Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-024-02982-x

OPEN

Mapping the landscape of university technology flows in China using patent assignment data

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The commercialization of intellectual property has become a fundamental avenue for universities to improve regional competitiveness. However, large-scale empirical studies on patent transfers, reflecting technology and knowledge sharing, remain limited. This study used social network analysis to investigate university technology flows in China based on patent assignments from technological, organizational, and regional perspectives. The results firstly revealed clear stage characteristics in the number of university patent assignments with the improvement of the Chinese version of the Bayh-Dole Act. Secondly, popular technologies in university technology flows mainly concentrated on measurement, testing, digital transmission, and other areas in which enterprises lack international competitive advantage. Thirdly, central actors comprised prestigious universities focusing on science, engineering, and comprehensive disciplines, along with intellectual property-focused enterprises. Finally, university technology flows gradually delocalized, and varied regional patterns exist owing to a spatial mismatch between university knowledge supply and regional demand. These findings have several practical and policy implications for government and university management in terms of promoting emerging technologies and clarifying universities' functions in regional and national innovation systems. This study contributes to the economic geography literature on regional innovation.

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Introduction

Universities have been considered key sources of knowledge for regional economic growth since the emergence of the knowledge economy (Agasisti et al., 2019; Huggins et al., 2016). Through technology flows, universities can generate revenue and research funding while providing knowledge and skills to enterprises (Janeiro et al., 2013; Link et al., 2007). Enterprises can adapt such knowledge and skills to drive technological progress and product innovation (Chang, 2017; Huggins et al., 2012). Since the 1980s, several countries have imitated the conditions created by the American Bayh-Dole Act to boost regional competitiveness (Grimaldi et al., 2011; Mowery and Sampat, 2005). However, university technology flows (UTFs) perform relatively poorly in most countries, except the United States (Kempton, 2019). Hence, methods to facilitate UTFs and the applications of relevant research gradually attracted global attention.

Research on UTFs has attracted considerable attention in recent years, and progress has been made in three primary aspects. The first stream of literature is based on the regional innovation system and relevant frameworks and emphasizes the localization of university knowledge spillovers and local research and development (R&D) investment in universities (Mukherji and Silberman, 2021; Lehmann and Menter, 2016). The second stream focuses on the roles of proximity in shaping the university technology flow network (UTFN). Geographical, cognitive, and institutional proximity have been extensively examined and compared (Alpaydın and Fitjar, 2021; D'Este et al., 2013). The third stream investigates factors influencing the commercialization of intellectual property in universities, such as technology transfer office (Conti and Gaule, 2011), patent quality (Fisch et al., 2016), and government policy (Yi and Long, 2021; Ejermo and Toivanen, 2018).

So far, little attention has been paid to UTFN within a country, and studies focusing on technology fields central to UTFs, the roles of different types of universities in UTFs, and methods of implementing university innovation policies in different regions are scarce. Therefore, this study aims to examine UTFs from a network perspective using patent assignment data and identify popular technologies, key organizations, and regional patterns of UTFs. This study seeks to provide new insights into the dilemma of commercializing intellectual property in Chinese universities. Universities are the key drivers of the transition from resource- to innovation-driven development (Po et al., 2016). Nevertheless, despite various incentives and massive investment in universities, China's commercialization rate of academic patents has long remained below 5%, compared to over 50% in the United States (Ma et al., 2022).

This study makes several theoretical and practical contributions. Firstly, this study contributes to the literature on the third mission and the roles of universities in regional innovation by examining their emerging trends in the UTFN. Secondly, it contributes to the literature on regional innovation systems by illustrating the process of delocalization of UTFs and the different positioning of regions in UTFN. Finally, this study has implications for policymakers and university administrators in terms of understanding and shaping universities' roles in innovation systems, promoting the commercialization rate of intellectual property in universities, and enhancing the capacity of universities to serve regional innovation. Our findings provide theoretical guidance, methodological support, and practical references for improving the structure and function of UTFs.

Literature review

University technology and technology flows. Since the emergence of the knowledge economy, universities have been recognized as pivotal sources of knowledge for economic growth (Agasisti et al., 2019; Huggins et al., 2016). Through education and conducting scientific research, universities create human capital and innovative knowledge, fostering business innovation and regional competitiveness (Kempton, 2019; Leten et al., 2014). Following the Soviet model, the Chinese university system primarily emphasized human resource development (Wang and Vallance, 2015). After the reform and opening up, key universities were encouraged to evolve into research centers; however, it was not until the 1980s that research was formally acknowledged as their second mission (Chen et al., 2016). Regional development became their third mission only after China transitioned to a socialist market economy in the mid-1990s (Wang et al., 2013). Considering the relatively short period since the adoption of this third mission, China turned to the success stories of the United States and Europe to prompt universities to directly contribute to economic development through technology transfer (Yi and Long, 2021; Po et al., 2016).

