BACKGROUND PAPER

Is City Innovation Accumulative?

Fushu Luan, Yang Chen, Ming He, and Donghyun Park

IS CITY INNOVATION ACCUMULATIVE?

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Abstract

Scientific progress and technology advance spillovers within and across linked cities over time. We use more than 5 million of citation pairs during 1985–2015 to calculate and map the innovation network in 7 macro areas, 31 provinces, and 289 cities in the People's Republic of China during 1985–2004. The pre-existing innovation network is interacted with past year patent growth to predict how closely the upstream invention links with the new innovation since 2005. The strong predictive power remains even when we account for the importance of invention and the policy uncertainty. A city innovates more with more past innovations to build upon.

Keywords

patents, innovation, network, policy

JEL Classification

O31, O53, R11

I. INTRODUCTION

Economic growth and long-term well-being is largely driven by technology innovation and knowledge creation. Economic historians identify and acknowledge that the essential feature of innovation process as being cumulative in the development of new technology, documenting how past successes and failures serve as devices that affect the pace and direction of future technological inquiry (Rosenberg 1976, Schmookler 1996, and Scotchmer 1990). This observation echoes Sir Issac Newton's earlier description of "standing on the shoulders of giants"[1] and has been widely documented in the economics of innovation literature (Hall and Harhoff 2012 and Galasso and Schankerman 2015).

Though some studies provide empirical evidence supporting this viewpoint emphasizing that technology advance in one sector or one technology field rests on prior invention (Williams 2010 and Burman and Stern 2011), there is a paucity of research looking at whether and how recent innovation links with past accumulation and how information diffuses across space and over time from a geographical perspective. Specifically, we are interested to explore (i) the network structure of information flow that accompanies the creation of new knowledge and ideas from each of these regions to all the others, (ii) how closely the connected past year upstream invention within and across regions shapes the current innovation in the focal area, and (iii) if the importance of invention in different areas is heterogeneous and to what extent the variation of invention importance facilitates the growth of follow-on innovation.

Our analysis follows the endogenous growth model in technological innovation where the flow of new ideas depends on the stock of ideas and inputs that are used to produce these ideas (Acemoglu, Akcigit, and Kerr 2016). The stock of ideas matters as Meisenzahl and Mokyr (2012) have described that follow-on innovation to a larger extent improved, debugged, adapted to uses, or combined into new applications a myriad of small and medium cumulative micro inventions. The inputs used to produce ideas could be human capital, physical capital, intellectual or knowledge capital possessed by individuals, production units, research institutions, and government agencies. The flow of tangible or intangible inventive ingredients through mobility of labor and capital facilitates the spillover of technology and knowledge from one to the other regions and propels the formation of closely linked innovation network.

At regional level, Wang, Ning, Li, and Prevezer (2014) explore the geography of city innovation in the People's Republic of China (PRC) within a spatial panel regression

[1] Sir Issac Newton himself acknowledged, "If I have seen far, it is by standing on the shoulders of giants."

analysis and find the externalities of local knowledge spillovers are not confined to the region; similar results are derived from the Organisation for Economic Co-operation and Development regions and the European Union. (Moreno, Paci, and Usai 2005; and Usai 2011). However, they fail to capture how information and ideas flow from one to the each other which leads to their results. Climbing atop of their shoulders we open this black box using patent citations to calculate the innovation network which identifies the strength of spillovers in inventive activities across regions and aids our understanding of innovation geography.

We analyze 3.6 million patents in the PRC during 1985–2015 to track the information flow of technology and knowledge and construct more than 5 million citation pairs. This large invention sample is used to calculate the citation matrix and map the innovation network in 7 macro areas, 31 provinces, and 289 cities, respectively. Specifically, we calculate the weighted in-degree, out-degree, closeness, and betweenness centrality to measure the importance of innovation in each city across different time periods.[2] We find that in the innovation network some cities are major inventors with higher in-degree centrality. These cities work in macro inventions and dedicate to bring major technological breakthroughs. A few cities play the tweaker's role in the sense that they have the workman and resources to improve and debug an existing invention and these cities have higher out-degree centrality as well as closeness centrality and betweeness centrality. Other cities are implementers with skilled workmen capable of constructing, installing, operating, and maintaining complex equipment and devices and these cities have the lowest in-degree centrality, closeness, and betweenness centrality but highest out-degree centrality.

We suppose that new invention in a focal city rests on past innovations from her own and all other cities (complete network) through the well-depicted innovation network. Therefore, using the pre-existing city innovation network interacted with the past patent growth in each of these cities we construct the measure of upstream invention. We then predict how closely the upstream invention (1995–2004) predicts the follow-on innovation in the focal city (2005–2015). In the baseline fixed-effect estimation 82% of the variation of new invention in the focal city could be explained by variation of the upstream invention.

We also identify that innovation importance enhances the focal city's inventive capacity and strengthens the upstream-downstream linkage. Accounting for policy uncertainty and using only the external network analysis do not change these main results. Speaking to the questions with regard to innovation network and its predictive power on new downstream

[2] We consider patents published during 2005–2014 (the third 10-year in our sample) citing that of 1995–2004 (the second 10-year), patents of 1995–2004 (the second 10-year) citing that of 1985–1994 (the first 10-year) and the patents of 2005–2014 (the third 10-year) citing that 1985–1994 (the first 10-year).

invention, we offer fresh quantitative evidence which well informs the innovation practitioners, academic researchers and policy makers in understanding the regional innovation network structure, identifying key regional innovators in the regional innovation system and allocating private and public research and development funds efficiently.

Section II describes the data and explains how variables are constructed using patent data. Section III presents the network analysis. The main results are shown in section IV where we consider cases of complete and external network in predicting the downstream innovation. Section V discusses the main results and provides concluding remarks with policy implications.

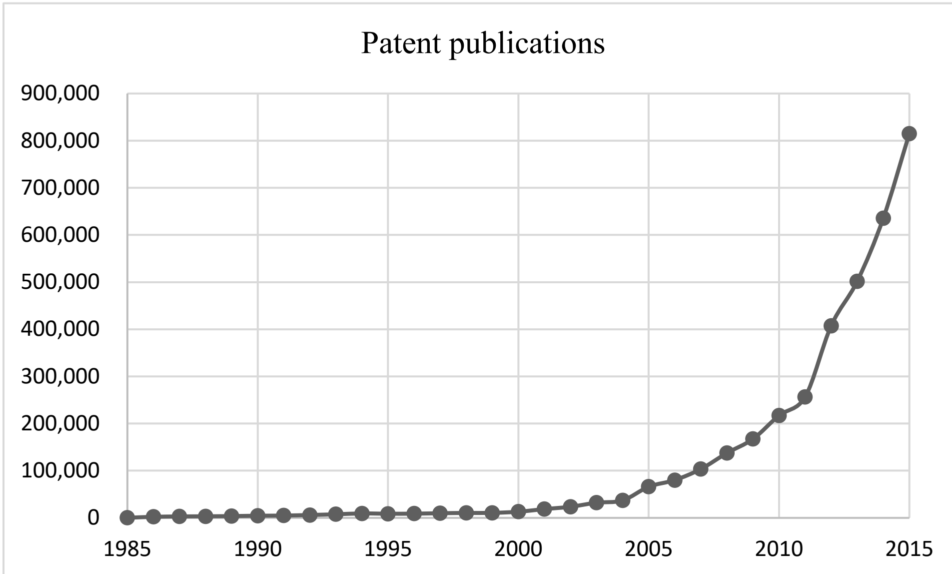
II. DATA AND VARIABLES

A. Data

We compile the patent data from the State Intellectual Patent Office in the PRC and include data for 3,607,466 patents in the PRC between 1985 and 2015. This dataset contains rich information for each patent's application and publication information such as the patent application and publication number, the application and publication date, the applicant's name and address, as well as the important citation information. Since the citation is based on each patent's publication number, we thus construct the patent citation pairs using their publication information.

Figure 1 presents the number of patent publications from 1985 to 2015 on a continuous rising trend. The size of patents starts to take off from 2000, increasing from approximately 13,000 in 2000 to 220,000 in 2010, a nearly tenfold growth. The growth is even faster within the most recent decade. Innovation outputs in the PRC have exploded since 2010, reaching more than 800,000 in in 2015, which is more than the aggregated patent publications in the first 25 years within 1985–2009.

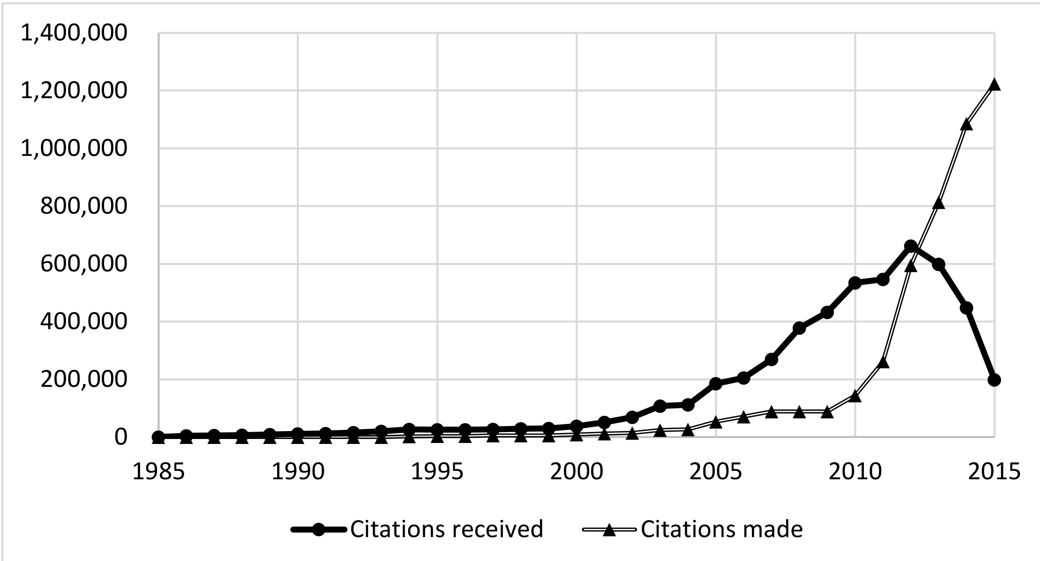
Figure 1: Number of Patent Publications during 1985–2015



Source: National Intellectual Property Administration (1985-2015).

We obtain 5,083,049 pairs of patent citations during 1985–2015 across cities using citation information. These more than five million pairs of patent citations are used to create the variables of interests to test our hypotheses. Figure 2 presents citations made and received from 1985 to 2015. The number of citations made climbs in the 11th and 12th 5-year plan periods when Government of the PRC issues a series of policies to promote innovation. The figure also shows a truncation effect around 2012 on citations received.

Figure 2: Citations Made and Received by Publication Year



Sources: National Property Administration (1985-2015); authors' calculations.

B. Descriptions of the Main Variables

We use the Amap application to geocode each patent's address information to identify in which city that patent is created. Next we aggregate patents published in the same city to measure city-specific innovation outputs. To analyze whether and to what degree a city's innovation depends on the upstream accumulative inputs across cities and over time, we combine the pre-existing innovation network structure and the past invention to construct the upstream innovation. We also account for the impact of the time-variant city-specific innovation quality modelled by three main centrality indices.

1. Upstream Innovation

We model the upstream innovation by combining both the rate of knowledge and technology spillover and the previous invention outputs. The external upstream innovation of city i in year t is defined as:

$$\hat{P}_{it} = \sum_{k \neq i} \sum_{a=1}^{10} CiteRate_{i \to k,a} P_{k,t-a} \quad (1)$$

where $P_{k,t-a}$ is the patenting in city k $(k \neq i)$ at a diffusion lag a from the year t[3].

[3] For the complete upstream innovation calculation, the first summation term includes $k = i$, while the case of $k \neq i$

Following Acemoglu, Akcigit, and Kerr (2016), we construct the citation network matrix to capture the rate of knowledge spillovers which varies across cities:

$$CiteRate_{i \to i',a} = \frac{Cit_{i \to i',a}}{Pat_{i'}} \quad (2)$$

where $CiteRate_{i \to i',a}$ is the rate at which patents in city i cite patents in i' for each of the first ten years (diffusion lag: $a = [1,10]$) after the latter's invention; $Cit_{i \to i',a}$ is the number of patent citations received by city i' from city i with a time lag a; $Pat_{i'}$ is patent counts in city i' for each of the first ten years. The rate of knowledge and technology spillover rests on the invention age and its diffusion lag.

2. City-Specific Innovation Centrality Indices

In the innovation network, we regard each city as a node and they are connected by an edge through the link of patent citations. Following Freeman (1978), the centrality concept of an innovation network is built by applying three classic centrality measures of node: the degree centrality, the closeness centrality, and the betweenness centrality. The calculation of centrality takes the direction of patent citations into consideration.

The weighted degree centrality focuses on the number of connections between nodes to measure the involvement and strength of a node in the weighted directed network. Specifically, the weighted degree centrality (Estrada and Bodin 2008) for a node v_i is formalized as:

$$C_{WD}(v_i) = \sum_{j=1}^{J} \omega_{ij} a(v_j, v_i)$$

where $a(v_j, v_i) = 1$ if and only if v_j and v_i are connected by a line and 0 otherwise; ω_{ij} is the number of lines that v_j and v_i are connected. Generally, nodes with a higher degree or more connections with others are more central in the network structure relative to others and tend to have a greater ability to influence others. Larger value of $C_{WD}(v_i)$ implies the node v_i has direct contacts with packs of other nodes. In our case, the higher the weighted degree centrality for a city, the higher impacts are generated from city i's invention. Considering the direction of citation flows, we use the weighted in-degree centrality to measure which cities' invention are cited most over time and the weighted out-degree centrality to evaluate how a city's innovation relies on other cities' invention outputs.

The degree centrality depicts the innovation links among cities, while it fails to measure how fast knowledge and technology diffuses from one to the other (Borgatti 2005). We,

is considered in the external network only.

therefore, account for the closeness centrality that measures the average shortest-path distance from a focal node to all the others, based on which we can tell which cities are most in need of support from the others in the whole innovation network. The closeness centrality (Beauchamp 1965) of a node v_i is defined as:

$$C_C(v_i) = \frac{n-1}{\sum_{j=1}^{J} d(v_j, v_i)}$$

where $d(v_j, v_i)$ is the distance between two nodes in the network, and the summation expression calculates distances from v_i to all the other nodes. The closeness centrality focuses on the extent of influence over the entire network. The node that is closest on average to the rest is spatially represented at a central position. The higher the closeness centrality, the faster the knowledge spreads from one place to the others in the network.[4]

In addition to the degree and closeness centrality, we are concerned with a city's intermediary role in facilitating knowledge and technology spillover. We thus use the betweenness centrality (Freeman 1978 and Brandes 2001) to count the number of shortest paths between two other nodes passing through a specific node:

$$C_B(v_i) = \sum_{i \neq j, i \neq k, j \neq k} d_{k-i-j}$$

where d_{k-i-j} considers all geodesics linking node k and node j that pass through node i. If these paths are regarded as channels for knowledge diffusion, the nodes sitting on multiple paths are the key linking points. In our context, cities with a higher betweenness centrality play more pivotal intermediary role to diffuse information through the citation network.

3. Policy Uncertainty

To control for policy uncertainly that might affect city innovation, we manually collect the name list of party secretaries in each city from Baidu encyclopedia and scrape their curriculum vitaes to get their turnover information across cities. Specifically, turnover is constructed using the number of replacements of party secretary for a specific city-year pair to proxy local policy uncertainty. If turnover=0 there is no change of the local leader and the innovation-related policy uncertainty is minimized; if turnover=1 the party secretary is replaced by another one and the policy uncertainty would greatly increase. The descriptive statistics for the main variables are summarized in Table 1 from which we can see that the mean of turnover is about 26% implying on average a lower local policy uncertainty.

[4] This measure is not applicable to networks with disconnected components since nodes belongs to different components are assumed to have infinite distance between them (Opsahl et al. 2010).

Table 1: Descriptive Statistics

Main Variables	Obs	Mean	Std. Dev.	Min	Max
Number of patents	3,729	904.58	3716.75	0	79722
Upstream_complete	3,729	253.75	1434.40	0	43625
Upstream_external	3,729	181.68	905.00	0	26424
Weighted_indegree_complete	3,729	1200.76	6597.53	0	165485
Weighted_indegree_external	3,729	939.81	4771.18	0	112349
Weighted_outdegree_complete	3,729	1200.76	5965.94	0	154720
Weighted_outdegree_external	3,729	939.81	4162.95	0	97861
Closeness_centrality_complete	3,729	0.53	0.15	0	1
Closeness_centrality_external	3,729	0.53	0.15	0	0.98
Betweenness_centrality_complete	3,729	263.16	890.36	0	18182
Betweenness_centrality_external	3,729	263.16	890.36	0	18182
Policy_stability	3,700	0.26	0.44	0	2

Source: Authors' calculations.

III. The Network Analysis

In this section, we map and visualize the innovation structure using city-to-city citation data, and analyze if the pre-existing network properties are stable over time. The stability condition enables us to use the pre-existing network properties to construct the upstream innovation.

We start the network analysis from a macro-regional perspective dividing all cities in the PRC into seven regions—the East, the North, the South, the Center, The Southwest, the Northeast and the Northwest. Second, we use the heat map to construct the citation matrix across provinces, and next we plot the innovation centrality of cities in the innovation network map across multiple periods.

Table 2 presents the intra- and inter-regional patent citations in the full time period from 1985 ro 2015, patents in the third 10-year (2005–2014) citing patents in the first 10-year (1985–1994), patents in the second 10-year (1995–2004) citing patents in the first 10-year (1985–2004) and patents in the third 10-year (2005–2014) citing patents in the first 10-year (1985–1994). In the full time period (Panel A), the eastern region produces patents that have the highest number of intra- and inter-regional citations received and made and

invention in the northwest has the least amount of citations in all periods. As compared with other regions, we find that the northwest has the largest share of inter-regional citations made and received as compared with other regions which implies that the innovation capacity in this area is largely sourced from other areas.

