

Evolutions of China's Inter-regional R&D Collaboration Patterns: Based on the Three-dimensional Analysis of Organization, Geography and Technology

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Abstract. Inter-regional collaboration plays an important role in booting the flow of knowledge and technology between cross-border actors. The existing research focus on collaboration pattern itself and its spatial characteristics, but ignored its technological characteristics. This paper proposes a three-dimensional analytical framework, and applies the framework to the Chinese case by examining collaborative invention patent applications from 1985 to 2015. Results show that, first, the evolutions of China's inter-regional R&D collaboration patterns differ greatly; second, geographic constraint on China's inter-regional knowledge flows mainly exists in early period, especially for two patterns (inter-regional collaboration between enterprises, and between enterprises and academic institutions); third, China's inter-regional R&D collaboration mainly took place in related technological fields in early period, but in unrelated technological fields for two patterns (inter-regional collaboration between academic institutions, and between enterprises and academic institutions) in the last two periods. Chemistry and Metallurgy, Physics, Electricity are main collaborative fields.

Introduction

Due to globalization and regionalization processes, cross-border collaboration has become a new appeal. As a channel of open innovation, inter-regional R&D collaboration boots the flow of knowledge and technology between cross-border actors. Specifically, China, after a series of reforms of the S&T system, especially after the proposal of innovation-driven development strategy in year 2006, has experienced a rapid growth in inter-regional R&D collaboration, and regards inter-regional collaboration as an important policy issues, in order to strategically narrow the regional difference in innovation. So, more and more scholars begin to pay attention to the dynamic features or patterns of inter-regional collaboration.

One important strand of literature deals with the geographical dimension of inter-regional R&D collaboration. Relevant research mainly investigated the spatial characteristics of inter-regional R&D collaboration which changed over time, by using the social network analysis [1-3]. Other strand of literature highlights the organizational dimension of inter-regional R&D collaboration. Studies discovered the organizational backgrounds of innovative actors in inter-regional R&D collaboration, and stated that due to different reward systems in different organizations, diverse and conflictive motivations shape inter-regional R&D collaboration [4-6]. Also, a few researchers discuss a combination of the above two dimensions. Relevant research mainly focus on the distinct spatial features of inter-regional R&D collaboration with different types of organizations [7-9]. The existing literature has paid more attention to the quantity but ignored the structure of inter-regional collaboration, however, for the studies which focused on the structure they emphasized on the collaboration pattern itself and its spatial characteristics more than technological characteristics which should be viewed as an important consideration. In other words, scholars has recognized the "region and organization" boundaries which exist in inter-regional R&D collaboration, but ignored the technological boundary of inter-regional R&D collaboration. Systematic and empirical studies have seldom been carried out regarding the patterns of inter-regional R&D collaboration across regional, organizational and technological boundaries. In this paper, we

advance a three-dimensional analytical framework for identifying regional choices of inter-organization collaboration, and comparing the geographical and technological distribution characteristics between different choices. Then, we apply the framework to the longitudinal analysis of China's inter-regional R&D collaboration in its 31 regions by using invention patenting activities as a measure. Certainly, findings from the Chinese case may not be applicable to other countries, but the inter-regional collaboration evolution patterns identified in our study could be useful for policymakers elsewhere.

The remainder of this paper is structured as follows. The next section presents a framework for studying the evolutions of inter-regional R&D collaboration patterns. Then follows the empirical study from China, including data, methods and research results. The last section offers conclusions based on our analysis.

