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EVALUATION OF INNOVATIVE KNOWLEDGE SPILLOVER EFFECTS BASED ON DEA

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Abstract. *Innovative knowledge spillover is a new branch of knowledge spillovers. The sender of innovative knowledge spillover has stronger intention of active spillover than the receiver, which is different from the general knowledge spillover. Based on the evaluation indexes of innovation knowledge spillover proposed, we take Zhongguancun Science Park as an example to evaluate the innovative knowledge spillover effects. As the banner of China's innovation and development, its innovative knowledge spillover has become an important factor of economic development, productivity improvement and industrial transformation in a certain sense. We choose personnel in S&T activities, expenditure for S&T activities and technological turnover outwards provinces as the main input-output indicators of innovative knowledge spillovers, and use the DEA model to evaluate the nine major sub-parks of Zhongguancun. The empirical results indicate that, from the perspective of input and output, Fengtai Park has the best innovative knowledge spillover effect.*

Keywords: Innovative knowledge, Spillover effect, DEA model

1. **Introduction.** Innovation is the main driving force of regional economic development. It is widely agreed that innovative ability directly determines regional competitive advantages. Innovative knowledge is a kind of unique core technology with independent intellectual property including both original and introduction-absorption afterwards innovation. It can be the technology, products, brands and services in both basic research and application area. The innovative knowledge spillovers exist due to the externality nature of knowledge [1]. Knowledge spillovers are commonly thought to happen from universities and research institutes to industry innovations [2]. Lots of evidences have been raised. Jaffe et al. studied state-level corporate patent activity [3]; and Acs et al. confirmed patent activities influenced by spillovers [4]. Knowledge spillovers have been measured by patents until now [5]. Innovative knowledge spillovers are quite different from the traditional knowledge spillovers, especially under the innovation-driven development background. Its effect does not limit to patents, also reflects in other aspects such as the promotion of economic development, translation into practical productive forces and the industrial restructuring or upgrading. Therefore, innovative knowledge spillovers are not confined from universities and research institutions to enterprises; and not limited to the perspective of knowledge spillover receivers [6]. From the spillover motivation and spillover form, innovation knowledge spillovers are different from the general knowledge spillovers. The side of innovative knowledge spillovers has stronger active spillover intention. Until now, few studies have focused on the mechanism and measurement of

knowledge spillovers from the perspective of knowledge spillover senders. It is worthy to explore the innovative knowledge spillover effects of developed area to the rest from the perspective of senders.

It may be not authoritative to measure the innovative knowledge spillover effects according to the index system established here, but this does not hinder the innovation knowledge spillover effect evaluation from the angle of input and output. Therefore, data envelopment analysis (DEA), introduced by Charnes et al. [7], may be a suitable method for innovation knowledge spillover evaluation, especially for certain object. DEA is proved to be a satisfactory method to assess the relative efficiencies of multi-input multi-output production units [8], and there has been used for kinds of situations [9]. In this paper, practical conclusions are drawn based on the empirical analysis of Zhongguancun using DEA model, which may be different from the people's visual impression of Zhongguancun; however, the analysis shows that our conclusion is more reasonable.

The structure of this paper is organized as follows. Section 2 provides evaluation indexes on innovation knowledge spillovers. Section 3 presents DEA model. Section 4 shows numerical results by applying the model to the case study of innovation knowledge spillovers in Zhongguancun Science Park. Finally, Section 5 discusses the conclusions of this paper and future work.

2. **The Evaluation Indexes of Innovative Knowledge Spillover.** Innovative knowledge spillover not only has the general characteristics of tacit knowledge, but also has some unique characteristics due to the close relationship with innovation activities. Thus, the dynamic mechanism of innovative knowledge spillovers is different from the general knowledge spillovers. The power of innovative knowledge spillover mainly comes from the driving force of the sender, the receiver, the government support and the market competition.

2.1. **Indexes selection.** In the '2014 Global Innovation Index Report', The World Intellectual Property Organization evaluated the innovation ability about 140 countries worldwide according to policy environment, human capital development and research, infrastructure, market complexity, commercial complexity, knowledge and technology output and creative output which contained 81 indexes. The indexes were divided into innovation input and output; and the innovative indexes were obtained through the calculation of innovative efficiency based on the ratio of output to input [10]. In 2013, the Ministry of Science and Technology made evaluation according to three different levels: the nation, regions and enterprises, in which the index system mainly involved innovation resource allocation, knowledge creation, enterprise innovation, innovation effect and innovation environment [11]. The existing system of innovative ability is similar to some extent home and abroad, involving the allocation of resources, innovation input, innovation output and innovation environment. Therefore, we choose the indexes in line with the existing authoritative index system and relevant literature emphasizing the characteristics from the perspective of spillover senders.

2.2. **Indexes design.** The innovative spillover index system is divided into three parts: the allocation of resources, innovation output and policy environment in this paper.