Looking at the citations patterns in panels B, C, and D, it shows that ceteris paribus the inter-regional citations made of patents in the north exceeds that of the east since the second 10-year. Comparing Panel C and Panel D, we find that invention in the second 10-year (1995–2004) generated from the northwest, southwest and northeast regions have a significant rise in terms of the inter-regional citations received than that of the first 10-year (1985–1994).

Table 2: Intra- and Inter regional Patent Citations across Different Time Periods

Region	Citing					Cited				
	total	intra	inter	intra%	inter%	total	intra	inter	intra%	inter%
	Panel A: Full Time Period, 85-15									
East	1961426	1030945	930481	52.56	47.44	1794813	1030945	763868	57.44	42.56
North	869895	348752	521143	40.09	59.91	979768	348752	631016	35.60	64.40
South	732183	285274	446909	38.96	61.04	715204	285274	429930	39.89	60.11
Center	338530	83066	255464	24.54	75.46	356288	83066	273222	23.31	76.69
Southwest	315899	73293	242606	23.20	76.80	291006	73293	217713	25.19	74.81
Northeast	243218	67133	176085	27.60	72.40	311859	67133	244726	21.53	78.47
Northwest	164884	37191	127693	22.56	77.44	177097	37191	139906	21.00	79.00
	Panel B: Patents of 05-14 Cites that of 85-94									
East	15626	7519	8107	48.12	51.88	25117	7519	17598	29.94	70.06
North	16040	3792	12248	23.64	76.36	10886	3792	7094	34.83	65.17
South	3342	728	2614	21.78	78.22	6230	728	5502	11.69	88.31
Center	7245	1078	6167	14.88	85.12	6106	1078	5028	17.65	82.35
Southwest	5809	955	4854	16.44	83.56	5166	955	4211	18.49	81.51
Northeast	9553	1273	8280	13.33	86.67	4885	1273	3612	26.06	73.94
Northwest	3498	313	3185	8.95	91.05	2723	313	2410	11.49	88.51
	Panel C：Patents of 95-04 Cites that of 85-94									
East	8415	2944	5471	34.99	65.01	9293	2944	6349	31.68	46.37
North	9401	3100	6301	32.98	67.02	8688	3100	5588	35.68	55.48
South	2166	413	1753	19.07	80.93	2792	413	2379	14.79	17.36
Center	4524	849	3675	18.77	81.23	4177	849	3328	20.33	25.51
Southwest	3308	751	2557	22.70	77.30	3616	751	2865	20.77	26.21
Northeast	5666	1375	4291	24.27	75.73	4986	1375	3611	27.58	38.08
Northwest	2064	310	1754	15.02	84.98	1992	310	1682	15.56	18.43
	Panel D: Patents of 05-14 Cites that of 95-04									
East	107861	53232	54629	49.35	50.65	144896	53232	91664	36.74	63.26
North	101962	33133	68829	32.50	67.50	77733	33133	44600	42.62	57.38

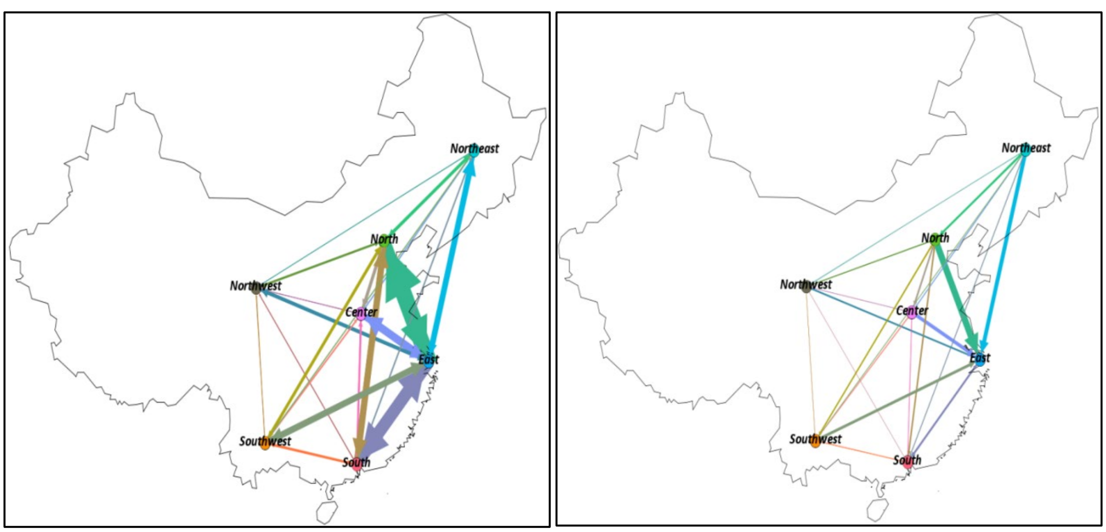
South	48145	19173	28972	39.82	60.18	57125	19173	37952	33.56	66.44
Center	40128	11037	29091	27.50	72.50	35162	11037	24125	31.39	68.61
Southwest	27009	5645	21364	20.90	79.10	26384	5645	20739	21.40	78.60
Northeast	41143	7324	33819	17.80	82.20	26733	7324	19409	27.40	72.60
Northwest	16350	2442	13908	14.94	85.06	14565	2442	12123	16.77	83.23

Notes: The definitions of the seven macro regions are given in Table A1 in the Appendix. The time period covers patent citation from 1985 to 2015. The first 10-year is from 1985 to 1994; the second 10-year is from 1995 to 2004, and the third 10-year is from 2005 to 2014.

Source: Authors' calculations.

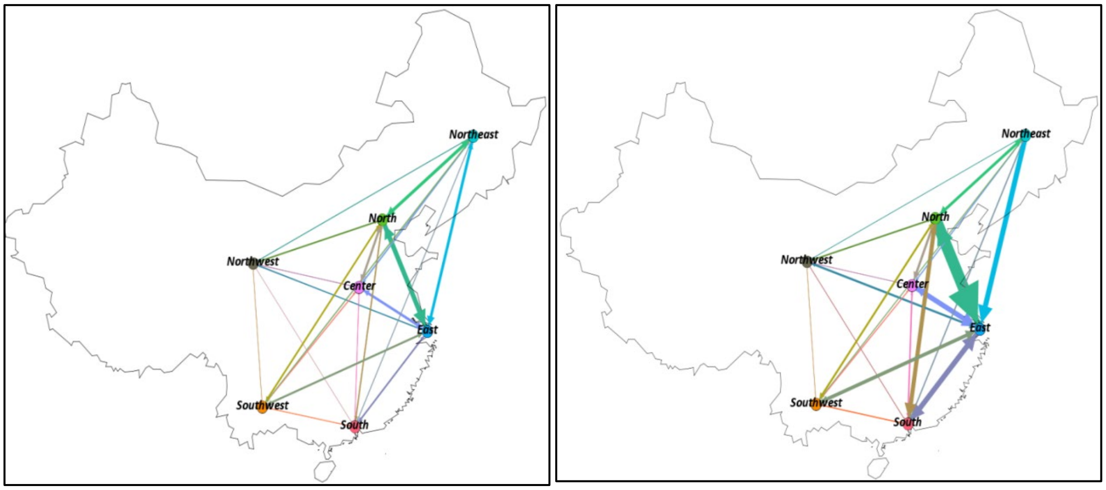
In Figure 3 we plot the inter-regional citation pairs across the seven macro regions in multiple time periods with different colors. The thicker the lines, the more citations are produced from the pairs of connected regions. The north with Beijing as the innovation center, the east with Shanghai as the innovation center and the south with Guangzhou and Shenzhen as the invention bases are the three with the most intensive inter-regional patent citation linkages. The northeast pair has the largest size of mutual citations, followed by the east-south, east-center and north-south citation pairs. The fewer citations between the north and south, the northeast and the south, the northeast and the northwest suggest that the diffusion of knowledge might partially be negatively affected by geographic distances.

Figure 3: Inter-regional Patent Citations across Multiple Periods



(a) Full time Period, 85-15

(b) Patents of 05-14 Cites that of 85-94



(c) Patents of 95-04 Cites that of 85-94 **(d) Patents of 05-14 Cites that of 95-04**

Sources: National Intellectual Property Administration; authors' calculations.

After analyzing the intra- and inter-regional citation patterns, we then construct the patent citation matrices across 31 provinces covering the full time period from 1985 to 2015 and present the heat map in Figure 4.[5] Each row shows the proportion of citations made by the citing provinces and each column represents the proportion of citations received by the cited provinces. The darker the color, the higher ratio of citation is made in the colored cell. The block diagonals indicative of within-province citations usually have darker colors than the non-diagonal cells of inter-province citations. Invention in provinces of Guangdong and Beijing in blue is associated with the largest percentage of intra-province citations, followed by Jiangsu and Shanghai in purple. Figure 4 also shows a pattern of agglomeration of citation received in a few provinces. The majority of citations received concentrates in six developed provinces—Beijing, Guangdong, Jiangsu, Shandong, Shanghai, and Zhejiang. Invention originated in these six provinces are heavily cited by all the other provinces in the PRC.

Figure 5 presents a more detailed across-province innovation network at the provincial level. All three panels demonstrate a striking diamond structure inclusive of Beijing, Sichuan, Guangdong, and Shanghai being the four largest vertices in the innovation network. With the Beijing–Guangdong citation link as the axle wire the diamond further evolves into two citation triangles. To the east of the axle wire, the Beijing-Shanghai–Guangdong citation triangle contains seven smaller circles including Jiangsu and Zhejiang emerging as smaller nodes linking with other provinces; to the west axle wire, we have

[5] We also construct similar citation matrices across other time periods and present in the Appendix Figures A1.1–A1.3.

another citation triangle formed connecting Beijing, Sichuan, and Guangdong and through smaller nodes of Shannxi, Sichuan, and Hubei provinces.

After mapping the regional and provincial innovation network, we proceed using the city-to-city citation pairs to explore the network properties modelled by three centrality indices. Table 3 lists the top 15 cities that have the highest number of citations made and received across various time periods[6]. Most of them are as expected the provincial capitals such as Nanjing (the capital city of Jiangsu), Hangzhou (the capital city of Zhejiang), Guangzhou (the capital city of Guangdong), Wuhan (the capital city of Hubei), Chengdu (the capital city of Sichuan), Changsha (the capital city of Hunan), Shenyang (the capital city of Liaoning), Harbin (the capital city of Heilongjiang), Jilin (the capital city of Changchun), Xi'an (the capital city of Shannxi), and Shijiazhuang (the capital city of Hebei). Among the four centrally-affiliated cities, the citations made and received in Chongqing as compared with Beijing, Shanghai and Tianjin is much weaker and not listed into the top 15. Notably, there are three noncapital cities that produce highly influential invention: Shenzhen, Suzhou, and Dalian. Dalian has been ranking the 11th in the citation received during the first 10-year study period; Shenzhen's ranking has been significantly increased to the third in terms of both citations made and received during the second 10-year and Suzhou has been a rising star in patents citing and patents cited during the most recent decade.

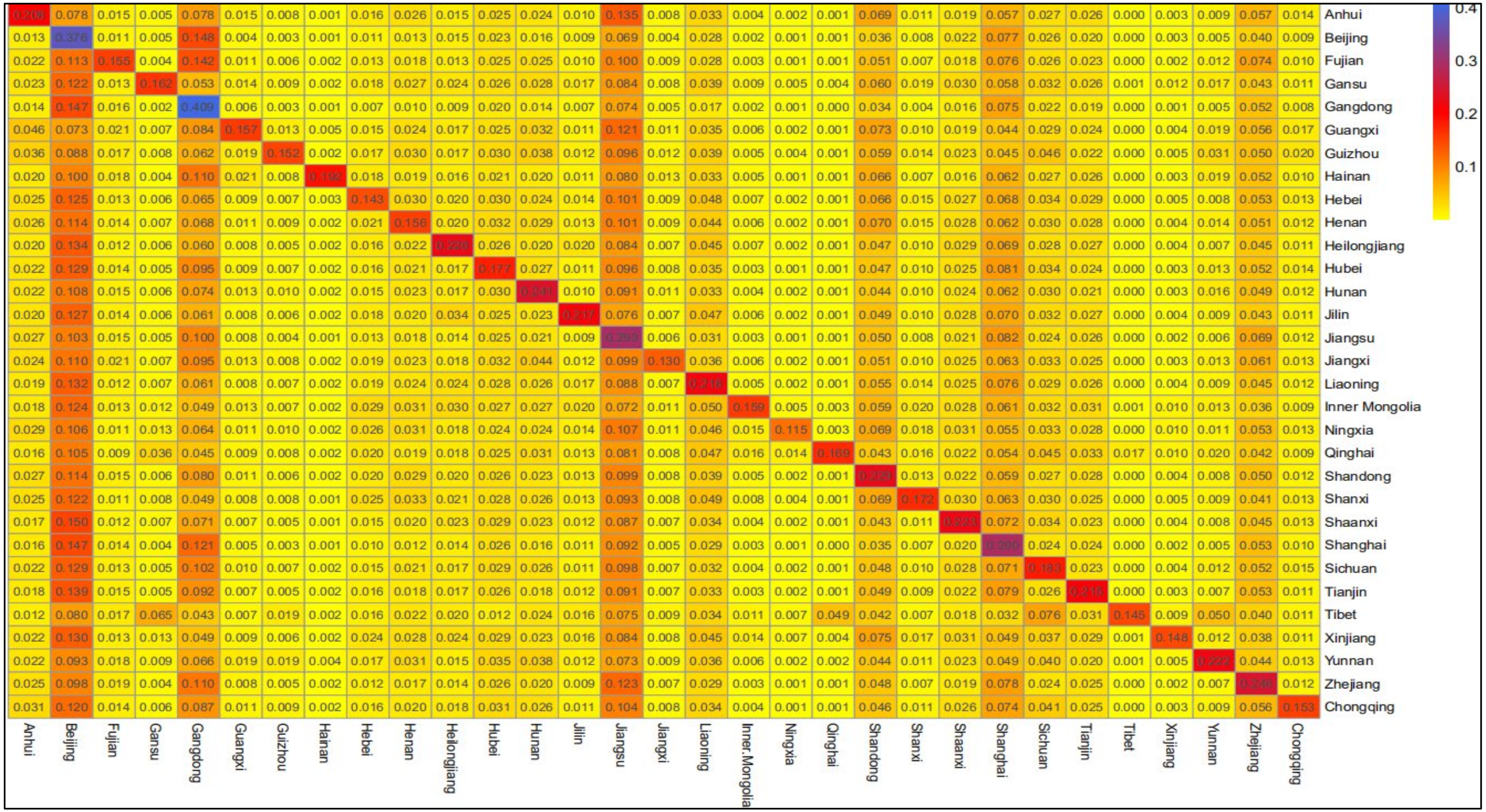
Figure 6 maps the weighted in-degree and out-degree centrality for all cities. Consistent with Table 3, the larger nodes such as Beijing, Shanghai, Guangzhou, and Shenzhen with more citations made and received have higher values of centrality than other cities. Figure 7 plots the closeness and betweenness centrality. From Figure 7(a), we identify that Beijing and Chengdu are the two super-spreaders of technology and knowledge information and next to them are cities of Shanghai, Tianjin, Jinan, Chongqing, Qingdao, Guangzhou, Wuhan, Suzhou, and Nanjing. These cities are among the top 10 measured by the values of closeness centrality. The cities with the lowest values are largely located in the western provinces such as Qinghai, Xinjiang, Tibet, and Yunnan provinces. The standard deviation of the closeness centrality calculated using the full-period citation data is about 0.12 which tells that the information diffusion speed across cities does not have a significant variation. In contrast, great variability of between centrality are shown from Figure 7(b) which measures the degree of control over information flowing from or to a specific node in the innovation network. Specifically, Chengdu surpasses Beijing in the control over

[6] The top 15 cities ranked by centrality measures are presented in the Appendix Table A2.

information as the vertex of the highest betweenness. In 29 provinces, the capital cities as expected have the highest information control. The cases are different in the provinces of Shangdong and Guangxi. In Shandong, the coastal city of Qingdao has replaced Jinan as the largest technology broker; in Guangxi, the city of Liuzhou has replaced Nanning in controlling information flow. And notably, though the city of Suzhou has a larger in- and out-degree centrality and closeness centrality, its betweeness centrality is relatively lower than the other two noncapital cities Nantong and Zhenjing. Through the analysis of these network properties, we could identify the key nodes (players) in the innovation networks and quantify the degree of their influences in invention, the average length of citation and the control of information flow. The results well inform policy makers in identifying and nurturing city leaders in building the innovative clusters considering different targets—invention influence, knowledge diffusion and information control.

We also map the innovation networks across multiple time periods and present them in the Appendix Figures A3.1–A3.6 considering patents in the third 10-year (2005–2014) citing that of the first 10-year (1985–1994), patents in the second 10-year (1995–2004) citing that of the first 10-year (1985–1994), and patents in the third 10-year (2005–2014) citing that of the second 10-year (1995–2004).

