Empirical Research on Spatial Diffusion Process of Knowledge Spillovers

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Abstract. Firstly, this paper gave a brief review of the core issues of previous studies on spatial distribution of knowledge spillovers. That laid the theoretical foundation for further research. Secondly, this paper roughly described the diffusion process of solar patents in Beijing-Tianjin-Hebei and the Pearl River Delta regions by means of correlation analysis based on patent information of the application date and address of patentee. After that, this paper introduced the variables of spatial distance, knowledge absorptive capacity, knowledge gap and pollution control and built the empirical model of patent, and then collecting data to test them. The results showed that knowledge absorptive capacity was the most significant factor than the other three, followed by the knowledge gap. The influence of spatial distance on knowledge spillovers was limited and the most weak influence factor was pollution control.

1. Introduction

The research of knowledge spillovers began with the discussion of economic externalities. The battle of ideas about knowledge spillovers happened in 1960s. In that stage, knowledge as an endogenous variable was subsumed into the economic growth model. Due to the characteristic of externalities of knowledge, it was not appropriate to only regard enterprises as an object of knowledge spillovers. So economic geographers began to pay attention to the spatial distribution of knowledge spillovers, and thought the propagation distance of knowledge spillovers was an importance factor affecting the economic benefits of knowledge spillovers.

In the models of technology diffusion among countries geographical distance was often regarded as an important factor. In the related research, different researchers had different perspectives and methods to analyze it. Fischer used spatial econometrics approaches to confirm the spatial effect of knowledge spillovers, and thought that spillovers effect transcended the geographical scope of administrative division and had a significant distance attenuation trend. Jaffe et al. use patent citation data as an alternative to knowledge flow, finding out its flow trajectory by drawing patent citation network and then making the knowledge spillovers process more dominant. Coe and Helpman build a CH(Coe-Helpman) model to measure the influence of R&D investment on productivity, using trade flow to measure the intensity of knowledge spillovers, and found that the contribution from R&D investment to productivity in the domestic was more than abroad, which indirectly proved the characteristics of localization of knowledge spillovers. Keller collected manufacturing data for 1970-1995 from 14 CEO countries, analyzing the influence of R&D investment in France, Germany, Japan, Britain and the United States on other nine OECD member countries’ productivity. They found that knowledge spillovers declined with the extension of geographical distance, and the distance of earnings half decayed of knowledge spillovers between countries was about 1200 kilometers. Bode et
al. found that knowledge spillovers between regions contributed most to regional innovation, but being affected by transaction cost only part of the knowledge spillovers can be used by neighborhoods.

In China spatial statistics about R&D, knowledge spillovers and innovation confirmed that knowledge spillovers had its spatial limitation, and geographic distance was an important factor. Literature research found that a consensus was emerging among researchers that knowledge spillovers were important and spatial effect of it did exist. However there were different opinions about the main factors promoting knowledge spillovers, and the comparative analysis of regional difference of knowledge spillovers was still lacking.

2. Analysis of spatial diffusion process of knowledge spillovers based on the quantity of patent, the date of application and address of patentee

2.1. Sample selection and data sources

Although knowledge spillovers were not equivalent to patent outputs, and some forms of knowledge spillovers were even intangible, which made it difficult to measure the knowledge spillovers comprehensively and accurately. Compared with other measurement variables, patent had the advantages of openness, standardization, stability and mutual reference, and it was an alternative index with high credibility to measure knowledge spillovers.

We collected solar invention patent data in 1985-2016 and explored spatial diffusion process. The reason for selecting the solar patent was that oil shortage and petrochemical pollution being more and more serious in China, environmental protection and alternative energy technology was always the focus of attention everywhere, so it was representative and persuasive to select solar patent as sample data.

In China, the gap of economic development in different regions was big. The characteristics of knowledge spillovers in different regions were different. It was necessary to control basic this kind of regional difference when selecting sample data. So we selected two urban agglomerations of Beijing-Tianjin-Hebei and the Pearl River Delta as spatial data samples. Solar patent data from 1985-2015 was from China Patent Database Retrieval System.