The allocation of resources contains R&D expenditures or the ratio of R&D expenditures and total income, technological personnel or percentage of technological personnel, foreign direct investment, cooperative project expenditures home and abroad, and expenditures of technology introduction. Considering both the statistics caliber and availability of data, the core indicators can be summed up as technological personnel and technological activities expenditures.

Innovation output refers to the output in the process of innovative knowledge spillovers which will reflect the spillover effect from the view of output. It mainly includes technical income or total revenue, total exports, sales revenue of new products or its ratio, the number of valid patents or patents granted, the transfer of patent ownership and licensing revenues or technical contract turnover. Also, considering both the statistics caliber and availability of data, the core indicators can be summed up as the number of patents granted and technical contract turnover.

The environment policy is mainly reflected in the degree of government's support from the perspective of finance, including the use of science and technology funds or the ratio of R&D expenses supported by government departments.

In conclusion, considering the availability of data, from the perspective of input-output, the core indexes are technological personnel, technological activities expenditures, number of patents granted and technical contract turnover.

3. **DEA Method.**

DEA is a linear programming model represented by the ratio of output and input. It tries to maximize the efficiency of service unit through the comparison of service efficiency between the certain unit and other similar units, in which efficiency of 100% is called the relatively efficient unit, otherwise invalid units in which efficiency scores below 100%. Charnes, Cooper and Rhodes represented the DEA linear programming model with formulas, which we called the CCR model.

3.1. **The definition of variables.**

Let E_k $(k = 1, 2, \ldots, K)$ denote the efficiency ratio of unit k, and K is the total number of units under assessment.

Let u_j $(j = 1, 2, \ldots, M)$ denote the coefficient of output j, and M is the given total number of output types. u_j denotes the decline of relative efficiency with the reduction of output per unit.

Let v_i $(i = 1, 2, \ldots, N)$ denote the coefficient of input i, and N is the given total number of input types. v_i represents the increase of relative efficiency with the reduction of input per unit.

Let O_{jk} denote number of output j created by unit k.

Let I_{ik} denote number of input i used by unit k.

3.2. **The objective function.**

Given a group of coefficients u that accompany each kind of output, and a group of coefficients v that accompany each kind of input, the objective function is the maximum of the ratio.

$$\max E_e = \frac{u_1 O_{1e} + u_2 O_{2e} + \cdots + u_M O_{Me}}{v_1 I_{1e} + v_2 I_{2e} + \cdots + v_N I_{Ne}} \tag{1}$$

Here, e denotes the code of evaluation unit.

3.3. **The constraints.**

$$\frac{u_1 O_{1k} + u_2 O_{2k} + \cdots + u_M O_{Mk}}{v_1 I_{1k} + v_2 I_{2k} + \cdots + v_N I_{Nk}} \leq 1.0 \quad (k = 1, 2, \ldots, K) \tag{2}$$

All coefficients are positive and non-zero. In order to use the standard linear programming model, the objective function and constraints are deformed, and the mathematical model is as follows.

3.4. **The mathematical model.**

In order to solve Formula (1), the linear programming with fractional form, we adjust the units input for 1. The goal function and subjects are as follows.

$$\max E_e = u_1 O_{1e} + u_2 O_{2e} + \cdots + u_M O_{Me}$$
$$\begin{cases} v_1 I_{1e} + v_2 I_{2e} + \cdots + v_N I_{Ne} = 1 \\ u_1 O_{1k} + u_2 O_{2k} + \cdots + u_M O_{Mk} \\ -(v_1 I_{1k} + v_2 I_{2k} + \cdots + v_N I_{Nk}) \le 0 \quad k = 1, 2, \ldots, K \\ u_j \ge 0 \quad j = 1, 2, \cdots, M \\ v_i \ge 0 \quad i = 1, 2, \cdots, N \end{cases} \tag{3}$$

Empirical evidence: $K \ge 2(N + M)$.

4. **The Empirical Analysis.** We take Zhongguancun as an example. Zhongguancun is the first state-level high-tech park and national independent innovative demonstration zone. After years of development, it has formed 16 sub-parks which gathered nearly 2 million high-tech enterprises. In 2013, the total income (TI) of 9 parks like Haidian accounts to 96.7% of all, so we only take the main 9 parks as the research sample.

4.1. **The evaluation of innovative knowledge spillover effect.** The core input indexes are personnel in S&T activities (PSTA) and expenditure for S&T activities (ESTA), while the core output indexes are technological turnover outwards provinces (TTOP), as shown in Table 1. Since Zhongguancun undertakes the pilot task of science and technology, it has played a decisive role in the national innovation development process. To some extent, the innovation-driven development reflects not only in published papers, but also the transformation of scientific and technological achievements into productive forces. Therefore, we choose the technological turnover outwards provinces rather than the traditional patents number as output indicator.

