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Urban Hierarchy of Innovation Capability and Inter-city Linkages of Knowledge in Post-reform China

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Abstract: The 2000s has witnessed increasing interests in cities′ role of innovation in the era of knowledge-based economy. Compared with substantial empirical analysis on the world city hierarchy of innovation, this paper attempts to examine the national urban hierarchy of innovation capability in China, in terms of ranking systems, spatial pattern and inter-city linkages of knowledge during the post-reform period since the late 1970s. Based on quantitative analysis such as principal component factor analysis and clustering analysis, this paper identifies the five-tier hierarchy of innovation, which is headed by Beijing and Shanghai, followed by the capital cities of each province and regional centre cities. The development of China′s urban hierarchy of innovation capability has been driven by such factors as the scale of innovation, scientific scale, innovation potential and innovation environment. The paper further investigates the inter-city linkages of knowledge measured by the number of co-authored papers among the cities. Beijing is positioned in the central position of the knowledge diffusion and knowledge cooperation innovation. More knowledge diffusion among high level cities has occurred than that among the low level cities as well as between the low level cities and high level cities, and provincial capital cities and the regional central cities.
Keywords: urban hierarchy; innovation capability; inter-city linkages of knowledge; Chinese cities

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1 Introduction

The 2000s has witnessed increasing interests in cities′ role of innovation in the era of knowledge-based economy. There have emerged dramatic paradigm transitions in the era of globalization with a proliferation of empirical research on the changing geographies of ′urban systems′ (Pred, 1977). Population size of cities is typically used to define ′national urban hierarchies′. The ongoing globalization has changed dramatically the nature and functions of cities and regions, which have become the concentrated nodes of innovation and centers of knowledge flows. Existing literature on urban systems has focused primarily on the production and economic functions. Little has been done to reflect the changing patterns of national-level urban hierarchy from the perspective of innovation and knowledge based on economy. In the contemporary globalization era, the importance of knowledge and innovation in developing urban and regional competition has been widely recognized. Productivity and competitiveness has been increasing based on the generation and distribution of new knowledge (Castells and Hall, 1994). No cities or regions can develop without substantial linkages of sources of innovation and production. It was acknowledged that major cities and regions have become important nodes of innovation (Bell, 1997). So far little has been done to examine urban hierarchy from the perspectives of innovation capability and inter-city linkages of knowledge, with very few exceptions primarily based on

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global level analysis (Matthiessen *et al*, 2002; 2006a; 2006b; 2010).

Since 2000, increasing efforts have been taken to examine the global city hierarchy and inter-city linkages at the global level. There emerged a fundamental movement from world city formation to world city network (WCN) formation: scholars focused on the intercity linkages in the global system, as parts of multiple transnational urban networks (Taylor, 2004). Nevertheless, recent criticism of WCN literature has pointed out its emphasis on a few large metropolitan centers in developed countries while the research on city network in developing countries is still limited (Derudder *et al*., 2010a). Furthermore, in comparison with increasing empirical analysis of global urban network, relatively little has been done on the changing patterns of urban networks at national levels. There is a need to study the intercity knowledge linkages and the functioning of cities from perspective of global knowledge diffusion and industrial upgrading in developing countries (Wei *et al*., 2010). This is particular relevant to China which has tried to develop an innovation and knowledge-based economy since the early 2000s (Lu and Wei, 2007a).

This paper contributes to the literature through investigating the urban hierarchy of innovation capability in Chinese cities. It explores the major characteristics and changes of innovative cities and intercity linkages of knowledge during the post-reform period since the late 1970s. This paper aims to deepen our understanding about the knowledge diffusion between Chinese cities and provides a reference for the research on intercity knowledge linkages in the era of globalization.

2 Reconceptualizing Urban Hierarchy and Inter-city Linkages in Era of Globalization

The ongoing globalization has changed the function of cities from domestic oriented production and consumption to the nodes of global-local network of capital and information flows. Globalizing cities have also become centers of knowledge creation and diffusion. Howkins (2002) demonstrated how creative clusters in the US had played an important role in economic growth. Florida (2002) has argued that regions and urban areas with the best economic performance have the largest number of creative workers. The importance of knowledge and innovation in regional and urban competition has been widely recognized. Productivity and competitiveness were increasing based on the generation and distribution of new knowledge (Castells and Hall, 1994). It was acknowledged that major cities and metropolis have become important nodes of innovation (Bell, 1997). Since 2000, the geography of 'urban system' (Pred, 1977) has changed with paradigm transition in the increasing globalization. Data from national census and population size of cities in particular are typically used to define 'national urban hierarchies' (Pred, 1973). In response to the functions of innovation and knowledge creation in cities and regions, there emerged two major theoretical perspectives on the emerging functions of innovation in cities and regions. School of innovation milieu has stressed the local innovation mechanism, but it neglected spatial dissemination of innovation. National, regional innovation systems theory focused on 'structural' dissemination of knowledge among actors, without sufficient attention given to the innovation network and the prominent roles of the cities in the national and regional systems of innovation. A growing body of literature has discussed the development of knowledge based on economy in individual cities while researchers tend to ignore innovation linkages among cites. So far little has been done to investigate the relationship between urban networks and inter-city linkages of knowledge, with very few exceptions mainly on the global level (Matthiessen *et al*., 2002; 2006a; 2006b; 2010). Matthiessen *et al*. (2002) analyzed the strength, interrelations and nodality of global research centers, based on science citation index data for the period of 1997–1999. Based on registrations of total output from science, medicine and technical research, they found a highly concentration pattern of research with a small number of important urban units (Matthiessen *et al*., 2002). They also found networks of cooperation within the research community were controlled by a few strong nodes, leaders and followers. Matthiessen *et al*. (2006a), through the analysis of global top-level research centers over time, identified and examined patterns of winners and losers using time series data during the periods of 1996–1998, 1999–2001 and 2002–2004. They further discussed cooperation patterns in peer communities using data on co-authorship 2002–2004 for total research output. Matthiessen *et al*. (2006b; 2010) analyzed subsets of data representing different types of research in association with the world cities network (Friedmann, 1986;

Sassen, 1991; Castells, 1996; Taylor, 2004). Besides the analysis of collaborative research outputs, GaWC (Globalization and World Cities Study Group and Network) group (Taylor, 2004) attempted to examine the hierarchy of world cities based on connectivity of business service networks. In contrast to the increasing efforts on the global city hierarchy of knowledge flows, little has been done on the national level city hierarchy of innovation, particularly in some developing countries such as China.