2.2. Patent diffusion process

| Table 1. The patent rankings in Beijing-Tianjin-Hebei and the Pearl River Delta |
|-----------------------------|-------------------|-----------------|----------------|-----------------|
| Ranking | City       | Number of patents in 1985-2016 | Ranking | City       | Number of patents in 1985-2016 |
| 1      | Beijing   | 2498              | 1      | Shenzhen  | 1184              |
| 2      | Tianjin   | 1040              | 2      | Guangzhou | 483               |
| 3      | Baoding   | 250               | 3      | Foshan    | 337               |
| 4      | Langfang  | 35                | 4      | Dongguan  | 293               |
| 5      | Tangshan  | 26                | 5      | Zhongshan | 277               |
| 6      | Zhangjiakou | 19             | 6      | Zhuhai    | 108               |
| 7      | Cangzhou  | 8                 | 7      | Huizhou   | 81                |
| 8      | Chengde   | 6                 | 8      | Jiangmen  | 50                |
|        |           |                   | 9      | Zhaoping  | 7                 |

From Table 1 we can see the solar patents in 1985-2016 were mainly concentrated in one or two cities of two regions, and they were known as central cities. The central city of Beijing-Tianjin-Hebei region was Beijing, and the Pearl River Delta was Shenzhen, and they had the absolute dominance in the solar patent application in 1985-2016.
From Figure 1, we can see the solar patents had been growing step by step in a stable trend in Beijing and Tianjin, but had little development in other cities.

From Figure 2, we can see the solar patents in the Pearl River Delta had been growing step by step in a stable trend. From the point of view of quantity of patents, Shenzhen had an absolute advantage, and its satellite cities were also much more active than those in Beijing-Tianjin-Hebei. Guangzhou, Zhuhai, Dongguan and Huizhou were catching up with each other.
Table 2. Spearman rank correlation coefficient of innovation diffusion between satellite cities and central city in Beijing-Tianjin-Hebei

|          | Beijing | Baoding | Tianjin | Tangshan | Zhangjiakou | Chengde | Cangzhou | Langfang |
|----------|---------|---------|---------|----------|-------------|---------|----------|----------|
| Beijing  | 1.000   |         |         |          |             |         |          |          |
| Baoding  | .853**  | 1.000   |         |          |             |         |          |          |
| Tianjin  | .900**  | .875**  | 1.000   |          |             |         |          |          |
| Tangshan | .696**  | .753**  | .736**  | 1.000    |             |         |          |          |
| Zhangjiakou | .554**  | .680**  | .653**  | .771**   | 1.000       |         |          |          |
| Chengde  | .137    | .121    | .188    | .042     | .251*       | 1.000   |          |          |
| Cangzhou | .037    | .019    | .022    | .011     | .081        | .167    | 1.000    |          |
| Langfang | .813**  | .917**  | .828**  | .795**   | .363        | .212    | .193     | 1.000    |

**, When the confidence level (bilateral) is 0.01, the correlation is significant.
*  When the confidence level (bilateral) is 0.05, the correlation is significant.

From Table 2 we can see that the relevance of Tianjin, Baoding, Tangshan, Zhangjiakou and Beijing was very obvious, but the development of the solar patents were slow in Chengde, Cangzhou and Langfang closer to Beijing, and the first solar patent appeared in 2007 with the lag for nearly 20 years.

Table 3. Spearman rank correlation coefficient of innovation diffusion between satellite cities and central city in the Pearl River Delta

|          | Guangzhou | Shenzhen | Zhuhai | Foshan | Jiangmen | Zhaoping | Huizhou | Dongguan | Zhongshan |
|----------|-----------|----------|--------|--------|----------|----------|---------|----------|-----------|
| Guangzhou| 1.000     |          |        |        |          |          |         |          |           |
| Shenzhen | .929**    | 1.000    |        |        |          |          |         |          |           |
| Zhuhai   | .901**    | .910**   | 1.000  |        |          |          |         |          |           |
| Foshan   | .875**    | .891**   | .955** | 1.000  |          |          |         |          |           |
| Jiangmen | .781**    | .813**   | .819** | .811** | 1.000    |          |         |          |           |
| Zhaoping | .264      | .423     | .171   | .513   | .518*    | 1.000    |         |          |           |
| Huizhou  | .691**    | .641**   | .756** | .727** | .788**   | .448*    | 1.000   |          |           |
| Dongguan | .848**    | .895**   | .911** | .935** | .832**   | .503*    | .729**  | 1.000    |           |
| Zhongshan| .811**    | .810**   | .864** | .890*  | .860*    | .432*    | .747**  | .888*    | 1.000     |

