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Decline of the center: The decentralizing process of knowledge transfer of Chinese universities from 1985 to 2004

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Abstract

University knowledge transfer, which contains both codified and non-codified knowledge, is an important source of industry innovativeness. The geographic constraint on university knowledge flows, which is commonly observed in Western countries, makes proximity with universities a big plus in creating learning regions. No systematic study has been conducted in China regarding such geographic constraint on knowledge transfer and its implications on China's nation and regional innovation systems. Taking advantage of the Chinese patent data, this paper examines the geographic variations in university–industry collaborations in China from 1985 to 2004 and shows a decentralizing/localizing trend in knowledge flows from university to industry. The blockmodel analysis further reveals the roles of different provinces and municipalities in the National Innovation System and how those had changed over time. Besides showing a vivid picture of the knowledge exchange patterns among Chinese provinces and municipalities, the results suggest that the geographic constraint on knowledge flows only becomes salient in China in recent years due to the administrative decentralization and the economic reform. As a result of these changes, less favored regions are further left behind not only due to their shortage of local university resources, but also because of the reduced extra-local knowledge support, which constitutes an important supplemental resource for regional development.

Keywords: University knowledge transfer; Decentralization; Uneven regional development; China; Patent data

1. Introduction

1.1. The impact of public research on industry

Economists have traditionally seen knowledge produced by the public sector as public goods contributing to economic growth (Arrow, 1962; Nelson, 1959). Numerous studies have examined the impact of academic research on industry innovation. For example, Adams (1990) has found that basic research has a significant effect on increasing industry productivity, although the effect might be delayed for 20 years. Similarly, through a survey of R&D executives from 76 randomly selected firms, Mansfield (1991) estimated that 10% of industrial innovations were dependent on the academic research conducted within the prior 15 years. Rosenberg and Nelson (1994) have shown that universities, as the institutions conducting basic research, contribute significantly to industry innovation. In his famous report *Science—The Endless Frontier*, Bush (1945) attributed America's advantage in technology to its strong base in science. According to the linear model Bush proposed in his report, scientific findings from curiosity-driven research will be absorbed by applied science, and in turn

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used in industry. Although driven by pure curiosity, basic science will eventually generate useful products. Bush's report had a big impact on the U.S. science policy. The research funding for basic science increased significantly after World War II.

Due to the increased international competition and fiscal constraints, universities have been expected to contribute to the national economy in a more direct way in the past 20 years, i.e., by conducting more applied research and making the results available for commercial use. Stokes (1997) has criticized the traditional view that splits curiosity-driven and use-driven research and advocates use-inspired basic research. This line of argument adds an interactive component to the traditional linear model—questions raised by industry could help improve current theory or even suggest new directions of theoretical research (for a detailed discussion, see Kline, 1985 and Brooks, 1994). Therefore, governments of many countries have been strengthening universities' roles in their national innovation systems by encouraging more interactions between universities and industry (e.g., see Ballesteros and Rico, 2001; Beesley, 2003; Etzkowitz and Leydesdorff, 2000; Liu and White, 2001; Nelson, 1993).

Unlike many Western countries that have experienced a transition in science policy from curiosity-driven to use-driven, the Chinese government has been advocating a use-driven science policy since its establishment, requiring research institutes and universities to serve the national economy by solving practical problems for industry (Hong, 2006). This science policy essentially divides technological R&D from industry production, with universities and research institutes actively engaged in downstream industrial projects and enterprises focusing on fulfilling assigned producing quota. Compared to developed countries where firms are a major source of innovation, the extensive involvement of public research in industry R&D in China constitutes an important character of her National Innovation System. Therefore, industry heavily relies on universities and research institutes for technology improvement while contributing little to scientific research. As a result, university–industry interactions in China are often unidirectional, with the knowledge flowing from university to industry.

Although the important role of university in the National Innovation System has long been recognized in China, no systematic study has been conducted regarding the pattern of knowledge flows from university to industry. This paper is intended to present a dynamic analysis of the thirty provinces and municipalities regarding their production and utilization patterns of university knowledge and the university knowledge transfer networks among them, in order to show the geographic variations in knowledge transfer activities and to deepen our understanding of university's role in China's national and regional innovation systems.

1.2. History of China's science policy

China, now making the transition from a planned economy to a market economy, has an institutional context and level of economic development very different than the Western countries where most innovation studies were conducted. When the People's Republic of China was founded in 1949, research was the territory of research institutes overseen by the Chinese Academies of Science, local governments, and various industrial ministries (Chinese Education Ministry, 1999; Liu and White, 2001). Yet, it was also argued that conducting research in universities would help solve practical problems. Hence universities were encouraged to collaborate closely with industry, for example, in solving production problems for factories (Ministry of Education, 1999; Yuan, 2002). Unfortunately, the chaos in the Cultural Revolution severely stunted the development of scientific research. Order in universities and research institutes was not restored until 1978, when a development guideline for science and technology was announced at the national science congress held in Beijing.

The mid-1980s witnessed several reforms in science policy. The most significant change was cutting government research funding to push research units to the market. From 1986 to 1993, government research funding decreased at an annual rate of 5% (Zhou et al., 2003, p. 24). Universities began to establish their own enterprises at that time, a practice officially approved by the central government in 1991. Sales by university start-ups were RMB 1.8 billion in 1991, and increased to RMB 2.9 billion in 1992 and RMB 37.9 billion in 1999[1] (Zhou et al., 2003, p. 19). During this same period, industry funding became the most important source of research funding for universities (in contrast to the U.S. or Japan, where it represented less than 10% of the total).

Another wave of reform on Chinese universities began in December 1994, when a national forum encouraged institutional merge and decentralization in jurisdiction for efficiency purpose (Hayhoe, 1996; Yang, 2000). As the results, 103 institutions combined into 42 comprehensive ones as of 1996 (Yang, 2000) and 612 institutions had been reduced to 250 by 2000 (Zhou et

[1] One dollar was about 8 RMB in the 1990s.

al., 2003). Among the 358 national universities, only 35 of them were still controlled by a central ministry, the Ministry of Education. The other 323 were administered by both the 62 central ministries they used to subordinate to and their local governments. The percentage of national universities dropped from 51% in 1995 to 9% in 2002 (Zhou et al., 2003). The decentralization reform has the implication of promoting collaborations between universities and local industries.