Early studies of cities as part of a hierarchy system were nationwide except for a few territorial studies on globally recognized cities like London and New York. In the 1980s, scholars started to study ′globalized′ cities represented by the research on ′world cities′ (Friedmann, 1986) and ′global cities′ (Sassen, 1991). The 2000s has witnessed the movement from world city formation to world city network formation: scholars study cities in the context of global systems of relationships, as parts of multiplex transnational urban networks (Taylor, 2004). Nevertheless, there has emerged more recent criticism on the existing World City Network (WCN) literature that more emphasis has focused on only a few large metropolitan centers in developed countries (Derudder *et al*., 2010a). The lack of analysis of cities in developing countries is reflected by two ′maps′: one is that the geographical map of world cities wherein most cities of the ′South′ are missing; and other one is that the conceptual map of world cities which focuses on a narrow range of global economic process so that many connections between cities within nations are missing (Derudder *et al*., 2010b). It was argued that cities located in core countries have on average grown relatively more powerful and prestigious in the recent decades. And, cities located in core/developed countries are relatively more likely to play an active, primary role in the network, while cities in developing countries are more likely to play a passive, isolate role (Alderson *et al*., 2010). In comparison with increasing empirical analysis on the global urban network, there is a need to study the changing patterns of urban networks at national levels especially in developing countries.

China has also become a research hotspot in terms of innovation and knowledge diffusion from developed countries to developing countries. A rich body of literature has devoted to regional and national innovation system (Wang, 2001; Gu and Lundvall, 2006). Recent efforts have been taken to explore the roles of cities in developing the innovation systems at regional levels (Wei *et al*., 2012). For example, Wu and Liu (2003) analyzed the role of cities in urban clusters in the Changing (Yangtze) River Delta. Gu (1998) categorized cities into three levels of innovation according to their respective strength of technical innovation. Sui (2004) proposed a concept of innovation circle of large cities. Based on a large-scale survey of ICT firms in Beijing, Shanghai-Suzhou and Shenzhen-Dongguan, Zhou *et al.* (2011) pointed out that although Beijing received the smallest amount of FDI, the city outperformed other cities in terms of technology dynamism. Since 2001, from the perspective of urban competitiveness, the Research Group of China Science and Technology Development published annual reports entitled ′Report of Regional Innovation Capability′ (The Research Group of China Technological Development Strategy, 2006) based on provincial levels. As a matter of fact, the majority of the existing empirical studies have tended to focus on either specific regions in China or specific dimension of innovation. Little has been conducted on the national urban network of innovation particularly the roles of cities as nodes of innovation in the national innovation network in the era of global economy.

In fact, in the post-reform period since the late of 1970s, the dynamics of China development has changed from production factors, such as labors, capital, land and technology, to innovation and knowledge (Lu and Wei, 2007b). ′Building an innovation-oriented country by 2020′ was set for the first time as a target in China′s Fourth National Conference on Science and Technology held in January 2006, so as to promote ′scientific development′ emphasized in the National Medium-and-Long Term S&T Development Plan (2006–2020). Following Shenzhen, other 16 cities, including Dalian, Qingdao, Xiamen, Shenyang, Xi′an, Guangzhou, Chengdu, Nanjing, Hangzhou, Jinan, Hefei, Zhengzhou, Changsha, Suzhou, Wuxi and Yantai, were selected as experimenting bases by the State Reform and Development Commission to build innovation-oriented cities. A number of studies have devoted to quantify the innovation capabilities of cities (Zhou, 2010). It is not the intension of this study to find out the most innovative city in China, or measure the innovation abilities of various cities. Instead, the paper aims to update the literature on urban system from the perspective of innovation and knowledge diffusion, with a particular emphasis on the positions of cities in the national innovation-oriented urban system, as well as the inter-city linkages of knowledge in China.

3 Urban Hierarchy of Innovation Capabilities in Post-reform China

3.1 Major factors determining cities′ innovation capabilities in China

This paper attempts to explore the national urban hierarchy of innovation through a comprehensive data set. First of all, a set of indicators consisting of four categories including 32 variables to cover the major index of innovation, innovation contents and innovation environment are selected (Table 1). The main sources of the data are from China Statistical Yearbooks of China (SSB, 2007). Other data, such as governmental supports and socio-economic factors were collected from questionnaire and expert interviews. A dataset of 73 cities, which include all the provincial capital cities and the majority

Table 1 Indicators of urban hierarchy of innovation in Chinese cities

Indicator and corresponding variable	Unit
I. Intellectual innovative ability	
X_1: Number of higher education institutions	unit
X_2: Number of faculty in higher education institutions	persons
X_3: Number of scientists and engineers	persons
X_4: Raito of R&D expenditure to GDP	%
X_5: Number of published papers	copies
X_6: Books owned in public library per 100 people	copies
X_7: Number of internet users	users
X_8: Proportion of college graduated people in total population	%
II. Technical innovative ability	
X_9: Number of industrial enterprises	unit
X_{10}: Number of foreign investment enterprises	unit
X_{11}: R&D expenses of industrial enterprises above designated size	10^4 yuan
X_{12}: Research institution attached in industrial enterprises above designated size	unit
X_{13}: Employed persons of information transmission, computer service, software industry, scientific research, technical service and geologic investigation industry	10^4 persons
X_{14}: Number of granted patent	item
X_{15}: Number of technical expertise	persons
X_{16}: General level of high-tech industry	%
X_{17}: Gross output of national level high-tech industry	10^4 yuan
III. Governmental support	
X_{18}: Financial input of education and science	10^4 yuan
X_{19}: Public education expenditure per person	yuan
X_{20}: Level of administrative protection system of intellectual property	%
X_{21}: Level of centre of education, science and culture in city	%
X_{22}: Loans of financial institution by end of year	10^4 yuan
X_{23}: Environmental assessment of social service	%
X_{24}: Foreign capital actual use in current year	10^3 USD
IV. Social-economic factors	
X_{25}: GDP	10^4 yuan
X_{26}: Total population of urban area by end of year	10^4 persons
X_{27}: Revenue of postal service and telecommunications	10^4 yuan
X_{28}: Number of mobile phones	users
X_{29}: Proportion of sunny days of city	%
X_{30}: Beauty level of artificial environment of city	%
X_{31}: Convenience of physical location	%
X_{32}: Environmental assessment of human resources	%

of prefecture-level cities, except Taiwan, Hong Kong and Macao, were collected. These 73 cities could reflect the general profile of the innovation capabilities in Chinese cities. The data of the 73 cities in the year 2006 has been chosen for the analysis.

Using SPSS 13.0 software and factor analysis methods, we identify main factors of the innovation capabilities of Chinese cities. The variables of the sample cities are standardized to eliminate the dimensional impact on the evaluation results and make the mean of the standardized variables as 0, variance as 1. The standardized formula is:

$$y_{ij} = \frac{x_{ij} - \overline{x}_i}{s_i} \qquad (i = 1, 2, \ldots, n)$$

Where y_{ij} is the standardized value of variable i of index j; x_{ij} is the original value of variable i of index j; x_i is the mean of all the variables; s_i is the standard deviation

Through re-calculating, we get the relevant coefficient matrix R and find out the correlation of variables and the eigenvalue, contribution rate and cumulative contribution rate of relevant matrix R (Table 2).