**, When the confidence level (bilateral) is 0.01, the correlation is significant.
*  When the confidence level (bilateral) is 0.05, the correlation is significant.

From Table 3 we can find that the trend of spatial diffusion of knowledge spillover was very easy to be seen, and there was an obvious radiation effect of innovation from central city to satellite cities. In Guangzhou, Foshan, Dongguan and Zhongshan the development of solar patents was very rapid, and Jiangmen and Huizhou also have a developing trend, Only Zhaoping far from Shenzhen having a slow development.

3. The empirical test of spatial diffusion process of knowledge spillovers

3.1. Model derivation and variable definition

Based on Caniels and Verspagen’s spatial knowledge attenuation classic model, city i receiving knowledge spillovers from city j can be expressed as follows:
\[
S_{ij} = \frac{\delta_j}{\gamma_{ij}} \left( \frac{1}{d_j} \right)^{\frac{1}{2}}
\]

(1)

\[
G_{ij} = \frac{k_{ij}}{k_i}
\]

Represented the knowledge gap between two cities, \(\delta_j\) presented learning and absorptive ability of city \(i\), \(\gamma_{ij}\) presented spatial distance between the two. In order to further clarify the relative differences in absorptive capacity in different cities, the model was transformed into and taking logarithm as follows:

\[
\ln S_{ij} = \ln a_{ij} \cdot \frac{1}{\delta_i} + \frac{1}{\delta_i} \cdot G_{ij}^{(x)} \cdot \beta_{ij} r_{ij} + \epsilon
\]

(2)

Taking into account the data stability and continuity, the dependent variable of the empirical model was the average of patent application in 2014 and 2015, and then using the common log of them. Considering robustness of the empirical results, the independent variables were 2014 and 2015 cross-sectional data. The spatial distance and the absorptive capacity were the control variables. Taking into account the environmental pollution promoting the development of solar technology, the more serious the environmental pollution, the stronger the desire to absorb solar-related knowledge, so we selected knowledge gap and pollution control as control variables (as shown in Table 4). Combined with the four factors of spatial distance, knowledge gap, absorptive capacity and pollution control, we built the following empirical model on the basis of formula (2):

\[
\ln S_{ij} = \ln a_{ij} \cdot \beta_{ij} G_{ij}^{(x)} + \beta_{\gamma} G_{ij}^{(x)} + \beta_{\gamma} G_{ij}^{(b)} \cdot \beta_{ij} r_{ij} + \epsilon
\]

(3)

### Table 4. The meanings of these variables

| Variable type       | Variable name                          | Definition                                      | Calculation formula |
|---------------------|----------------------------------------|------------------------------------------------|--------------------|
| Dependent variable  | Number of patent application           | The quantity of patent application in satellite cities | \(\text{Ins}\)     |
| Independent variable| spatial distance                      | Traffic distance from the central city to satellite cities | \(\text{Inr}_{ij}\) |
|                     | absorptive capacity                   | The ratio of per capita R&D expenditure of central city to satellite cities | \(G_{ij}^{(x)} = \ln\left(\text{aborp}_{ij} / \text{aborp}_{j}\right)\) |
| Control variable    | knowledge gap                         | The ratio of per capita GDP of satellite cities to central city | \(G_{ij}^{(x)} = \ln\left(\text{gap}_{ij} / \text{gap}_{j}\right)\) |
|                     | pollution control                     | The ratio of the comprehensive treatment rate of three wastes of satellite cities to central city | \(G_{ij}^{(x)} = \ln\left(\text{pollu}_{ij} / \text{pollu}_{j}\right)\) |

Data were mainly collected from 2015 and 2016 China City Statistical Yearbook.
The spatial distance between satellite city and central city was shown in Figure3, data were from 2345 highway mileage query system (http://tools.2345.com/jiaotong/lc.htm). From Figure3 we can see Langfang was closest to central city--Beijing. But there were few solar patents in Langfang. That was say, Langfang didn’t benefit from solar patent diffusion from Beijing. It indicated that spatial distance was not an important constraint factor of knowledge spillovers.