While the Chinese government is currently committed to innovation-driven development, it continues to face several critical issues, such as underinvestment in basic research, excessive regional disparities in innovation, and overdependence on foreign technology (Gu, 2023; Jimenez-Moro et al., 2023; Zhou et al., 2021). The last issue is closely related to UTFs, which can reduce enterprises' dependence on foreign technologies. Hence, China must promote UTFs to realize indigenous innovation (Wu and Zhou, 2012). UTFs have a strong geographical dimension and are largely confined to the region in which the university is located (Hewitt-Dundas, 2013). Governments have stimulated more interaction between academia and industry and issued various initiatives to encourage universities to become major contributors to technological advancement. Nevertheless, the potential of universities to generate advanced technological patents or commercialized products remains limited due to their emphasis on the quantity rather than the quality of innovative efforts (Gong and Peng, 2018; Fisch et al., 2016; Luan et al., 2010). Therefore, systematic examination of UTFs is essential to improve technology management and inform innovation policymaking.

UTFs through patent assignments. UTFs can be categorized as formal and informal. Formal technology flows encompass or directly result in legal instruments, such as patents, licenses, or royalty agreements (Link et al., 2007). Informal technology flows focus on informal exchange processes where property rights are secondary, such as academic consulting, joint publications, and technical assistance (Hu and Zhang, 2021). Owing to the limited data on informal technology flows, scholars often rely on formal technology transfer channels to track UTFs (Perkmann and Walsh, 2007). Considering that patents contain approximately 80% of the newly published information on technological innovation (Asche, 2017), they are the most widely used innovation indicator in empirical research (Dziallas and Blind, 2019). Therefore, several existing research on UTFs, including knowledge spillovers (Mowery and Ziedonis, 2015), collaborative research (Chang, 2017), and technology transactions (Hu and Zhang, 2021), are based on the analysis of university patents.

Existing research has predominantly examined UTFs based on patent citations and joint patents. Several empirical studies use patent citations as an indicator to investigate the extent of localized university knowledge spillovers (Adams, 2002; Jaffe et al., 1993; Varga, 2003). However, patent citations have a limited ability to measure the economic value of academic patents or track tacit knowledge flows. They are typically employed to assess the technological value (Yang et al., 2021a). While some empirical studies have attempted to use patent citations to explore the economic value of patents (Vimalnath et al., 2018; Trajtenberg, 1990), their accuracies have been questioned (Fischer and Leidinger, 2014; Sreekumaran Nair et al., 2011). Patent citations are primarily used to detect explicit knowledge flows; however, their ability to track tacit knowledge flows is limited because they are characterized by uncompensated interactions that do not involve market transactions or interpersonal relationships (Noh and Lee, 2019). Recently, joint patents have gained popularity as indicators of collaborative innovation between universities and enterprises. Compared to patent citations, joint patents are more likely to reflect real interactions (Yang et al., 2021b). Nonetheless, joint patents are undirected relationships (Yang et al., 2021b), hindering the ability to explore the direction of knowledge flows between universities and firms (Ye et al., 2020a, 2020b). Additionally, joint patents do not capture the economic value of technology flows.

Using patent assignment data can address these deficiencies. The primary purposes of university patenting are generating revenue for universities and providing technological knowledge to enterprises (Siegel et al., 2004; Link et al., 2007). Universities sell their patent ownership to enterprises for economic value, and enterprises acquire academic patents to use the technology contained in the patent. Enterprises' willingness to pay depends on the technological value encapsulated in the patent (Drivas et al., 2016). Additionally, non-codified knowledge is often transferred from universities to enterprises to effectively commercialize patented technology (Agrawal, 2006). Therefore, this study uses university patent assignments for empirical research.

Patent assignment network and social network analysis. Social network analysis is a structuralist paradigm that conceptualizes social life regarding the structures of relationships between actors rather than categories of actors (Scott and Carrington, 2011). Thus, social network analysis assists in mapping interactions among interdependent and interrelated actors, including technology flows, knowledge spillovers, and population migration. Any type of social network analysis must be based on relational data represented by links between actors (Silk et al., 2017). University patent assignments are naturally relational (Ponds et al., 2010) and can be used as a window to probe technology flows between universities and enterprises. Existing studies have examined UTFN using various network analysis metrics, such as centrality, network density, and gatekeeper (Françoso and Vonortas, 2022; Hu and Zhang, 2021; Capellari and De Stefano, 2014). Social network analysis can identify key players in technological innovation, main destinations of technology flows, and emerging trends in technological development (Chang, 2022).

