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Spatial Pattern and Benefit Allocation in Regional Collaborative Innovation of the Yangtze River Delta, China

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Abstract: As an important step enhancing regional innovation, researches on collaborative innovation have attracted much more attention recently. One significant reason is that cities can get excessive benefits while they take collaborative innovation activities. Based on the theories of innovation geography, this paper takes the collaborative innovation of the Yangtze River Delta (YRD) Urban Agglomeration as a case study and measures the collaborative innovation capacity from innovation actors and innovation cities by adopting the catastrophe progression model. Then on this basis, the study depicts the spatial pattern and the benefit allocation of collaborative innovation by using the coupling collaborative degree model and benefit allocation model of collaborative innovation. The results show that: 1) The collaborative innovation capacity of cities in the Yangtze River Delta has strengthened largely, while the capacity still is not high enough. Cities with high collaborative innovation capacity are concentrated in Shanghai, the southern part of Jiangsu, and Hangzhou Bay, yet the cooperation of the universities-industries-research institutes need to improve. 2) The spatial pattern of collaborative innovation of the Yangtze River Delta presents several innovation circles, which are in Suzhou-Wuxi-Changzhou Metropolitan Circle, Nanjing Metropolitan Circle, Hangzhou Metropolitan Circle, Ningbo Metropolitan Circle, and Hefei Metropolitan Circle. Shanghai plays the role of the central city of collaborative innovation, while Suzhou, Nanjing, Hangzhou, Ningbo, and Hefei act as sub-central cities. 3) The benefit each city allocated from collaborative innovation activities has increased. However, the allocations of the benefit show that cities with higher innovation capacity have significant advantages in most cases, which lead to serious disparities in space.

Keywords: Yangtze River Delta (YRD); collaborative innovation; spatial pattern; benefits allocation

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1 Introduction

Innovation is the driving force of regional economic growth, while the city is the carrier of it. Regional collaborative innovation can help innovation resources flow into cities within the regions, then realize the transfer and transformation of innovation resources and maximize the benefits of collaboration (Grant, 1996; Storper and Venables, 2004; Rigby and Essletzbichler, 2006; Esposito and Rigby, 2019). As the development of regional integration accelerated, collaborative innovation has become a new direction and pattern leading regional development. The Yangtze River Delta (YRD) Urban Agglomeration is located at the intersection of 'One Belt and One Road' and 'Yangtze River Economic Belt'. It bears dual tasks of driving the development of

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the western area and at the same time participating in global competition externally. With the regional integration of the YRD Urban Agglomeration becoming one of the national important development agendas, the role of YRD Urban Agglomeration played in global competition has been further highlighted. As one of the world's urban agglomerations, the economic growth in the cities of YRD Urban Agglomeration is full of vitality (Cao et al., 2018; Li and Phelps, 2019). The strong economic basis, the high-quality human resources, the well-established intellectual property system, have all helped the vitality and competitiveness of regional innovation of YRD Urban Agglomeration to improve greatly. However, due to the unbalanced spatial distribution of innovative resources and impeded resource flow, the collaborative innovation performance still needs to be improved. Hence, it is of great significance in both theoretical and practical industrial transformation and helps to upgrade through discussions on how to promote the integration of innovation in-depth in the YRD Urban Agglomeration.

As an important force driving global economic growth, regional innovation has always been a hot topic that studying over years in economic geography (Döring and Schnellenbach, 2006). The strand of 'regional innovation' literature can retrospect to Schumpeter, who believed that innovation could introduce new products, new methods, and open new markets, discover new supplies of resources, and form new organizational forms (Schumpeter, 1934). Many researchers found that regions that clustered enterprises, universities, and research institutes always tend to have strong innovation capacity through regional innovation studies (Bonaccorsi and Piccaluga, 1994; Philbin, 2008; Peng et al., 2019). These insights demonstrated that their cooperation or communication in innovation activities is determinant. Through cooperation or communication, explicit and tacit innovation resources such as new products or new ideas could circulate to every corner of the region and realize transformation to get even more benefits than before (Håkansson, 1989; Malmberg and Maskell, 1997; 2002; Cooke and Morgan, 1998). This can be regarded as the theoretical and empirical foundation of collaborative innovation research.

Since innovation cannot be independent from innovators, researchers believe that innovation actors should be considered primarily (Cooke, 1997; Tödtling and Trippl, 2005). From innovation actors, universities, public or private funding organizations, large and small-sized firms are the key constitutions (Etzkowitz and Leydesdorff, 2000; Acs et al., 2002; Asheim and Coenen, 2005). However, these actors are often considered as independent and have no relation with each other in traditional concepts because researchers believe that innovation activities are isolated and linear. Yet with the emergence of some new findings on the 'innovation system', researchers have started to consider that innovation activities are evolutionary, non-linear, interactive, and cooperative. It is easy to understand that independent innovation is always not an easy job. Driven by cost-saving, and resource endowment, organizational actors are spontaneously linked through knowledge spillovers, flows of funds, and some face-to-face communication, which is not always visible (Cooke et al., 1997; Kaneva and Untura, 2019). Besides, linkages between organizational actors are also equally important. One of the significant characterizes of collaborative innovation researchers argued is that it can use various elements or resources through linear or non-linear interaction to create synergy effect (i.e., '1 + 1 > 2' effect), which can not be realized by one single innovation actor or regions (Chen, 2010). From the view of cooperative game theory, due to the complementarity of knowledge innovation, knowledge can be transferred and shared in both innovation actors and cities, thus generating the synergy effect and would benefit all participants in collaborative innovation (Docherty et al., 2004). Thus, the concept of collaborative innovation can be concluded as follows: It is an ability generated by combined, divided, cooperated, or integrated core resources (human capital or material capital) and other auxiliary resources of regions, to help regions to achieve the maximum innovation benefits eventually (Hansen, 2015; Herstad and Ebersberger, 2015).

Most existing researches have made many probes in collaborative innovation. A strand of study has been concentrated on the composition of collaborative innovation (Anselin et al., 1997). Researchers in this strand consider that collaborative innovation may include micro and macro collaboration (Li and Phelps, 2019). For micro collaboration, they claim that innovation actors like enterprises, universities, research institutes as well as governments and agents are indispensable. These innovation actors may share talents, capital, or tacit knowledge to generate higher benefits, which cannot be created only by themselves (Liu et al., 2017). Regarding the macroscope, they believe that material resources such as technologies, knowledge, capital, information or talents, *etc*. are indispensable components. They believe that utilizing the resources circulated among cities is the key point to bring more benefits (Docherty et al., 2004).