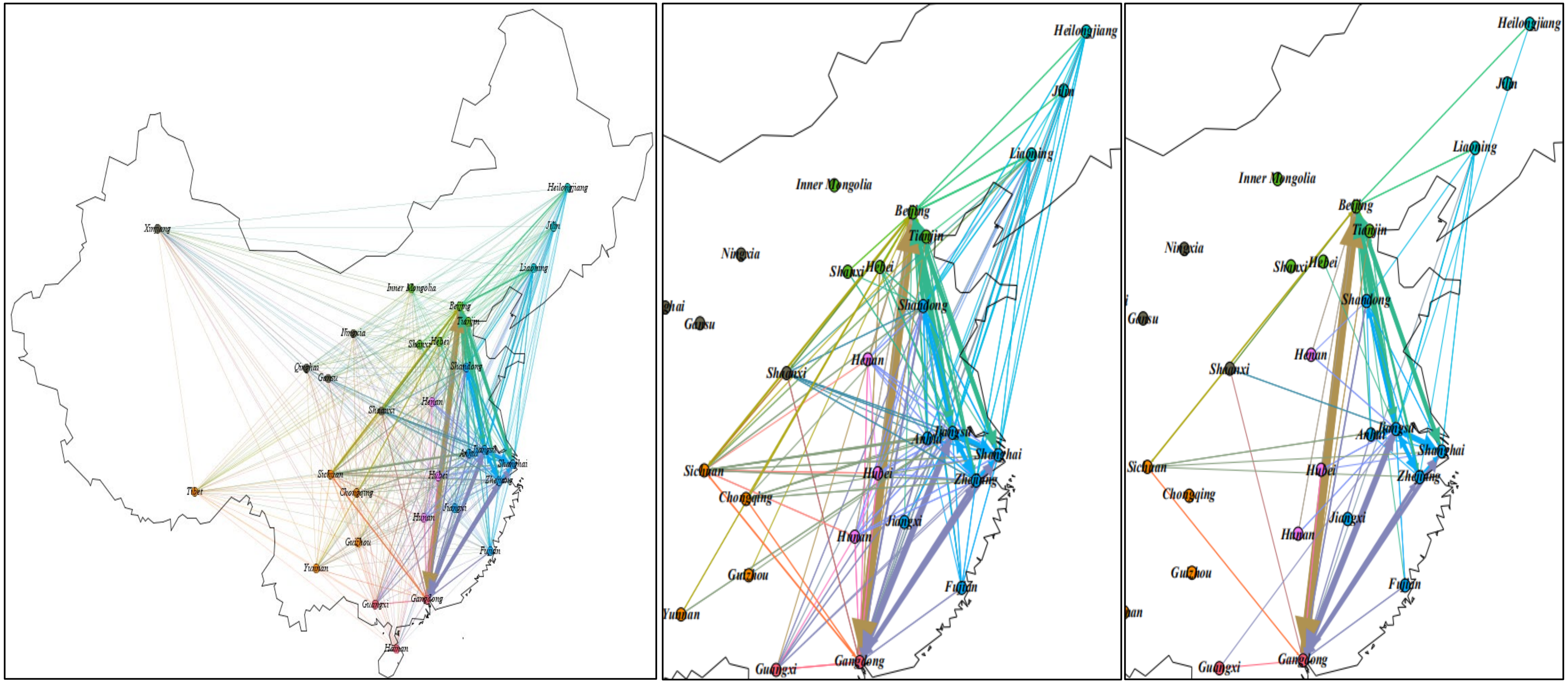
Figure 4: Citation Matrix across 31 Provinces, Full Time Period (1985–2015)



Notes: Each row includes the ratio of citation made for the citing provinces. Each column includes the ratio

Sources: National Intellectual Property Administration; authors' calculations.

Figure 5: External Innovation Network at the Provincial Level, Full Time Period



(a) (b) (c)

Notes: Panels (a), (b), and (c) display the case of the external patent citations at the provincial level with different thresholds, where panel (a) includes the full set of citations. To improve the readability and avoid having too many arrows, we only display edges for cities of patent cites larger than the threshold of 3239 (at least above 80% of the total province-to-province citations) and 8574 units (60% of the total) are displayed in panel (b) and (c), respectively. The provincial names are labelled in each map. The color of the nodes represents different provinces. Arrows display the color of the province of citation made (origin).

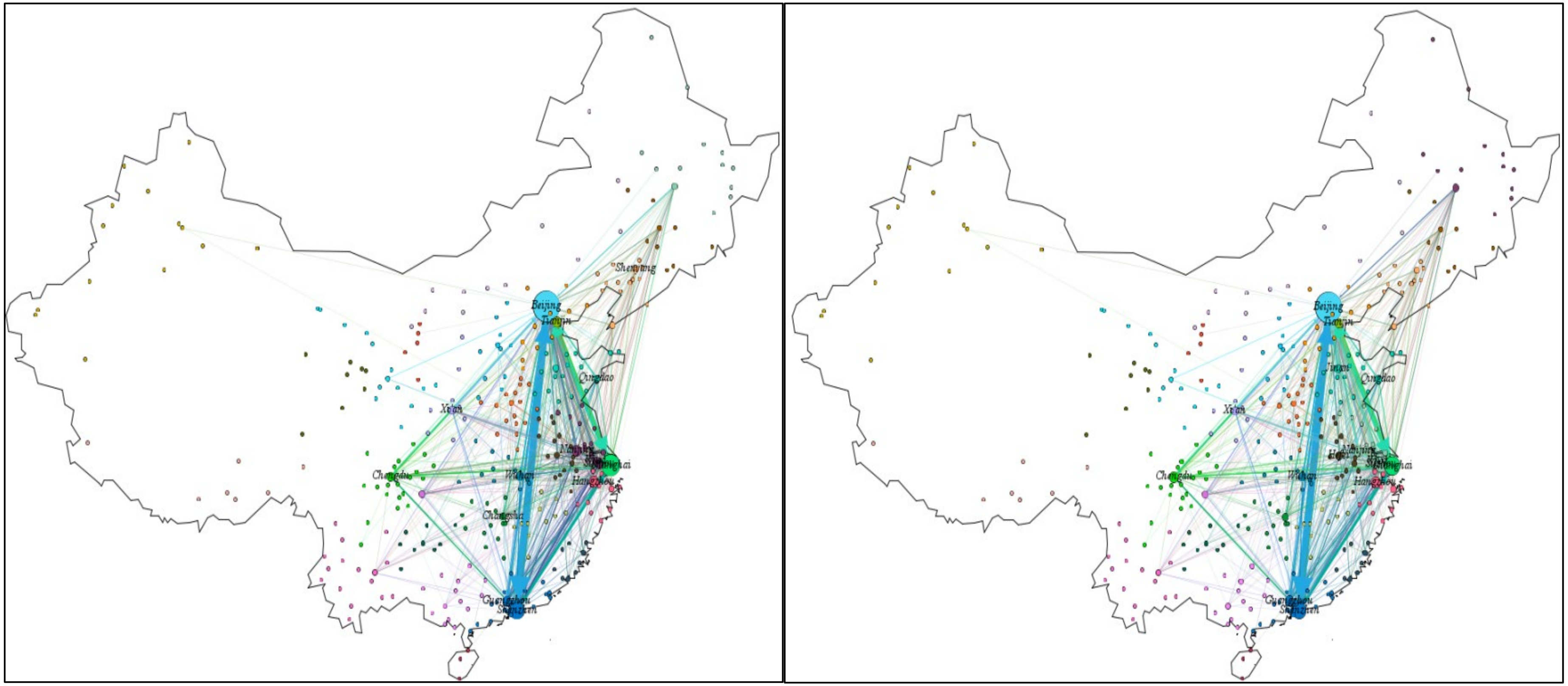
Sources: National Intellectual Property Administration; authors' calculations.

Table 3: Top 15 Cities Based on Number of Citations across Different Time Periods

Period	Full Time Period		05-14 Cites 85-94		95-04 Cites 85-94		05-14 Cites 95-04	
Rank	**Citing**	**Cited**	**Citing**	**Cited**	**Citing**	**Cited**	**Citing**	**Cited**
1	Beijing	Beijing	Beijing	Beijing	Beijing	Beijing	Beijing	Beijing
2	Shenzhen	Shanghai	Shanghai	Shanghai	Shanghai	Shenyang	Shanghai	Shanghai
3	Shanghai	Shenzhen	Suzhou	Shenyang	Shenyang	Shanghai	Shenzhen	Shenzhen
4	Suzhou	Nanjing	Hangzhou	Tianjin	Chengdu	Tianjin	Hangzhou	Tianjin
5	Nanjing	Hangzhou	Nanjing	Chengdu	Wuhan	Chengdu	Nanjing	Wuhan
6	Hangzhou	Suzhou	Chengdu	Nanjing	Tianjin	Wuhan	Tianjin	Guangzhou
7	Guangzhou	Guangzhou	Tianjin	Wuhan	Guangzhou	Nanjing	Changsha	Changsha
8	Chengdu	Tianjin	Shenzhen	Xi'an	Harbin	Guangzhou	Guangzhou	Nanjing
9	Tianjin	Wuhan	Guangzhou	Changsha	Nanjing	Harbin	Suzhou	Chengdu
10	Wuhan	Chengdu	Xi'an	Guangzhou	Dalian	Xi'an	Chengdu	Shenyang
11	Xi'an	Xi'an	Wuhan	Dalian	Kunming	Dalian	Wuhan	Hangzhou
12	Wuxi	Wuxi	Jinan	Harbin	Xi'an	Changsha	Xi'an	Xi'an
13	Jinan	Changsha	Qingdao	Hangzhou	Hangzhou	Hangzhou	Jinan	Dalian
14	Qingdao	Harbin	Changsha	Jinan	Changsha	Jinan	Qingdao	Changchun
15	Hefei	Shenyang	Wuxi	Changchun	Changchun	Shijiazhuang	Harbin	Harbin

Sources: National Intellectual Property Administration; authors' calculations.

Figure 6: Weighted Degree Centrality at the City Level, Full Time Period

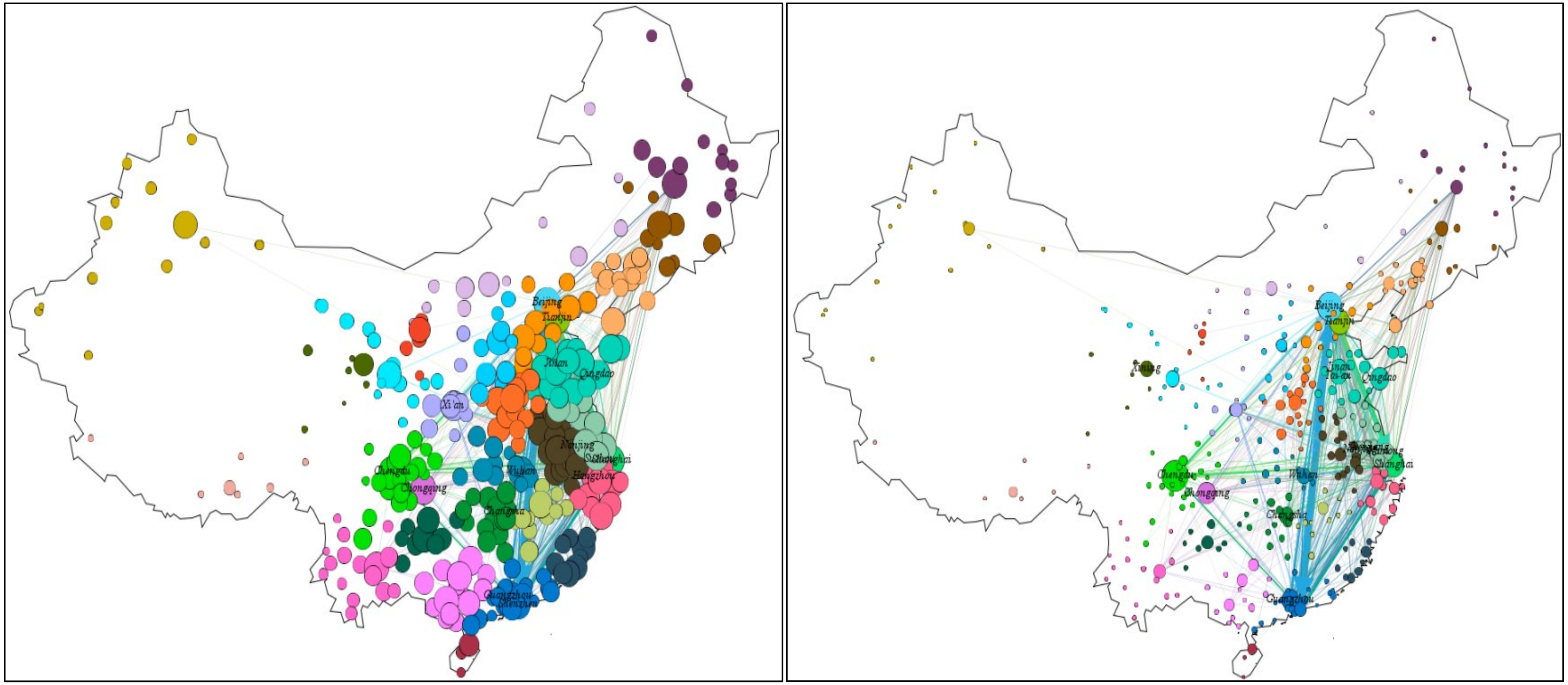


(a) Weighted in-degree centrality **(b) Weighted out-degree centrality**

Notes: Panels (a) and (b) compare the case of the weighted in-degree centrality (cited) versus weighted out-degree centrality (citing). To improve the readability and avoid having too many arrows, we only display edges for cities with patent cites larger than the threshold 482 units (at least above 60% of the total city-to-city citations) are displayed. According to the values of centrality in each case, the names of top fifteen cities are labelled in each map. The color of the nodes represents different provinces. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Figure 7: Closeness Centrality and Betweenness Centrality at the City Level, Full Time Period



(a) Closeness centrality **(b) Betweenness centrality**

Notes: Panels (a) and (b) compare the case of the closeness centrality versus betweenness centrality. To improve the readability and avoid having too many arrows, we only display edges for cities with patents cite larger than the threshold 482 units (at least above 60% of the total city-city-citations) are displayed. According to the values of centrality in each case, the names of top fifteen cities are labelled in each map. The colors of the nodes represents different provinces. Arrows display the colors of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

IV. THE EMPIRICAL MODEL AND MAIN RESULTS

A. The Empirical Model

In this section we test whether and to what degree the upstream innovation could predict the downstream innovation for a specific city-year using the city pair citation data. The baseline model follows Acemoglu, Akcigit and Kerr (2016) and is formulated as in equation (1):

$$lnP_{it} = \beta_{up} ln\hat{P}_{it} + \gamma_t + \mu_i + \varepsilon_{it} \quad (1)$$

where P_{it} measures the innovation outputs in city i and time t; $\hat{P}_{it}$ is the upstream innovation which is built upon the past year accumulation of patents in all the cities (the case of complete network) and the knowledge spillover across cities. γ_t denotes the time trend and μ_i accounts for the city fixed effect. ε_{it} is the disturbance.

Equation (2) further accounts for the quality of invention for each city by including the city-specific time variant centrality index and equation (3) estimates how the importance of innovation (lagged by one period) in one city moderates the link of upstream and downstream invention.

$$lnP_{it} = \beta_{up} ln\hat{P}_{it} + \beta_c lncentrality_{i,t-1} + \gamma_t + \mu_i + \varepsilon_{it} \quad (2)$$

$$lnP_{it} = \beta_{up} ln\hat{P}_{it} + \beta_c lncentrality_{it} + \beta_{up\times c} \hat{P}_{it} * lnCentrality_{it} + \gamma_t + \mu_i + \varepsilon_{it} (3)$$

Considering the role of policy uncertainly in affecting the innovation outputs, in equation (4) we include the measure of policy uncertainty and an interaction term with the upstream innovation. We expect a negative sign of β_p which suggests that a higher level of policy uncertainty attributed to local leader's reshuffle may impede city innovation capacity. In model (5) we control for both the innovation centrality as well as the policy uncertainly and their moderation effects on the predictive power of the accumulated past year innovation on downstream innovation.

$$lnP_{it} = \beta_{up} ln\hat{P}_{it} + \beta_p Policy_{it} + \beta_{up\times p} ln\hat{P}_{it} * Policy_{it} + \beta_c lncentrality_{i,t-1} + \gamma_t + \mu_i + \varepsilon_{it} \quad (4)$$

$$lnP_{it} = \beta_{up} ln\hat{P}_{it} + \beta_p Policy_{it} + \beta_c lncentrality_{i,t-1} + \beta_{up\times p} ln\hat{P}_{it} * Policy_{it} + \beta_{up\times c} \hat{P}_{it} * lnCentralty_{i,t-1} + \beta_{up\times p\times c} \hat{P}_{it} * Policy_{it} * lnCentralty_{i,t-1} + \gamma_t + \mu_i + \varepsilon_{it} \quad (5)$$

B. The Main Results: Complete Network

Table 4 reports the baseline results estimated as in equation (1). We find that upstream innovation has significantly positive impact on the downstream innovation. The estimated coefficient (0.864) in column (1) indicates a strong relationship between predicted and actual patent number. With two-way fixed effects we find that 82% of the variation in the actual patent publications could be explained by the change of upstream invention. The baseline results provide evidence showing that innovation in cities in the PRC rest on its own and others' cumulative innovation and greatly benefits from the knowledge and technology spillover from one to the other.

Table 4: Upstream and Innovation
(complete network)

	(1)	(2)
$ln\hat{P}$	0.864***	0.621***
	(0.007)	(0.041)
Constant	1.850***	2.438***
	(0.033)	(0.085)
Time FE	No	Yes
City FE	No	Yes
Observations	3,585	3,585
R-squared	0.794	0.821
Number of id	335	335

Notes: *(**, ***): significance at the 10% (5%, 1%) level. Robust standard errors are reported in parentheses. Dependent variable is log of the number of patents.

Source: Authors' calculations.

Table 5 differs from Table 4 when including the degree, the closeness and the between centrality. The more citation received, the higher level of invention is created (column 1); the more citations made, the more patents are published (column 2); a city with a shorter citation path on average increases its innovation capacity (column 3); and a city with a larger controlling power over information flow produces more patents (column 4). Overall, we identity a positive association between a city's innovation quality and its outputs.

Table 5: The Estimation with Centrality Control
(complete network)

	(1)	(2)	(3)	(4)
$ln\hat{P}$	0.595***	0.362***	0.460***	0.531***
	(0.058)	(0.041)	(0.041)	(0.040)
$l.lnW\_ind$	0.038			
	(0.037)			
$l.lnW\_outd$		0.302***		
		(0.022)		
$l.lnclo$			2.197***	
			(0.198)	
$l.lnbet$				0.094***
				(0.012)
Constant	2.258***	1.879***	4.239***	2.249***
	(0.104)	(0.088)	(0.193)	(0.096)
Time FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Observations	3,238	3,190	3,186	3,144
R-squared	0.822	0.847	0.838	0.839
Number of id	335	331	331	328

Notes: *(**, ***): significance at the 10% (5%, 1%) level. Robust standard errors are reported in parentheses. Dependent variable is log of the number of patents.

Source: Authors' calculations.