A Framework for Studying the Evolutions of Inter-Regional R&D Collaboration Patterns

We advance a three-dimensional analytical framework for studying the evolutions of inter-regional R&D collaboration patterns (Figure 1). First, based on organizational dimension, there exist two types of organization: enterprise (E) and academic institutions (A). We can identify the collaboration patterns by analysing invention patents stemming from a corporate environment or an academic environment or a combination of the two. Specific to inter-regional R&D collaboration, it consists of three forms of collaboration: inter-regional collaboration between enterprises (IR-EE), inter-regional collaboration between academic institutions (IR-AA), inter-regional collaboration between enterprises and academic institutions (IR-EA). Secondly, based on geographical dimension, we can investigate the characteristics of spatial distribution of inter-regional R&D collaboration. As for the “double dimensions” (Organization and Geography), a comparative analysis of different spatial features of the above three inter-regional R&D collaboration patterns can be provided. Thirdly, based on technological dimension, we can investigate the characteristics of technological distribution of inter-regional R&D collaboration. As for the “double dimensions” (Organization and Technology), a comparative analysis of different technological features of the three inter-regional R&D collaboration patterns can be provided. Fourth, the three dimensions of inter-regional R&D collaboration change over time. So the analytical framework provides the possibility of multi-perspective to investigate evolution patterns of inter-regional R&D collaboration.

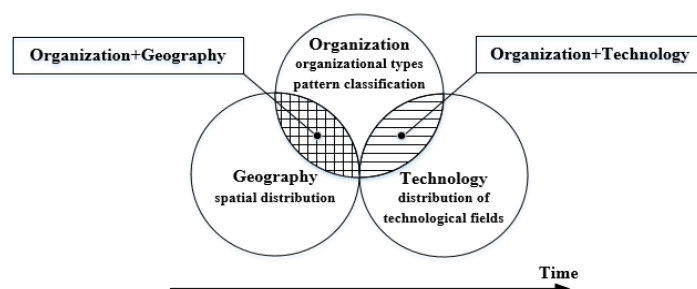


Fig. 1 Analytical framework of inter-regional R&D collaboration: based on three dimensions (Organization-Geography-Technology)

Data and Methods

R&D collaboration exists in a variety of forms such as licensing, alliances, joint project, joint ventures. Empirically, data on co-authorship and co-patent (especially co-invention) are used to measure R&D collaboration since they can provide relatively complete information on the outcome of collaboration. Taking advantage of the patent data in State Intellectual Property Office (SIPO), we apply patents jointly applied for invention for our analysis. The SIPO database was searched in Jun 2016. We draw China's patent applied for invention data between 1985 and 2015. Then we did the data processing as follow: first, patents with two or more assignee names (organizations but not individuals) were kept; second, the information of above organizations' address were identified, then the organizations from foreign counties and Hong Kong, Macao and Taiwan were dropped in order to capture China's inter-regional collaboration; third, the organizational types were identified[10], specifically, for industry sectors,

assignee names could be company (gongsi), factory (chang), group (jituan), enterprise (qiye), or a combination of several of them, for academic sectors, assignee names could be university (daxue), college (xueyuan), school (xuexiao), research center (yanjiuzhongxin) or institute (yanjiusuo); fourth, we split co-invention into pairs of inter-organizational collaboration, then deleted the pairs of organizations who came from same region, so far we got all the data of China's inter-regional R&D collaboration. According to the two attributes of organization-organizational type and address, we gathered these pairs at the regional level, thereby obtained the amount of inter-regional R&D collaboration innovation output overall and the amounts of three patterns respectively. In order to illustrate the dynamics of inter-regional R&D collaboration, we divided the entire period into three periods of unequal length: 1985-1998, 1999-2006, and 2007-2015. 1999 and 2006 were viewed as the two key years, taking into account the evolution of China's economic transition and the reform of S&T system.

Three main methods were used in our studies: describe statistics, social network analysis and entropy index method[11] (to measure technological diversification index).

Evolutions of China's Inter-Regional R&D Collaboration Patterns

The Evolutions of China's Inter-Regional R&D Collaboration Patterns-Based on Organizational Dimension

We counted the overall and the three patterns' numbers of China's inter-regional R&D collaboration in three periods by two standards-total patents and total pairs. Specifically, the numbers of the three patterns all showed an exponential increase in the third period compared to the first two periods, but there are marked differences in proportion. IR-EA accounted for 66.25% in the first period, only for 31.61% in the third period. With IR-EE, the opposite is true, it became the dominant pattern in the third period. The proportion of IR-AA decreased period by period.