Another strand of studies is focused on why cities are willing to take part in collaborative innovation. The most conceivable reason for researchers is its potential benefits. Just as scholars state briefly in their papers, the benefit especially on shared of human resources, new technologies, high-quality facilities, and specialized services agents brought from collaborative innovation activities, have greatly increased their willingness (Docherty et al., 2004; Hansen and Mattes, 2018). Innovation actors such as scientific and technological firms could also be benefited from collaboration innovation activities, and these benefits are mainly coming from those located in the innovation clusters (Marshall, 1920; Amin and Thrift, 1992). In this way, collaborative innovation can be regarded as a mechanism that facilitates regions in sharing various kinds of resources, material capital, and policy suggestions, to help them raise economic returns. Besides, as the peripheries of cities, administrative boundaries are faced with the economic depression most of the time, which can be supposed that once the economy of these boundaries are developed, it may help the cities' economy step into a higher stage. This is similar to the fact that some cities or regions can benefit from collaborative innovation activities of cross-regional boundaries (Edmunds, 1993).

How to measure collaborative innovation is another issue that concerned scholars both at home and abroad, and that is indeed hard work because some of the technology and knowledge diffusion are invisible. Therefore, visible cooperation is vital to measurement. Some researchers try to use patent citations and discover that geographical distance is determinate to collaborative innovation due to their findings of a mass of cooperation coming from the same state (Jaffe et al., 1993). However, a growing number of studies found that the impact of geographical distance is not the only determining factor in recent years. Some researchers demonstrate this point by means of following paper trails by citations between some high-tech patents, and they further note that as national border affects the impact of geographical distance on collaborative innovation, the collaboration in the specific industry easily occurs among regions where technological proximity exists (Laursen and Salter, 2006; Balland, 2012).

Comprehensively speaking, most existing researches discussed a lot on the composition, dynamic mechanism, and measurement model of regional collaborative innovation from an empirical view. The empirical studies mainly focused on measuring the level or spillover effect of regional collaborative innovation by using the gravity model, synergetic degree model, spatial panel data model, *etc* (Niu and Liu, 2012; Liu, 2016; Sheng and Ma, 2017). However, many studies may only emphasize specific innovation actors or specific innovation regions, while comprehensive studies that combined both innovation actors and regions remain to be strengthened (Lin, 2016; Su and Fang, 2017). On this basis, the study talks about the collaborative innovation capacity from innovation actors and cities. Then it depicts the spatial evolution patterns of collaborative innovation and analyzes the collaborative innovation activities. After that, the research tries to calculate the benefits cities in the YRD Urban Agglomeration will get from collaborative innovation activities, and then find some implications for cities engaged in the integration of YRD Urban Agglomeration.

2 Methods and Database

2.1 Study area

The YRD Urban Agglomeration studied in this paper includes 26 cities, which include Shanghai, Jiangsu Province (which include Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yancheng, Yangzhou, Zhenjiang, and Taizhou), Zhejiang Province (which include Hangzhou, Ningbo, Shaoxing, Huzhou, Jiaxing, Jinhua, Zhoushan, Taizhou), and Anhui Province (which include Hefei, Wuhu, Ma'anshan, Tongling, Anqing, Xuancheng, Chizhou, Chuzhou) (Fig. 1).

2.2 Index construction

Regional collaborative innovation capacity refers to a capacity that realizes the flow of knowledge, talent, technology, and other innovative resources across regions and organizations, form regional innovation systems and attain the demand of improving the innovation level of the whole region (Feldman, 1994; Agrawal,

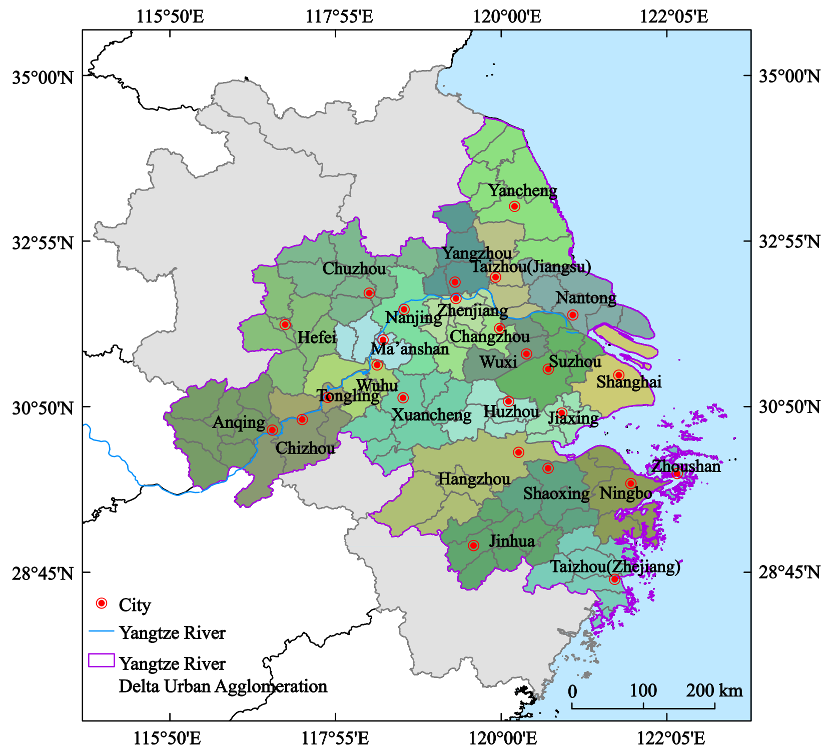

Fig. 1 Cities in the Yangtze River Delta

2001). Therefore, this paper believes that researchers should make considerations comprehensively in both micro and macro scopes. From the microscope, indicators should include all innovation actors involved in the process of collaborative innovation, which is named as collaborative innovation of inter-actors in this paper. This can be interpreted as: by mutual communication and cooperation, innovation actors (such as universities, scientific research institutes, enterprises, *etc*.) within the city can achieve the innovation resources configuration efficiently. From a macroscope, indicators could be considered as the collaborative innovation of cities, which is named as collaborative innovation of inter-cities. It could be interpreted as: with the enhancement of regional innovation activities and integration of the cross-district administrative barriers, resources might circulate both initiatively and unconsciously in various cities. Thus, the probability of cooperation and communication between cities would increase, which improves the innovation of the whole region. The specific indicators of collaborative innovation capacity can be seen in Table 1.