UTFs have attracted significant attention owing to their increasingly prominent role in innovation strategies. However, their development faces many challenges (Kempton, 2019), and UTFs must be constructed and managed to address these complexities. Therefore, research should explore how UTFs emerge, cross regions, and show how key actors interact to support this process. Nonetheless, UTFs in China have not been comprehensively examined (Ye et al., 2020a, 2020b). Furthermore, in-depth quantitative analyses exploring the key components, technology flow modes, and evolutionary paths of UTFs in China are lacking. Thus, this study uses the network and spatiotemporal approaches and adopts the technological, organizational, and regional perspectives to bridge these gaps in the literature. This study poses the following research questions:

- What is the structure of the UTFN?
- Who are the key actors in UTFs?
- What are the most popular technological fields?
- What roles do different regions play?

Methodology

Data sources. Patents are categorized into invention, utility model, and design, with invention patents being the most innovative (Cai, 2018; Jiang et al., 2017). University patents are commonly transferred through assignments, licenses, and pledges, among which assignments are the primary channel for patent transactions in Chinese universities (Gong et al., 2020). Therefore, invention patent assignments are the acceptable choice to examine UTFs in China. All patent data used in this study were obtained from the incoPat patent data platform[1]. IncoPat is one of the most professional commercial patent information platforms in China and contains more than 180 million patents from 120 countries. Through comprehensive data integration, over 400 fields were retrieved from this database, including information on patent assignors and assignees, patent legal status, and the International Patent Classification (IPC).

To extract patents transferred from universities to enterprises, we established specific search conditions. First, we obtained patent data based on organization type. We set the assignor type as "university" (including regular university, junior college, and adult college) and the assignee type as "enterprise" and extracted all patents transferred from universities to enterprises between 2001 and 2021. Second, the names of universities were disambiguated using a list of higher-education institutions released by the Chinese Ministry of Education in 2021[2], which includes 1270 regular universities, 1486 junior colleges, and 256 adult colleges. The names of enterprises were disambiguated using Qichacha enterprise data platform[3]. Qichacha is a well-known business information database in China and contains records of over 100 million companies, from which fields such as former name, address, and industry can be extracted. Third, extensive manual checks were conducted to ensure data accuracy. The final dataset included 65,055 patents transferred from 882 universities to 24,869 companies within mainland China.

Network indicators and tools. This study used social network analysis to examine UTFs. The UTFN was constructed using information on the assignors and assignees from university patent assignments. To observe the evolutionary pattern, the network was categorized into three stages: 2001–2007, 2008–2014, and 2015–2021. In this network, nodes represented universities or firms, and links denoted the relationships of patent assignment records. Key network indicators included degree centrality, weighted degree centrality, and network density. Degree centrality measured the sum of nodes directly connected to a focal node, which was the sum of indegree and outdegree. Weighted centrality was the sum of the number of connections to a focal node, which was the sum of the weighted indegree and outdegree (Liu et al., 2022). Network density is the ratio of the actual number of connections to the potential maximum number of connections in the network (Li et al., 2021).

We used Gephi software (Bastian et al., 2009) to build the UTFN and calculate network indicators. Gephi is a leading software package for visualizing and exploring various networks and can calculate network indicators such as centrality, in-degree, and network density (Hu and Zhang, 2021). To present the geographical distribution of university-transferred patents at a city level, the maps were produced using ArcGIS—a software package with powerful mapping and spatial analysis capabilities. To present the UTFN in a geographical view at the city level, the network mapped using Gephi was overlaid on the base map of China in ArcGIS.

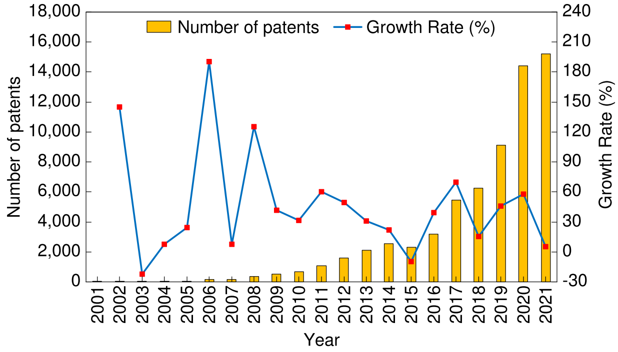

Fig. 1 University patent transfer frequency and growth rate between 2001 and 2021.