3.2. Description of model test results
This paper had two tests, one with absorptive capacity and one without it. Using cross-section data of the independent variables in 2014 and 2015, F-test showed that the fitness of the two models were ideal, and the DW test was near 2 (saw Table1, Table2), indicating that there was no obvious autocorrelation problem. And the VIFs were between 1 and 2, indicating that there were no obvious multiple collinearity.

Table5. Model1 results with four independent variables

| Model1 summary⁹ |  |
|---|---|---|---|---|---|
| model | R | R square | Adjusted R square | The error of standard estimation | Durbin-Watson |
| 1 | .773⁸ | .598 | .464 | 1.344 | 1.702 |

a. forecast variables: (constant), pollution control, traffic distance, knowledge gap, absorptive capacity.

b. dependent variable: patent

Table6: Model2 results without the variable of absorptive capacity

| Model2 summary⁹ |  |
|---|---|---|---|---|
| model | R | R square | Adjusted R square | The error of standard estimation | Durbin-Watson |
| 1 | .656⁸ | .430 | .299 | 1.537 | 1.464 |

a. forecast variables: (constant), pollution control, traffic distance, knowledge gap.
b. dependent variable: patent

Table 7. Tree Generated by Training model results

| Model     | Model1 Non-standardized coefficient B | VIF  | Model2 Non-standardized coefficient B | VIF  |
|-----------|---------------------------------------|------|---------------------------------------|------|
| 1         | (constant)                            |      |                                       |      |
| traffic   | -.219                                 | -1.791 | -.200                                 | 1.227 |
| absorp    | .726                                  | 1.366  |                                       |      |
| gap       | -.389                                 | 1.914  | -1.429                                 | 1.416 |
| pollu     | .134                                  | 1.252  | .106                                  | 1.185 |

a. dependent variable: patent

Statistical analysis results showing as Table 7.

(1) Spatial distance had some impact on knowledge spillovers, but the degree of it was limited and had no significant increased even on condition of controlling the variable of absorptive capacity.

(2) When controlling the variable of absorptive capacity, the fitting degree of model 2 was obviously reduced. It showed that the absorptive capacity had a significant effect on spatial knowledge spillovers. To enhance the knowledge absorption capacity of the surrounding cities can damp the rate of spatial velocity attenuation of knowledge spillovers.

(3) Economic gap had a negative impact on the diffusion of knowledge spillovers. The greater the gap, the more obvious the damping effect of spatial spillovers, which showed that economic development and knowledge flow was mutually restrictive.

(4) Compared with the other three factors, environmental pollution control had the least influence on the spatial diffusion of knowledge spillovers. We can clearly see from the statistical data that there were little gap between satellite cities and central city. The impact of environmental pollution on the spatial diffusion of knowledge spillovers was very limited.

4. Conclusion
This paper analyzed spatial knowledge spillovers in Beijing-Tianjin-Hebei and the Pearl River Delta, finding that the spatial distance had an unstable effect on the spatial attenuation of knowledge spillovers, and there were obvious geographical differences. Absorptive capacity will effectively damp the speed of knowledge spillovers, and the different regions with better absorptive capacity in the same radius of knowledge attenuation would receive more innovative knowledge. This is the reason that the distance of Langfang to Beijing was much smaller than Foshan to Shenzhen, but knowledge spillovers between two were obviously different. Economic gap had a negative impact on spatial knowledge spillovers. It’s not difficult to understand why innovative radiation from Beijing to its surrounding cities was smaller than Shenzhen. To enhance the level of regional knowledge spillovers and the scope of innovation radiation, it’s necessary to narrow the economic gap between cities.

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