Collaborative innovation of inter-actors can be measured by the scale of innovation actors and the interaction of innovation actors. That is because regional collaborative innovation capacity not only depends on one individual innovation actor but relies on multiple innovation actors' interaction. In other words, no matter which innovation actor is missing, the enhancement of the region's collaborative innovation capacity will be constrained. The scale of innovation actors includes the scale of multiple innovation actors, mainly concerning universities and enterprises; the interaction of innovation actors is examined by cooperation data of patent and scientific paper (Table 1).

The collaborative innovation of inter-cities is observed by the innovation scale of cities, the innovation spillover, and the innovation environment. The innovation scale of cities should be considered because once some city's innovation scale has a huge gap with others, the collaborative innovation capacity of the whole region would be constrained. Indicators to measure the innovation scale of cities, Innovation spillover, and the innovation environment can be seen from Table 1.

2.3 Methods

2.3.1 Catastrophe progression method

Most existing researches often use the coefficient method and entropy weight method to measure the indicators. Although it can fix the weight of each indicator ob-

Table 1 Indicators of collaborative innovation capacity

Indicator	First-level indicators	Second-level indicators	Third-level indicators
Collaborative innovation capacity	Collaborative innovation of inter- actors	Scale of innovation actors	The number of college students / person
			The number of invention patent applications by universities / piece
			The number of invention patent applications by enterprises / piece
			The output value of new products of industrial enterprises above designated size / 100 million yuan (RMB)
		Interaction of innovation actors	The number of co-invention patent applications by universities-enterprises / piece
			The number of co-invention patent applications by universities-enterprises-scientific research institute / piece
	Collaborative innovation of inter-cities	Innovation scale of cities	The output value of high-tech industry / 100 million yuan (RMB)
			R & D personnel full-time equivalent / (person/year)
			The proportion of R & D found investment / %
			The number of patent applications granted / piece
		Innovation spillover	The number of newly signed project contracts with foreign investors / piece
			High-tech industry exports / 100 million dollars (USD)
			The number of scientific paper co-publication with another city in YRD Urban Agglomeration / piece
			The number of patents co-application with another city in YRD Urban Agglomeration / piece
		Innovation environment	Government expenditure ratio of technology / %
			Amount of FDI / 10 thousand dollars (USD)
			Amount of teleservice / 100 million yuan (RMB)
			The density of highway network / %

jectively, the stability of the result might be variated by years or specific parameters. The catastrophe progression method can help to avoid the subjectivity of the result while revealing the relative relation between control variables and state variables. The cusp catastrophe model (two control variables), dovetail catastrophe model (three control variables), and butterfly catastrophe model (four control variables) could be selected according to the number of control variables (Chen et al., 2006). Specific formulas are as follows:

$$v(x) = x^4 + ux^2 + vx \quad (1)$$

$$v(x) = x^5 + ux^3 + vx^2 + wx \quad (2)$$

$$v(x) = x^6 + tx^4 + ux^3 + vx^2 + wx \quad (3)$$

where $v(x)$ is the potential function of the catastrophe model; x is the state variable; u, v, w, t are control variables for x. The normalized cusp catastrophe model, swallowtail catastrophe model, and butterfly catastrophe model are as follows:

$$x_u = u^{1/2}, x_v = v^{1/3} \quad (4)$$

$$x_u = u^{1/2}, x_v = v^{1/3}, x_w = w^{1/4} \quad (5)$$

$$x_t = t^{1/2}, x_u = u^{1/3}, x_v = v^{1/4}, x_w = w^{1/5} \quad (6)$$

2.3.2 Coupling collaborative degree model

The study adopts the coupling collaborative degree model to estimate the intensity when two cities take collaborative innovation activities in the YRD Urban Agglomeration. The specific formula is as follows (Wang, 2017):

$$C_{AB} = \left[U_A U_B / \left(\frac{U_A + U_B}{2} \right)^{1/2} \right]^2 \quad (7)$$

where C_{AB} represents the coupling degree of collaborative innovation activities between city A and city B. U_A and U_B are the collaborative innovation capacity of A and B respectively.

$$D_{AB} = \sqrt{C_{AB}(\alpha U_A + \beta U_B)} \quad (8)$$

where α, β is the undetermined coefficient. Since cities must cooperate with each other when they take collaborative innovation activities, so $\alpha = \beta = 0.5$. D_{AB} infers to the coupling collaborative degree of city A and city B.

2.3.3 *Benefit allocation model of collaborative innovation*

To measure the benefits produced when cities take collaborative innovation activities, the study referenced the diagram of benefit allocation structure (Yang et al., 2007) of collaborative innovation (Fig. 2).

In the diagram, S_{AOB} represents the total benefits of collaborative innovation between city A and city B. S_{AOC}, S_{BOC} represent the benefits of city A and city B allocated in the collaborative innovation activities respectively. K_{OA} and K_{OB} are the slopes of L_{OA} and L_{OB}, which can be expressed by the capacity of collaborative innovation of city A and city B. K_{OA}=1–U_A; K_{OB}=1/(1–U_B). The specific formulas are as follows:

$$L_{OA} = L_{OB} = U_A U_B D_{AB} \tag{9}$$

$$S_{AOB} = \frac{1}{2} U_A U_B D_{AB} \left[\arctan\left(\frac{1}{1-U_B} - \arctan(1-U_A) \right) \right] \tag{10}$$

$$S_{AOC} = \frac{1}{2} U_A U_B D_{AB} \left[\frac{\pi}{4} - \arctan(1-U_A) \right] \tag{11}$$

$$S_{BOC} = \frac{1}{2} U_A U_B D_{AB} \left[\arctan\left(\frac{1}{1-U_B} \right) - \frac{\pi}{4} \right] \tag{12}$$

$$Benefit\ \text{ratio}_A = S_{AOC} / S_{BOC} \tag{13}$$

2.4 Database

The paper takes 26 cities in the YRD Urban Agglomeration as the research units. Statistical data used in this study are acquired from Shanghai Statistical Bureau (http://tjj.sh.gov.cn/), Jiangsu Statistical Bureau (http://tj.jiangsu.gov.cn/), Zhejiang Statistical Bureau (http://tjj.zj.gov.cn/), Anhui Statistical Bureau (http://tjj.ah.gov.cn/), and Department of Science and Technology of Anhui Province (http://kjt.ah.gov.cn/). The number of patents applied and cooperated; the number of scientific papers published and cooperated are acquired and calculated from the State Intellectual Property Bureau (https://www.cnipa.gov.cn/) and Chinese Periodic Database (http://qikan.cqvip.com/).