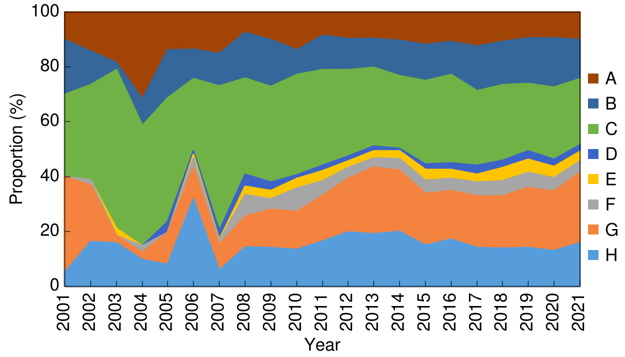

Fig. 2 Changing trends in technology fields at the IPC section level. A, human necessities; B, performing operations, transporting; C, chemistry, metallurgy; D, textiles, paper; E, fixed constructions; F, mechanical engineering, lighting, heating, weapons, blasting; G, physics; H, electricity.

Results

Technological-level information analysis

Temporal variation. Between 2001 and 2021, a total of 65,055 patents were transferred from universities to enterprises. Figure 1 illustrates the evolution of patent assignments in chronological order. Overall, the number of patent assignments shows a significant upward trend, with an average annual growth rate of nearly 40%, indicating that an increasing number of academic patents are being transferred to enterprises. Based on the annual number of patent assignments, the period can be divided into three phases with intervals of seven years: 2001–2007, 2008–2014, and 2015–2021.

The first phase (2001–2007) exhibits a low number of patent assignments, with high volatility in the growth rate, owing to the lack of appropriate incentive policies. In 2000, the Ministry of Science and Technology issued the Opinions on Strengthening the Protection and Management of Science and Technology-Related Intellectual Property Rights, which allowed universities to retain their ownership of government-funded inventions. However, as intangible assets, patents resulting from government-funded research programs are subject to regulations regarding the management of state-owned assets, and their disposal requires the approval of administrative units at all levels (Yi and Long, 2021). Therefore, in principle, universities have no right to dispose of patents.

In 2007, the National People's Congress passed an amended Science and Technology Progress Law, known as the Chinese version of the Bayh-Dole Act, which delegated the right to dispose of academic patents to universities. Nonetheless, the revenues generated from patents were largely retained by the central government, resulting in the number of patent assignments during this period stabilizing at a relatively low level of less than 3000 per year.

To further promote university patent transfers, the Law on Promoting the Transformation of Scientific and Technological Achievements of the People's Republic of China was revised by the State Council in 2015. This revision mandated that universities and researchers retain all income generated from academic patent transfers. This significantly stimulated universities' enthusiasm to engage in patent transactions, and the number of patent assignments skyrocketed to 9,092 in 2019. The surge in 2020 and 2021 may be attributed to the COVID-19 pandemic, which led enterprises to seek domestic university knowledge as an alternative to foreign sources.

Popular technologies. In patent information analyses, the IPC is often used to analyze the technology domains of patents, as each technological classification in a patent is assigned according to its intrinsic nature, function, application, or purpose (Balland and Boschma, 2022). A complete IPC consists of hierarchical symbols representing sections, classes, subclasses, and main groups or subgroups[4]. This study uses the section and subclass levels as the basis for classifying technology fields to examine the changing trends in patents transferred from universities.

Figure 2 illustrates the annual proportions of patents at the section level and the corresponding changes over time. The proportions of each section changed dramatically before 2008 but remained relatively stable after 2008. Specifically, the share of patents in Categories C (chemistry, metallurgy) and G (physics) was considerably higher than that in other technology fields, accounting for nearly 50% of all patents. However, Category C has gradually decreased, and Category G has gradually increased in recent years. Patents in Categories A (human necessities), B (performing operations, transporting), and H (electricity) accounted for another 40%. Category A and H have declined, whereas Category B has gradually grown in more recent years. Throughout this period, few patents were related to Categories D (textiles, paper), E (fixed constructions), and F (mechanical engineering, lighting, heating, weapons, blasting), which together accounted for the remaining 10% of all patents. Overall, the structure of UTFs at the section level was similar to that of national knowledge flows (Yang et al., 2021b).