The results show that the variance of 32 variables mainly concentrate in the six principal components (or the main factors) and the eigenvalues of the six principal components are greater than 1, and the cumulative variance accounts for 86.054% of the total of original variables. After Orthogonal rotation, we select the first four principal components whose eigenvalues greater than 4 to analyze the innovation capabilities of cities. The cumulative contribution of these four principal components is 80.796%, which well represents the innovation capabilities of selected cities.

The initial principal component factor analysis can not give a more satisfactory explanation for some components. Therefore, through factor orthogonal rotation and the 'variance maximization', we get the component load-value matrix after varimax (Table 3). The table reflects the correlation between variables and components. Based on the variables within four main factors, we are able to summarize the main factors that contribute to innovation capability.

The first principal component factor is mainly derived from the variables of X_{10}, X_9, X_7, and X_{25}. The loadings of these variables are 0.922, 0.887, 0.879, and 0.858, which respectively represent the number of foreign investment enterprises, number of industrial enterprises, number of internet users and GDP. The first principal factor can be defined as the factors of the scale of innovation capability, and its eigenvalue is 11.113, which can explain 34.727% of the variance of the original variables. Through the analysis of the factor scores, we conclude that Shanghai, Shenzhen, Guangzhou, Beijing, Tianjin are at the top five cities in terms of scale of innovation capability; these cities are often firstly chosen cities for foreign investment and transnational enterprises; the sizes of their economies are larger than other cities and they also own plenty of amenity facilities. In short, the scale of innovation capability is consistent with the city system in China.

The second principal components factor consists of variables of X_{15}, X_{13}, X_3, X_5, and X_4, which represent number of technical expertise; employed persons of information transmission, computer service, software industry, scientific research, technical service and geologic investigation industry; number of scientists and engineers; number of published papers; the ratio of R&D expenditure to GDP. The contributions of these variables to the second principal factor are respectively 0.929, 0.803, 0.764, 0.728, and 0.710, the second factor can be defined as the efficiency of scientific research, and its eigenvalue is 5.237, which can explain 16.364%

Table 2 Total and percentage of variance of principal components

Principal component	Eigenvalues and contribution rate			Eigenvalue and contribution rate after orthogonal rotation		
	Eigenvalue	Contribution rate (%)	Cumulative contribution rate (%)	Eigenvalue	Contribution rate (%)	Cumulative contribution rate (%)
1	18.761	58.629	58.629	11.113	34.727	34.727
2	3.467	10.836	69.465	5.237	16.364	51.092
3	2.210	6.907	76.372	5.085	15.890	66.981
4	1.416	4.424	80.796	4.421	13.815	80.796
5	1.116	2.756	83.552			
6	1.085	2.502	86.054			

Table 3 Load-value matrix of four principal components across 32 variables after rotation

Variable system	Component load-value matrix after rotation			
	Principal component 1	Principal component 2	Principal component 3	Principal component 4
X_1: Number of higher education institutions	0.304	0.303	0.845	0.131
X_2: Number of faculty in higher education institutions	0.278	0.325	0.874	0.106
X_3: Number of scientists and engineers	0.523	0.764	0.197	0.023
X_4: Ratio of R&D expenditure to GDP	0.090	0.710	0.239	0.107
X_5: Number of published papers	0.488	0.728	0.401	0.068
X_6: Books owned in public library per 100 people	0.605	0.188	0.384	–0.021
X_7: Number of internet users	0.879	0.223	0.304	0.102
X_8: Proportion of college graduated people to total population	0.075	0.056	0.517	0.570
X_9: Number of industrial enterprises	0.887	0.107	0.143	0.338
X_{10}: Number of foreign investment enterprises	0.922	0.016	0.119	0.255
X_{11}: R&D expenses of industrial enterprises above designated size	0.830	0.249	0.115	0.272
X_{12}: Research institution attached in industrial enterprises above designated size	0.453	0.200	0.348	0.495
X_{13}: Employed persons of information transmission, computer service, software industry, scientific research, technical service and geologic investigation industry	0.437	0.803	0.371	0.017
X_{14}: Number of granted patent	0.812	0.428	0.011	0.084
X_{15}: Number of technical expertise	0.231	0.929	0.138	0.017
X_{16}: General level of high-tech industry	0.546	0.212	0.275	0.745
X_{17}: Gross output of National level high-tech industry	0.607	0.465	0.379	0.245
X_{18}: Financial input of education and science	0.796	0.412	0.275	0.159
X_{19}: Public education average expenditure per person	0.372	0.083	0.065	0.734
X_{20}: Level of administrative protection system of intellectual property	0.062	–0.031	0.266	0.807
X_{21}: Level of centre of education, science and culture in city	0.405	0.390	0.757	0.142
X_{22}: Loans of financial institution by end of year	0.784	0.433	0.39	0.140
X_{23}: Environmental assessment of social service	0.471	0.439	0.467	0.009
X_{24}: Foreign capital actual use in current year	0.839	0.142	0.297	0.309
X_{25}: GDP	0.858	0.301	0.325	0.192
X_{26}: Total population of urban area by the end of year	0.582	0.275	0.59	0.154
X_{27}: Revenue of postal service and telecommunications	0.832	0.387	0.3	0.104
X_{28}: Number of mobile phones	0.661	0.257	0.343	0.155
X_{29}: Sunny days of the city	0.032	–0.148	–0.234	0.614
X_{30}: Beauty level of artificial environment of the city	0.034	0.271	0.117	0.748
X_{31}: Convenience of physical location	0.381	–0.008	0.056	0.774
X_{32}: Environmental assessment of human resources	0.588	0.244	0.619	0.271

of the total variance of original variables. In terms of the efficiency of research, Beijing, Xi′an, Zhuhai, Lanzhou are the top four, which reflect that these cities have more talented professionals and owned abundant technical strengths. In particular, Beijing is the most prominent city in all aspects mentioned above, because of its high level of information industry and a large of body of professionals and technicians and growing of input in research. This finding is also consistent with what Wei *et al*. (2011) found that Beijing plays a leading role in the R&D network in China.

The third principal component factor is a combination of the variables of X_2, X_1, X_{21}, and X_{32}. The loadings are respectively 0.874, 0.845, 0.757, 0.619, which represent the number of faculty in higher education institutions, number of higher education institutions, level of centre of education, science and culture in city, and environmental assessment of human resources. The third factor can be defined as the potential of innovation, and its eigenvalue is 5.085, which can explain 15.89% of the total variance of the original variables. Based on the factor score, Wuhan, Nanjing, Guangzhou, Xi'an are top four, which reflect superior potential of innovation in these cities. Most of these cities are regional science and education centers and potential innovation centers.