Given the significant effect of network centrality in facilitating downstream innovation, we expect that the coefficient of upstream invention conditional on centrality should be positive. To test this hypothesis, we introduce four interaction terms of upstream innovation multiplied by centrality in Table 6. By demeaning the upstream innovation and centrality statistics, we find that the coefficients of these interaction terms $ln\hat{P} \times l.lnW\_ind$, $ln\hat{P} \times l.lnW\_outd$ and $ln\hat{P} \times l.lnbet$ are all positive and significant at least at the 5% significance level, among which the interaction of upstream with out-degree has the largest coefficient 0.05. This implies that for an average city a 10% of growth of forward citation intensifies its upstream-downstream innovation link by 0.5% (column 2). Similarly, if the in-degree centrality or betweenness increases by 10%, the strength of the link rises by 0.4% (column 1 and 4), and if the closeness increases by 10% the strength of this link rises by 3% though being significant only at 10% level (column 3).

Table 6: Upstream and Innovation with Centrality Interactions
(complete network)

	(1)	(2)	(3)	(4)
$ln\hat{P}$	0.541***	0.295***	0.428***	0.490***
	(0.067)	(0.046)	(0.048)	(0.042)
$l.lnW\_ind$	0.049			
	(0.038)			
$ln\hat{P} \times l.lnW\_ind$	0.042**			
	(0.020)			
$l.lnW\_outd$		0.304***		
		(0.022)		
$ln\hat{P} \times l.lnW\_outd$		0.050***		
		(0.013)		
$l.lnclo$			2.121***	
			(0.189)	
$ln\hat{P} \times l.lnclo$			0.295*	
			(0.156)	
$l.lnbet$				0.095***
				(0.012)
$ln\hat{P} \times l.lnbet$				0.041***
				(0.012)
Constant	2.280***	1.944***	4.225***	2.322***
	(0.103)	(0.087)	(0.184)	(0.096)
Time FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Observations	3,238	3,190	3,186	3,144
R-squared	0.823	0.849	0.839	0.840
Number of id	335	331	331	328

Notes: *(**, ***): significance at the 10% (5%, 1%) level. Robust standard errors are reported in parentheses. Dependent variable is log of the number of patents.

Source: Authors' calculations.

The role of policy uncertainty is considered in equations (4) and (5). Table 7 shows that an uncertain policy environment attributed to turnover of local political leader has negative impact on innovation though being statistically insignificant in all cases even when we account for the weighted in- and out-degree, closeness and betweenness centrality from column (2) to (5). Table 8 reports results based on the full model which are consistent with estimations from Table 5–7. The predictive power of upstream invention remains with coefficients varying from 0.3 to 0.5. Policy uncertainty has a negative impact though being insignificant at 10% significance level as shown in column 1. The centrality of city innovation significantly contributes to invention and in

particular, the in-degree, out-degree and betweenness centrality facilitates the linkage of upstream innovation within and across cities with the downstream invention. A caution might be paid to column (4) in Table 8 which implies that the negative impact of policy uncertainty on city innovation is stronger in a city of higher control of information flow in the innovation network than that of a city with lower value of betweenness, though the coefficient being insignificant. Thus the more central a city is in the innovation network, the more careful attention should be paid with regard to the change of leadership structure and policy on innovation.

In the above analyses we consider the complete network and the knowledge spillover across all cities including the focal city. We also carry on a robustness test excluding the focal city from the network and considers how upstream innovation in other cities predicts the invention in the focal city. In the case of external network, the only difference lies in the measure of upstream invention and other variables such as centrality statistics and policy uncertainly remains unchanged. We re-estimate equations (2) to (5) and find almost similar results. This confirms that innovation in cities is accumulative depending on not only its own but also others' past year creation and benefits from knowledge and technology diffusion from others. These results are presented in the Appendix Tables A4.1–A4.4.

Table 7: Upstream and Innovation with Policy Uncertainty
(complete network)

	(1)	(2)	(3)	(4)	(5)
$ln\hat{P}$	0.615***	0.573***	0.361***	0.455***	0.526***
	(0.041)	(0.056)	(0.041)	(0.041)	(0.041)
$Policy$	-0.012	-0.019	-0.014	-0.008	-0.015
	(0.016)	(0.017)	(0.017)	(0.017)	(0.017)
$ln\hat{P} \times Policy$	-0.036*	-0.010	-0.008	-0.012	-0.009
	(0.019)	(0.022)	(0.021)	(0.022)	(0.022)
$l.lnW\_ind$		0.057			
		(0.037)			
$l.lnW\_outd$			0.298***		
			(0.022)		
$l.lnclo$				2.179***	
				(0.202)	
$l.lnbet$					0.091***
					(0.012)
Constant	2.465***	2.246***	1.900***	4.241***	2.274***
	(0.085)	(0.107)	(0.088)	(0.194)	(0.095)
Time FE	Yes	Yes	Yes	Yes	Yes

City FE	Yes	Yes	Yes	Yes	Yes
Observations	3,556	3,213	3,167	3,163	3,124
R-squared	0.823	0.824	0.848	0.840	0.840
Number of id	333	333	329	329	326

Notes: *(**, ***): significance at the 10% (5%, 1%) level. Robust standard errors are reported in parentheses. Dependent variable is log of the number of patents.
Source: Authors' calculations.

Table 8: Full Model
(complete network)

	(1)	(2)	(3)	(4)
$ln\hat{P}$	0.519***	0.296***	0.422***	0.484***
	(0.065)	(0.046)	(0.047)	(0.042)
$Policy$	-0.010	0.012	0.001	-0.015
	(0.023)	(0.022)	(0.021)	(0.017)
$ln\hat{P} \times Policy$	0.014	-0.038	-0.013	-0.006
	(0.065)	(0.053)	(0.047)	(0.025)
$l.lnW\_ind$	0.067*			
	(0.037)			
$ln\hat{P} \times l.lnW\_ind$	0.042**			
	(0.020)			
$Policy \times l.lnW\_ind$	-0.011			
	(0.050)			
$ln\hat{P} \times l.lnW_{ind} \times Policy$	-0.010			
	(0.018)			
$l.lnW\_outd$		0.300***		
		(0.022)		
$ln\hat{P} \times l.lnW\_outd$		0.049***		
		(0.013)		
$Policy \times l.lnW\_outd$		0.043		
		(0.039)		
$ln\hat{P} \times l.lnW\_outd \times Policy$		-0.020		
		(0.016)		
$l.lnclo$			2.101***	
			(0.191)	
$ln\hat{P} \times l.lnclo$			0.306*	
			(0.157)	
$Policy \times l.lnclo$			0.115	
			(0.403)	
$ln\hat{P} \times l.lnclo \times Policy$			-0.102	
			(0.194)	
$l.lnbet$				0.093***
				(0.012)

$ln\hat{P} \times l.lnbet$				0.042***
				(0.012)
$Policy \times l.lnbet$				-0.003
				(0.022)
$ln\hat{P} \times l.lnbet \times Policy$				0.005
				(0.020)
Constant	2.268***	1.955***	4.225***	2.348***
	(0.105)	(0.086)	(0.183)	(0.095)
Time FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Observations	3,213	3,167	3,163	3,124
R-squared	0.825	0.850	0.841	0.842
Number of id	333	329	329	326

Notes: *(**, ***): significance at the 10% (5%, 1%) level. Robust standard errors are reported in parentheses. Dependent variable is log of the number of patents.

Source: Authors' calculations.

V. CONCLUSIONS

This paper models the accumulative innovation process from a geographical perspective using more than three millions of patent publication data in the PRC during 1985–2015. We map the innovation network at regional, provincial and city levels using more than five millions of citation pairs.

In the network analysis we find that at regional level invention in the eastern regions produces the most citations made and received both within and across regions. At the provincial level, the intra-province citations are significantly higher than the inter-provincial citations. Provinces like Guangdong, Beijing, and Jiangsu rank into the top three that are featured with internal citations made and received. Notably, the most influential inventions are agglomerated in six provinces. From the map we can identify an interesting diamond structure inclusive of Beijing (in the north), Sichuan (in the west), Guangdong (in the south), and Shanghai (in the east) being the four largest vertices in the innovation network.

In addition to Beijing and Shanghai, Guangzhou, and Shenzhen have higher values of in- and out-degree centrality than peers. Beijing and Chengdu are the two super-spreaders of information and technology and next to them are cities of Shanghai, Tianjin, Jinan, Chongqing, Qingdao, Guangzhou, Wuhan, Suzhou, and Nanjing. Chengdu surpasses Beijing in terms of information control with the highest betweenness centrality. In 29 provinces, capital cities as expected have higher betweeness centrality

than the noncapital cities, while Qingdao in Shangdong province and Liuzhou in Guangxi province have replaced their capital cities Jinan and Nanning to be the largest technology broker. A better understanding of city innovation features can be a valuable aid to policy makers in developing local and regional innovation system and allocating research and development fund efficiently.

Our finding of significant predictive power of upstream invention on growing new invention in the focal city suggests that research and development should be supported in a continuous way. A slack of invention in one period could be felt years later and generates undesirable economic and business outcomes. The good news from this research is that the importance of invention measured by centrality could spur more innovation activities. From policy perspective, an expedition of the patent examination process that fastens the disclosure of information greatly increases the invention visibility and its citations and this practice benefits the follow-on innovation. Last but not the least, a cautious heed should be paid to the change of local leadership structure that has weak but negative influence on the growth of innovation.

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APPENDIX

Table A1: Region's Name and Areas

Region	Provinces
Center	Henan, Hubei, Hunan
East	Anhui, Fujian, Jiangsu, Jiangxi, Shandong, Shanghai, Zhejiang
North	Beijing, Hebei, Inner Mongolia, Shanxi, Tianjin
Northeast	Heilongjiang, Jilin, Liaoning
Northwest	Gansu, Ningxia, Qinghai, Shaanxi, Xinjiang
South	Gangdong, Guangxi, Hainan
Southwest	Guizhou, Sichuan, Tibet, Yunnan, Chongqing

Source: Authors.

Table A2: Top 15 Cities in Different Kinds of Centrality

Rank	indegree	outdegree	weighted indegree	weighted outdegree	closnesscentrality	betweenesscentrality
1	bei jing	bei jing	bei jing	bei jing	bei jing	cheng du
2	cheng du	cheng du	shang hai	shen zhen	cheng du	bei jing
3	shang hai	shang hai	shen zhen	shang hai	shang hai	shang hai
4	guang zhou	tian jin	nan jing	su zhou	tian jin	tian jin
5	chong qing	ji nan	hang zhou	nan jing	ji nan	qing dao
6	nan jing	chong qing	su zhou	hang zhou	chong qing	chong qing
7	shen yang	guang zhou	guang zhou	guang zhou	guang zhou	guang zhou
8	tian jin	qing dao	tian jin	cheng du	qing dao	nan jing
9	harbin	nan jing	wu han	tian jin	su zhou	nan tong
10	hang zhou	wu han	cheng du	wu han	nan jing	ji nan
11	chang sha	su zhou	xi an	xi an	wu han	tai an
12	da lian	chang sha	wu xi	wu xi	chang sha	chang sha
13	ji nan	xi an	chang sha	ji nan	xi an	zhen jiang
14	shen zhen	hang zhou	harbin	qing dao	shen zhen	xi ning
15	xi an	shen zhen	shen yang	he fei	hang zhou	wu han

Notes: cities are selected based on the value of centrality.

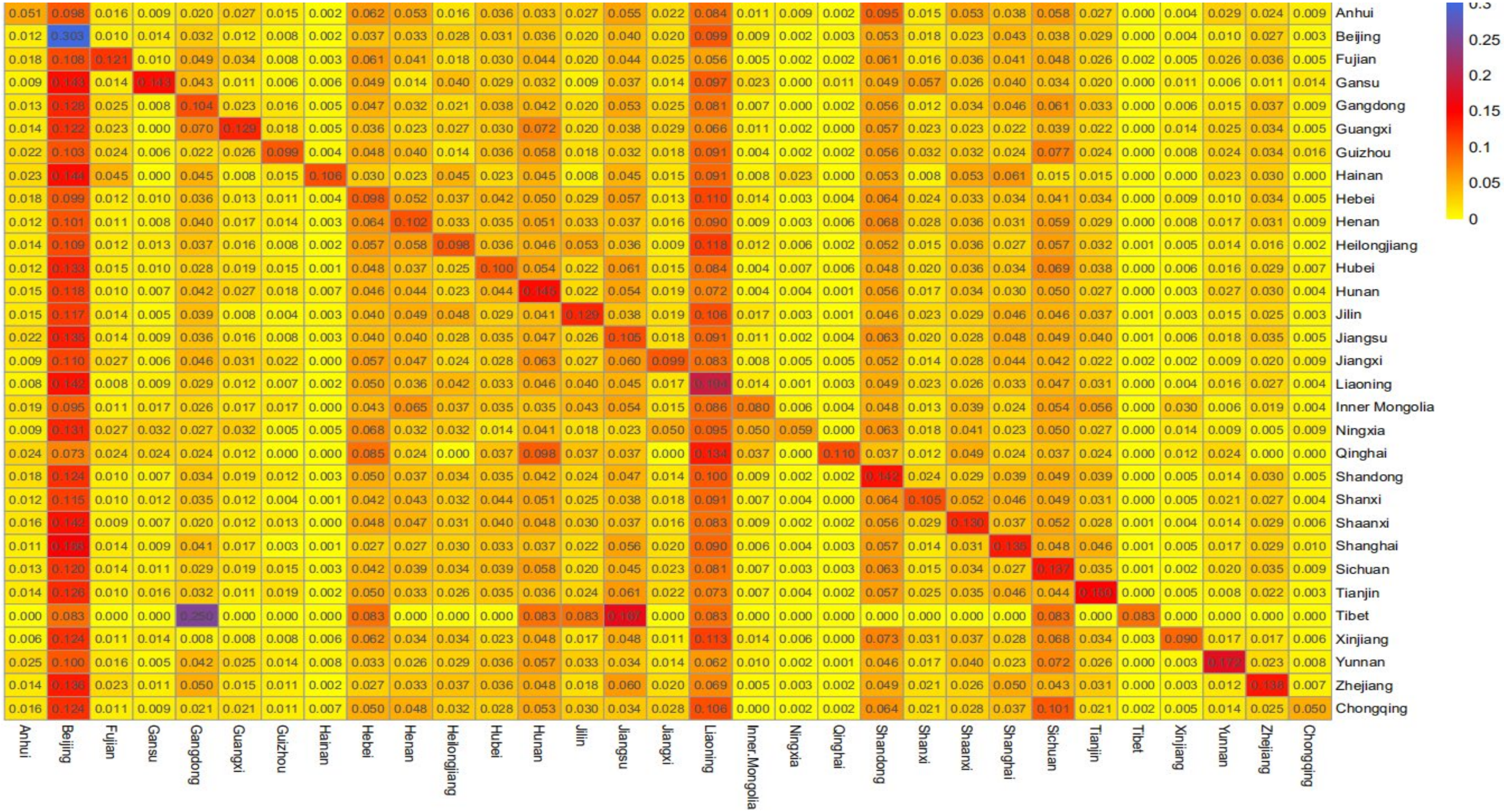
Sources: National Intellectual Property Administration; authors' calculations.

Figure A1.1: Citation Matrix across 31 Provinces, Patents of 05-14 Cites that of 85-94