In order to join the World Trade Organization (WTO), China has been trying to improve its legal environment for intellectual properties. In April 1999, the Ministry of Education issued a Chinese version of Bayh-Dole Act that allowed universities to retain titles to inventions that were derived from government funding and emphasized the protection and commercialization of university intellectual properties (Ministry of Education, 1999). In August 1999, the central government organized a National Innovation Congress and issued an act promoting commercialization of innovation and development of high-tech industry. Many local governments incorporated it into their local science policies (Liu and White, 2001). Since then, universities have become even more enthusiastic about transferring knowledge to industry.

1.3. Geographic constraint on knowledge flows from university to industry and learning regions

It has been a difficult question why regions differ in their innovation capabilities and economic performance. Those successful ones that have established themselves in the global market due to their possession of certain social and institutional assets, such as "institutional thickness" (Amin and Thrift, 1994), "untraded interdependencies" (Storper, 1995a), "social capital" (Morgan, 1997), and "relational assets" (Henry et al., 1996), are often called "learning regions" (MacKinnon et al., 2002). Tacit knowledge accumulated through close interactions within specialized industrial clusters has been regarded as a key component in constructing such learning regions. Several corner stone studies have argued that the difficulty in transferring this form of non-codified knowledge constitutes the competitive advantage of the successful learning regions in the global market where codified knowledge is supposed to be easily accessible (Cooke and Morgan, 1998; Morgan, 1997; Storper, 1997). Since the social and institutional assets including tacit knowledge in the successful regions are usually not transferable to or duplicable in less favored regions, these studies imply that regional development is path-dependent (Nelson and Winter, 1982) and less favored regions are often locked in their development trajectories that are predetermined by their irreversible past (Hudson, 1999). In contrast, Amin and Cohendet (1999) have criticized that tacit knowledge has been over emphasized by economic geographers and have argued that codified, extra-local knowledge has often been neglected as another important source of innovation that could help less favored regions break from their "locked-in" dilemma.

Knowledge transfer from universities, which is often embodied in codified forms (e.g., publications, patents, contract R&D projects) and sometimes contains tacit components (e.g., collaborative research, informal consultation), therefore becomes an important asset in creating learning regions. Whether a region is well embedded in knowledge transfer networks with local and extra-local universities is a good indicator of this region's innovation potential. By systematically analysing the geographic variations in knowledge transfer networks in China, we can detect regional differences in their accessibility to both local and extra-local knowledge resources and their potential of becoming learning regions, thus helping us study uneven regional development and providing policy makers with detailed guidance when designing China's national and regional innovation systems.

A number of studies have shown that university research enhances local industry innovativeness at the state level (Audrestch and Feldman, 1996; Branstetter, 2000; Jaffe, 1989) and the sub-state level (Anselin et al., 1997), suggesting a geographic constraint on knowledge flows from universities to industry. Treating patent citations as paths of knowledge flows, Jaffe and his colleagues (Henderson et al., 1998; Jaffe and Trajtenberg, 1996, 1999; Jaffe et al., 1993) have shown that knowledge spillovers are localized, especially in the early years when the knowledge is created. Based on the same methodology, Hicks et al. (2001) have found that corporate patents cite more locally produced academic papers, indicating that publication, as a channel transferring knowledge from academia to industry, is subject to geographic constraints. Zucker, Darby and their colleagues (Zucker and Darby, 1996; Zucker et al., 1994, 1998a,b) also emphasized that localized ties with star scientists were important for firm performance. Some firms even purposely located themselves near star scientists. These studies suggest that various forms of codified or non-codified knowledge from universities are also to a large extent constrained by geographic distance. Therefore, although the presence of universities is not a guarantee in promoting local innovativeness (Storper, 1995b), it seems to be a major prerequisite in creating learning regions. The university knowledge that is not constrained by geographic distance, while somewhat limited, should still constitute an important supplemental resource for regional development, especially for less favored regions where a local university base is often not available.

Then whether the findings regarding the geographic constraint on university knowledge transfer hold true for China, a transforming country that has a very different institutional context from Western countries? At least in the early years, the geographic constraint on knowledge flows should be to some extent alleviated by certain central ministries. In China, many highly specialized universities and research institutes were overseen by various central ministries and were expected to directly contribute to their corresponding industrial sectors. Therefore, universities could be brought together with enterprises by the central ministry they both belonged to, although they might not be located at the same place. However, with the impact of the planned economy being removed little by little, I expect this institutional effect to decline over time. As mentioned before, Chinese universities experienced a decentralizing reform for efficiency purpose in 1994 (Hayhoe, 1996; Yang, 2000). Since then the central ministries have gradually transferred their administrative power over universities to the local governments. Along with the jurisdiction shift of universities, central ministries' power over firms is declining too (Gordon and Li, 1991; Guthrie, 1997; Huang, 1996). The weakened control of ministries over both universities and firms could lessen the imposed cross-region but within-ministry collaborations and increase the chance of collaborations between universities and local industries.

The emerging market force could also lead to local university–industry collaborations as well. With the increasing importance of economic efficiency, proximity between universities and firms incurring less transaction cost (Williamson, 1981) should be preferred by rational agents. The combination of the changing institutional and economic conditions sets the potential for the prevalence of local university–industry collaborations in recent years. In other words, the geographic constraint on university knowledge flows found in Western countries was probably minor in the planned economy but has become salient in the market economy. Since the Chinese industrial sectors heavily rely on public research for technology improvement, universities have been a key source of both codified and tacit knowledge for industry. Being close to universities therefore becomes a more important prerequisite for creating learning regions in reforming China than in developed countries. The extra-local university knowledge, which had been distributed indiscriminately to industries across the country in the planned economy, would instead flow to the regions where an immediate economic return is expected. Those less favored regions that depended on the central ministries' intervention to receive extra-local knowledge would inevitably be left behind in the market economy.

It is worth mentioning that the market reform in China to some extent resembles the transition process from Keynesian welfare policies to neo-liberal economic policies Europe has gone through since the early 1980s (Amin and Tomaney, 1995; Amin and Thrift, 1995; Jessop, 1994; Mayer, 1994). As a result of that transition, Europe has experienced an uneven regional development (Amin and Thrift, 1995), with those advanced regions attracting more support and investment and those less favored regions marginalized or even abandoned by their nation states (Jessop, 1994; Mayer, 1994). Similarly, an increasing regional inequality has been observed in China during the marketization process. Amin and Thrift (1995) have suggested to develop knowledge transfer networks to promote those less favored regions, "These networks are not just intended to produce knowledge transfer but also a more general disposition to collaborate, a disposition which is most needed in less favored regions which are more likely to harbour unresponsive or undemanding firms" (Amin and Thrift, 1995, p. 55). Amin and Cohendet (1999) also suggested that developing extra-local knowledge transfer networks would help less favored regions break from their "locked-in" dilemma.