To further identify the most popular technology fields of the transferred academic patents, a Sankey diagram was drawn, as shown in Fig. 3, to explore the variations in the top 10 subclasses in three-year intervals from 2001 to 2021. The following trends are observed:

- In Category A, only Subclass A61K (preparations for medical, dental, or toiletry purposes) had active patent transfers throughout the period, peaking in 2004–2006 and 2010–2012, followed by a downward trend in recent years.
- Category G had two long-lived subclasses; G01N (investigating or analyzing materials by determining their chemical or physical properties) ranked first after 2012, and G06F (electric digital data processing) ranked second after 2015. This indicates that enterprises recently paid increasing attention to material and computer science. Other short-lived subclasses in Category G included G01R (measuring electric and magnetic variables) in 2013–2015 and G06T (image data processing or generation) in 2019–2021.
- Category H contained several subclasses of vibrant patent transfer. For instance, Subclass H04L (transmission of digital information) moved from sixth in 2007–2009 to fourth in 2016–2018 and subsequently dropped to ninth in 2019–2021. Other short-lived subclasses in Category H included H04Q (selecting) and H04J (multiplex

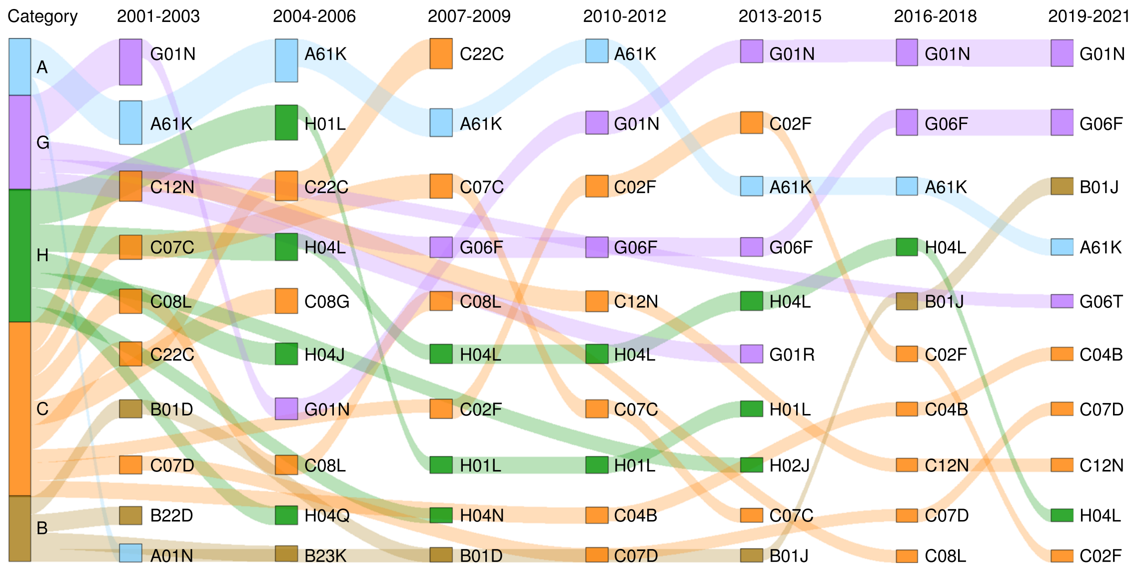

Fig. 3 Changing trends in the top 10 technology fields at the IPC subclass level. In each period, rectangles represent IPC subclasses, ranked from top to bottom according to the proportion of patents in each subclass to all patents. Colors indicate different IPC sections, and the width of the curves connecting the rectangles represents the proportion of patents transferred.

communication) in 2004–2006 and H04N (pictorial communication) in 2007–2009.

- Category C contained several subclasses with vibrant and long-lived transfers. For instance, C22C peaked in 2007–2009, and eventually fell out of the top 10 list, whereas C02F rose to second in 2013–2015, followed by a rapid decline in recent years. Other long-lived subclasses in Category C included C07C (acyclic or carbocyclic compounds), C07D (heterocyclic compounds), C08L (compositions of macromolecular compounds), etc.
- In Category B, only Subclass B01J (chemical or physical processes, their relevant apparatus) was of particular interest to enterprises, rising from tenth in 2013–2015 to third in 2019–2021. The other popular subclasses in Category B appeared only before 2010.
- Over the entire period, no popular technology fields were observed in Categories D, E, and F.