	Anhui	Beijing	Fujian	Gansu	Gangdong	Guangxi	Guizhou	Hainan	Hebei	Henan	Heilongjiang	Hubei	Hunan	Jilin	Jiangsu	Jiangxi	Liaoning	Inner.Mongolia	Ningxia	Qinghai	Shandong	Shanxi	Shaanxi	Shanghai	Sichuan	Tianjin	Tibet	Xinjiang	Yunnan	Zhejiang	Chongqing
Anhui	0.036	0.113	0.013	0.007	0.020	0.017	0.009	0.005	0.043	0.035	0.034	0.038	0.054	0.027	0.067	0.015	0.098	0.007	0.006	0.003	0.074	0.023	0.046	0.034	0.076	0.044	0.000	0.005	0.017	0.029	0.006
Beijing	0.011	0.287	0.010	0.021	0.028	0.009	0.006	0.001	0.027	0.029	0.030	0.033	0.034	0.027	0.043	0.013	0.096	0.009	0.002	0.002	0.055	0.021	0.025	0.046	0.051	0.033	0.000	0.007	0.011	0.025	0.006
Fujian	0.014	0.135	0.084	0.008	0.039	0.014	0.017	0.002	0.036	0.031	0.023	0.026	0.060	0.021	0.051	0.018	0.079	0.006	0.002	0.005	0.071	0.019	0.035	0.047	0.048	0.035	0.000	0.002	0.025	0.041	0.005
Gansu	0.021	0.141	0.021	0.064	0.043	0.017	0.012	0.004	0.035	0.033	0.041	0.035	0.043	0.014	0.039	0.002	0.054	0.012	0.002	0.006	0.076	0.031	0.041	0.045	0.054	0.037	0.000	0.004	0.033	0.033	0.010
Gangdong	0.014	0.151	0.020	0.007	0.063	0.025	0.010	0.003	0.034	0.024	0.023	0.036	0.046	0.027	0.056	0.019	0.093	0.010	0.002	0.003	0.065	0.015	0.026	0.064	0.051	0.039	0.000	0.006	0.018	0.041	0.006
Guangxi	0.011	0.112	0.033	0.008	0.070	0.102	0.018	0.006	0.028	0.033	0.026	0.028	0.070	0.023	0.038	0.016	0.080	0.008	0.001	0.004	0.062	0.021	0.030	0.028	0.055	0.021	0.000	0.001	0.033	0.028	0.006
Guizhou	0.025	0.104	0.009	0.005	0.029	0.014	0.081	0.005	0.033	0.033	0.022	0.025	0.068	0.014	0.048	0.021	0.090	0.009	0.013	0.007	0.057	0.034	0.039	0.025	0.073	0.031	0.000	0.001	0.042	0.029	0.017
Hainan	0.000	0.094	0.023	0.000	0.117	0.039	0.000	0.227	0.016	0.023	0.008	0.008	0.047	0.008	0.055	0.031	0.047	0.000	0.000	0.000	0.047	0.016	0.031	0.016	0.039	0.008	0.000	0.000	0.055	0.047	0.000
Hebei	0.016	0.134	0.014	0.008	0.037	0.015	0.008	0.004	0.089	0.043	0.028	0.038	0.049	0.028	0.049	0.014	0.104	0.004	0.005	0.004	0.076	0.025	0.023	0.036	0.067	0.026	0.001	0.004	0.010	0.030	0.010
Henan	0.012	0.137	0.012	0.008	0.027	0.016	0.011	0.001	0.044	0.082	0.033	0.035	0.047	0.028	0.052	0.016	0.093	0.012	0.001	0.002	0.073	0.031	0.042	0.036	0.047	0.039	0.000	0.006	0.020	0.030	0.007
Heilongjiang	0.012	0.170	0.011	0.013	0.044	0.008	0.006	0.002	0.036	0.031	0.099	0.030	0.033	0.046	0.040	0.014	0.108	0.010	0.003	0.005	0.061	0.016	0.026	0.038	0.052	0.035	0.000	0.005	0.011	0.033	0.004
Hubei	0.013	0.139	0.015	0.007	0.028	0.017	0.012	0.003	0.035	0.035	0.029	0.072	0.059	0.024	0.056	0.015	0.091	0.008	0.002	0.004	0.055	0.022	0.037	0.044	0.063	0.045	0.001	0.007	0.025	0.030	0.010
Hunan	0.014	0.154	0.014	0.007	0.041	0.022	0.010	0.001	0.033	0.028	0.030	0.039	0.133	0.023	0.048	0.020	0.081	0.005	0.004	0.003	0.057	0.021	0.033	0.033	0.045	0.038	0.000	0.005	0.024	0.028	0.003
Jilin	0.011	0.150	0.013	0.010	0.035	0.018	0.008	0.000	0.043	0.031	0.034	0.035	0.052	0.136	0.042	0.014	0.104	0.010	0.005	0.003	0.046	0.015	0.034	0.032	0.048	0.023	0.000	0.005	0.010	0.028	0.005
Jiangsu	0.018	0.142	0.015	0.010	0.029	0.015	0.010	0.002	0.035	0.030	0.028	0.040	0.050	0.025	0.086	0.015	0.094	0.006	0.007	0.004	0.065	0.017	0.032	0.058	0.050	0.046	0.000	0.004	0.014	0.047	0.006
Jiangxi	0.021	0.128	0.015	0.014	0.057	0.024	0.003	0.003	0.020	0.017	0.023	0.039	0.108	0.026	0.048	0.072	0.092	0.014	0.000	0.003	0.060	0.020	0.033	0.036	0.042	0.017	0.002	0.002	0.023	0.035	0.009
Liaoning	0.015	0.160	0.012	0.008	0.016	0.009	0.009	0.001	0.034	0.040	0.036	0.036	0.038	0.042	0.037	0.011	0.182	0.015	0.001	0.004	0.060	0.018	0.029	0.041	0.052	0.033	0.000	0.007	0.015	0.031	0.008
Inner Mongolia	0.021	0.110	0.013	0.019	0.025	0.013	0.008	0.004	0.038	0.023	0.042	0.036	0.044	0.059	0.038	0.025	0.070	0.078	0.006	0.000	0.099	0.019	0.030	0.023	0.063	0.032	0.000	0.013	0.017	0.025	0.004
Ningxia	0.012	0.176	0.006	0.018	0.024	0.035	0.000	0.006	0.082	0.024	0.029	0.018	0.012	0.024	0.047	0.029	0.124	0.035	0.035	0.000	0.059	0.018	0.047	0.000	0.047	0.029	0.000	0.000	0.024	0.035	0.006
Qinghai	0.000	0.127	0.029	0.039	0.000	0.000	0.010	0.010	0.049	0.029	0.049	0.020	0.020	0.000	0.098	0.029	0.078	0.010	0.010	0.127	0.020	0.020	0.039	0.020	0.078	0.029	0.010	0.010	0.020	0.010	0.010
Shandong	0.021	0.123	0.011	0.007	0.040	0.014	0.026	0.002	0.045	0.036	0.039	0.035	0.036	0.029	0.044	0.014	0.098	0.005	0.002	0.002	0.132	0.020	0.032	0.053	0.053	0.029	0.000	0.006	0.013	0.028	0.006
Shanxi	0.012	0.153	0.010	0.010	0.027	0.012	0.009	0.000	0.043	0.048	0.030	0.033	0.034	0.023	0.047	0.016	0.107	0.016	0.001	0.003	0.075	0.094	0.038	0.028	0.048	0.029	0.000	0.004	0.023	0.022	0.004
Shaanxi	0.015	0.180	0.010	0.012	0.025	0.014	0.006	0.001	0.037	0.028	0.031	0.026	0.043	0.028	0.051	0.013	0.085	0.010	0.002	0.003	0.064	0.030	0.083	0.054	0.054	0.033	0.000	0.004	0.018	0.029	0.009
Shanghai	0.010	0.172	0.012	0.015	0.032	0.011	0.009	0.002	0.026	0.022	0.024	0.041	0.035	0.030	0.064	0.014	0.098	0.006	0.002	0.001	0.052	0.021	0.034	0.099	0.049	0.045	0.002	0.005	0.016	0.044	0.006
Sichuan	0.019	0.129	0.014	0.013	0.024	0.017	0.012	0.002	0.038	0.028	0.028	0.041	0.054	0.023	0.052	0.016	0.074	0.011	0.002	0.004	0.059	0.022	0.041	0.044	0.124	0.036	0.001	0.006	0.020	0.036	0.012
Tianjin	0.011	0.157	0.010	0.011	0.029	0.015	0.010	0.001	0.029	0.031	0.036	0.032	0.038	0.026	0.052	0.013	0.113	0.005	0.004	0.007	0.064	0.017	0.034	0.049	0.055	0.099	0.000	0.007	0.006	0.034	0.007
Tibet	0.000	0.375	0.000	0.062	0.125	0.000	0.000	0.000	0.062	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.000	0.000	0.000	0.000	0.000
Xinjiang	0.008	0.134	0.014	0.022	0.022	0.005	0.011	0.003	0.052	0.033	0.046	0.060	0.027	0.014	0.033	0.016	0.085	0.011	0.005	0.005	0.079	0.025	0.033	0.033	0.060	0.038	0.000	0.068	0.019	0.025	0.014
Yunnan	0.013	0.135	0.019	0.006	0.048	0.022	0.023	0.011	0.036	0.024	0.018	0.037	0.075	0.017	0.034	0.013	0.069	0.007	0.003	0.000	0.051	0.012	0.029	0.025	0.047	0.040	0.000	0.007	0.150	0.023	0.006
Zhejiang	0.017	0.143	0.020	0.011	0.039	0.015	0.008	0.004	0.033	0.031	0.034	0.031	0.051	0.026	0.061	0.012	0.089	0.007	0.002	0.003	0.063	0.017	0.032	0.065	0.048	0.039	0.000	0.005	0.016	0.070	0.008
Chongqing	0.022	0.146	0.016	0.013	0.025	0.010	0.009	0.000	0.032	0.032	0.011	0.039	0.056	0.020	0.062	0.010	0.093	0.005	0.002	0.005	0.062	0.026	0.034	0.040	0.091	0.043	0.000	0.002	0.026	0.034	0.031

Sources: National Intellectual Property Administration; authors' calculations.

Figure A1.2: Citation Matrix across 31 Provinces, Patents of 95-04 cites that of 85-94

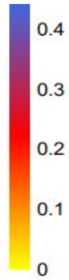


	Anhui	Beijing	Fujian	Gansu	Gangdong	Guangxi	Guizhou	Hainan	Hebei	Henan	Heilongjiang	Hubei	Hunan	Jilin	Jiangsu	Jiangxi	Liaoning	Inner.Mongolia	Ningxia	Qinghai	Shandong	Shanxi	Shaanxi	Shanghai	Sichuan	Tianjin	Tibet	Xinjiang	Yunnan	Zhejiang	Chongqing
Anhui	0.051	0.098	0.016	0.009	0.020	0.027	0.015	0.002	0.062	0.053	0.016	0.036	0.033	0.027	0.055	0.022	0.084	0.011	0.009	0.002	0.095	0.015	0.053	0.038	0.058	0.027	0.000	0.004	0.029	0.024	0.009
Beijing	0.012	0.303	0.010	0.014	0.032	0.012	0.008	0.002	0.037	0.033	0.028	0.031	0.036	0.020	0.040	0.020	0.099	0.009	0.002	0.003	0.053	0.018	0.023	0.043	0.038	0.029	0.000	0.004	0.010	0.027	0.003
Fujian	0.018	0.108	0.121	0.010	0.049	0.034	0.008	0.003	0.061	0.041	0.018	0.030	0.044	0.020	0.044	0.025	0.056	0.005	0.002	0.002	0.061	0.016	0.036	0.041	0.048	0.026	0.002	0.005	0.026	0.036	0.005
Gansu	0.009	0.143	0.014	0.143	0.043	0.011	0.006	0.006	0.049	0.014	0.040	0.029	0.032	0.009	0.037	0.014	0.097	0.023	0.000	0.011	0.049	0.057	0.026	0.040	0.034	0.020	0.000	0.011	0.006	0.011	0.014
Gangdong	0.013	0.128	0.025	0.008	0.104	0.023	0.016	0.005	0.047	0.032	0.021	0.038	0.042	0.020	0.053	0.025	0.081	0.007	0.000	0.002	0.056	0.012	0.034	0.046	0.061	0.033	0.000	0.006	0.015	0.037	0.009
Guangxi	0.014	0.122	0.023	0.000	0.070	0.129	0.018	0.005	0.036	0.023	0.027	0.030	0.072	0.020	0.038	0.029	0.066	0.011	0.002	0.000	0.057	0.023	0.023	0.022	0.039	0.022	0.000	0.014	0.025	0.034	0.005
Guizhou	0.022	0.103	0.024	0.006	0.022	0.026	0.099	0.004	0.048	0.040	0.014	0.036	0.058	0.018	0.032	0.018	0.091	0.004	0.002	0.002	0.056	0.032	0.032	0.024	0.077	0.024	0.000	0.008	0.024	0.034	0.016
Hainan	0.023	0.144	0.045	0.000	0.045	0.008	0.015	0.106	0.030	0.023	0.045	0.023	0.045	0.008	0.045	0.015	0.091	0.008	0.023	0.000	0.053	0.008	0.053	0.061	0.015	0.015	0.000	0.000	0.023	0.030	0.000
Hebei	0.018	0.099	0.012	0.010	0.036	0.013	0.011	0.004	0.098	0.052	0.037	0.042	0.050	0.029	0.057	0.013	0.110	0.014	0.003	0.004	0.064	0.024	0.033	0.034	0.041	0.034	0.000	0.009	0.010	0.034	0.005
Henan	0.012	0.101	0.011	0.008	0.040	0.017	0.014	0.003	0.064	0.102	0.033	0.035	0.051	0.033	0.037	0.016	0.090	0.009	0.003	0.006	0.068	0.028	0.036	0.031	0.059	0.029	0.000	0.008	0.017	0.031	0.009
Heilongjiang	0.014	0.109	0.012	0.013	0.037	0.016	0.008	0.002	0.057	0.058	0.098	0.036	0.046	0.053	0.036	0.009	0.118	0.012	0.006	0.002	0.052	0.015	0.036	0.027	0.057	0.032	0.001	0.005	0.014	0.016	0.002
Hubei	0.012	0.133	0.015	0.010	0.028	0.019	0.015	0.001	0.048	0.037	0.025	0.100	0.054	0.022	0.061	0.015	0.084	0.004	0.007	0.006	0.048	0.020	0.036	0.034	0.069	0.038	0.000	0.006	0.016	0.029	0.007
Hunan	0.015	0.118	0.010	0.007	0.042	0.027	0.018	0.007	0.046	0.044	0.023	0.044	0.145	0.022	0.054	0.019	0.072	0.004	0.004	0.001	0.056	0.017	0.034	0.030	0.050	0.027	0.000	0.003	0.027	0.030	0.004
Jilin	0.015	0.117	0.014	0.005	0.039	0.008	0.004	0.003	0.040	0.049	0.048	0.029	0.041	0.129	0.038	0.019	0.106	0.017	0.003	0.001	0.046	0.023	0.029	0.046	0.046	0.037	0.001	0.003	0.015	0.025	0.003
Jiangsu	0.022	0.135	0.014	0.009	0.036	0.016	0.008	0.003	0.040	0.040	0.028	0.035	0.047	0.026	0.105	0.018	0.091	0.011	0.002	0.004	0.063	0.020	0.028	0.048	0.049	0.040	0.001	0.006	0.018	0.035	0.005
Jiangxi	0.009	0.110	0.027	0.006	0.046	0.031	0.022	0.000	0.057	0.047	0.024	0.028	0.063	0.027	0.060	0.099	0.083	0.008	0.005	0.005	0.052	0.014	0.028	0.044	0.042	0.022	0.002	0.002	0.009	0.020	0.009
Liaoning	0.008	0.142	0.008	0.009	0.029	0.012	0.007	0.002	0.050	0.036	0.042	0.033	0.046	0.040	0.045	0.017	0.194	0.014	0.001	0.003	0.049	0.023	0.026	0.033	0.047	0.031	0.000	0.004	0.016	0.027	0.004
Inner Mongolia	0.019	0.095	0.011	0.017	0.026	0.017	0.017	0.000	0.043	0.065	0.037	0.035	0.035	0.043	0.054	0.015	0.086	0.080	0.006	0.004	0.048	0.013	0.039	0.024	0.054	0.056	0.000	0.030	0.006	0.019	0.004
Ningxia	0.009	0.131	0.027	0.032	0.027	0.032	0.005	0.005	0.068	0.032	0.032	0.014	0.041	0.018	0.023	0.050	0.095	0.050	0.059	0.000	0.063	0.018	0.041	0.023	0.050	0.027	0.000	0.014	0.009	0.005	0.009
Qinghai	0.024	0.073	0.024	0.024	0.024	0.012	0.000	0.000	0.085	0.024	0.000	0.037	0.098	0.037	0.037	0.000	0.134	0.037	0.000	0.110	0.037	0.012	0.049	0.024	0.037	0.024	0.000	0.012	0.024	0.000	0.000
Shandong	0.018	0.124	0.010	0.007	0.034	0.019	0.012	0.003	0.050	0.037	0.034	0.035	0.042	0.024	0.047	0.014	0.100	0.009	0.002	0.002	0.142	0.024	0.029	0.039	0.049	0.039	0.000	0.005	0.014	0.030	0.005
Shanxi	0.012	0.115	0.010	0.012	0.035	0.012	0.004	0.001	0.042	0.043	0.032	0.044	0.051	0.025	0.038	0.018	0.091	0.007	0.004	0.000	0.064	0.105	0.052	0.046	0.049	0.031	0.000	0.005	0.021	0.027	0.004
Shaanxi	0.016	0.142	0.009	0.007	0.020	0.012	0.013	0.000	0.048	0.047	0.031	0.040	0.048	0.030	0.037	0.016	0.083	0.009	0.002	0.002	0.056	0.029	0.130	0.037	0.052	0.028	0.001	0.004	0.014	0.029	0.006
Shanghai	0.011	0.166	0.014	0.009	0.041	0.017	0.003	0.001	0.027	0.027	0.030	0.033	0.037	0.022	0.056	0.020	0.090	0.006	0.004	0.003	0.057	0.014	0.031	0.135	0.048	0.046	0.001	0.005	0.017	0.029	0.010
Sichuan	0.013	0.120	0.014	0.011	0.029	0.019	0.015	0.003	0.042	0.039	0.034	0.039	0.058	0.020	0.045	0.023	0.081	0.007	0.003	0.003	0.063	0.015	0.034	0.027	0.137	0.035	0.001	0.002	0.020	0.035	0.009
Tianjin	0.014	0.126	0.010	0.016	0.032	0.011	0.019	0.002	0.050	0.033	0.026	0.035	0.036	0.024	0.061	0.022	0.073	0.007	0.004	0.002	0.057	0.025	0.035	0.046	0.044	0.160	0.000	0.005	0.008	0.022	0.003
Tibet	0.000	0.083	0.000	0.000	0.250	0.000	0.000	0.000	0.083	0.000	0.000	0.000	0.083	0.083	0.167	0.000	0.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.000	0.083	0.000	0.000	0.000	0.000
Xinjiang	0.006	0.124	0.011	0.014	0.008	0.008	0.008	0.006	0.062	0.034	0.034	0.023	0.048	0.017	0.048	0.011	0.113	0.014	0.006	0.000	0.073	0.031	0.037	0.028	0.068	0.034	0.003	0.090	0.017	0.017	0.006
Yunnan	0.025	0.100	0.016	0.005	0.042	0.025	0.014	0.008	0.033	0.026	0.029	0.036	0.057	0.033	0.034	0.014	0.062	0.010	0.002	0.001	0.046	0.017	0.040	0.023	0.072	0.026	0.000	0.003	0.172	0.023	0.008
Zhejiang	0.014	0.130	0.023	0.011	0.050	0.015	0.011	0.002	0.027	0.033	0.037	0.036	0.048	0.018	0.060	0.020	0.069	0.005	0.003	0.002	0.049	0.021	0.026	0.050	0.043	0.031	0.000	0.003	0.012	0.138	0.007
Chongqing	0.016	0.124	0.011	0.009	0.021	0.021	0.011	0.007	0.050	0.048	0.032	0.028	0.053	0.030	0.034	0.028	0.106	0.000	0.002	0.002	0.064	0.021	0.028	0.037	0.101	0.021	0.002	0.005	0.014	0.025	0.050

Sources: National Intellectual Property Administration; authors' calculations.