The fourth principal component factor is composed of the variables of X_{20}, X_{31}, X_{30}, X_{16} and X_{19}. The loadings of the fourth principal factor are respectively 0.807, 0.774, 0.748, 0.745, and 0.734. They are the level of administrative protection system of intellectual property, convenience of physical location, Beauty level of artificial environment of the city, level of high-tech industry, public education average expenditure per person. We defined them as the factor of innovation environment and its eigenvalue is 4.421, which can explain 13.82% of the total variance of the original variables. In terms of the innovation environment, Wuxi, Xiamen, Ningbo, Suzhou, Zhuhai are top five. These cities are known in China for their livability, favorable geographical location, protection system of intellectual property rights and high education investment. They are characterized by good living environment and developing platforms for the innovational activities. Therefore, they have advantages for attracting creative talents and develop innovation capabilities.

3.2 Urban hierarchy of innovation capabilities in Chinese cities

Although the principal component analysis reflects the innovative capabilities of different cities from different perspectives, innovation abilities are combined effect of four main factors. In order to comprehensively compare the innovation ability and identify the hierarchy of city level innovation capabilities, we take factor loadings as weights after the orthogonal rotation to calculate the comprehensive factor score of each city. In other words, the weight is 0.34727 for the first main factor, 0.16364 for the second main factor, 0.1589 for the third main factor, and 0.13815 for the fourth main factor. Therefore the formula is as follows:

$$Z = 0.34727Z_1 + 0.16364Z_2 + 0.1589Z_3 + 0.13815Z_4$$

Z is integrated scores; Z_1, Z_2, Z_3, Z_4 are the score of main factor of each city; the score was calculated by the SPSS.

We get the scores of Z_1, Z_2, Z_3, Z_4 and Z (integrated score) using the SPSS, and then rank the cities according to the Z score. The results are listed in Table 4.

According to composite score of factors, we can outline the hierarchy of innovation capabilities of Chinese cities (Fig. 1). As shown in Fig. 1, the geography of innovation capabilities at the city level shows the following characteristics: 1) the three major urban agglomerations in China, the Changjiang River Delta, Beijing-Tianjin-Tangshan Region and the Zhujiang River Delta have highest levels of innovation capabilities; 2) in the western and central regions of China and Northeast China, the regional innovation centers are mainly located at capital or equivalent level cities. Because of more research institutions, human capital and the sizes of economy, these cities occupy an important position in the regional innovation systems.

According to the scores of innovation ability, we also employ cluster analysis to categorize all the sample cities into five groups (Table 5). As indicated, the hierarchy of Chinese cities in terms of innovation capability is a pyramid-type system. Only a limited number of cities are of high level innovation performance while a large number of cities are less innovative. Shanghai and Beijing are the two cities in the first group with the composite scores of 2.251902 and 1.861347, which are much higher than other cities. These two cities play a leading role in all the Chinese cities in terms of the ability of knowledge innovation, technological innovation and the governmental support and competitiveness. They can be regarded as national innovation center city in China. Shenzhen, Guangzhou and Tianjin are in the secondary group. Their composite scores are higher than 0.5, but are still much lower than those of Beijing and Shanghai; these cities could be named second national innovation center city in China.

The cities like Hangzhou, Nanjing, Chongqing, and Wuhan are located in the third level in the hierarchy. These cites have owned a certain degree of economic strengths, human capital advantage and better advantage of the geographical environment and innovation, but they are limited in innovation capacity. They have enormous potential of innovation and can be regarded as regional innovation center city in China. The cities, like Zhongshan, Changsha, Harbin, *etc*. are located in the fourth level of innovation hierarchy. Their composite scores are generally lower. These cites are weak in the ability of independent innovation and main input of knowledge and technology is from outside, but they are playing important role in local innovation. Therefore, they can be regarded as local innovation center city.

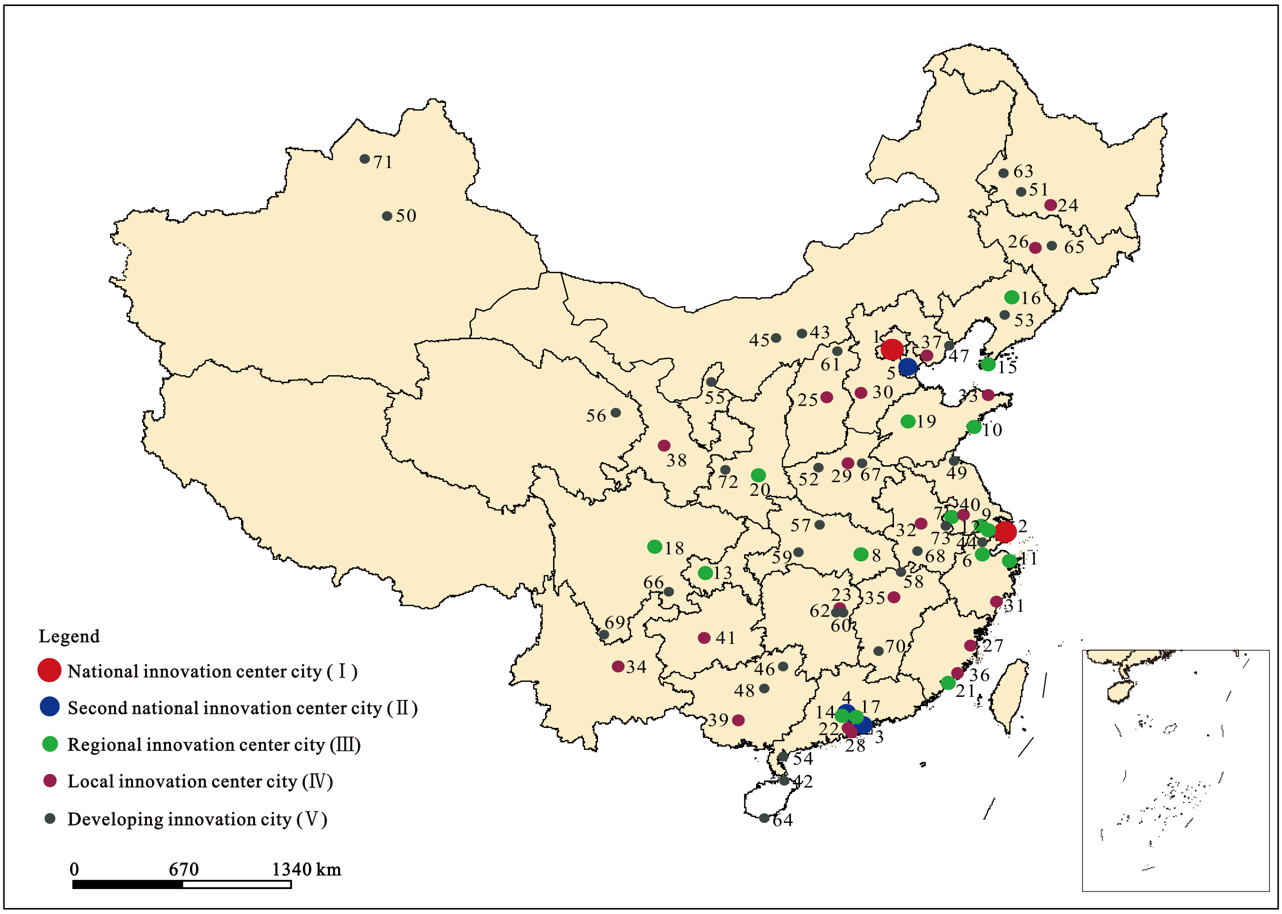
Table 4 Order and scores of city innovation ability