Regional distributions. Based on the addresses of universities and enterprises, geographical distribution maps of university patents provided and acquired by cities in China between 2001 and 2021 were drawn (Fig. 4). As shown in Fig. 4a, university patents with transferred characteristics are mainly concentrated in the eastern coastal regions and provincial capitals in Northeast, Central, and Western China, which is consistent with the regional inequality of university distribution. These regions host the most prestigious universities in China. University patents in eastern coastal areas are primarily distributed in provincial capitals (or municipalities), such as Beijing, Tianjin, Shanghai, Nanjing, Hangzhou, Guangzhou, and other economically developed regions. University patents in Central China are typically distributed in provincial capitals, such as Taiyuan, Zhengzhou, Wuhan, Hefei, Nanchang, and Changsha. Patents in Northeast China are mostly distributed in the three provincial capitals: Harbin, Changchun, and Shenyang. Patents in the western region are primarily distributed in the three provincial capitals (or municipalities): Xi'an, Chengdu, and Chongqing. Other regions had less than 150 patents.

As shown in Fig. 4b, university patents are mainly transferred to Eastern China and the provincial capitals in Central, Northeastern, and Western China, which is similar to the spatial pattern of university knowledge supply. However, compared to patent supply, there is a certain degree of spatial mismatch between university knowledge supply and regional knowledge demand. Universities transfer patents elsewhere owing to a lack of absorption capacity in the host region, and regions with a weak supply of knowledge from local universities search elsewhere. For instance, the supply of knowledge from universities in Harbin, Changchun, and Shenyang in Northeast China, where economic development has been declining since the 1990s, has exceeded regional absorption capacity, resulting in the partial use of university knowledge by other regions. The Pearl River Delta—an economic core but knowledge periphery—has a demand for university knowledge that exceeds the supply within the region, creating the need to access university knowledge outside the region. Nonetheless, a mismatch exists between university technology supply and regional technology demand for technological specialization. For instance, enterprises in Tianjin have absorbed many patented technologies in G01N, G06F, C02F, and A61K, whereas the technologies provided by universities in Tianjin are mostly concentrated in G06F, B01D, G01N, and C07D.

Organization-level UTFN

Topological structure. Table 1 presents the topological structure of UTFN during three periods. The number of nodes and links increased rapidly, while the network density continued to decrease between 2001 and 2021, indicating that the connections between nodes gradually loosened with the expansion of network size. Centralization is generally employed to measure the extent to which a network is organized around or dominated by specific nodes. In-centralization increased from 0.009 in 2001–2007 to 0.017 in 2008–2014 and subsequently decreased to 0.002 in 2015–2021. Out-centralization decreased from 0.056 in 2001–2007 to 0.050 in 2008–2014 and to 0.026 in 2015–2021, suggesting that the network is decentralizing in terms of technology outflows.

The average outdegree and indegree, as well as the average weighted outdegree and indegree, show an upward trend, indicating an increasing number of links between universities