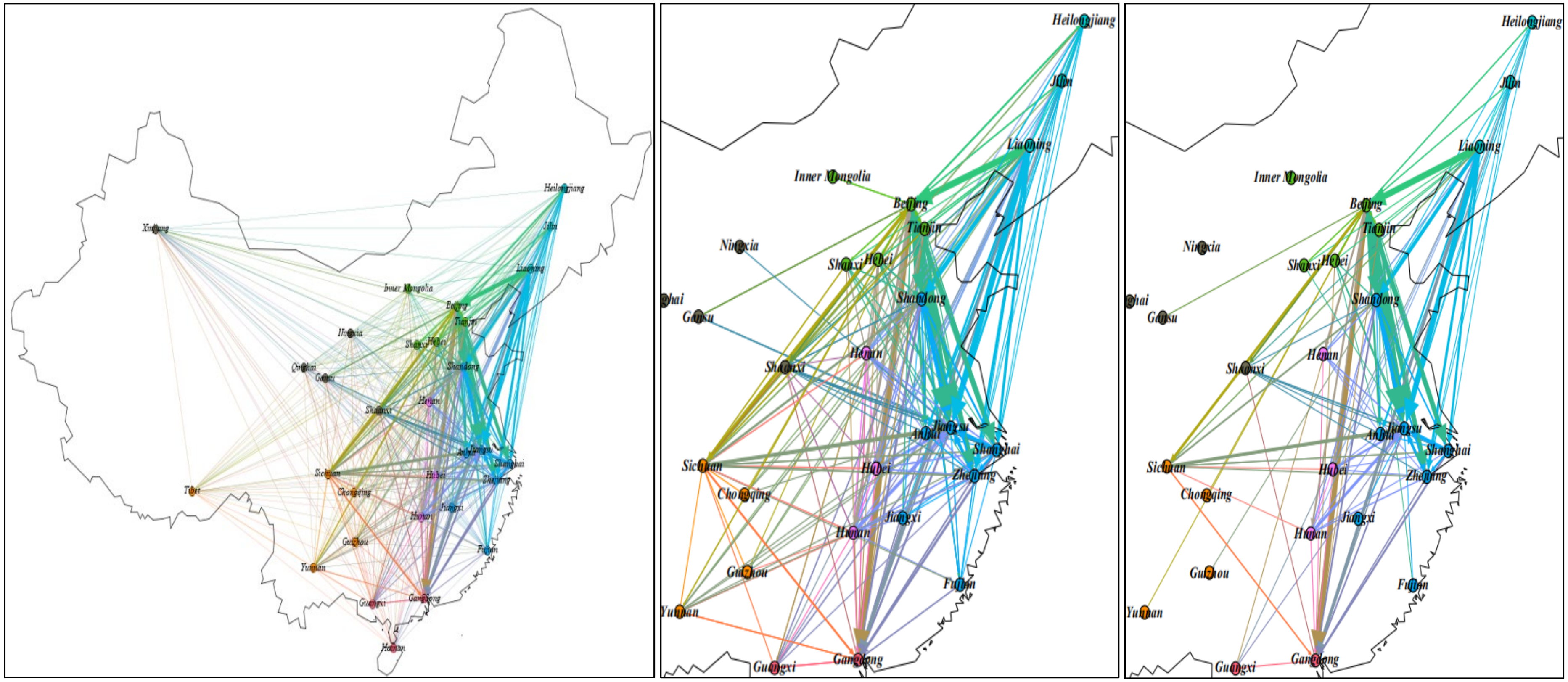
Figure A1.3: Citation Matrix across 31 Provinces, Patents of 05-14 Cites that of 95-04

Anhui	Beijing	Fujian	Gansu	Gangdong	Guangxi	Guizhou	Hainan	Hebei	Henan	Heilongjiang	Hubei	Hunan	Jilin	Jiangsu	Jiangxi	Liaoning	Inner.Mongolia	Ningxia	Qinghai	Shandong	Shanxi	Shaanxi	Shanghai	Sichuan	Tianjin	Tibet	Xinjiang	Yunnan	Zhejiang	Chongqing	
0.043	0.128	0.014	0.007	0.060	0.014	0.013	0.003	0.042	0.041	0.047	0.043	0.047	0.024	0.054	0.018	0.064	0.009	0.004	0.002	0.072	0.014	0.028	0.064	0.044	0.031	0.001	0.006	0.017	0.039	0.009	Anhui
0.009	0.391	0.009	0.010	0.100	0.005	0.004	0.002	0.017	0.015	0.017	0.028	0.021	0.019	0.042	0.007	0.049	0.004	0.002	0.001	0.037	0.013	0.019	0.087	0.027	0.022	0.000	0.004	0.008	0.027	0.006	Beijing
0.013	0.138	0.091	0.006	0.112	0.012	0.008	0.004	0.024	0.025	0.019	0.041	0.041	0.019	0.053	0.014	0.053	0.007	0.003	0.001	0.055	0.012	0.021	0.085	0.036	0.026	0.000	0.005	0.018	0.051	0.009	Fujian
0.013	0.157	0.009	0.101	0.052	0.008	0.011	0.003	0.027	0.028	0.031	0.036	0.033	0.032	0.041	0.009	0.060	0.010	0.012	0.006	0.056	0.018	0.031	0.062	0.038	0.024	0.003	0.021	0.020	0.036	0.009	Gansu
0.009	0.179	0.012	0.003	0.346	0.009	0.005	0.002	0.013	0.013	0.014	0.030	0.021	0.014	0.042	0.009	0.030	0.003	0.001	0.001	0.031	0.006	0.019	0.092	0.027	0.021	0.000	0.003	0.009	0.031	0.006	Gangdong
0.013	0.117	0.019	0.007	0.088	0.084	0.020	0.006	0.030	0.031	0.039	0.036	0.048	0.022	0.047	0.021	0.059	0.009	0.005	0.002	0.064	0.013	0.023	0.046	0.051	0.023	0.001	0.008	0.024	0.037	0.008	Guangxi
0.015	0.112	0.014	0.010	0.052	0.017	0.112	0.003	0.029	0.030	0.036	0.040	0.050	0.025	0.045	0.026	0.060	0.010	0.006	0.003	0.049	0.015	0.024	0.042	0.066	0.019	0.001	0.008	0.041	0.033	0.011	Guizhou
0.013	0.139	0.018	0.006	0.099	0.017	0.009	0.132	0.021	0.035	0.022	0.028	0.025	0.024	0.049	0.013	0.060	0.007	0.003	0.001	0.037	0.008	0.014	0.084	0.032	0.012	0.000	0.009	0.024	0.044	0.014	Hainan
0.013	0.149	0.012	0.009	0.056	0.012	0.009	0.004	0.119	0.034	0.032	0.034	0.031	0.026	0.051	0.013	0.072	0.009	0.004	0.002	0.071	0.021	0.026	0.060	0.039	0.030	0.000	0.007	0.010	0.035	0.010	Hebei
0.013	0.142	0.011	0.009	0.058	0.012	0.012	0.002	0.041	0.093	0.039	0.040	0.039	0.022	0.054	0.017	0.069	0.013	0.004	0.001	0.073	0.019	0.028	0.059	0.039	0.023	0.002	0.006	0.017	0.033	0.009	Henan
0.012	0.173	0.011	0.009	0.046	0.007	0.009	0.003	0.033	0.028	0.145	0.031	0.028	0.033	0.041	0.009	0.074	0.010	0.004	0.001	0.053	0.016	0.024	0.078	0.034	0.025	0.001	0.006	0.014	0.034	0.009	Heilongjiang
0.013	0.154	0.013	0.006	0.084	0.010	0.009	0.002	0.026	0.023	0.025	0.158	0.036	0.019	0.053	0.013	0.050	0.005	0.003	0.001	0.046	0.014	0.024	0.090	0.038	0.023	0.000	0.004	0.017	0.034	0.008	Hubei
0.008	0.088	0.010	0.005	0.046	0.012	0.013	0.002	0.015	0.016	0.016	0.026	0.444	0.014	0.032	0.011	0.034	0.005	0.003	0.001	0.033	0.011	0.017	0.046	0.027	0.017	0.000	0.003	0.013	0.024	0.006	Hunan
0.012	0.144	0.013	0.007	0.048	0.007	0.009	0.002	0.030	0.025	0.046	0.031	0.023	0.190	0.040	0.012	0.070	0.013	0.004	0.003	0.046	0.017	0.021	0.073	0.034	0.024	0.001	0.007	0.013	0.027	0.008	Jilin
0.013	0.160	0.012	0.007	0.084	0.007	0.006	0.003	0.026	0.022	0.023	0.035	0.031	0.021	0.141	0.011	0.058	0.007	0.002	0.001	0.055	0.014	0.021	0.102	0.035	0.032	0.000	0.004	0.011	0.049	0.008	Jiangsu
0.020	0.141	0.017	0.008	0.079	0.014	0.011	0.002	0.025	0.026	0.026	0.037	0.053	0.020	0.048	0.099	0.054	0.008	0.006	0.002	0.055	0.016	0.018	0.066	0.044	0.025	0.001	0.007	0.017	0.043	0.013	Jiangxi
0.012	0.160	0.010	0.011	0.050	0.009	0.007	0.002	0.028	0.023	0.033	0.033	0.027	0.027	0.043	0.009	0.213	0.009	0.004	0.002	0.055	0.018	0.022	0.080	0.032	0.028	0.001	0.007	0.011	0.027	0.008	Liaoning
0.012	0.133	0.010	0.010	0.052	0.007	0.012	0.002	0.049	0.029	0.053	0.025	0.031	0.036	0.037	0.019	0.072	0.092	0.009	0.004	0.055	0.032	0.023	0.060	0.043	0.034	0.001	0.012	0.016	0.025	0.007	Inner Mongolia
0.005	0.152	0.015	0.016	0.053	0.015	0.007	0.003	0.041	0.031	0.016	0.025	0.024	0.020	0.050	0.010	0.060	0.033	0.138	0.002	0.064	0.023	0.015	0.057	0.027	0.017	0.003	0.032	0.011	0.027	0.010	Ningxia
0.016	0.137	0.014	0.012	0.024	0.008	0.008	0.002	0.024	0.008	0.030	0.030	0.028	0.014	0.034	0.002	0.059	0.038	0.038	0.158	0.026	0.020	0.022	0.067	0.067	0.038	0.014	0.020	0.016	0.020	0.010	Qinghai
0.014	0.142	0.012	0.008	0.064	0.011	0.010	0.002	0.043	0.043	0.036	0.032	0.033	0.025	0.045	0.015	0.068	0.013	0.004	0.002	0.141	0.022	0.026	0.059	0.037	0.029	0.002	0.007	0.011	0.034	0.009	Shandong
0.016	0.147	0.011	0.009	0.041	0.010	0.008	0.004	0.038	0.039	0.031	0.031	0.031	0.023	0.048	0.009	0.066	0.016	0.008	0.002	0.062	0.133	0.033	0.067	0.038	0.022	0.001	0.008	0.009	0.029	0.009	Shanxi
0.015	0.175	0.011	0.012	0.065	0.007	0.007	0.004	0.032	0.026	0.026	0.034	0.027	0.024	0.050	0.010	0.055	0.009	0.004	0.002	0.048	0.018	0.129	0.085	0.040	0.028	0.000	0.007	0.012	0.030	0.009	Shaanxi
0.011	0.185	0.011	0.008	0.097	0.005	0.004	0.002	0.017	0.014	0.015	0.034	0.020	0.025	0.057	0.007	0.049	0.004	0.002	0.000	0.036	0.013	0.020	0.260	0.031	0.027	0.000	0.004	0.008	0.036	0.009	Shanghai
0.013	0.149	0.010	0.006	0.078	0.011	0.011	0.004	0.028	0.021	0.024	0.036	0.039	0.020	0.054	0.012	0.050	0.006	0.002	0.003	0.045	0.013	0.023	0.084	0.157	0.022	0.001	0.005	0.021	0.037	0.014	Sichuan
0.009	0.154	0.012	0.006	0.063	0.006	0.006	0.002	0.021	0.015	0.025	0.026	0.020	0.024	0.049	0.012	0.053	0.006	0.004	0.001	0.050	0.012	0.019	0.088	0.029	0.230	0.000	0.004	0.009	0.034	0.006	Tianjin
0.006	0.124	0.024	0.018	0.036	0.000	0.006	0.000	0.018	0.030	0.030	0.024	0.018	0.024	0.077	0.000	0.041	0.000	0.000	0.136	0.059	0.012	0.018	0.030	0.071	0.024	0.053	0.012	0.071	0.018	0.024	Tibet
0.015	0.155	0.012	0.010	0.036	0.009	0.009	0.003	0.035	0.036	0.033	0.033	0.036	0.024	0.039	0.009	0.066	0.018	0.014	0.007	0.074	0.024	0.032	0.043	0.039	0.022	0.001	0.129	0.009	0.021	0.006	Xinjiang
0.014	0.113	0.017	0.010	0.055	0.017	0.019	0.006	0.027	0.024	0.028	0.041	0.041	0.019	0.046	0.015	0.050	0.009	0.005	0.003	0.045	0.015	0.025	0.049	0.047	0.019	0.001	0.005	0.187	0.034	0.013	Yunnan
0.013	0.143	0.015	0.005	0.107	0.010	0.009	0.003	0.022	0.021	0.023	0.035	0.030	0.018	0.067	0.012	0.053	0.006	0.002	0.001	0.051	0.011	0.021	0.091	0.035	0.030	0.000	0.005	0.013	0.139	0.008	Zhejiang
0.017	0.150	0.014	0.008	0.076	0.013	0.016	0.004	0.027	0.022	0.022	0.044	0.040	0.021	0.052	0.017	0.056	0.008	0.002	0.001	0.051	0.013	0.025	0.081	0.055	0.025	0.000	0.005	0.016	0.039	0.079	Chongqing



Sources: National Intellectual Property Administration; authors' calculations.

Figure A2.1: External Innovation Network at the Provincial Level, Patents of 05-14 Cites that of 85-94

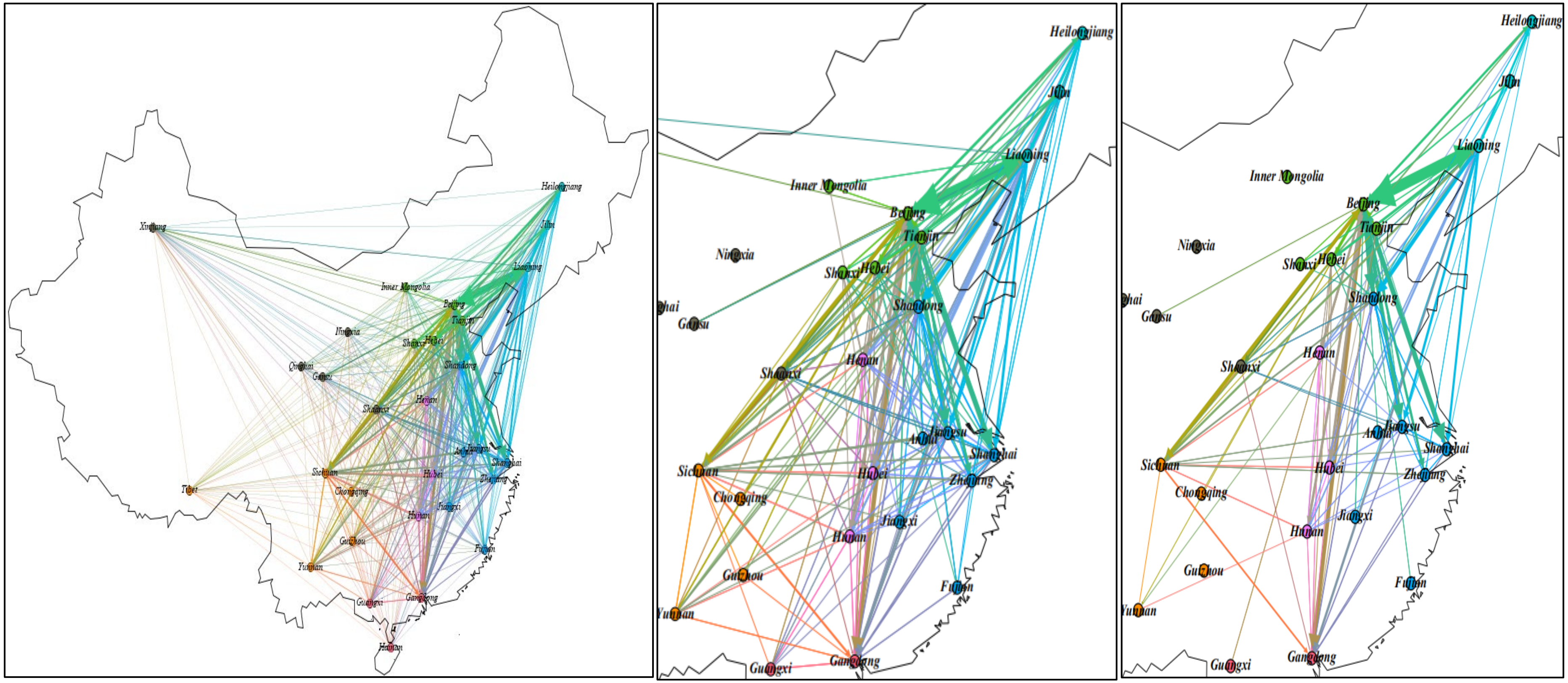


(a) (b) (c)

Notes: Panels (a), (b), and (c) display the case of the external patent citations at the provincial level with different thresholds, where panel (a) includes the full set of citations. To improve the readability and avoid having too many arrows, we only display edges for cities with patents cite larger than the threshold 49 (at least above 80% of the total province-to-province citations) and 105 (at least above 60% of the total province-to-province citations) units are displayed in panel (b) and (c), respectively. The provincial names are labelled in each map. The color of the nodes represents different regions. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Figure A2.2: External Innovation Network at the Provincial Level, Patents of 95-04 Cites that of 85-94