Table 1. Input-output indexes of Zhongguancun in 2013 [12]

No.	Park	Input indexes PSTA person	Input indexes ESTA 10^8 yuan	Output indexes TTOP 10^8 yuan
1	Haidian	275518	702	842
2	Fengtai	25532	56	477
3	Changping	33706	76	42
4	Chaoyang	52529	153	213
5	Daxing-Yizhuang	37098	116	93
6	Xicheng	19081	40	72
7	Dongcheng	14395	65	225
8	Shijingshan	11923	51	30
9	Tongzhou	7435	16	2

Construct mathematic model like Formula (3). They are linear programming problems, which can be calculated as follows by using linear programming software.

4.2. **The evaluation results.** Fengtai is a relatively effective park according to Table 2, which means that Fengtai is relatively effective, followed by Dongcheng park, from the perspective of input-output effect of innovative knowledge spillover. There is still much room of improvement for the others.

The ratio of technological turnover outwards provinces and total income (TTOP/TI) is also listed in Table 2. From Figure 1 we can see that, there is a high correlation between the evaluation based on DEA and the ratio.

The correlation degree shows that the absolute incidence degree is up to 0.98. Over all, the ratio of TTOP/TI in Fengtai and Dongcheng are much higher than other 7 parks, which draws the same conclusion as DEA model. The total income, planning area,

TABLE 2. The estimations

		v_1	v_2	u_1	E_i	TTOP/TI
1	Haidian	3.6E-06	0	1.9E-04	0.164	6.72%
2	Fengtai	3.9E-05	0	2.1E-03	1	14.47%
3	Changping	3E-05	0	1.6E-03	0.067	1.44%
4	Chaoyang	1.9E-05	0	1.0E-03	0.217	5.99%
5	Daxing-Yizhuang	2.7E-05	0	1.4E-03	0.135	2.44%
6	Xicheng	0	0.025	2.9E-03	0.211	6.80%
7	Dongcheng	6.9E-05	0	3.7E-03	0.838	29.46%
8	Shijingshan	8.4E-05	0	4.5E-03	0.136	2.55%
9	Tongzhou	0	0.062	7.2E-03	0.017	0.66%

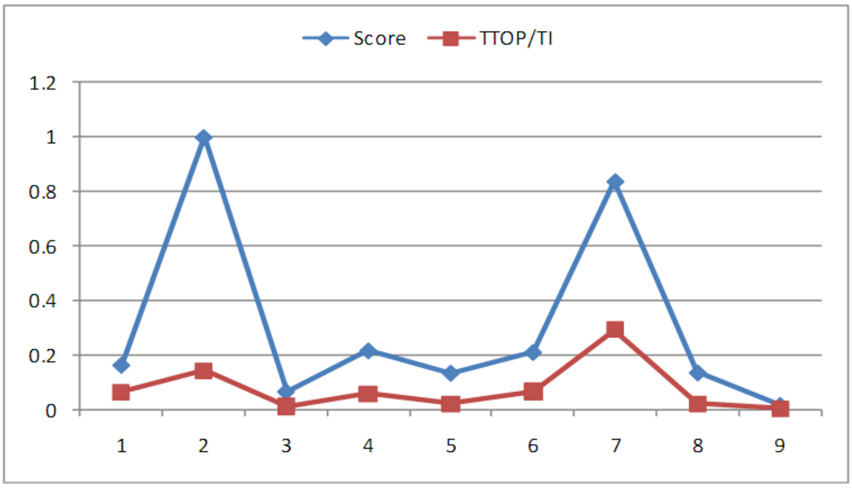

FIGURE 1. The evaluation based on DEA and TTOP/TI

technological personnel, technological activities expenditures, patents granted, invention patents granted and the TTOP of Haidian amounted to 42.49%, 40.41%, 57.73%, 55.12%, 47.6%, 63.33% and 42.17% of the total 9 parks respectively (11.17%, 4.09%, 5.35%, 4.36%, 7.63%, 5.83% and 23.87% in Fengtai), which shows its considerable influence to others in innovative knowledge spillovers from the perspective of total and relative amount. However, Fengtai is better from the perspective of input and output; that is to say, the innovation in Haidian is more represented in invention patents while its active spillover is less than Fengtai.

5. **Conclusion.** From the side of spillover senders, on the one hand, the evaluation indexes of innovative knowledge spillovers are established, which develops and enriches the theory and measurement methods of knowledge spillovers. On the other hand, the efficiency of 9 parks in Zhongguancun is clearly identified through the evaluation using DEA model. For example, Fengtai, instead of Haidian, is relatively effective which is different from the common opinion that Haidian park plays a leading role. Therefore, this study can provide meaningful references for the future development of Zhongguancun. Unlike traditional knowledge spillovers, the influence of innovative knowledge spillovers on senders may be greater than on receivers. Consequently, a further mechanism research is needed to find the corresponding measures to support innovative knowledge spillovers, which will also enrich the knowledge spillovers theory to better present the leading role of spillover senders.

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