City	FAC4_1	FAC4_2	FAC4_3	FAC4_4	Score	Order
Shanghai	6.66859	–0.79574	0.63495	–0.25029	2.251902347	1
Beijing	1.31256	8.01436	0.66274	–0.0814	1.861346558	2
Shenzhen	3.38567	–0.05718	–1.75551	0.03654	0.892482148	3
Guangzhou	1.38511	–0.77987	2.10721	0.05188	0.695392114	4
Tianjin	1.37312	–0.57981	1.22346	0.41962	0.634341571	5
Hangzhou	0.34061	–0.50118	1.06413	1.72087	0.443098987	6
Nanjing	–0.01185	–0.33241	2.1356	0.65334	0.371095039	7
Wuhan	–0.52806	–0.49598	3.31675	0.4166	0.320043302	8
Suzhou	0.36385	–0.21481	–0.52845	1.83244	0.260383562	9
Qingdao	0.14367	–0.20861	–0.07336	1.65585	0.232854114	10
Ningbo	0.39505	–0.59404	–0.56206	2.0088	0.228184694	11
Wuxi	–0.244	0.37076	–0.43137	2.13212	0.201944971	12
Chongqing	0.21157	–0.08018	0.96109	–0.08465	0.201374062	13
Foshan	0.32122	–0.00929	-0.9495	1.6825	0.191591679	14
Dalian	0.48731	–0.73663	0.27853	0.66986	0.185485587	15
Shenyang	0.1234	–0.59488	1.678	–0.2369	0.17941342	16
Dongguan	1.01708	–0.90763	–0.79719	0.68114	0.172102798	17
Chengdu	–0.31509	0.25529	1.08916	0.44815	0.167333798	18
Jinan	–0.07211	–0.46254	1.54699	0.05717	0.152983061	19
Xi′an	–0.80355	0.72308	1.87523	–0.0095	0.135937625	20
Xiamen	–0.28724	0.32901	–0.76042	2.05061	0.116550395	21
Zhongshan	0.11069	0.10311	–1.15118	1.53332	0.084217893	22
Changsha	–0.34522	–0.09787	1.33756	–0.1129	0.061041153	23
Harbin	–0.40072	–0.04179	1.35829	–0.31049	0.026941538	24
Taiyuan	–0.10803	–0.13829	1.08777	–0.72456	0.012603335	25
Changchun	–0.63529	0.16442	1.51179	–0.38612	–0.00683052	26
Fuzhou	–0.18823	–0.5285	0.5407	0.24336	–0.03231296	27
Zhuhai	–0.53188	0.40797	–0.98841	1.746	–0.03379421	28
Zhengzhou	–0.54013	–0.13336	1.2447	–0.18674	–0.03740928	29
Shijiazhuang	–0.41686	0.14524	0.7977	–0.32086	–0.03856818	30
Wenzhou	0.03259	–0.36499	–0.84795	1.01091	–0.04349147	31
Hefei	–0.83023	0.19056	1.00472	0.34847	–0.0493396	32
Yantai	–0.11288	–0.25579	–0.61445	0.89483	–0.05507265	33
Kunming	–0.5821	–0.08531	0.3116	0.78124	–0.05866445	34
Nanchang	–0.63113	–0.29164	1.32267	–0.0582	–0.06476455	35
Quanzhou	–0.55374	0.11919	–0.99015	1.57834	–0.1120802	36
Tangshan	–0.52476	0.34939	–0.28775	0.39834	–0.11575203	37
Lanzhou	–0.54807	0.40666	0.40877	–0.49595	–0.12734437	38
Nanning	–0.44745	–0.06446	0.03445	0.23899	–0.12744362	39
Zhenjiang	–0.46914	0.09992	–0.78268	1.01002	–0.13140093	40

Continued Table 4

City	FAC4_1	FAC4_2	FAC4_3	FAC4_4	Score	Order
Guiyang	–0.2526	–0.17444	0.11918	–0.33928	–0.14419959	41
Haikou	–0.63412	–0.34214	0.03201	0.57235	–0.1920421	42
Hohhot	–0.37891	–0.12882	0.34153	–0.73592	–0.20006241	43
Huzhou	–0.41817	–0.03897	–0.87575	0.58457	–0.20999328	44
Baotou	–0.16723	0.08504	–0.14173	–1.07102	–0.21464033	45
Guilin	–0.43048	–0.12665	–0.52746	0.26675	–0.21717968	46
Qinhuangdao	–0.61268	0.3908	–0.49557	0.05986	–0.21929129	47
Liuzhou	–0.70944	0.16548	–0.49303	0.51903	–0.22592655	48
Lianyungang	–0.46264	–0.01634	–1.09642	0.77433	–0.23058232	49
Urumqi	–0.2963	0.0096	0.11424	–1.10203	–0.23541787	50
Daqing	0.13152	–0.20206	–0.4001	–1.42678	–0.2480777	51
Luoyang	–0.42912	0.20143	–0.6013	–0.27282	–0.24929515	52
Anshan	0.24946	–0.39077	–0.46626	–1.47223	–0.25479292	53
Zhanjiang	–0.24875	–0.11807	–1.1543	0.13234	–0.27083989	54
Yinchuan	–0.17921	–0.12277	–0.15217	–1.26187	–0.28083149	55
Xining	–0.12617	–0.34781	–0.15821	–1.13128	–0.28215659	56
Xiangfan	–0.22732	0.10487	–0.79136	–0.69304	–0.28327107	57
Jujiang	–0.23027	–0.11846	–0.68511	–0.57319	–0.28740084	58
Yichang	–0.0698	–0.14499	–0.64584	–1.00402	–0.28929495	59
Zhuzhou	–0.13831	–0.11442	–0.58598	–0.9459	–0.29054291	60
Datong	–0.30781	0.28342	–0.71081	–0.86966	–0.29360557	61
Xiangtan	–0.06087	–0.2028	–0.58969	–1.136	–0.30496466	62
Qiqihaer	–0.01373	–0.17783	–0.58171	–1.34373	–0.31193814	63
Sanya	–0.37168	–0.08386	–0.88709	–0.20432	–0.31198157	64
Jilin	0.09899	–0.27615	–0.43727	–1.67779	–0.31208182	65
Yibin	–0.22166	0.00337	–0.99258	–0.58959	–0.31559722	66
Kaifeng	–0.37068	0.09835	–0.78821	–0.57423	–0.31720849	67
Anqing	–0.36358	0.07944	–0.83616	–0.52112	–0.31811942	68
Panzhihua	–0.1311	–0.00996	–0.90335	–1.06861	–0.33832774	69
Ganzhou	–0.08821	–0.2186	–0.72372	–1.1586	–0.34146409	70
Karamay	0.00594	–0.15505	–0.44124	–1.84837	–0.34877495	71
Baoji	–0.05167	–0.16182	–0.73091	–1.3699	–0.34981695	72
Ma′anshan	–0.03773	–0.07528	–0.72777	–1.56067	–0.35667053	73