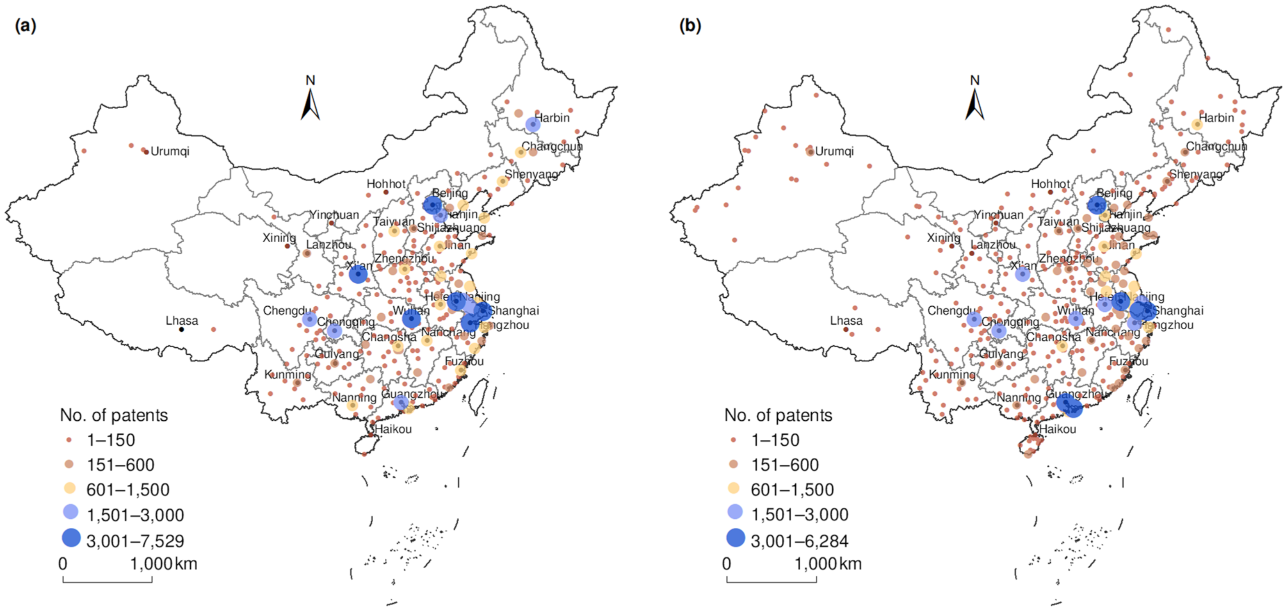

Fig. 4 Geographical distribution of university patent supply and demand. Map **a** is the spatial distribution of university patent supply at the city level. Map **b** is the spatial distribution of university patent demand at the city level. The nodes represent the cities. Node size indicates the number of university patents.

Table 1 Topological structure of the UTFN.

Indicator	2001-2007	2008-2014	2015-2021
Number of nodes	362	4144	22348
Number of links	282	4178	24271
Density	0.00216	0.00024	0.00005
Out-centralization	0.056	0.050	0.026
In-centralization	0.009	0.017	0.002
Average outdegree (indegree)	2.907 (1.064)	10.420 (1.116)	28.059 (1.130)
Average weighted outdegree (indegree)	5.196 (1.902)	21.935 (2.350)	64.457 (2.595)
CV of average outdegree (indegree)	1.134 (0.294)	1.952 (1.102)	1.868 (0.828)
CV of average weighted outdegree (indegree)	1.365 (1.167)	2.248 (3.418)	2.333 (3.478)

Note: CV denotes coefficient of variation.

and enterprises within the network. Notably, the average weighted outdegree significantly surpasses the average outdegree, indicating that universities tend to establish links with many enterprises with multiple patent transfers. Conversely, the differences between the average indegree and average weighted indegree are minimal, indicating that enterprises tend to establish connections with a single university. Furthermore, the average outdegree considerably surpasses the average indegree, and the average weighted outdegree exceeds the average weighted indegree, suggesting that universities dominate the network.

The coefficient of variation of the average weighted outdegree (indegree) shows an upward trend throughout the study period, indicating an increasing heterogeneity among universities (enterprises) in terms of selling (buying) patents. The coefficient of variation of the average outdegree increased from 1.134 in 2001–2007 to 1.952 in 2008–2014 and decreased to 1.868 in 2015–2021. This indicates a narrowing of differences between universities occupying central positions within the network during the periods of 2008–2014 and 2015–2021. The changing trend in the average indegree mirrors that of the average outdegree.

Key organizations. In this section, we explore the differences between universities and enterprises to identify the organizations that play a central role in the UTFN. In total, 882 universities sold at least one patent to enterprises, and 24,869 enterprises bought at least one patent from universities. Between 2001 and 2021, the number of nodes steadily increased, indicating that universities and enterprises were increasingly involved in the UTFN. Between 2001 and 2005, few nodes were identified in the network. After the implementation of the independent innovation strategy in 2006 and the innovation-driven development strategy in 2013, the number of universities and enterprises experienced a period of rapid growth. Between 2016 and 2021, the number of nodes in the network was considerably higher than that in the other periods.

However, universities and enterprises exhibited significant differences in patent transfer behaviors. For instance, a few universities transferred a large majority of patents (e.g., approximately 67% of patent assignments were from 10% of the universities). This is similar to the situation in the United States (Hu and Zhang, 2021). Similarly, a few enterprises purchased numerous academic patents (e.g., 10% of enterprises bought approximately 51% of all patents).

Overall, 985/211 project universities occupy a more central position within the network, as these universities possess substantial average outdegree and average weighted outdegree. Compared with non-985/211 project universities, 985/211 project universities have advantages in research funding and technological innovation, and their official reputation helps expand their research strength and patent quality over a larger geographical scope and mitigates the problems of information asymmetry (Hong and Su, 2013; Nie et al., 2023). Moreover, these universities must maintain and enhance their prestige through continuous patent transfers to obtain more research funding and policy support. Hence, 985/211 project universities have sufficient motivation and ability to occupy central positions within the network. However, the average weighted outdegree of 985/211 project universities as a proportion of all universities decreased from 83.135% in 2001–2007 to 68.122% in 2008–2014 and 41.716% in 2015–2021, suggesting that the trend is shifting with the rapid expansion of the UTFN.