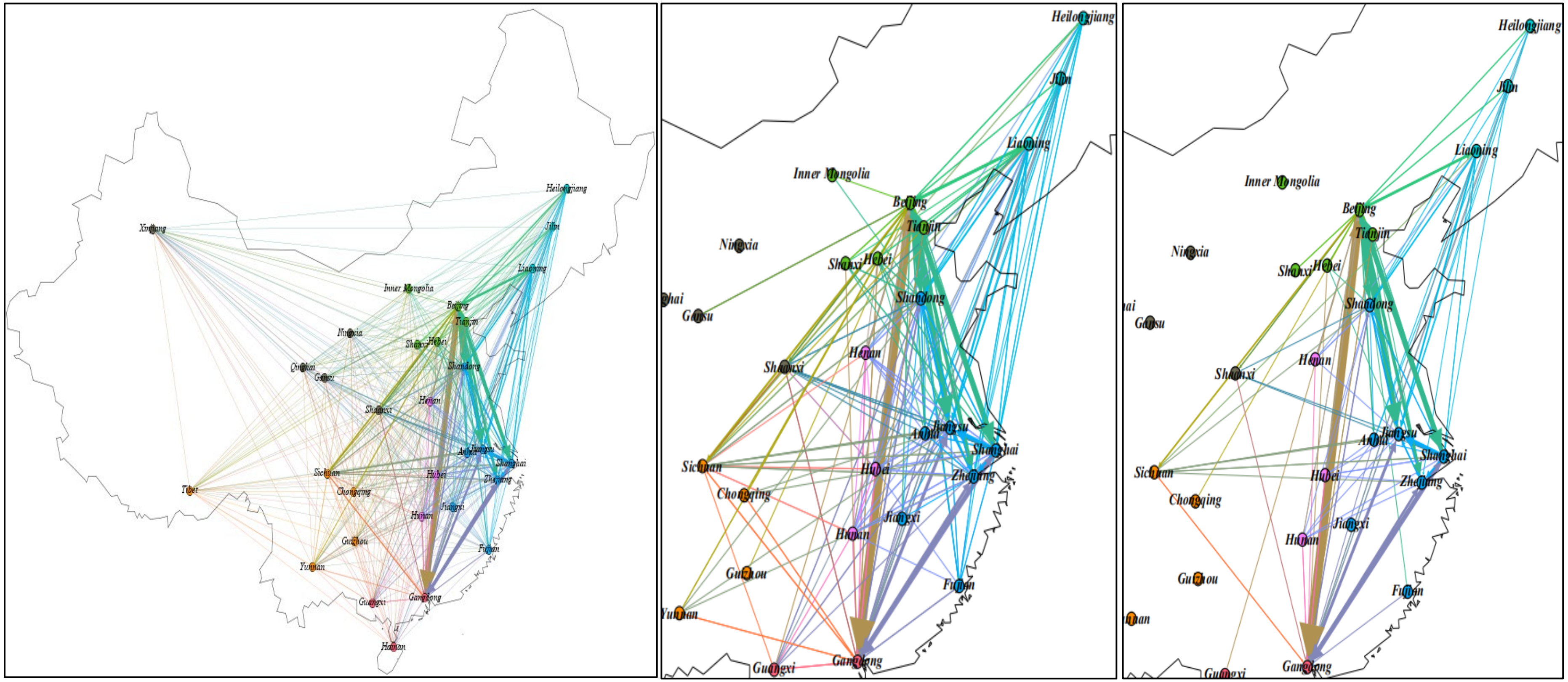


(a) **(b)** **(c)**

Notes: Panels (a), (b), and (c) display the case of the external patent citations at the provincial level with different thresholds, where panel (a) includes the full set of citations. To improve the readability and avoid having too many arrows, we only display edges for cities with patents cite larger than the threshold 29 (at least above 80% of the total city-to-city citations) and 52 (at least above 60% of the total city-to-city citations) units are displayed in panel (b) and (c), respectively. The provincial names are labelled in each map. The color of the nodes represents different regions. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Figure A2.3: External Innovation Network at the Provincial Level, Patents of 05-14 Cites that of 95-04

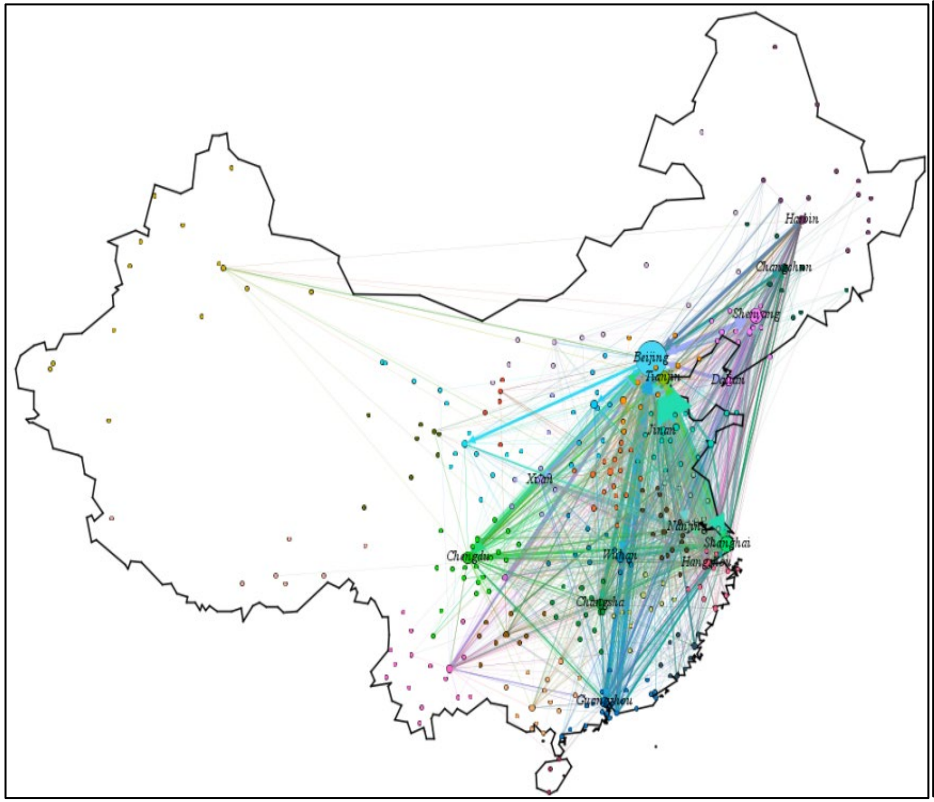


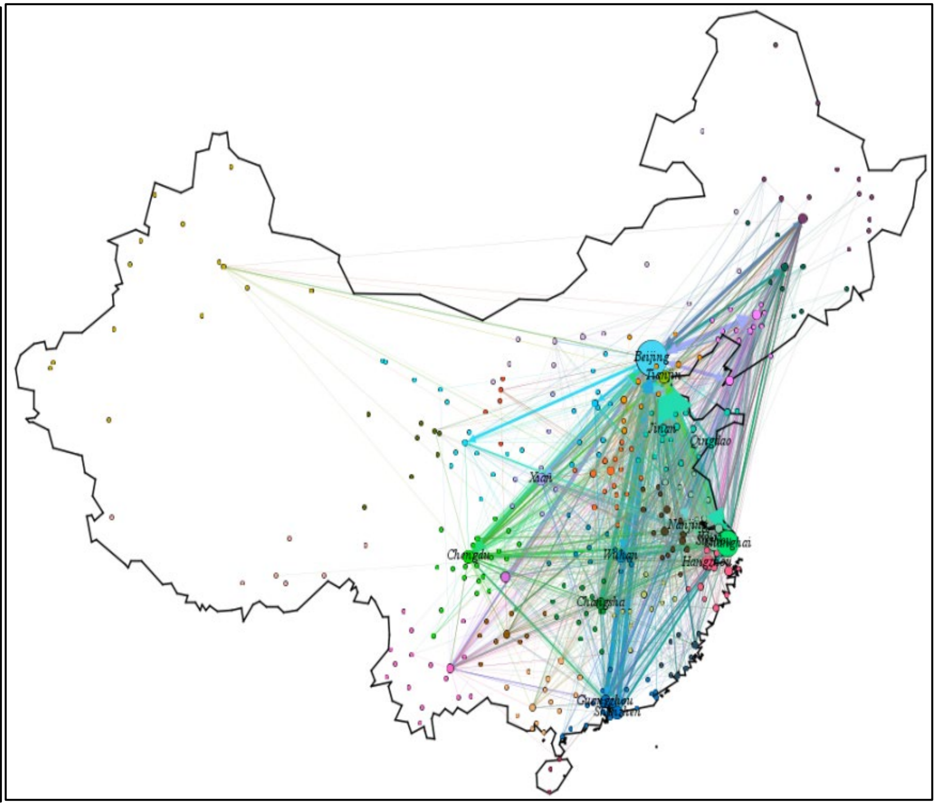
(a) **(b)** **(c)**

Notes: Panels (a), (b), and (c) display the case of the external patent citations at the provincial level with different thresholds, where panel (a) includes the full set of citations. To improve the readability and avoid having too many arrows, we display only patents cite larger than the threshold 285 (at least above 80% of the total city-to-city citations) and 617 (at least above 60% of the total city-to-city citations) units are displayed in panel (b) and (c), respectively. The provincial names are labelled in each map. The color of the nodes represents different regions. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Figure A3.1: Weighted Degree Centrality at the City Level, Patents of 05-14 Cites that of 85-94



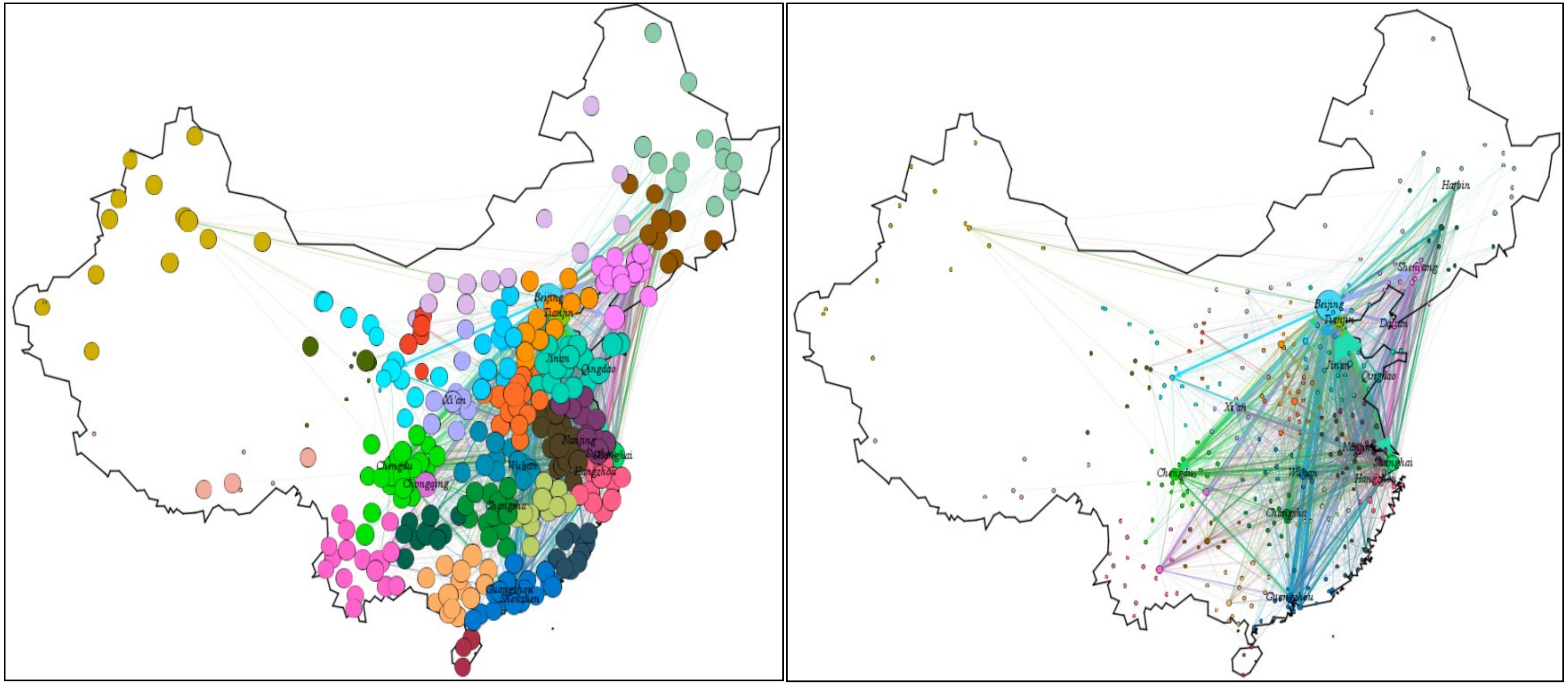


(a) Weighted in-degree centrality **(b) Weighted out-degree centrality**

Notes: Panels (a) and (b) compare the case of the in-degree centrality (cited) versus out-degree centrality (citing). Similarly, panels (c) and (d) also compare the case of the in-degree centrality (cited) versus out-degree centrality (citing) but with weights. To improve the readability and avoid having too many arrows, only patents cite larger than the threshold 5 units (i.e. 60% of the total) are displayed. According to the values of centrality in each case, the names of top fifteen cities are labelled in each map. The color of the nodes represents different provinces. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Figure A3.2: Closeness Centrality and Betweenness Centrality at the City Level, Patents of 05-14 Cites that of 85-94

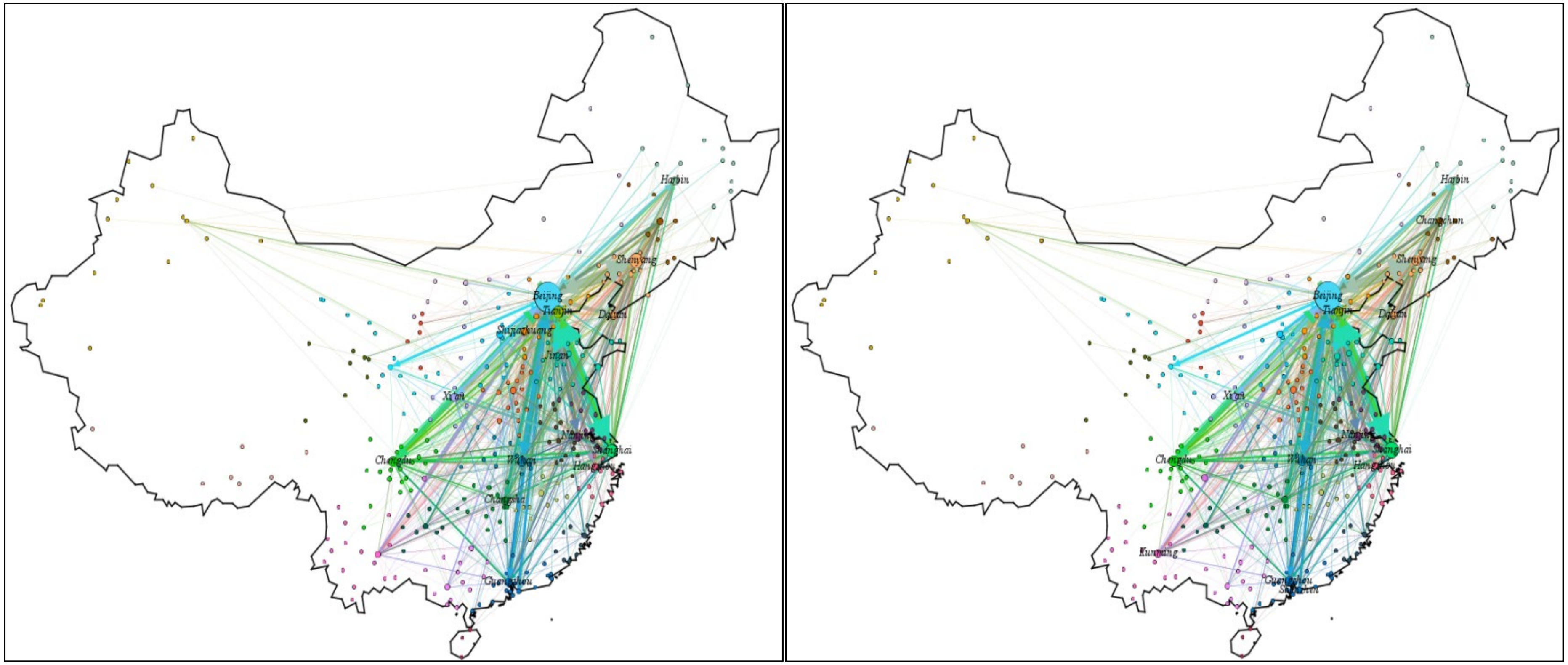


(a) Closeness centrality **(b) Betweenness centrality**

Notes: Panels (a) and (b) compare the case of the closeness centrality versus betweenness centrality. To improve the readability and avoid having too many arrows, only patents cite larger than the threshold 5 units (i.e. 60% of the total) are displayed. According to the values of centrality in each case, the names of top fifteen cities are labelled in each map. The color of the nodes represents different provinces. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Figure A3.3: Weighted Degree Centrality at the City Level, Patents of 95-04 Cites that of 85-94