A number of cities like Haikou, Hohhot, Huzhou, Baotou, *etc*., are at the fifth level of innovation hierarchy. These cities are weak in the ability of independent innovation and their innovation generally depends on the technology diffusion from regional innovation centers, but innovation facilities and environments are being formed, and can be defined as developing innovation city. It need to state that no comparability across different years of the same kind cities. It does not means absolute raising and falling in innovation capability in the cluster analysis, but it just shows that the speed of capabilities-promoting of different cities and the relative gap



1. Shanghai; 2. Beijing; 3. Shenzhen; 4. Guangzhou; 5. Tianjin; 6. Hangzhou; 7. Nanjing; 8.Wuhan; 9. Suzhou; 10. Qingdao; 11. Ningbo; 12.Wuxi; 13. Chongqing; 14. Foshan; 15. Dalian; 16. Shenyang; 17. Dongguan; 18. Chengdu; 19. Jinan; 20. Xi′an; 21. Xiamen; 22. Zhongshan; 23. Changsha; 24. Harbin; 25. Taiyuan;26. Changchun; 27. Fuzhou; 28. Zhuhai; 29. Zhengzhou; 30. Shijiazhuang; 31. Wenzhou; 32. Hefei; 33. Yantai; 34. Kunming; 35. Nanchang; 36. Quanzhou; 37. Tangshan; 38. Lanzhou; 39. Nanning; 40. Zhenjiang; 41. Guiyang; 42. Haikou; 43. Hohhot; 44. Huzhou; 45. Baotou; 46. Guilin; 47. Qinhuangdao; 48. Liuzhou; 49. Lianyungang; 50. Urumqi; 51. Daqing; 52. Luoyang; 53. Anshan; 54. Zhanjiang; 55. Yinchuan; 56. Xining; 57. Xiangfan; 58. Jujiang; 59.Yichang; 60. Zhuzhou; 61. Datong; 62. Xiangtan; 63. Qiqihaer; 64. Sanya; 65. Jilin; 66. Yibin; 67. Kaifeng; 68. Anqing; 69. Panzhihua; 70. Ganzhou; 71. Karamay; 72. Baoji; 73. Ma′anshan

Fig. 1 Hierarchy of Chinese cities for innovation capability

Table 5 Hierarchy of Chinese cities for innovation capability

Hierarchy	Feature description	Score range	Cities
First grade	National innovation center city (Ⅰ)	FAC ≥ 1	Shanghai, Beijing
Second grade	Second national innovation center city (Ⅱ)	0.5 ≤ FAC< 1	Shenzhen, Guangzhou, Tianjin
Third grade	Regional innovation center city (Ⅲ)	0.1 ≤ FAC< 0.5	Hangzhou, Nanjing, Wuhan, Suzhou, Qingdao, Ningbo, Wuxi, Chongqing, Foshan, Dalian, Shenyang, Dongguan, Chengdu, Jinan, Xi′an, Xiamen
Fourth grade	local innovation center city (Ⅳ)	–0.15 ≤ FAC < 0.1	Zhongshan, Changsha, Harbin, Taiyuan, Changchun, Fuzhou, Zhuhai, Zhengzhou, Shijiazhuang, Wenzhou, Hefei, Yantai, Kunming, Nanchang, Quanzhou, Tangshan, Lanzhou, Nanning, Zhenjiang, Guiyang
Fifth grade	Developing innovation city (Ⅴ)	FAC < –0.15	Haikou, Hohhot, Huzhou, Baotou, Guilin, Qinhuangdao, Liuzhou, Lianyungang, Urumqi, Daqing, Luoyang, Anshan, Zhanjiang, Yinchuan, Xining, Xiangfan, Jiujiang, Yichang, Zhuzhou, Datong, Xiangtan, Qiqihar, Sanya, Jilin, Yibin, Kaifeng, Anqing, Panzhihua, Ganzhou, Karamay, Baoji, Ma′anShan

between the pace of change.

4 Inter-city Linkages of Knowledge in Post-reform China

We also analyze the co-authorship papers of the top 25 cities of innovation ability in China, based on China Academic Journal Full-text Database (CAJ)① under the network of China National Knowledge Infrastructure (CNKI) during the period of 2004–2006. The specific measures are: we should search for one assumed city from the ′Author location′ option; then press the ′search results′ to search results and does the same way for corresponding city; and finally make a summary analysis to find geographical linkages among cities where the authors were located. Though this method is not accurate to demonstrate inter-urban innovation links, we can draw some regional features of innovation cooperation from this dimension.

The searching results show that the total number of published papers in Beijing is the top, accounting for approximate 25% of the total. It reflects that Beijing is the center of theoretical knowledge innovation in China and concerned with the position of cultural center in China. Shanghai has the second top of the amount of published papers of China, accounting for 12%, which shows that Shanghai is also one of the most important innovation bases. It was followed by other cities in this order: Wuhan, Guangzhou, Nanjing, Xi′an, Tianjin, Changsha, Harbin, Chengdu, Hangzhou, Chongqing, Jinan, Shenyang, Dalian, Shenzhen, Qingdao, Taiyuan, Xiamen, Suzhou, Wuxi, Ningbo, Foshan, Dongguan and Zhongshan (Fig. 2). In term of regional distribution, the eastern coastal cities are the main body in knowledge innovation and provincial capital or city with stronger economic strength, are regional knowledge innovation centers, because of agglomeration of researched institutions and universities. Secondary tier cities in the Changjiang River Delta and the Zhujiang River Delta, such as Suzhou, Wuxi, Ningbo, Foshan, Dongguan and Zhongshan are rising in terms of innovation performance.