Given the importance of Chinese universities in the national innovation system, building knowledge transfer networks with local and extra-local universities would be a good strategy to promote less favored regions. As argued by Amin and Thrift (1995), such networks not only constitute channels in transferring knowledge, but also play an important role in fostering an innovation spirit in less favored regions. Since a strong local university base is usually not available in less favored regions, connections with extra-local universities constitute an important supplementary asset for those regions. Studying the knowledge exchange patterns among the provinces and municipalities in China would help us understand regional variations in their knowledge transfer network resources and the fundamental reason why some regions have been left behind over the last two decades.

Taking advantage of the Chinese patent data, this paper examines the geographic variations in university–industry collaborations in China from 1985 to 2004 and specifically addresses the following questions: (1) what are the regional differences in knowledge production and utilization in China? (2) What is Beijing's role in the national knowledge exchange network? (3) How has the situation changed over time? Answers to these questions would help us understand the role of universities in China's national and regional innovation systems, the geographic constraint on university knowledge transfer in reforming China, the disadvantaged position of those less favored regions in the knowledge transfer networks, and the implications on China's uneven regional development.

To simplify the analyse in this paper and make them easier to read, the 20-year period of study is divided into four parts: 1985–1989, 1990–1994, 1995–1999, and 2000–2004. By 1985, the economic reform had proceeded for 7 years. The whole society was quite active in doing business and open to Western culture in the first period. The government began to push universities to the market and enterprises began to hire "Sunday engineers", those scientists and engineers who provided technical services to small private companies in their spare time. University–industry collaborations started to grow in scale, but the Tiananmen Square protest in 1989 might have held back the process. After a short retrogress, reform resumed in 1992. It can be imagined that universities and enterprises were cautious in their conduct in the second period. The reform on higher education sector launched in 1994 made the third period a transition point from centralization to localization for universities. Universities and enterprises are expected to change their collaboration pattern to some extent according to the decentralization policy. The issuing of the "Chinese Bayh-Dole Act" has induced a huge increase in university patent applications since 1999. Also, the National Innovation Congress held in 1999 further promoted university–industry collaborations. Therefore, the number of university–industry collaborations captured by joint patents is expected to be unprecedentedly high in the fourth period.

2. Data and methods

The Chinese patent law was enacted in 1984. The Chinese Intellectual Property Press provides a dataset with complete patent information since 1985. The database includes the names of inventions; the dates of application, publication, and grant; the names and addresses of inventors and assignees; and industry categories. By examining the assignee information, I identified patents applied for by universities and firms as co-applicants, suggesting successful collaborations between universities and firms.[2]

Table 1
Patents jointly applied for by higher education institutions and industrial entities from January 1, 1985 to July 10, 2005 (search made in September 2005)

	University	College	School
Company	4265	1288	81
Factory	411	261	32
Group	504	100	4
Enterprise	36	22	2

Source: http://www.patent.com.cn/.

Individual Chinese patent records are available for search on the website http://www.patent.com.cn/. By appropriately setting search conditions, I accessed patents jointly applied for by industrial and academic sectors. For industrial sectors, assignee names could be a company (*Gongsi*), a factory (*Chang*), a group (*Jituan*), an enterprise (*Qiye*), or a combination of several of them (e.g., *Qiye Jituan Gongsi*); for academic sectors, the assignee names could be a university (*Daxue*), a college (*xueyuan*), or a school (*xuexiao*). Thus I have 12 search combinations and get 7006 university–industry collaboration cases in total, as shown in Table 1.

The actual number of valid cases is much smaller (4559) because some cells in Table 1 have overlapped cases, and a bunch of cases were actually applied for by one entity (often times it was a university start-up keeping the name of the university in its company name).

[2] According to my interviews with Chinese scientists, university–industry collaboration, which has been encouraged by the government since the 1950s and is pursued by more and more companies due to China's economic reform, is one of the key mechanisms for transferring knowledge from university to industry. Since a complete archival collection of university–industry collaborations is difficult to access, joint patent, a proxy of successful collaborations, is used in this paper for analysis. Patents are not the only output from university–industry collaborations, of course. Co-authorship is a potential rival measure, suggesting collaborations at the basic science level. However, according to my interviews, firms typically collaborate with universities at the downstream level, and firms are not so interested in publications. One exception is university start-ups. Most research personnel working in university start-ups are still affiliated with the university; they are doing both academic research and industrial R&D to meet the evaluation criteria of both sectors. Therefore, university–industry ties identified by co-authorships might yield a highly biased sample, concentrating on university start-ups and a few large firms (probably international firms) conducting basic research. Indeed, the patent data might also over-sample high-performance firms, because many low-level collaborations do not produce any inventions. As this paper concerns how universities contribute to national innovativeness, university–industry collaborations resulting in patent applications are an appropriate measure.

From each patent, one or more (when there are more than two co-applicants) dyads composed of a higher education institution and a firm were formed. After further data cleaning,[3] 4087 such dyads remained. By identifying the locations of the firm and the university in a dyad, a knowledge flow record from the province where the academic sector is located to the province where the industrial sector is located was created. According to the four historical periods defined earlier, four 30 × 30[4] matrices of geographic knowledge flow from academia to industry were constructed, based on which network analyses were implemented and the following results were obtained.[5]

3. Results

3.1. Degree centrality

Figs. 1–4 show the simplest centrality measure of provinces based on degree (i.e. the number of ties between ego and alter provinces) in the four periods. Since the knowledge flows in these networks are directed from university to industry, outdegree of a province measures how many times its higher education sector has transferred technology to industry and indegree of a province indicates how many times its industrial sector has received knowledge from universities. These two measures reflect the knowledge production and utilization patterns of the provinces, from which we can see huge regional variations. For those hinterland provinces lacking a strong university base, ensuring a high indegree is especially important in bringing in extra-local knowledge.

The most noticeable change since 1985 is the dramatically increased patent co-applications by universities and firms, especially in the period of 2000–2004. However, a closer look reveals that those changes mainly occurred in the most advanced municipalities and coastal provinces, such as Beijing, Shanghai, Jiangsu, Zhejiang, Shandong, and Guangdong, thus suggesting a link between active university knowledge transfer and economic development. The group of Tianjin, Liaoning, Hubei, and Sichuan also contributed remarkably to the increase. The Liaoning province is an interesting case. It had been one of the most active knowledge producers and receivers in the early years (only secondary to Beijing in the period of 1985–1989). Yet it then experienced a 10-year stagnant period and caught up again in the 2000s. Changes in other provinces are either minor or negligible—many less favored regions have not been able to build up their knowledge transfer networks with universities over the last two decades and will probably be further left behind in their innovation capabilities and economic performance.