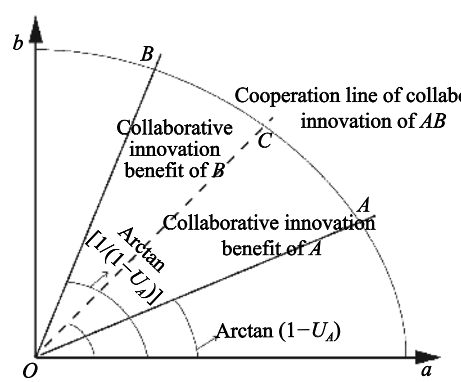

Fig. 2 Benefit allocation structure of collaborative innovation

3 Results

3.1 Capacity of collaborative innovation of YRD Urban Agglomeration

The catastrophe progression method is used to measure the capacity of collaborative innovation of 26 cities in the YRD Urban Agglomeration (Table 2). Then the collaborative innovation capacity has five levels, which includes extremely low capacity (0.0–0.2), low capacity (0.2–0.4), general capacity (0.4–0.6), high capacity (0.6–0.8), and extremely high capacity (0.8–1.0).

3.1.1 *Collaborative innovation of inter-actors*

It is clear that only when innovation actors (that is universities, scientific research institute, and enterprises) are within the region coupled, interacted, and cooperated effectively, the region can achieve the innovation resource configuration effectively (Becheikh et al., 2006). Thus, the collaborative innovation capacity of the region can be enhanced.

In general, the capacity of collaborative innovation of inter-actors in the YRD Urban Agglomeration has increased significantly, since the number of cities with higher capacity in collaborative innovation increased from 11 to 17 during 2010–2016. In terms of the scale of innovation actors, the result shows that Shanghai, Nanjing, and Suzhou have got the highest scores among 26 cities in the YRD Urban Agglomeration. Although it has a slight decline, the score of Shanghai is still as high as 0.937 and always ranked first in the YRD Urban Agglomeration. That is because Shanghai has both advantages in universities and enterprises, which becomes an important precondition of the high score on the scale of collaborative innovation of inter-actors. This makes cities in YRD Urban Agglomeration still have a certain gap compared to Shanghai. The notable ones are Nanjing and Suzhou. Although they have huge advantages in innovation actors, the two cities emphasize one specific innovation actor while ignoring the development of multiple innovation actors (for example, Suzhou has strong strength in the innovation resources of

Table 2 Score of collaborative innovation of inter-actors

City	Second-level indicator				First-level indicator	
	Scale of innovation actors		Interaction of innovation actors		Collaborative innovation of inter-actors	
	2010	2016	2010	2016	2010	2016
Shanghai	0.957	0.937	1.000	1.000	0.993	0.989
Nanjing	0.813	0.820	0.758	0.927	0.902	0.949
Wuxi	0.685	0.696	0.436	0.476	0.771	0.788
Changzhou	0.540	0.578	0.345	0.412	0.701	0.738
Suzhou	0.746	0.811	0.414	0.506	0.775	0.822
Nantong	0.511	0.533	0.338	0.369	0.691	0.709
Yancheng	0.342	0.401	0.134	0.260	0.533	0.624
Yangzhou	0.441	0.473	0.134	0.310	0.564	0.668
Zhenjiang	0.509	0.594	0.236	0.324	0.642	0.705
Taizhou (Jiangsu)	0.352	0.419	0.103	0.245	0.513	0.622
Hangzhou	0.830	0.799	0.756	0.685	0.905	0.878
Ningbo	0.570	0.631	0.236	0.302	0.658	0.704
Shaoxing	0.454	0.539	0.231	0.311	0.624	0.686
Huzhou	0.355	0.430	0.146	0.183	0.545	0.591
Jiaxing	0.423	0.500	0.176	0.258	0.585	0.651
Jinhua	0.391	0.419	0.146	0.299	0.557	0.648
Zhoushan	0.252	0.308	0.028	0.159	0.400	0.537
Taizhou (Zhejiang)	0.393	0.391	0.134	0.206	0.550	0.593
Hefei	0.591	0.741	0.366	0.471	0.722	0.796
Chuzhou	0.268	0.432	0.028	0.096	0.406	0.533
Ma’anshan	0.341	0.400	0.103	0.122	0.510	0.543
Wuhu	0.442	0.574	0.028	0.165	0.465	0.618
Xuancheng	0.135	0.138	0.028	0.082	0.341	0.402
Tongling	0.282	0.318	0.079	0.128	0.468	0.520
Chizhou	0.168	0.198	0.079	0.000	0.417	0.291
Anqing	0.245	0.370	0.028	0.097	0.397	0.515

enterprises but is relative lacks universities. Nanjing has a huge advantage in universities and research institutes but is relatively weak in enterprises). In addition, as Shanghai is accelerating its step to become a global city in the world, innovation resources from worldwide also keep flowing into Shanghai as well. That further helps Shanghai accelerate its speed on transforming to the original place of innovation, and meanwhile strengthen its siphon effect on talents, scientific research institutions, and other important innovation actors. All the abovementioned make great contributions to the high score of Shanghai. Besides, it is worth notice that the score of Chuzhou, Hefei, Wuhu, and Anqing have all improved greatly due to their carrying on the industry transfer from the leading cities in the YRD Urban Agglomeration. With the capital, technology, and other innovative resources flowing inward, innovation spillovers hence are generated and help to elevate cities’ innovation. In terms of the interaction of innovation actors, although the result shows that the score of cities in the YRD Urban Agglomeration has been enhanced slightly from 2010 to 2016, the overall circumstance is not well. The study found that although the YRD Urban Agglomeration has both quantity and quality universities, research institutes, and enterprises, these innovation actors seem over agglomerated in Shanghai, Nanjing, Hangzhou, *etc*. In view of other cities, they perform badly in either universities or enterprises. This leads to a significant regional difference in the score of the interaction of innovation actors.