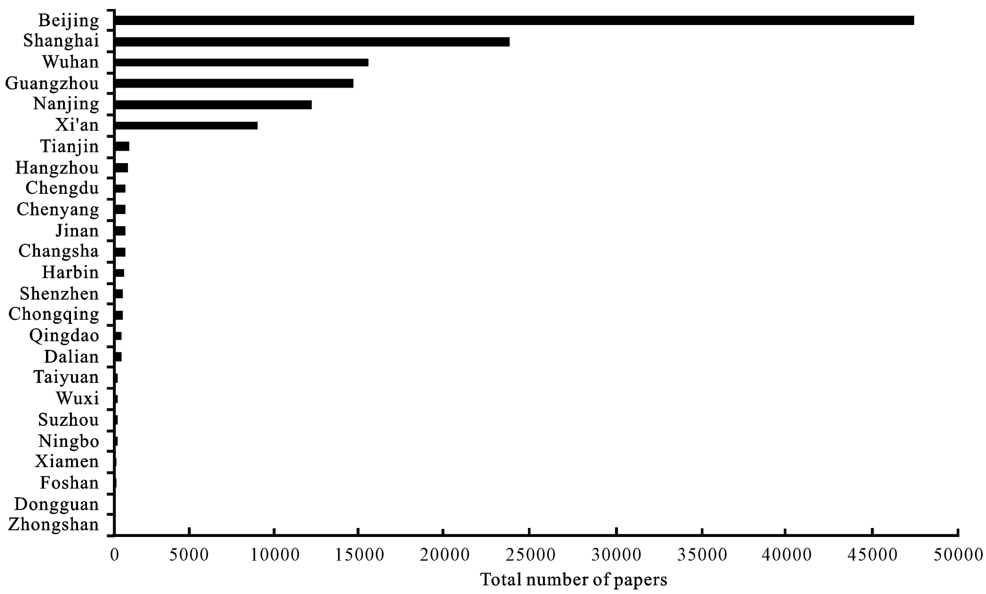


Fig. 2 Number of research papers of top 25 cities in China, 2004–2005

① China Academic Journals Full-text Database (CAJ) is the largest searchable full-text and full-image interdisciplinary Chinese journals database in the world, covering over 8460 titles since 1994. It included 5058 science and technology journals and 3402 social sciences and humanities journals by the end of 2007. The content is arranged into 10 series and 168 subjects for the convenience of academic research (http://ckrd85.cnki.net/kns50/). There are nine categories of subjects, including 1) Mathematics, Physics, Mecahnics, Astronomy; 2) Chemistry, Metallurgy, Environment, Mine industry; 3) Architecture, Energy, Traffic, Electromechanics; 4) Agriculture; 5) Medicine and public health; 6) Literature, History, Philosophy; 7) Politics, Military, Affairs, Law; 8) Education and social science; and 9) Economics and management

From total number of co-operative papers of inter-city, the total number of Beijing′s cooperative papers accounted for nearly a quarter of the total, indicating the Beijing′s core position in cooperative innovation, and from the cooperative partners to observe, the same conclusion could be got. From Table 6, the top 10 cities in the number of cooperative papers have cooperative relationship, suggesting that Beijing is the top city of knowledge diffusion in China. In term of regional characteristics of cooperation, Beijing has wide cooperative range, including more cooperative links with eastern cities of China, and also some cooperative links with middle and western cities of China. In general, more cooperative links occur in the larger cities and higher levels cities in innovation hierarchy. More cooperative links exist among neighboring cities than non-adjacent cities, and lower-ranks cities in innovation have less cooperative linkages. In province level, more cooperative links occur between provincial capital and prefecture-level cities. For instance, 90% of cooperative papers in Zhongshan City occur in the cities of the Zhujiang River Delta, especially in cooperation with the Guangzhou. In addition, the number of cooperative papers among high-level cities is much more than the number of cooperative papers between high ranking innovation cities and low ranking innovation cities as well as among low ranking cites.

Table 6 Top 10 cites in amount of co-authored papers in China

Cooperative city	Co-authored papers (copies)	Rank
Beijing and Shanghai	525	1
Beijing and Nanjing	464	2
Beijing and Wuhan	405	3
Beijing and Tianjing	373	4
Beijing and Xi′an	368	5
Beijing and Guangzhou	338	6
Beijing and Shenyang	253	7
Beijing and Harbin	232	8
Beijing and Jinan	224	9
Beijing and Chendu	200	10

In addition to several exception, the number of cooperative papers among cities have a more significant proportion of consistency with the total papers searched (Fig. 3). For example, from Fig. 2 and Fig. 3, the total number of co-authored papers in Beijing accounts for