As the capital city, Beijing is always the most outstanding one in the networks, both sending and receiving knowledge the most frequently. However, Beijing's role as the knowledge center has been declining over time. A detailed check of the matrices reveals that 70% of the knowledge produced by Beijing universities was sent to industry outside of Beijing in 1985–1989. Nevertheless, this percentage dropped to 48% in 1990–1994, 36% in 1995–1999, and 27% in 2000–2004. In other words, in the early years, universities in Beijing had functioned as the national knowledge center, providing the most knowledge support to industry nationwide. With the reform going on, however, the influence of Beijing's universities has been gradually confined to local areas. The industrial sector in Beijing has also been localized in terms of academic partner seeking. In 1985–1989, 50% of the knowledge Beijing's industrial sector received was from universities outside of

[3] For example, many patents applied for by "college(*xueyuan*)" turned out to be inventions of other research institutes named "*kexueyuan*" and some schools were found to be middle schools. Because this paper concerns China's university–industry collaborations, those joint patents applied for by foreign universities and firms are not included here. As for Hong Kong, Taiwan, and Macao, they have their own patent systems and those data are not included in the database used in this paper. Therefore, including them in the analyses will cause severe bias (e.g., Taiwan might be categorized as a backward instead of a self sustained area). Plus, only the address of the first applicant is given in the patent data, a few firms cannot be geographically located even at the provincial level. The records in 2005 are incomplete and not used in this paper. University start-ups are treated as universities in the dyads (based on my interviews, employees and even employers in those start-ups are usually university scientists working in both sectors. If they really get independent, they will take the university name out and thus become unidentifiable). Therefore, when an identified university start-up applies for a patent with a university, it is not considered as a university–industry collaboration and hence deleted from the dyad database.

[4] Besides Hong Kong, Taiwan, and Macao, there were 30 provinces and municipalities in China before 1997. The selection of Chongqing as the fourth municipality changed the situation. To make the analyses consistent, Chongqing is always treated as a city in Sichuan province, as it was before 1997.

[5] There are three types of patent in China: invention patent, utility patent, and design patent. There is considerable quality difference between different types of patent. For example, while invention patents go through a careful review process of many years, utility patents are virtually granted upon application. Therefore, collaborations ending up with different types of patent might have different structures. Since this paper only uses patent applications rather than granted patents as the proxy of university–industry collaborations, the quality difference between the pending patents is undetermined. Hence the results presented below are based on patent applications of all kind. Results for different types of patent application are available from the author.

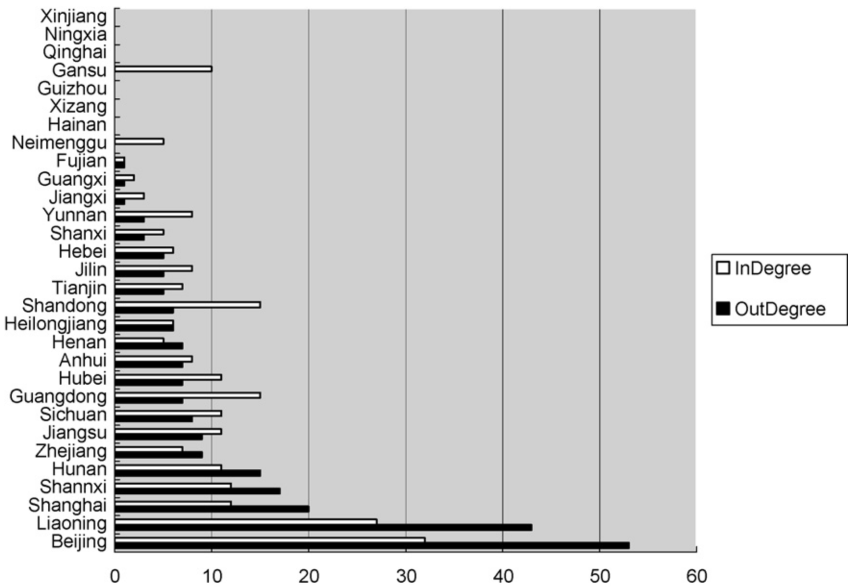

Fig. 1. Degree centrality of provinces and municipalities from 1985 to 1989.

Beijing. This percentage slightly fluctuated to 55% in 1990–1994 and 51% in 1995–1999, and then shrank to 30% in 2000–2004. Beijing's unique position as the dominant export center in the early years actually reflects the central government's effort in achieving regional equality in accessing public knowledge. As a result, even if those less favored regions lacked local university resources, they could still gain necessary knowledge support from Beijing or other places with the help of the central government. When such state intervention declines with the economic reform, the effect of geographic constraint on university knowledge flows becomes salient and Beijing's nationwide influence fades consequently.

Defining the percentage of outgoing knowledge as expansiveness and the percentage of incoming knowledge as attractiveness, Table 2 shows the pattern of knowledge exchange of the 30 provinces and municipalities from 1985 to 2004. As discussed above, Beijing is a declining center with decreasing connections to other provinces. The group of exporters consists of six provinces or municipalities with strong university bases. They provided remarkable knowledge services to industry in other provinces, but their own indus-

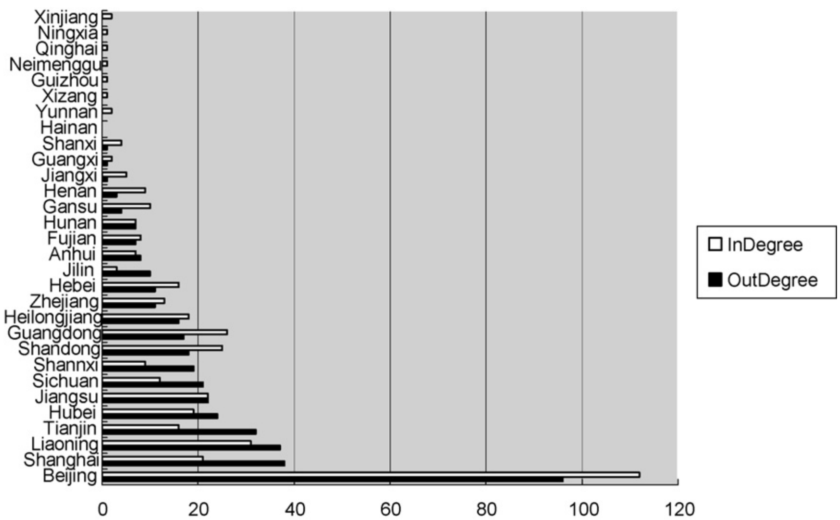

Fig. 2. Degree centrality of provinces and municipalities from 1990 to 1994.