Table 1 An overview of China's inter-regional R&D collaboration

Periods	Total patents				Total pairs			
	All	IR-EE	IR-AA	IR-EA	All	IR-EE	IR-AA	IR-EA
	Number	Number	Number	Number	Number	Number(%)	Number(%)	Number(%)
1985-1998	1251	189	334	947	1668	247 (14.81)	316 (18.94)	1105 (66.25)
1999-2006	5698	1494	669	3874	6847	1914 (27.95)	823 (12.02)	3138 (45.83)
2007-2015	101866	66648	8400	40024	157944	101527 (64.28)	9015 (5.71)	48374 (30.63)
1985-2015	108815	68331	9405	44845	166459	103688 (62.29)	10154 (6.10)	52617 (31.61)

The Spatial Characteristics of the Evolutions of China's Inter-Regional R&D Collaboration Patterns-Based on Organizational and Geographical Dimensions

Figure 2-4 shows dynamic network evolutions of IR-EE, IR-AA and IR-EA in the three historical periods. From Figure 2-4, the networks of the three patterns were sparse in the first period and were tight in the third period, which means a increasing trend in the last thirty years for whatever pattern. we found an interestion phenomenon: in the early period, inter-regional collaborations took place between adjacent regions more easily, but simultaneously, there existed a few regions who played a leading role in inter-regional knowledge flow, such as Beijing, Shanghai, Guangdong, Zhejiang etc; in the last period, more and more inter-regional collaborations between remote regions started to appear, and the unique position of the above regions as the dominant knowledge center declined.

