the background of regional synergy development is analyzed, which enriches the knowledge spillovers theory. On the other hand, by introducing the knowledge spillover impedance function in Caniëls spatial knowledge spillovers model, the generalized Caniëls spatial knowledge spillovers model is proposed; and we get reasonable explanation by the use of maximum entropy principle. Moreover, related factors combined in regional synergy development, the calculation of the knowledge stock gaps, learning ability, knowledge absorption parameters involved in the model has been described. Finally, the calculation of knowledge spillover effects in Beijing, Tianjin and Hebei province has been done. The result shows that in the circumstance of regional synergy development, active knowledge spillover effect in developed regions shows an increasing trend, which is consistent with the realistic situation. The spillover sender integrates the innovative resources through knowledge spillovers, which further enhances its ability to innovate. With the development of economy and technology, knowledge active spillovers will be a normal; and the operation mechanism and effect evaluation are worthy of studying further.

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