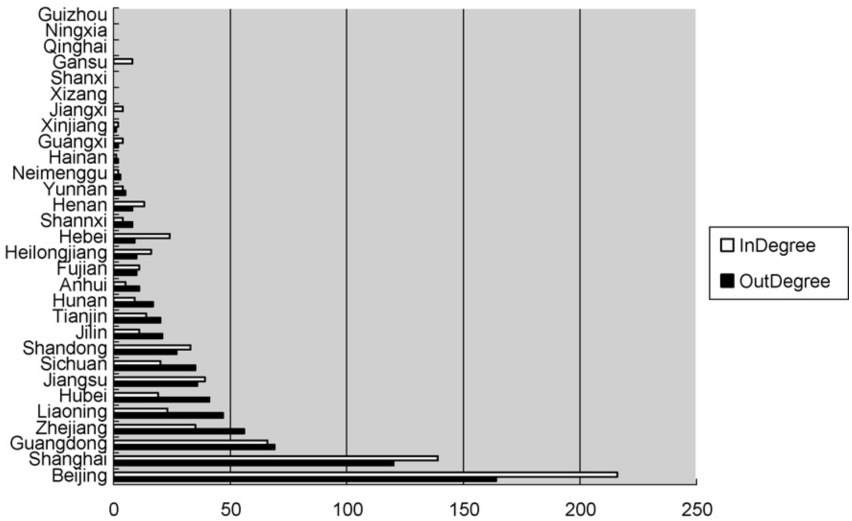

Fig. 3. Degree centrality of provinces and municipalities from 1995 to 1999.

try rarely reached out for academic advice. The group of active generalists includes nine provinces actively involved in knowledge exchange. They both contributed knowledge to and absorbed knowledge from other provinces. Distance seems not to be a problem for them. The Heilongjiang province is a special case, neither exporting nor importing knowledge actively. Most university–industry collaborations happened within the province. The group of importers does not have many good universities. Industry in these eight provinces heavily relied on academic knowledge from outside. The remaining five provinces are almost isolated from the knowledge exchange process. They barely filed any collaborative patents in the past 20 years. The groups of importers and isolates both suffer from their weak university bases, which make it difficult to build learning regions within these provinces. While the importers are utilizing knowledge transferred through their networks with extra-local universities, the isolates are further left behind due to their poor access to the local and extra-local knowledge. This crude categorization gives a rough profile of the provinces regarding their knowledge exchange patterns and networking resources.

3.2. Knowledge transfer networks

Figs. 5–8 show dynamic knowledge transfer networks of provinces and municipalities in the four historical

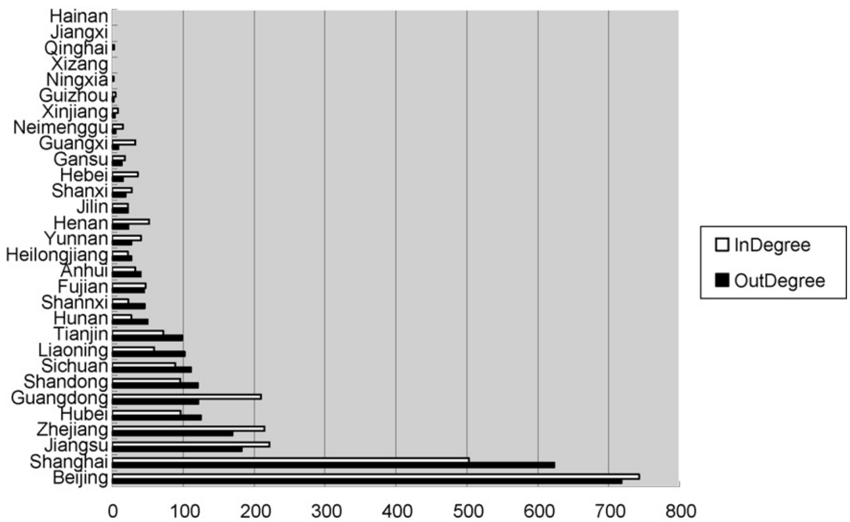

Fig. 4. Degree centrality of provinces and municipalities from 2000 to 2004.

Table 2
Expansiveness and attractiveness of the 30 provinces and municipalities

	Expansiveness (%)				Attractiveness (%)			
	1985–1989	1990–1994	1995–1999	2000–2004	1985–1989	1990–1994	1995–1999	2000–2004
Declining center								
Beijing	70	48	36	27	50	55	51	30
Exporter								
Tianjin	40	69	35	40	57	38	7	18
Hubei	29	42	54	35	55	26	0	16
Shanghai	55	61	33	34	25	29	42	18
Liaoning	44	35	60	49	11	23	17	12
Sichuan	13	52	54	41	36	17	20	27
Shannxi	47	58	63	63	25	11	25	26
Active generalist								
Jilin	60	80	67	50	75	33	36	50
Anhui	57	63	82	38	63	57	60	24
Shandong	17	50	44	61	67	64	55	51
Jiangsu	33	45	53	34	45	45	56	46
Zhejiang	78	27	46	29	71	38	14	44
Hunan	47	43	53	76	27	43	11	56
Guangdong	14	41	70	27	60	62	68	58
Fujian	100	29	30	33	100	38	36	36
Henan	71	67	13	43	60	89	46	75
Self sustainer								
Heilongjiang	17	25	10	41	17	33	44	27
Importer								
Hebei	40	18	11	33	50	44	67	72
Shanxi	0	0	N/A	26	40	75	N/A	50
Neimenggu	N/A	N/A	33	20	100	100	0	73
Jiangxi	0	0	N/A	N/A	67	80	100	100
Gansu	N/A	0	N/A	43	100	60	100	56
Guangxi	0	0	0	11	50	50	50	76
Yunnan	0	N/A	20	11	63	100	0	41
Xinjiang	N/A	N/A	0	0	N/A	100	50	50
Isolate								
Hainan	N/A	N/A	50	N/A	N/A	N/A	0	100
Guizhou	N/A	N/A	N/A	50	N/A	100	N/A	80
Xizang	N/A	N/A	N/A	N/A	N/A	100	N/A	N/A
Qinghai	N/A	N/A	N/A	N/A	N/A	100	N/A	100
Ningxia	N/A	N/A	N/A	0	N/A	100	N/A	50

periods. From Fig. 5, we can see this is a directed network. Knowledge flows from the province where the university is located to the province where the industry is located. The small loops indicate within-province collaborations. The whole network is quite sparse, indicating an inactive university–industry collaboration pattern in the first period. Beijing is the major knowledge exporting center. Nine remote provinces (Fujian, Jiangxi, Hainan, Guangxi, Guizhou, Xizang, Qinghai, Ningxia, Xinjiang) are isolated from the national knowledge exchange network.