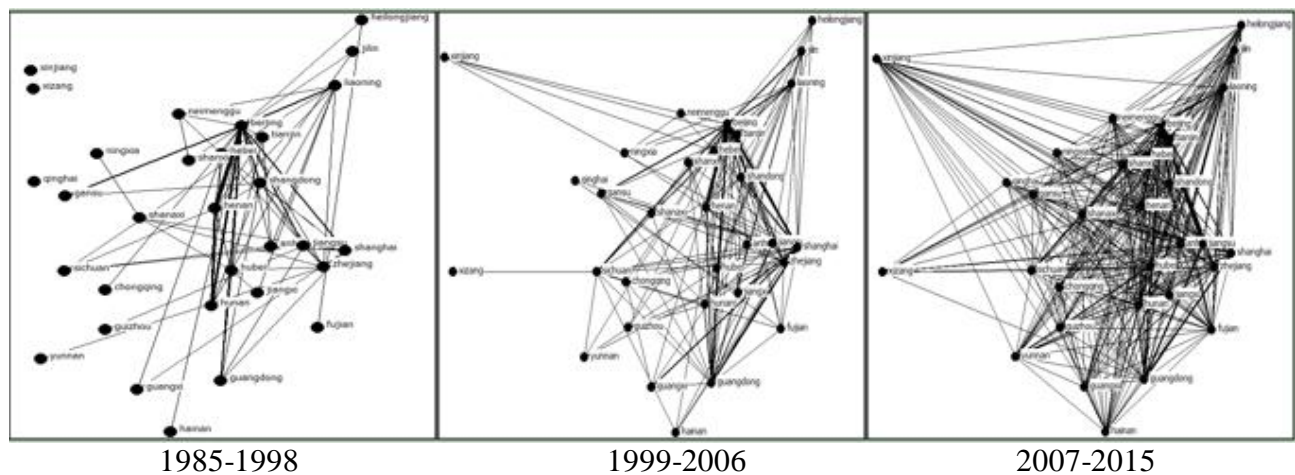


Fig. 2 Network evolution of IR-EE, 1985-2015

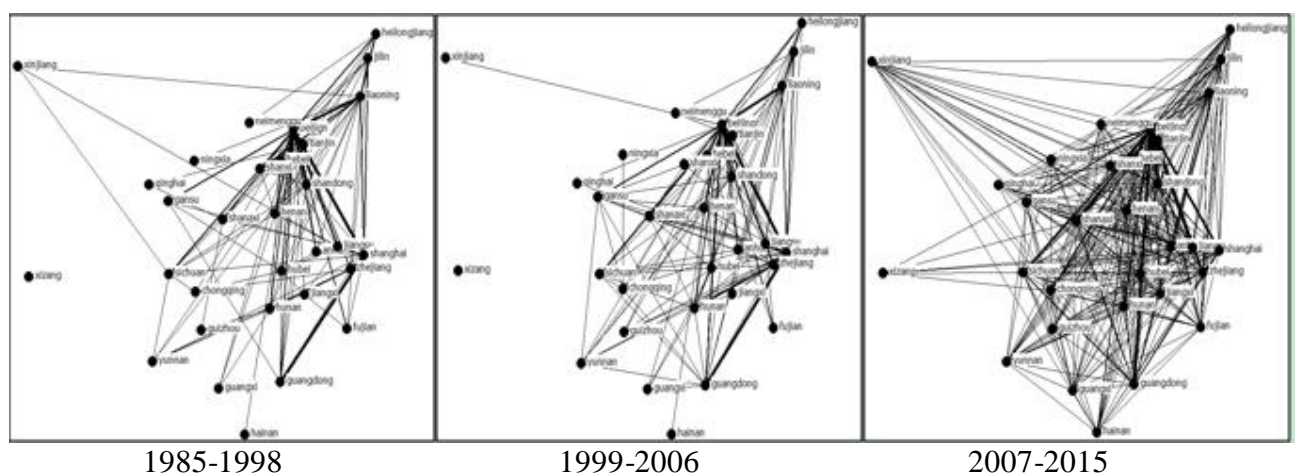


Fig. 3 Network evolution of IR-AA, 1985-2015

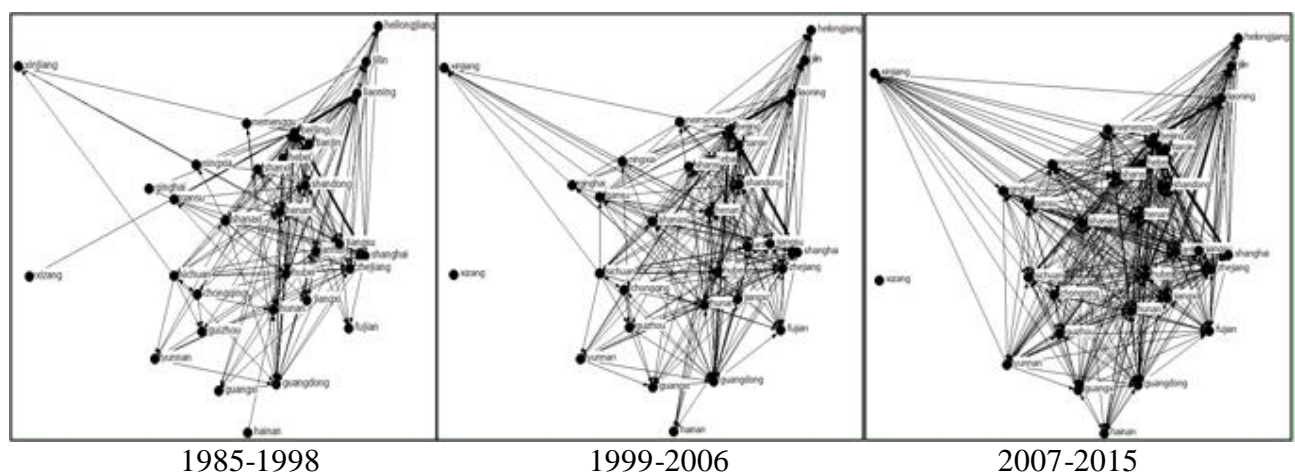


Fig. 4 Network evolution of IR-EA, 1985-2015

The Technological Characteristics of the Evolutions of China's Inter-Regional R&D Collaboration Patterns-Based on Organizational and Technological Dimensions