Overall, the collaborative innovation of inter-actors has been improved a lot during 2010–2016, and about 46.15% of 26 cities reached the average score. Besides, what can not be overlooked is that although it has strong strength in innovation actors, yet the interaction activities among multiple innovation actors are not enough. Innovation actors in the YRD Urban Agglomeration have strong strength in scientific research and R & D (Research and Development) but hardly interacted with each other. Thus, the result of lower integration in enterprises-universities-research institutes is also along with lower commercialization of research findings.

3.1.2 Collaborative innovation of inter-cities

The research of innovation geography points out that innovation activity would form an obvious core-periphery structure in space (Krugman, 1991). This structure makes resources spread from the core area to the periphery area, which results in the circulation of multiple innovation resources such as talents, technology, knowledge, capital, and information. All these helped regions to get the maximum synergy effect.

It can be seen from Table 3 that most cities in the YRD Urban Agglomeration have a high capacity in the innovation of inter-cities, which is quite different com-

Table 3 Capacity of collaborative innovation of inter-cities

City	Second-level indicator						First-level indicator	
	Innovation scale of cities		Innovation spillover		Innovation environment		Collaborative innovation of inter-cities	
	2010	2016	2010	2016	2010	2016	2010	2016
Shanghai	0.933	0.917	0.967	0.945	0.97	0.893	0.984	0.972
Nanjing	0.725	0.810	0.682	0.736	0.665	0.676	0.876	0.899
Wuxi	0.783	0.796	0.613	0.589	0.699	0.655	0.873	0.865
Changzhou	0.658	0.734	0.513	0.547	0.658	0.652	0.829	0.847
Suzhou	0.925	0.963	0.823	0.809	0.787	0.734	0.941	0.938
Nantong	0.697	0.769	0.501	0.532	0.659	0.597	0.832	0.841
Yancheng	0.458	0.599	0.370	0.400	0.509	0.512	0.741	0.774
Yangzhou	0.582	0.663	0.459	0.431	0.634	0.516	0.802	0.792
Zhenjiang	0.587	0.685	0.393	0.386	0.611	0.569	0.783	0.790
Taizhou (Jiangsu)	0.545	0.668	0.389	0.410	0.544	0.532	0.766	0.789
Hangzhou	0.804	0.812	0.571	0.561	0.655	0.619	0.862	0.856
Ningbo	0.764	0.800	0.500	0.498	0.659	0.576	0.841	0.835
Shaoxing	0.631	0.674	0.322	0.348	0.583	0.543	0.766	0.775
Huzhou	0.550	0.597	0.354	0.300	0.539	0.506	0.757	0.744
Jiaxing	0.615	0.674	0.350	0.349	0.664	0.649	0.782	0.788
Jinhua	0.580	0.598	0.334	0.383	0.535	0.481	0.756	0.765
Zhoushan	0.375	0.381	0.181	0.251	0.388	0.387	0.645	0.672
Taizhou (Zhejiang)	0.593	0.604	0.279	0.292	0.487	0.470	0.735	0.738
Hefei	0.564	0.740	0.390	0.456	0.655	0.755	0.783	0.837
Chuzhou	0.331	0.458	0.200	0.214	0.302	0.495	0.627	0.691
Ma'anshan	0.389	0.489	0.234	0.292	0.503	0.542	0.685	0.729
Wuhu	0.494	0.619	0.280	0.332	0.673	0.739	0.742	0.785
Xuancheng	0.321	0.394	0.112	0.124	0.412	0.318	0.607	0.612
Tongling	0.399	0.395	0.206	0.189	0.412	0.408	0.664	0.656
Chizhou	0.079	0.123	0.152	0.104	0.209	0.223	0.498	0.502
Anqing	0.248	0.211	0.174	0.150	0.379	0.380	0.610	0.589

pared to the serious polarization effect of the collaborative innovation of inter-actors. There are nine cities that got an 'extremely high capacity' on the capacity of collaborative innovation of inter-cities. From second-level indicators, there are numbers of cities that have a ‘high capacity in the indicator on the innovation scale of cities, the number of which increased from 7 to 11 during 2010–2016. About 80.77% of cities reached the average or above. It is worth noting that Suzhou has got the highest score on the innovation scale in the YRD Urban Agglomeration. That is mainly due to the settlement of large numbers of scientific research institutions in recent years, which brought with large numbers of high-quality human resources and became the inexhaustible motive force of Suzhou’s high-tech industry. Thus, the high-tech industry in Suzhou has been strengthened a lot. On the score of innovation spillover, the overall score of 26 cities is relatively low and presents a large regional difference, where technical proximity played an important role. For the city itself, the smaller the technical gap between cities, the more possible cities’ cooperation will be (h industry in Suzhou has been strengthened a lot. On the score of innovation spillover, the overall score of 26 cities is relatively low and presents a large regional difference, where technical proximity played an important role. For the city itself, the smaller the technical gap between cities, the more possible cities’ cooperation will be (Gertler, 2003). Therefore, cities with advanced technology seem to have more possibilities for collaborative innovation. In the innovation environment, there exist no extremely low capacity cities in the YRD Urban Agglomeration and the overall situation is not bad. However, about 69.23% of cities show a declining tendency. These are caused by the decreased support of the government in scientific and technological innovation.

3.2 Spatial pattern of collaborative innovation in YRD Urban Agglomeration

After analyzing the capacity of collaborative innovation of cities, the paper wants to further depict how cities in the YRD Urban Agglomeration collaborate in spatial-temporal changes. Therefore, the paper adopts equations 7 to 8 to calculate the value of coupling collaborative degree to measure the intensity when cities take collaborative innovation activities. After the calculation, the paper uses the line density method to depict the spatial pattern of collaborative innovation in YRD Urban Agglomeration.