In the second period, Beijing is still the center, situation changes little from the first period.

In the third period, Beijing's role as the center is challenged by several other provinces and municipalities, such as Shanghai and Guangdong.

In the fourth period, it is hard to tell the difference between Beijing and many other provinces from the network graph. From these graphs we see a decentralizing process over time. Beijing's unique position as the dominant export center declined and regional knowledge centers emerged instead. Self collaborations increased too, suggesting a localizing trend in collaborations. We can also see the overall network density have been increasing over time, indicating that university–industry collaborations did increase in scale as expected.

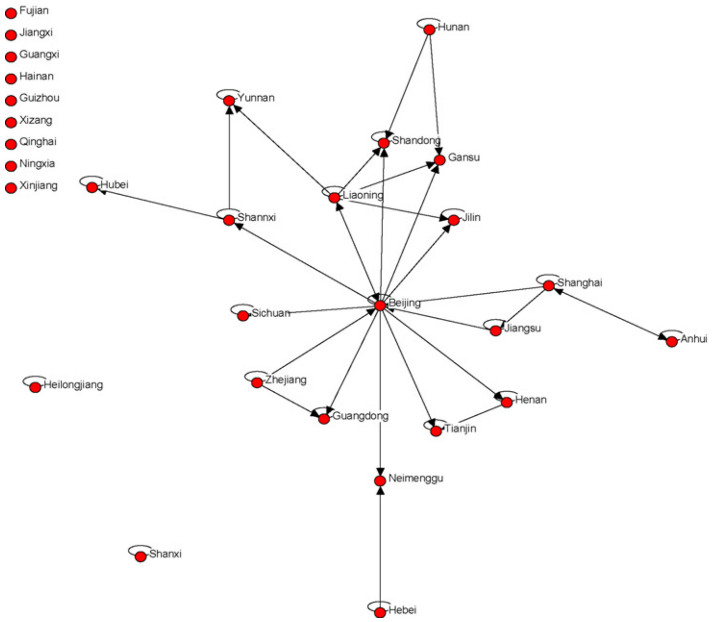

Fig. 5. Knowledge transfer network of provinces and municipalities from 1985 to 1989.

So what might have caused these changes? First, the decentralizing/localizing trend is intimately related to the changing economic and institutional environment. As the jurisdiction power over universities is shifted from central ministries to the local governments, within-ministry collaborations (those are often long-distance ones between Beijing and other provinces) are less likely to achieve. This simultaneously weakens Beijing's central role in the knowledge transfer network and fosters the local governments as a new institutional force that favors local collaborations. Also, with the prevalence of market-like conditions, many local governments have been motivated to promote the local economies through technology transfer and innovation (Yeung, 2000; Yeung

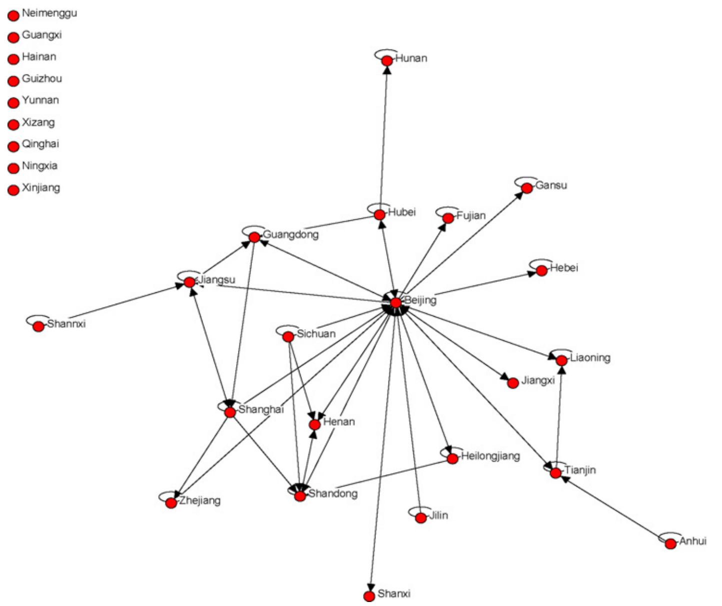

Fig. 6. Knowledge transfer network of provinces and municipalities from 1990 to 1994.

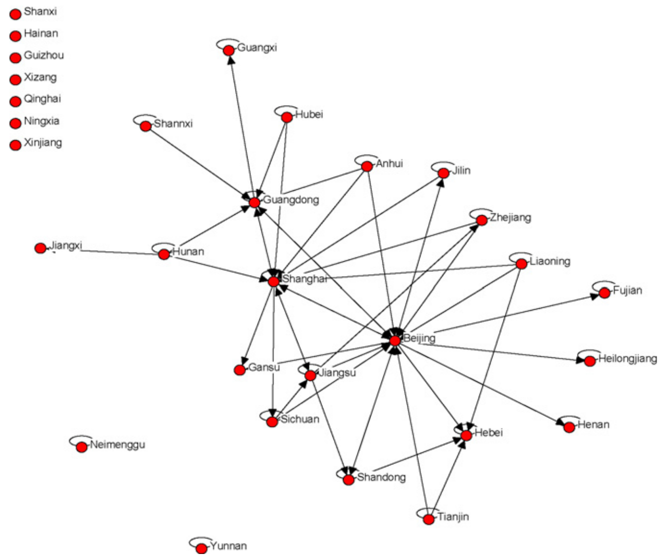

Fig. 7. Knowledge transfer network of provinces and municipalities from 1995 to 1999.

and Li, 2000). Therefore, although the geographic constraint on knowledge flows was to some extent alleviated by the central ministries in the early years, it seems to be inevitable in the new economic and institutional context. As a result, those advanced regions with strong university bases will benefit more from being close to universities, while those less favored regions will suffer more due to the shortage of local knowledge resources and the reduced extra-local knowledge support.