We investigated the technological characteristics of China's inter-regional R&D collaboration in the three periods (Table 2). First, as for technological distribution, the number of sectors differ in the three patterns and in the three periods. In the first two periods, China's inter-regional R&D collaboration mainly took place in Chemistry and Metallurgy fields (Sector C), in the last period, the number of collaboration in Physics and Electricity fields (Sector G and H) rose. Second, as for technological

diversification, in the first period, China's inter-regional R&D collaboration mainly took place in related technological fields, but the situation changed in the last periods, specifically, the collaboration started to take place in unrelated technological fields for IR-AA, and it only occurred in the third period for IR-EA. It is noticeable, however, that the collaboration nearly took place in related technological fields for IR-EE in the second period.

Table 2 The technological characteristics of China's inter-regional R&D collaboration

IPC	1985-1998				1999-2006				2007-2015			
	All	IR-EE	IR-AA	IR-EA	All	IR-EE	IR-AA	IR-EA	All	IR-EE	IR-AA	IR-EA
Number of Sectors												
A	163	21	65	93	1157	324	259	642	9469	5115	1534	3424
B	311	41	52	263	1454	335	71	1119	20036	11760	907	8791
C	811	147	207	633	3691	740	408	2775	34446	16001	2916	18504
D	29	2	7	20	203	66	25	128	1976	1013	159	1001
E	56	12	19	41	167	98	18	70	7132	5086	462	2407
F	68	8	16	49	236	121	21	115	7182	5244	422	2116
G	108	10	35	75	773	316	118	395	36123	26052	3696	12775
H	74	4	30	45	1066	326	174	591	27912	21659	2033	8735
Technological diversification index												
overall	3.53	3.14	3.26	3.51	3.34	3.49	3.06	3.20	3.65	3.61	3.33	3.48
related	1.99	1.83	1.65	2.04	1.68	2.89	1.41	1.66	1.83	1.81	1.57	1.72
unrelated	1.54	1.31	1.61	1.47	1.66	0.60	1.65	1.54	1.82	1.80	1.76	1.76

Conclusion and Discussion

In this study we try to enrich the existing research by proposing a three-dimensional analytical framework for studying the evolutions of inter-regional R&D collaboration patterns. An empirical studies based on the long China's co-patent data at the regional level has been conducted. According to the empirical results, we achieved three important findings.

First, the evolutions of China's inter-regional R&D collaboration patterns differ greatly, although the numbers of them all showed marked increase. The proportions of IR-EA and IR-AA both decreased period by period, but the proportion of IR-EE increased period by period, which means the dominant collaboration patterns changed from IR-EA to IR-EE in the last thirty years. It is mainly contributed by the reform of China's S&T system and the proposal of innovation-driven development strategy which deeply changed the roles of innovative actors, especially enterprise, and also influenced the inter-regional knowledge flow. Second, there existed geographic constraint on China's inter-regional knowledge flows in early period, especially for IR-EE and IR-EA, which has been confirmed in many related studies. We found that, the role of geographic constraint decreased along with the more and more inter-regional collaborations were built. Meantime, the unique positions of some regions which played core roles in inter-regional knowledge flow also declined. Third, the technological distributions of China's inter-regional R&D collaboration were relatively concentrative in early period and collaboration mainly took place in related technological fields; but the distributions became relatively dispersed in last period, and collaboration started to take place in unrelated technological fields for IR-AA and IR-EA. China's inter-regional R&D collaboration mainly took place in Chemistry and Metallurgy, Physics, Electricity fields.

In the Chinese context, the discussion about the inter-regional collaboration maybe bring more policy implications. The multi-dimensional analysis perspective helps us to get the whole picture of

inter-regional collaboration, only in this way can the state guide inter-regional knowledge flow and solve regional imbalance by making some pointed policies, especially industry-related policies.

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