The scale, density, and the scope of the spatial pattern of the collaborative innovation of inter-actors extended a lot (Fig. 3). The spatial pattern presents several collaborative innovation circles in space, which are the Suzhou-Wuxi-Changzhou Metropolitan Circle, Nanjing Metropolitan Circle, and Hangzhou Metropolitan Circle (Suzhou, Nanjing, and Hangzhou are the core respectively). It is obvious to see that the Suzhou-Wuxi-Changzhou Metropolitan Circle has the highest network density. However, the barriers in administration, culture, and technology between each city have hindered the in-

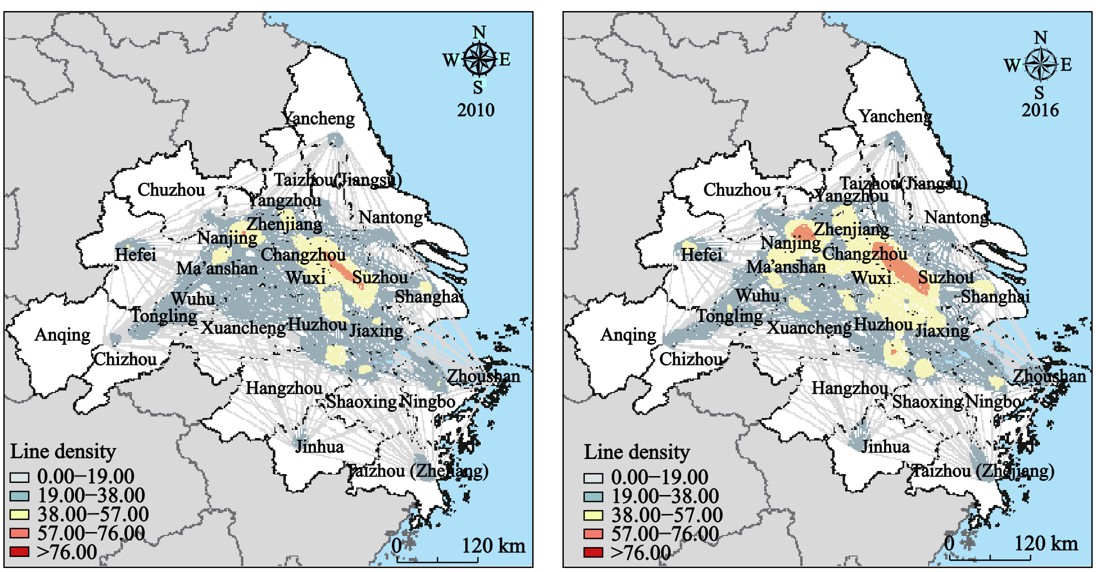

Fig. 3 Spatial pattern of collaborative innovation of inter-actors in 2010 and 2016

teraction or integration of innovation actors to some extent. According to the results, the value of coupling collaborative degree between Shanghai and Nanjing are the highest in 2016, almost 3.26 and 3.11 times of Chuzhou (has lowest coupling collaborative degree) city respectively. The disparity of collaborative innovation in space was huge.

On the variation of the spatial pattern of collaborative innovation of inter-cities, the coupling collaborative degrees of cities in the YRD Urban Agglomeration have improved a lot from 2010 to 2016 (Fig. 4). However, the scale, density, and scope of the network have not shown any obvious extend. The coupling collaborative degrees of inter-cities of cities are not bad, and the restriction of administrative boundary on collaborative innovation to cities has decreased to some extent. The administrative boundaries restriction in the southern part of Jiangsu and the northern part of Zhejiang have decreased significantly. That is because with the integration of the YRD Urban Agglomeration enhanced a lot, innovation resources have a better circulation on the cross-administrative district. Moreover, through this circulation, the enclaves located between every two cities that were always undervalued in the past become important nodes that help the flow of complementary resources. Thus, the restrictions of administrative boundary on collaborative innovation in the YRD Urban Agglomeration have been reduced. Another notable finding show from Fig. 3 is that although geographical proximity is important to collaborative innovation, technology proximity seems to have the same importance on collaborative innovation. This can be traced to the phenomenon that strong collaborative innovation happens between cities that both have strong technology, while weak collaborative innovation happens between cities that are both weak in technology skills.

Comprehensively, it is obvious to see that the scale, density, and scope of the collaborative innovation network in the YRD Urban Agglomeration have been enhanced a lot from 2010 to 2016. Researchers found that innovation resources usually gather to the central city of innovation system first, and then begin with the second diffusion that from the central city to the sub-central cities (Brown and Cox, 1971; Pred, 1975; Salman and Saives, 2005; Mellett et al., 2009). Hence, as the central city in the collaborative innovation of the YRD Urban Agglomeration, Shanghai always absorbs the innovative resources first and then through the secondary diffusion spreads to sub-central cities (corresponding to Nanjing, Suzhou, Hangzhou, Ningbo, and Hefei). However, when innovative resources spread from the sub-central cities to their surrounding cities (corresponding to cities within Nanjing Metropolitan Circle, Suzhou-Wuxi-Changzhou Metropolitan Circle, Hangzhou Metropolitan Circle, Ningbo Metropolitan Circle, Hefei Metropolitan Circle), due to the constraint of their relatively lower innovation capacity the innovative resources may persistently preferential to these sub-central cities. Thus, this may result in serious regional disparities. That is why the capacity of the south of Anhui

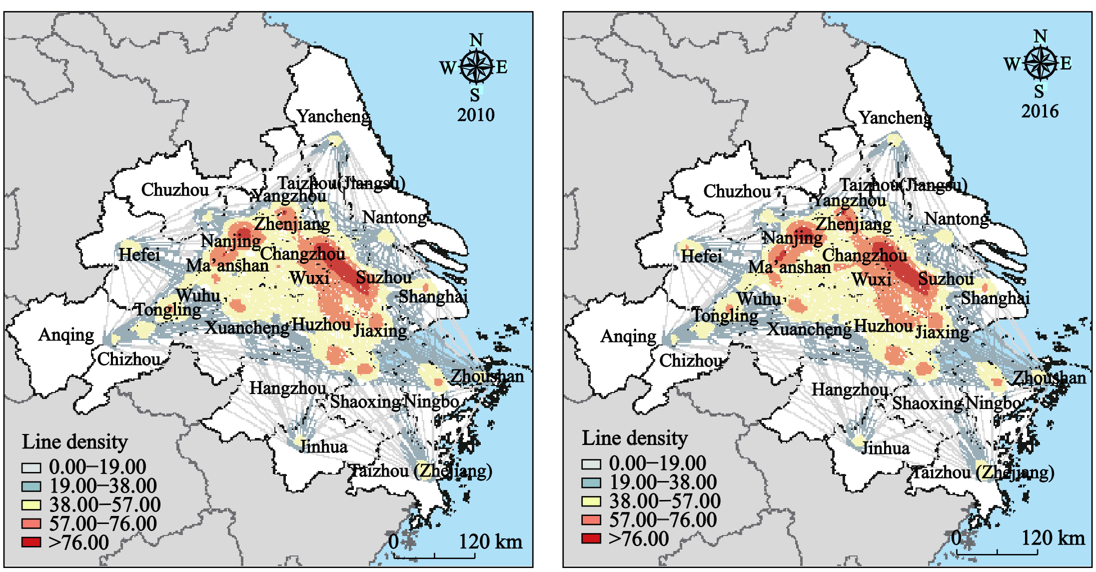

Fig. 4 Spatial pattern of collaborative innovation of inter-cities in 2010 and 2016