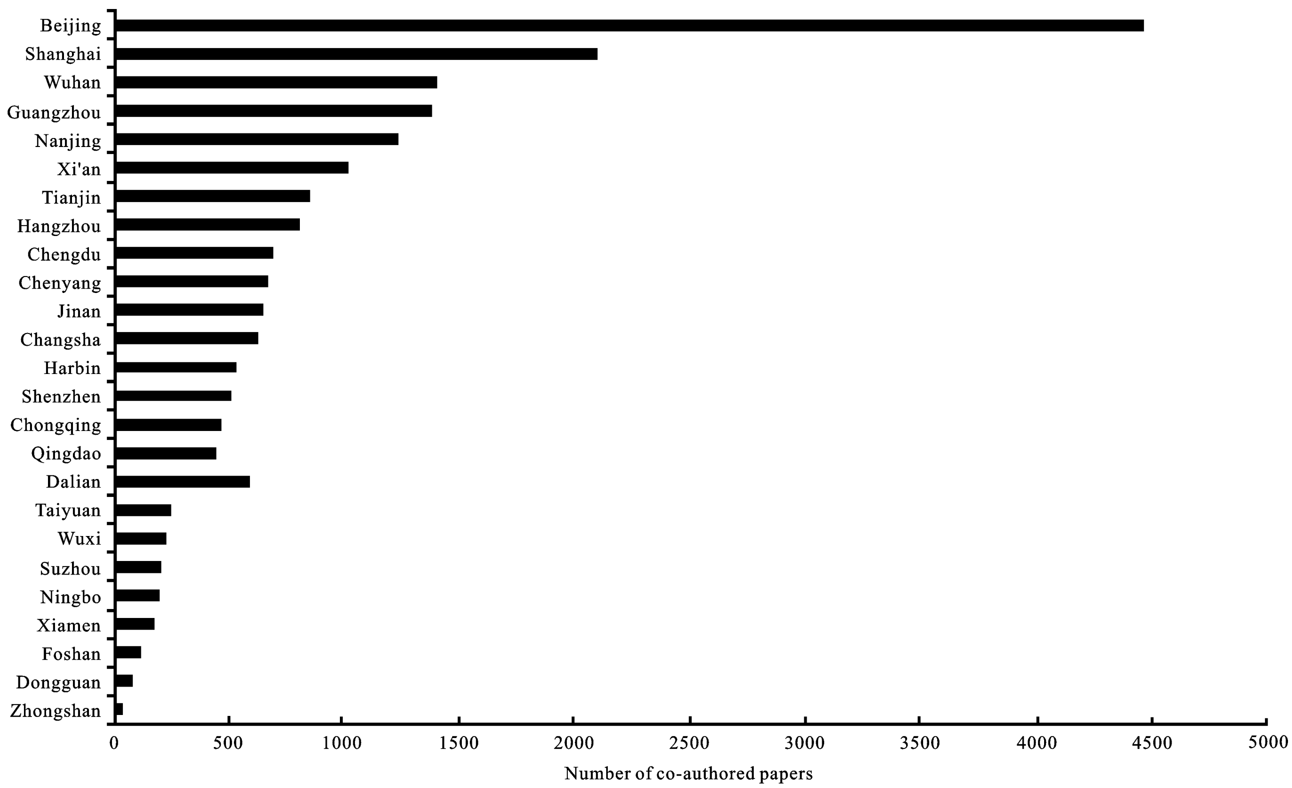


Fig. 3 Co-authored papers in top 25 cities in China, 2004–2005

22.85 % of the total. This is roughly the same as Beijing's share in total published papers. In addition, the numbers of published papers in other cities also have some positive relationship with the number of cooperative papers in these cities. This demonstrates that the innovation hierarchy of cities has certain correlation with the diffusion of knowledge.

This paper also uses the numbers of expected co-authored papers to show the position of relative importance of cities in the cooperative research. We compare the differences between the actual co-authored number of papers and the expected collaborative papers. We assume that the numbers of potential co-authored papers in particular cities can be determined by the number of co-authored papers of all cities and their shares in cooperative network. As shown in Equation (1), based on the actual number of cooperative papers, we can calculate the amount of expected co-authored papers in the following way:

$$COPUBEXP_i = \sum_{i=1}^{n} COPUB_i \times (PUB_i / \sum_{i=1}^{n} PUB_i) \quad (1)$$

where the $COPUBEXP_i$ is the number of expected co-authored papers in city i; the $COPUB_i$ is the total number of cooperative papers in city i; the PUB_i is the amount of published papers in city i; n is the number of cities.

Using Equation (1), we can calculate the differences between the number of expected co-authored papers and the numbers of actual co-authored papers so as to visually understand the corresponding position of the cities in the innovation networks. Table 7 is the results of co-authored papers of top 25 cities in China.

The results show that, the difference of the number of

Table 7 Contrast between amounts of expected papers with co-authored papers in each city

City	Published papers (piece)	Proportion of total papers (%)	Co-authored papers (piece)	Expected papers (piece)	Differences
Beijing	46872	24.93	4446	4860	–414
Shanghai	23160	12.32	2081	2401	–320
Guangzhou	14029	7.46	1393	1455	–62
Nanjing	11588	6.16	1370	1202	168
Wuhan	14919	7.94	1224	1547	–323
Xi'an	8393	4.46	1007	870	137
Tianjin	841	4	841	779	62
Hangzhou	799	3.28	799	640	159
Chengdu	683	3.51	683	684	–1
Chenyang	661	2.94	661	573	88
Jinan	638	3.04	638	593	45
Changsha	618	3.66	618	713	–95
Harbin	579	1.65	521	322	199
Shenzhen	521	3.14	499	613	–114
Chongqing	499	1.21	461	236	225
Qingdao	461	1.68	434	328	106
Dalian	434	3.53	579	688	–109
Taiyuan	242	0.99	242	192	50
Wuxi	222	0.77	222	150	72
Suzhou	202	0.94	202	184	18
Ningbo	191	0.69	191	134	57
Xiamen	169	0.97	169	189	–20
Foshan	109	0.36	109	70	39
Dongguan	74	0.27	74	53	21
Zhongshan	30	0.11	30	21	9
Total	188011	100	19494	19494	0

expected co-authored papers and the numbers of actual co-authored papers in Beijing, Shanghai, Wuhan, Shenzhen, Changsha, Dalian, Guangzhou, Shenzhen, Xiamen and Chengdu are negative (Table 7). It indicates that researchers in these cities outperform in both publishing papers and co-authored papers and the independent innovation ability of these cities is stronger than the other cities or their surrounding cities. while, the difference of the number of expected co-authored papers and the numbers of actual co-authored papers in Harbin, Nanjing, Xi′an, Hangzhou, Qingdao, *etc*. are positive, it indicates these cities fail to reach the role what they should play in co-operation and innovation in their regions and their independent innovation ability of these cities is not stronger enough.

5 Conclusions

Conventional studies of urban functions have generally put emphasis on economic functions, neglecting the increasing functions in terms of innovation and creation. This paper has examined the spatial pattern of China′s urban system from the perspective of innovation and inter-city linkages of knowledge. Existing literature on the urban systems in China has primarily focused on the urban economic function, with little attention paid to the innovation function. It is argued that in the era of knowledge economy, cities and regions have become the nodes of innovation and knowledge flows.

Using the principal component analysis and cluster analysis, the study indicates that the Chinese innovation system consists of five levels of hierarchical innovation system: Beijing and Shanghai are located in the top of this hierarchy as national innovation center city; Shenzhen, Guangzhou and Tianjin are the secondary centers in the national hierarchy; other cities, like Hangzhou, Nanjing and Wuhan are at the third level in the hierarchy and act as regional center of innovation and knowledge diffusion; cities like Zhongshan, Changsha, Harbin and Taiyuan are at the fourth level as the local center of innovation cities; while cities like Haikou, Hohhot and Huzhou are at the fifth level as developing innovation city. The eastern coastal cities have the important positions in the China′s regional innovation system. The capital cities of each province and the cities with more developed economy have generally been the centers of regional innovation systems. The Chinese innovation system is mainly driven by four important factors, i.e., the scale of innovation capacity, the scale and efficiency of researchers and institutions, the potentials of innovative activities and the environment of innovation.

Through investigating the co-authorship papers among the cities, we also analyze the intercity innovative relationship. The results show that Beijing has been in the central position of the knowledge building and also plays a leading role in cooperative innovation, which is consistent with the recent research on the technology dynamism in different regions and cities in China. There are more intensive cooperative innovation activities among high level cities than those among the low level cities as well as between the low level cities and high level cities. Capital cities of province and the regional central cities where local economy is more developed have played a vital role in knowledge diffusion. The emerging roles of cities have been widely recognized in building ′innovation-oriented country′ in China. More studies are needed to further examine the changing patterns of the innovation systems and inter-city linkages of knowledge diffusion in China and other developing countries, so as to establish a solid conceptual framework.

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