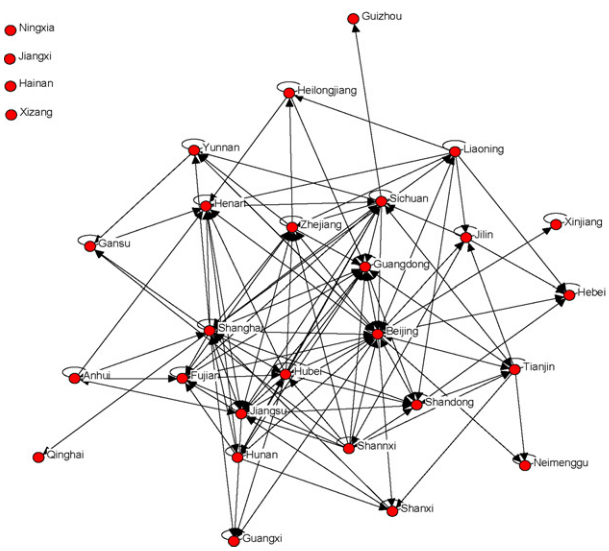

Fig. 8. Knowledge transfer network of provinces and municipalities from 2000 to 2004.

As for the increased university–industry collaborations, one major reason is that the market competition introduced by the reforms forces state-owned enterprises to improve their products and processes. As mentioned earlier, most Chinese enterprises do not have in-house R&D facilities and only concentrate on production. With the increased market pressure, more and more enterprises seek help from the public research sector. Since universities are also under financial pressure, university–industry collaboration is mutually beneficial and becomes much more common. Also, the passage of the Chinese “Bayh-Dole Act” and the National Innovation Congress contributed to the increase in patent applications.

3.3. Blockmodel analysis for the four periods

Although the categorization based on expansiveness and attractiveness captures the knowledge exchange pattern to some extent, it is neither accurate nor fine-grained enough. It only considers the connection between ego and non-ego provinces, and the categorization is composed without strict calculation. Blockmodel analysis (White et al., 1976), in contrast, takes every tie between ego and alter provinces into consideration and accordingly allocates structurally equivalent[6] provinces into the same block by apply-

[6] When two actors in a network have identical relationships to other actors, they are structurally equivalent.

	1 B	2 T	15 S	3 H	7 J	6 L	4 S	12 A	16 H	18 H	8 H	10 J	13 F	17 H	19 G	9 S	11 Z	26 S	22 S	20 G	30 X	5 N	24 Y	27 G	25 X	14 J	21 H	28 Q	29 N	23 G
1 Beijing	1	1	1	1	1	1	1		1	1		1		1	1	1	1			1	1	1	1							
2 Tianjin	1	1	1		1		1								1				1			1								
15 Shandong	1	1	1	1											1															
3 Hebei	1			1																										
7 Jilin	1			1	1													1	1											
6 Liaoning	1		1	1	1	1			1		1					1	1													
4 Shanxi							1					1				1														
12 Anhui								1	1			1	1			1														
16 Henan	1								1			1							1											
18 Hunan	1						1		1	1			1	1	1	1			1											
8 Heilongjiang									1		1				1															
10 Jiangsu	1		1					1				1	1		1	1	1			1										
13 Fujian	1												1	1	1		1													
17 Hubei	1		1						1			1		1	1	1	1		1	1										
19 Guangdong	1									1					1	1														
9 Shanghai	1		1			1		1	1	1		1	1	1	1	1	1		1	1			1	1				1		
11 Zhejiang	1										1	1			1	1	1						1							
26 Shannxi	1	1	1									1	1	1	1		1	1						1						
22 Sichuan	1	1								1		1	1		1	1	1		1				1							1
20 Guangxi																				1										
30 Xinjiang																					1									
5 Neimenggu																						1								
24 Yunnan																							1	1						
27 Gansu									1															1						
25 Xizang																														
14 Jiangxi																														
21 Hainan																														
28 Qinghai																														
29 Ningxia																														
23 Guizhou																														

Fig. 9. Blockmodel of the 2000–2004 matrix.

ing mathematical algorithms. The advantage of using blockmodel analysis in this study is that the real knowledge transfer structure can be detected solely based on the relational data. The clustering process is backed up by mathematical calculation rather than prior assumptions. The results will not only reveal the current status of the provinces and municipalities in the knowledge exchange network, but also show us the dynamic process through which they achieved the present positions.

The latest matrix (2000–2004) was first analyzed by blockmodelling technique,[7] resulting in seven blocks as shown in Fig. 9. We can see that the first and the fourth blocks are the most active knowledge exporters. Interestingly, the area the fourth block reaches includes the most inactive seventh block which is even neglected by the first block, where the capital city is located. Again, this suggests the decline of Beijing as the knowledge center. However, in Northern China, Beijing is still the source of wisdom. Tianjin and Shandong maintain close interaction with Beijing, and they together constitute the first block with the strongest solidarity. The three Northern provinces in the second block is a periphery group of the first block. The two blocks exchange knowledge extensively, primarily through Beijing.

The fourth block includes the most advanced provinces in Southeast China, one province in Central China, and two Western provinces possessing good universities. They become knowledge centers in their surrounding areas and Beijing's national influence hence fades. Just as the second block is peripheral to the first block, the third block, composed of five mid-level provinces, is peripheral to the fourth block. Considering Shanxi, Henan, and Heilongjiang in the third block are all in Northern China, their intimacy with the fourth block implies Beijing's decline in attraction. However, the fourth block seems willing to exchange knowledge with the first block, though it sends more than receives.

The fifth and sixth blocks are located in backward areas, with limited higher education resources and production capability. They barely export any knowledge services, but they receive knowledge support either from the first and fourth blocks or from themselves. The seventh block is even poorer. It hardly has any innovation activity and looks isolated from the national rush for modernization. Through blockmodel analysis, we can clearly see how the provinces and municipalities differ in their connections with extra-local knowledge resources and thus estimate their innovation potentials.