has been strengthened a lot, but cooperation among industries-universities-research institutes still needs to be pushed as much as possible. The main reason is that most innovation actors in the YRD Urban Agglomeration have strong independent innovation capacity, which causes them always to prefer self-dependence in innovation. Therefore, it results in little collaboration among industries-universities-research institutes and a lower conversion rate of technological achievements.

3.3 Benefit allocation of collaborative innovation

The analysis above clearly depicts the spatial pattern when every two cities take collaborative innovation activities in the YRD Urban Agglomeration. Whereupon, it may take the problem to the front that what is the impetus for cities to take collaborative innovation activities. It is easy to understand that collaborative innovation could create '1 + 1 > 2 effects' when two cities take collaborative innovation activities they can get much more benefits that can not be created only by one city. Hence, that the excessive benefits cities could get from collaborative innovation activities is one important determination. However, the allocation of excessive benefit between every two cities may not be the same. Thus, how cities allocate excessive benefits when they take collaborative innovation activities is another key point the paper wants to further illustrate. For this purpose, the paper uses the result of coupling collaborative degree and then adopts Equations (10)–(14) to calculate the benefit each city gets in collaborative innovation (Table 4). After the calculation and thorough analysis of the result in detail, the research finds that the results of benefit allocation between the central city and sub-central cities, sub-central cities, and their surrounding cities could approximately reflect the situation of the YRD Urban Agglomeration. The paper divides the calculation into four ranks: extremely low benefit (0–0.2), low benefit (0.2–0.4), general benefit (0.4–0.6), high benefit (0.6–0.8), extremely high benefit (0.8–1.0).

Comprehensively speaking, the benefit that each city gets from collaborative innovation activities has been enhanced significantly. Six pairs of cities rank at an extremely high benefit in 2016, while there are only three pairs in 2010. The significant increase occurred mainly between the sub-central city, sub-central city, and their surrounding cities, yet still needs to be enhanced for there are no pairs of cities reaching high benefit. From the total benefit, Shanghai and Nanjing, Shanghai and Suzhou, Shanghai and Hangzhou are the highest, with 0.669, 0.675, and 0.654 respectively. Zhoushan-Taizhou (Zhejiang) gets the lowest score, only 0.298. It is easy to find from the result that cities with higher collaborative innovation capacity usually seem to get more benefits. On benefit allocation and benefit ratio, the research finds that cities with higher collaborative innovation capacity have obvious advantages compared to cities with lower ones. The larger the capacity gap between them is, the more disparity of benefit allocation would be.

The greater the gap between them is, the more unbalance benefit allocation will be. That is because when cities take collaborative innovation activities, high-capacity cities usually have a stronger ability to absorb high-quality innovation resources. Whereas, cities with lower capacity have few advantages to attract innovation resources, thus resulting in lower benefit allocation. Another notable finding is that some cities such as Zhoushan, Ma'anshan have significant advantages in geographical location (they are geographically close to sub-Central Cities, and have fewer restrictions on administrating boundaries and cultural barriers with sub-Central Cities), and they should have more chances to engage in more collaborative innovation activities. However, due to the limitation of innovation capacity, these cities cannot load substantial innovation resources flowed from the relocation of industry. Thus, the possibility of these cities to take collaborative innovation activities has reduced a lot.

4 Discussion and Conclusions

4.1 Discussion

1) It is easy to find that the collaborative innovation capacity of innovation actors in the YRD Urban Agglomeration is still not high enough. Innovation actors prefer to take innovation activities by themselves, which may reduce the possibility of collaboration innovation (Etzkowitz and Leydesdorff, 2000). One of the important reasons is the imbalanced spatial configuration of innovation actors in the YRD Urban Agglomeration. For instance, universities and research institutes with strong scientific research strengths are located mainly in Shanghai and Nanjing, while enterprises such as high-tech enterprises and private enterprises are mainly located in Suzhou, Shanghai, Nanjing, Wuxi, Hangzhou,

Table 4 Benefit allocation and benefit ratio of collaborative innovation in 2010 and 2016