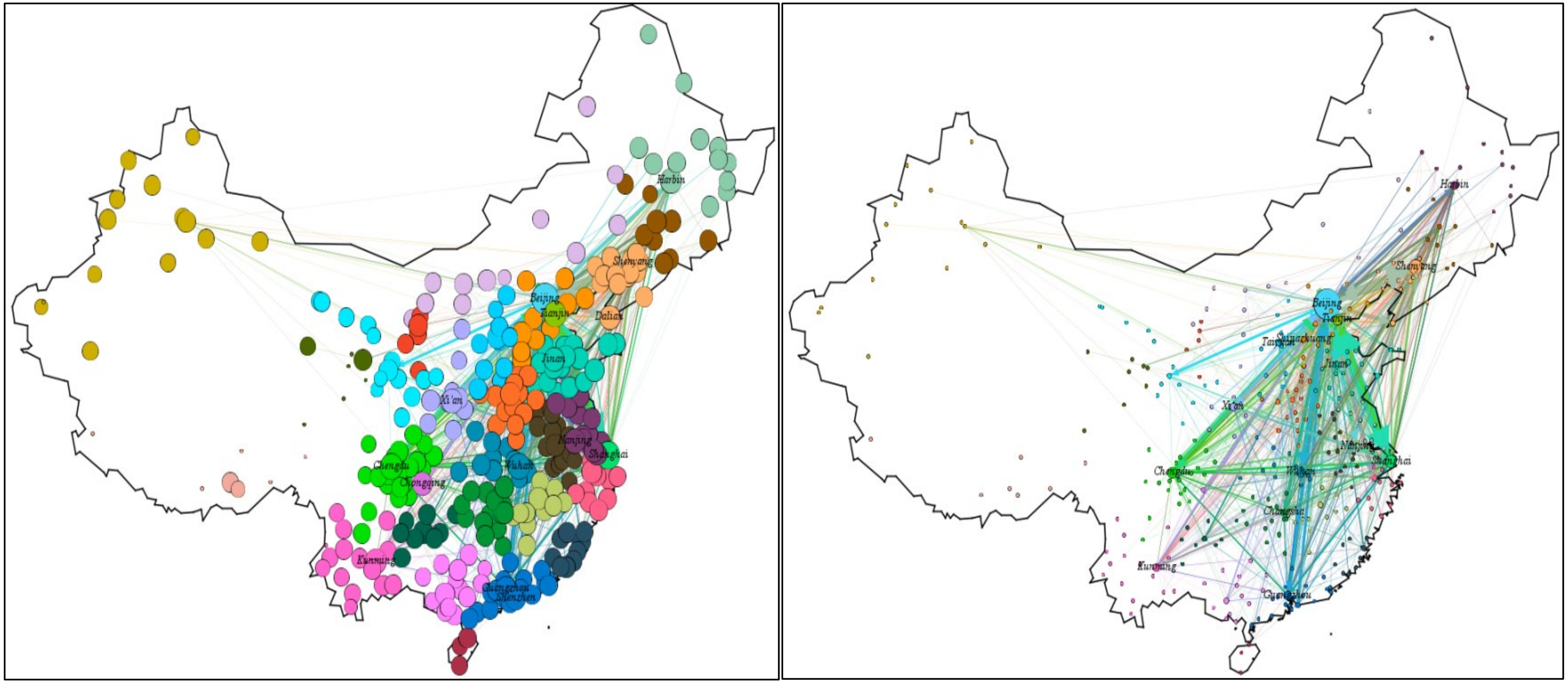


(a) Weighted in-degree centrality **(b) Weighted out-degree centrality**

Notes: Panels (a) and (b) compare the case of the indegree centrality (cited) versus outdegree centrality (citing). Similarly, panels (c) and (d) also compare the case of the indegree centrality (cited) versus outdegree centrality (citing) but with weights. To improve the readability and avoid having too many arrows, only patents cite larger than the threshold 3 units (i.e. 60% of the total) are displayed. According to the values of centrality in each case, the names of top fifteen cities are labelled in each map. The color of the nodes represents different provinces. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Figure A3.4: Closeness Centrality and Betweenness Centrality at the City Level, Patents of 95-04 Cites that of 85-94

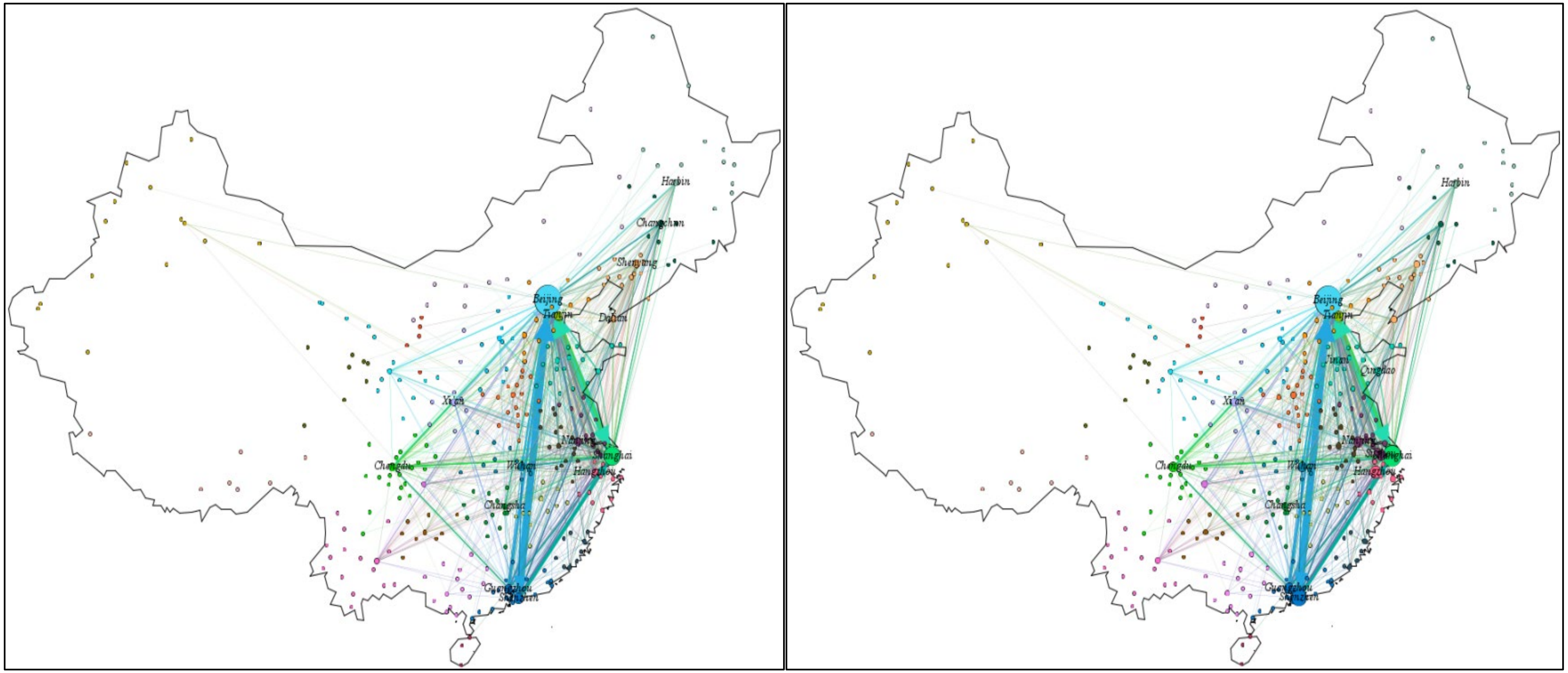


(a) Closeness centrality **(b) Betweenness centrality**

Notes: Panels (a) and (b) compare the case of the closeness centrality versus betweenness centrality. To improve the readability and avoid having too many arrows, only patents cite larger than the threshold 3 units (i.e. 60% of the total) are displayed. According to the values of centrality in each case, the names of top fifteen cities are labelled in each map. The color of the nodes represents different provinces. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Figure A3.5: Weighted Degree Centrality at the City Level, Patents of 05-14 Cites that of 95-04

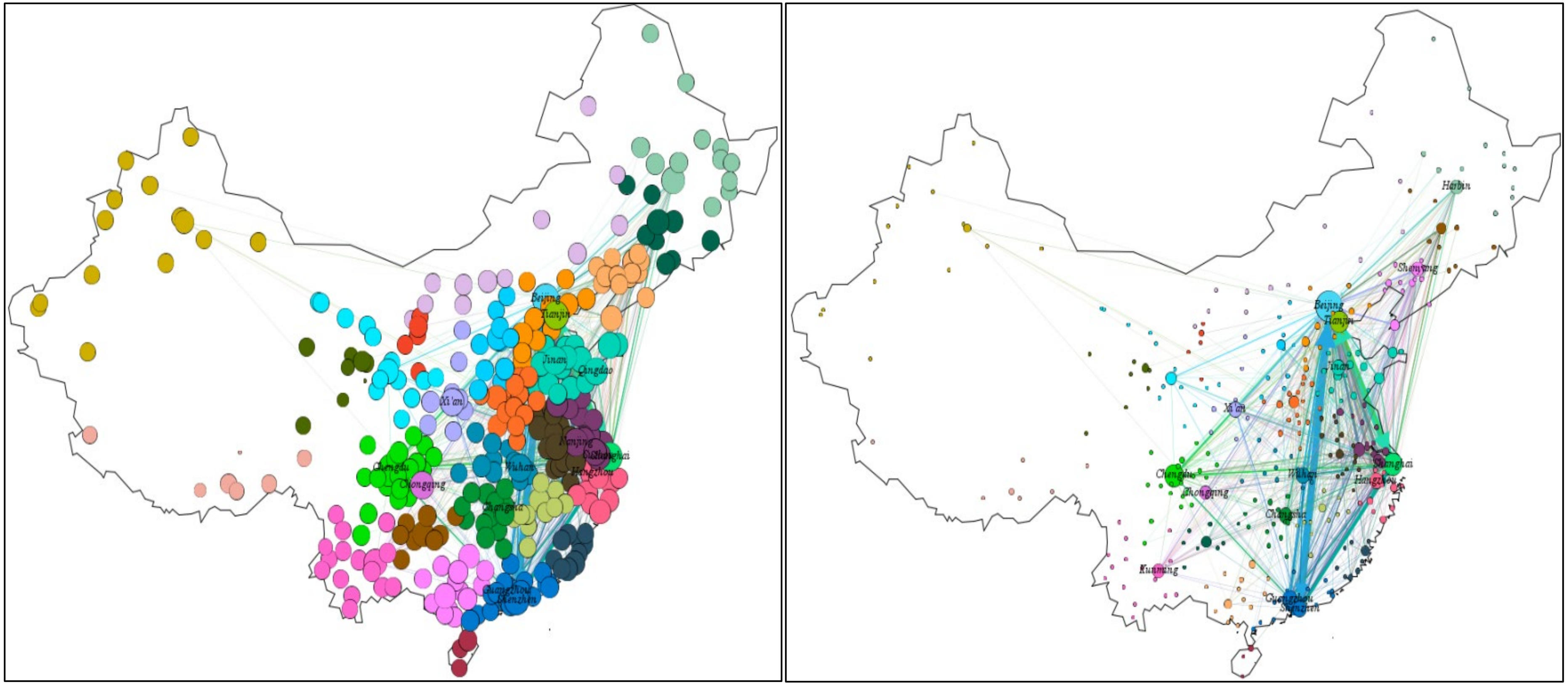


(a) Weighted in-degree centrality **(b) Weighted out-degree centrality**

Notes: Panels (a) and (b) compare the case of the in-degree centrality (cited) versus out-degree centrality (citing). Similarly, panels (c) and (d) also compare the case of the in-degree centrality (cited) versus out-degree centrality (citing) but with weights. To improve the readability and avoid having too many arrows, only patents cite larger than the threshold 35 units (i.e. 60% of the total) are displayed. According to the values of centrality in each case, the names of top fifteen cities are labelled in each map. The color of the nodes represents different provinces. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Figure A3.6: Closeness Centrality and Betweenness Centrality at the City Level, Patents of 05-14 Cites that of 95-04



(a) Closeness centrality **(b) Betweenness centrality**

Notes: Panels (a) and (b) compare the case of the closeness centrality versus betweenness centrality. To improve the readability and avoid having too many arrows, only patents cite larger than the threshold 35 units (i.e. 60% of the total) are displayed. According to the values of centrality in each case, the names of top fifteen cities are labelled in each map. The color of the nodes represents different provinces. Arrows display the color of the province of citation made (origin).

Sources: National Intellectual Property Administration; authors' calculations.

Table A4.1: Upstream and Innovation
(external network)

	(1)	(2)	(3)	(4)	(5)	(6)
$ln\hat{P}$	0.877***	0.616***	0.610***	0.360***	0.446***	0.523***
	(0.007)	(0.044)	(0.058)	(0.040)	(0.042)	(0.041)
$l.lnW\_ind$			0.010			
			(0.037)			
$l.lnW\_outd$				0.313***		
				(0.021)		
$l.lnclo$					2.312***	
					(0.199)	
$l.lnbet$						0.100***
						(0.012)
Constant	1.914***	2.503***	2.387***	1.901***	4.392***	2.298***
	(0.034)	(0.086)	(0.110)	(0.086)	(0.191)	(0.095)
Time FE	No	Yes	Yes	Yes	Yes	Yes
City FE	No	Yes	Yes	Yes	Yes	Yes
Observations	3,585	3,585	3,237	3,186	3,186	3,144
R-squared	0.789	0.817	0.818	0.846	0.836	0.836
Number of id	335	335	335	331	331	328

Notes: *(**, ***): significance at the 10% (5%, 1%) level. Robust standard errors are reported in parentheses. Dependent variable is log of the number of patents.
Source: Authors' calculations.

Table A4.2: Upstream and Innovation with Centrality Interactions
(external network)

	(1)	(2)	(3)	(4)
$ln\hat{P}$	0.553***	0.295***	0.411***	0.478***
	(0.067)	(0.045)	(0.049)	(0.042)
$l.lnW\_ind$	0.019			
	(0.036)			
$ln\hat{P} \times l.lnW\_ind$	0.046**			
	(0.021)			
$l.lnW\_outd$		0.313***		
		(0.021)		
$ln\hat{P} \times l.lnW\_outd$		0.050***		
		(0.014)		
$l.lnclo$			2.230***	
			(0.190)	
$ln\hat{P} \times l.lnclo$			0.316*	

			(0.162)	
$l.lnbet$				0.101***
				(0.012)
$ln\hat{P} \times l.lnbet$				0.044***
				(0.012)
Constant	2.414***	1.971***	4.376***	2.374***
	(0.109)	(0.087)	(0.182)	(0.095)
Time FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Observations	3,237	3,186	3,186	3,144
R-squared	0.819	0.848	0.837	0.838
Number of id	335	331	331	328

Notes: *(**, ***): significance at the 10% (5%, 1%) level. Robust standard errors are reported in parentheses. Dependent variable is log of the number of patents.
Source: Authors' calculations.

Table A4.3: Upstream Innovation and Policy Uncertainty
(external network)

	(1)	(2)	(3)	(4)	(5)
$ln\hat{P}$	0.609***	0.589***	0.358***	0.440***	0.517***
	(0.044)	(0.056)	(0.040)	(0.041)	(0.041)
$Policy$	-0.013	-0.020	-0.013	-0.008	-0.015
	(0.016)	(0.016)	(0.017)	(0.017)	(0.017)
$ln\hat{P} \times Policy$	-0.035*	-0.009	-0.009	-0.012	-0.008
	(0.019)	(0.022)	(0.021)	(0.022)	(0.022)
$l.lnW\_ind$		0.027			
		(0.036)			
$l.lnW\_outd$			0.310***		
			(0.021)		
$l.lnclo$				2.300***	
				(0.204)	
$l.lnbet$					0.097***
					(0.012)
Constant	2.532***	2.379***	1.921***	4.401***	2.326***
	(0.086)	(0.113)	(0.087)	(0.192)	(0.094)
Time FE	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Observations	3,556	3,212	3,163	3,163	3,124
R-squared	0.819	0.820	0.848	0.838	0.838
Number of id	333	333	329	329	326

Notes: *(**, ***): significance at the 10% (5%, 1%) level. Robust standard errors are reported in parentheses. Dependent variable is log of the number of patents.
Source: Authors' calculations.

Table A4.4: Full Model
(external network)

	(1)	(2)	(3)	(4)
$ln\hat{P}$	0.530***	0.294***	0.403***	0.471***
	(0.064)	(0.045)	(0.048)	(0.042)
$Policy$	-0.008	0.012	0.002	-0.014
	(0.023)	(0.022)	(0.021)	(0.017)
$ln\hat{P} \times Policy$	0.014	-0.028	-0.010	-0.006
	(0.066)	(0.052)	(0.047)	(0.025)
$l.lnW\_ind$	0.036			
	(0.036)			
$ln\hat{P} \times l.lnW\_ind$	0.046**			
	(0.020)			
$Policy \times l.lnW\_ind$	-0.008			
	(0.051)			
$ln\hat{P} \times l.lnW_{ind} \times Policy$	-0.014			
	(0.019)			
$l.lnW\_outd$		0.309***		
		(0.021)		
$ln\hat{P} \times l.lnW\_outd$		0.049***		
		(0.014)		
$Policy \times l.lnW\_outd$		0.034		
		(0.038)		
$ln\hat{P} \times l.lnW\_outd \times Policy$		-0.020		
		(0.017)		
$l.lnclo$			2.214***	
			(0.193)	
$ln\hat{P} \times l.lnclo$			0.330**	
			(0.163)	
$Policy \times l.lnclo$			0.090	
			(0.401)	
$ln\hat{P} \times l.lnclo \times Policy$			-0.113	
			(0.198)	
$l.lnbet$				0.098***
				(0.012)
$ln\hat{P} \times l.lnbet$				0.045***
				(0.012)
$Policy \times l.lnbet$				-0.002
				(0.022)
$ln\hat{P} \times l.lnbet \times Policy$				0.003
				(0.021)
Constant	2.406***	1.985***	4.383***	2.402***
	(0.112)	(0.086)	(0.181)	(0.093)

Time FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Observations	3,212	3,163	3,163	3,124
R-squared	0.821	0.849	0.838	0.840
Number of id	333	329	329	326

Notes: *(**, ***): significance at the 10% (5%, 1%) level. Robust standard errors are reported in parentheses. Dependent variable is log of the number of patents.

Source: Authors' calculations.

Highlights:

- The eastern regions produce the most citations made and received both within and across regions.
- Intra-province citations are significantly higher than the inter-provincial citations. And the most influential inventions are agglomerated in six provinces.
- From the map, we can identify an interesting diamond structure inclusive of Beijing (in the north), Sichuan (in the west), Guangdong (in the south), and Shanghai (in the east) being the four largest vertices in the innovation network.
- In addition to Beijing and Shanghai, Guangzhou and Shenzhen have higher values of in- and out-degree centrality than peers. Beijing and Chengdu are the two super-spreaders of information and technology.
- The importance of invention measured by centrality could spur more innovation activities.
- The upstream invention has strong predictive power on new innovation in the focal city.

Policy Implications:

- A better understanding of city innovation features can be a valuable aid to policy makers in developing local and regional innovation system and allocating research and development fund efficiently.
- Our finding of significant predictive power of upstream invention on growing new invention in the focal city suggests that research and development should be supported in a continuous way. A slack of invention in one period could be felt years later and generates undesirable economic and business outcomes.
- An expedition of the patent examination process that fastens the disclosure of information greatly increases the invention visibility and its citations and this practice benefits the follow-on innovation.
- A cautious heed should be paid to the change of local leadership structure that has weak but negative influence on the growth of innovation.