Table 3
Block densities in 1985–1989

	1	2	3	4	5	6	7
1	0.56	0.22	0.07	0.13	0.11	0.17	0.00
2	0.22	0.44	0.00	0.00	0.11	0.33	0.00
3	0.13	0.00	0.20	0.03	0.00	0.10	0.00
4	0.13	0.00	0.03	0.16	0.00	0.06	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.25	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4
Block densities in 1990–1994

	1	2	3	4	5	6	7
1	0.78	0.33	0.27	0.17	0.00	0.17	0.06
2	0.33	0.33	0.00	0.00	0.00	0.00	0.00
3	0.13	0.00	0.12	0.00	0.00	0.00	0.00
4	0.29	0.00	0.05	0.23	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.25	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5
Block densities in 1995–1999

	1	2	3	4	5	6	7
1	0.67	0.44	0.13	0.17	0.00	0.17	0.00
2	0.22	0.44	0.00	0.08	0.00	0.00	0.00
3	0.07	0.00	0.16	0.10	0.00	0.00	0.03
4	0.25	0.00	0.00	0.30	0.04	0.06	0.00
5	0.00	0.00	0.00	0.00	0.22	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.25	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Imposing the latest blockmodel to all previous matrices, we then obtain a complete picture regarding how the current knowledge exchange pattern was finalized after years of evolution. Tables 3–6 show the changes in block

Table 6
Block densities in 2000–2004

	1	2	3	4	5	6	7
1	1.00	0.56	0.27	0.33	0.44	0.17	0.00
2	0.44	0.50	0.13	0.17	0.00	0.00	0.00
3	0.13	0.00	0.20	0.33	0.00	0.00	0.00
4	0.58	0.04	0.20	0.57	0.13	0.31	0.04
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.10	0.00	0.00	0.50	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[7] In this paper, the algorithm of CONCOR is used to partition actors into blocks by iteratively calculating correlations of adjacent columns of the matrix. But CONCOR treats one tie the same as multiple ties, which causes biased results. For example, Guizhou is no par with Shanghai. But in the analysis of the matrix of 2000–2004, Guizhou is in the same block with Shanghai just because they both have ties with Guangdong, regardless Guizhou only has one tie with Guangdong in 5 years while Shanghai has many ties. To reduce such bias, a tie with strength of one is treated as accidental and coded as 0. Ties with strength greater than one are coded as 1. The blockmodelling results presented here and the previous knowledge transfer networks are based on the dichotomized matrices.

densities[8] over the four periods. Densities in diagonal blocks show the strength of within-block connections. Densities in non-diagonal blocks show the strength of inter-block relations. Apparently, the first and second blocks from the 2000 to 2004 matrix have their historical precedence. Their within-block densities have been high since 1985, indicating a tradition of within-block collaboration. The interaction between the first and second blocks was also incomparably high in the early years and is still strengthening in recent years.

As discussed above, the fourth block is a rising knowledge center. Its member provinces did not particularly favor each other back in the 1980s. A plausible explanation to its stably growing within-block density is that these provinces either have very good universities or have a strong industrial base. Many of them have both. Their strong capability and their being far from Beijing make them regional engines of innovation during the economic reform. Similar situations and responsibilities lead to similar policies, working styles, learning processes, and ultimately, a homophile effect which makes collaboration with each other preferable. The third block had been close to the first block in the first 10 years. After the mid-1990s, however, it began to interact with the fourth block. In the period of 2000–2004, its focus has shifted to the fourth rather than the first block. These changes over time show us an interesting historical track regarding how the current knowledge exchange pattern was finalized and bring attention to some exemplar provinces that have successfully expanded their knowledge transfer networks.

The situation of the remaining three blocks has not changed much since the mid-1980s, suggesting that the knowledge transfer networks have not been improved much in many less favored regions, although the Chinese government has begun to take policy initiatives to help those underdeveloped regions since 1998 (e.g., see Goodman, 2004; Holbig, 2004). Given that most less favored regions are already suffering from the shortage of local university resources, their failure in expanding their knowledge transfer networks with extra-local universities will deteriorate their innovation capability and have them locked in their development trajectories. Why have some regions been successful in building regional knowledge centers and expanding their knowledge transfer networks while other regions have failed? Can less favored regions learn a lesson from those successful ones and how? These are interesting research questions deserving further study. Also, building knowledge transfer networks and fostering those critical social and institutional assets in less favored regions would be a long-term process that requires patience and efforts.

4. Conclusion

At this point, the research questions raised at the beginning of this paper can be answered. First, degree centralities of the provinces and municipalities show regional variations in their knowledge production and utilization patterns. According to expansiveness and attractiveness, the 30 provinces and municipalities can be classified into 6 categories: declining knowledge center, knowledge exporter, active generalist, self sustainer, knowledge importer, and isolate. This distinction describes the knowledge exchange patterns of individual provinces and municipalities and conveys a crude picture regarding regional variations in knowledge bases and willingness to exchange resources with outside counterparts at the provincial level. The blockmodel analysis draws a refined map of the knowledge exchange patterns among provinces and municipalities, from which we can identify the roles of different provinces and municipalities in the National Innovation System. The fourth block (Jiangsu, Fujian, Hubei, Guangdong, Shanghai, Zhejiang, Shannxi, and Sichuan) turns out to be the main engine of innovation implement by university–industry collaborations. It has become a national knowledge distributor, outperforming Beijing in many non-Northern areas and even attracting some Northern provinces.

Second, Beijing is still the most active municipality in technology transfer from university to industry. The decline in its omnipresent influence is consistent with the decentralizing policy since the mid-1990s. The shift of jurisdiction power of universities from central to local control, strengthened universities' connections with local governments and local industries. In the early years, universities in Beijing had needed to take the responsibility of providing knowledge support to industries across the country, but the decentralizing process somewhat relieved the Beijing's universities of their burden. Regional universities took a bigger share of industrial projects and universities in Beijing also shifted their focus to local industrial sectors. However, as the capital city, Beijing is still a super star in the knowledge exchange network, especially in Northern China.

Third, over the past 20 years, we have seen a decentralizing/localizing trend in university–industry collaborations due to the changing economic and institutional context. The geographic constraint on knowledge

[8] Density is the ratio of present ties to potential ties, excluding diagonal cells.

flows commonly observed in Western countries only becomes salient in recent years due to the administrative decentralization and the economic reform. As a result, advanced regions either receive more knowledge support from local universities or benefit from their well expanded knowledge transfer networks, while less favored regions are further marginalized due to the decreased knowledge support allocated by the central government. Another significant change is the overall increase in university–industry collaborations embodied in joint patent applications, reflecting the growing importance of university in China's National Innovation System.

From the over time blockmodel analysis, we see a China full of contradictions. The consistent collaboration among Northern provinces, centered around Beijing, indicates stability; the emergence of the fourth block shows vitality; the stagnancy of the remote areas hints inequality. Prosperity coexists with poverty; transition occurs without agitating the core area. This is what China has been going through. Uneven regional development has been a common problem for many countries. And the regional divide has been growing in China due to the strengthening market condition and the weakening state intervention. Although fostering local and extra-local knowledge transfer networks seems to be an efficient way to create learning regions, the implementation process is not unanimously successful and calls for further study.

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