Metropolitan circle	City *A* and City *B*	2010				2016			
		S_{AOC}	S_{BOC}	S_{AOB}	Benefit ratio	S_{AOC}	S_{BOC}	S_{AOB}	Benefit ratio
Center and sub-center	Shanghai-Nanjing	0.349	0.330	0.679	1.060	0.356	0.344	0.699	1.034
	Shanghai-Hangzhou	0.347	0.326	0.673	1.064	0.338	0.316	0.654	1.068
	Shanghai-Suzhou	0.344	0.322	0.666	1.069	0.346	0.329	0.675	1.052
	Shanghai-Ningbo	0.308	0.268	0.576	1.149	0.310	0.274	0.585	1.130
	Shanghai-Hefei	0.307	0.266	0.573	1.153	0.323	0.294	0.618	1.099
	Nanjing-Hangzhou	0.299	0.298	0.597	1.004	0.310	0.300	0.610	1.033
	Nanjing-Suzhou	0.297	0.294	0.591	1.009	0.318	0.312	0.630	1.018
	Nanjing-Ningbo	0.266	0.245	0.511	1.084	0.285	0.260	0.545	1.092
	Nanjing-Hefei	0.264	0.243	0.507	1.088	0.297	0.279	0.576	1.063
	Hangzhou-Suzhou	0.294	0.292	0.586	1.005	0.292	0.297	0.589	0.985
	Hangzhou-Ningbo	0.263	0.243	0.506	1.080	0.262	0.248	0.509	1.057
	Hangzhou-Hefei	0.261	0.241	0.503	1.083	0.273	0.265	0.539	1.029
	Suzhou-Ningbo	0.260	0.242	0.501	1.075	0.272	0.254	0.526	1.074
	Suzhou-Hefei	0.258	0.240	0.498	1.078	0.284	0.272	0.556	1.045
Nanjing Metropolitan Circle	Nanjing-Zhenjiang	0.254	0.228	0.482	1.116	0.277	0.249	0.526	1.112
	Nanjing-Yangzhou	0.247	0.217	0.463	1.138	0.272	0.242	0.515	1.124
	Zhenjiang-Yangzhou	0.187	0.183	0.370	1.020	0.208	0.206	0.413	1.011
Suzhou-Wuxi-Changzhou Metropolitan Circle	Suzhou-Wuxi	0.279	0.272	0.551	1.026	0.288	0.278	0.565	1.036
	Suzhou-Changzhou	0.263	0.247	0.510	1.065	0.278	0.263	0.542	1.058
	Wuxi-Changzhou	0.246	0.237	0.484	1.038	0.254	0.249	0.503	1.021
Hangzhou Metropolitan Circle	Hanghzou-Jiaxing	0.244	0.215	0.458	1.134	0.248	0.226	0.474	1.096
	Hangzhou-Huzhou	0.234	0.201	0.436	1.163	0.233	0.205	0.438	1.140
	Hangzhou-Shaoxing	0.246	0.219	0.465	1.126	0.250	0.230	0.480	1.090
	Jiaxing-Huzhou	0.170	0.166	0.336	1.026	0.185	0.178	0.363	1.040
	Jiaxing-Shaoxing	0.179	0.180	0.359	0.993	0.198	0.199	0.397	0.994
	Huzhou-Shaoxing	0.168	0.173	0.341	0.968	0.179	0.188	0.367	0.956
Ningbo metropolitan Circle	Ningbo-Zhoushan	0.161	0.132	0.293	1.214	0.186	0.163	0.350	1.139
	Ningbo-Taizhou (Zhejiang)	0.190	0.175	0.365	1.087	0.202	0.187	0.388	1.081
	Zhoushan-Taizhou (Zhejiang)	0.116	0.130	0.247	0.895	0.145	0.153	0.298	0.949
Hefei metropolitan Circle	Hefei-Wuhu	0.180	0.161	0.341	1.118	0.226	0.210	0.436	1.078
	Hefei-Ma'anshan	0.178	0.158	0.336	1.127	0.209	0.184	0.392	1.136
	Wuhu-Ma'anshan	0.134	0.133	0.267	1.007	0.172	0.164	0.336	1.054

Notes: 1) Given the limited space available, Table 4 only lists the results of the central city and sub-central city, sub-central city, and their surrounding cites. 2) The division of the central city, sub-central city, Nanjing Metropolitan Circle, Suzhou-Wuxi-Changzhou Metropolitan Circle, Hangzhou Metropolitan Circle, Ningbo Metropolitan Circle, and Hefei Metropolitan Circle are referred from 'Development plan of the Yangtze River Delta Urban Agglomeration'

etc. Thus, solving the imbalance of spatial configuration may be one of the key points. Cities that lack high-quality universities can seek collaborative innovation activities from project cooperation, talent introduction policies, *etc*.; cities that are weak in industry innovation can absorb innovation resources to develop competitive industries, and at the same time improve the business environment. This may help to enhance the collaborative innovation of inter-actors and improve the technological innovation system of industries-universities-research institutes.

2) Moreover, most cities in the YRD Urban Agglom-

eration are weak in research and development, so their industry innovation is relatively low. Lower innovation capacity means lower attractiveness of various kinds of innovation resources. For most cities that rely on undertaking the industry's relocation from central cities, since they have neither enough capital nor have no matching infrastructure, it is quite hard for them to take the task. In this case, it is necessary to discover their local advantages to seeking cooperation with other technical enterprises and import the key sector of manufacturing and industry innovation settled. In addition, the restriction of administrative boundaries in collaborative innovation is also notable. The junctions of each administrative boundary have huge advantages in collaborative innovation, such as the G60 Science & Technology innovation valley of YRD Urban Agglomeration, and YRD Urban Agglomeration Hi-tech city located at the junction of Jinshan district in Shanghai and Pinghu in Jiaxing. These initiatives are attempting to make the enclaves that have always been the 'administrative isolated land' of regional economic development transformed into an innovative highland of technology.

4.2 Conclusions

(1) In brief, the collaborative innovation capacity of cities in the YRD Urban Agglomeration has been enhanced gradually, especially in Shanghai, the southern part of Jiangsu Province, and Hangzhou bay, *etc*. Although each innovation actors keep a high growth rate, the interaction of industries-universities-research institutes is still stagnated, which results in the low rate of commercialization of scientific and technological achievements.

(2) The scale, density, and scope of the collaborative innovation network have been enlarged significantly, and the restriction on administrative boundaries has been reduced, especially in the southern part of Jiangsu Province. In addition, in the spatial pattern of collaborative innovation of the YRD Urban Agglomeration, Shanghai plays the role of the central city, while Nanjing, Suzhou, Hangzhou, Ningbo, and Hefei hold the host of sub-central cities. These sub-central cities are in Suzhou-Wuxi-Changzhou Metropolitan Circle, Nanjing Metropolitan Circle, Hangzhou Metropolitan Circle, Ningbo Metropolitan Circle, and Hefei Metropolitan Circle respectively.

(3) The benefit each city allocated from collaborative innovation has increased. However, cities with higher collaborative innovation capacity can easily absorb high-quality innovation resources, so they usually have more advantages in benefit allocation. Hence, the spatial disparity of benefit allocation in the YRD Urban Agglomeration tends to become more and more serious.

(4) There are still some limits to this research. First, the research attempt to calculate the collaborative innovation in quantitation, which may not conclude all invisible collaborative innovation activities. Second, the paper only chooses two-time nodes. This is because, in 2010, the 'regional planning of the YRD Urban Agglomeration' clarified to build the YRD Urban Agglomeration as the world center of the modern manufacturing industry; in 2016, the 'development plan of the YRD Urban Agglomeration' placed the urban integration of the metropolitan circles in the YRD Urban Agglomeration. These two-time nodes can roughly depict the collaborative innovation in this period. Overall, this paper is an attempt to study regional collaborative innovation and may enlighten researchers on collaborative innovation in other regions or states.

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