Specifically, science, engineering, and comprehensive universities have recently started to occupy more central positions in the UTFN. The average weighted outdegree for science, engineering, and comprehensive universities over the three periods was 5.816, 27.252, and 85.065, respectively, whereas the average weighted outdegree for other universities over the three periods was 5.921, 22.895, and 51.880, respectively, suggesting that the widening gap occurred only in the last few years. University type determines its development priority, disciplinary structure, and innovation orientation. Thus, universities that focus on science and engineering have technical advantages in patenting and commercialization activities. As shown in Table 2, the universities with the highest patent assignments focused on science, engineering, and comprehensive disciplines. In addition, universities located in economically developed regions experienced faster growth in patent transfers. For instance, Changzhou University, which sold few patents before 2014, exhibited an annual weighted outdegree of 148.125 in 2014–2021; Nantong University's annual weighted outdegree in 2001–2018 was less than 4, whereas the figure was close to 130 in 2019–2021; Zhejiang Sci-Tech University sold few patents before 2017, whereas the annual weighted outdegree in 2018–2021 was more than 120. These rising stars are located in the Yangtze River Delta megalopolis, which is China's most innovative and dynamic region, suggesting that regional technological needs stimulate universities' participation in technology transfer activities to some extent.

Regarding enterprises, the position difference across all industries within a network is relatively small. Across all industries, the most common types of enterprises with high average indegree and average weighted indegree within the network are in the leasing and business services sectors, as well as electricity, heat, gas, and water production and supply. As shown in Table 3, eight of the top ten enterprises based on weighted indegree are intellectual property service companies, such as Guangdong Gaohang Intellectual Property Operations Co., Ltd. and Zhejiang Pinchuang Intellectual Property Service Co., Ltd. Two of the eight firms are operated by universities: Liyang Changda Technology Zhuanyi Center Ltd., operated by Changzhou University, and Jiangyin Zhichanghui Intellectual Property Operation Co., Ltd., operated by Jiangsu University. Another university-run technology enterprise, HIT Robot Group Co., Ltd., is operated by the Harbin Institute of Technology. These university-run enterprises either act as intermediaries to assist universities in transferring their potential technologies to other companies or directly commercialize their patents.

Table 2 Top 10 weighted outdegrees in the UTFN.

Rank	University Name	Region name	Outdegree
1	Tsinghua University	Beijing	1537
2	Zhejiang University of Technology	Hangzhou	1374
3	Jiangnan University	Wuxi	1356
4	Harbin Institute of Technology	Harbin	1208
5	Shanghai Jiao Tong University	Shanghai	1202
6	Changzhou University	Changzhou	1200
7	Jiangsu University	Zhenjiang	1157
8	Xi'an Jiaotong University	Xi'an	1041
9	Zhejiang University	Hangzhou	1016
10	Beijing University of Technology	Beijing	1015

Spatial-level UTFN

Spatial distance. According to previous literature on the geography of university knowledge spillovers, UTFs decrease with increasing distance. Figure 5 depicts the distribution of UTFs by distance intervals between 2001 and 2021. The distance reaches up to 4100 km; however, nearly 45% of academic patents are assigned to enterprises within 100 km, indicating that UTFs are highly geographically localized. A sharp decrease occurs in the proportion when the distance exceeds 100 km but is less than 400 km, and no apparent decline for the 500–1100 km range. This indicates that geographical distance has no substantial restriction on distant UTFs (Mukherji and Silberman, 2021). UTFs for distances of 900–1100 km show a moderate increase, likely because of the flows between major cities in China. The proportion of UTFs decreases once the distance exceeds 1100 km. The proportion of each distance interval is less than 1% when the distance exceeds 2000 km.

To observe variations in geographical distance, we calculate the average annual distance between 2001 and 2021 (Fig. 6). Additionally, we categorize UTFs into three based on the location of universities and enterprises: intra-city (academic patents assigned to enterprises from the same city); inter-city within provinces (academic patents assigned to enterprises from different cities but in the same province); inter-city across provinces (academic patents assigned to enterprises from different cities in different provinces). Overall, the geographical distance of UTFs showed an increasing trend with fluctuations. In 2002, the minimum distance reached was 210 km, after which an increasing trend was observed. The average distance peaked at 561 km in 2020 due to the decreasing share of intra-city patent transfers. As shown in Fig. 6, intra-city patent transfers dominated the process of UTF in the early period. Nevertheless, the proportion of intra-city patent transfers peaked at 74% in 2003, followed by a slow decline. The proportion of inter-city patent assignments across provinces increased significantly

Table 3 Top 10 weighted indegrees in the UTFN.

Rank	Enterprise name	Region name	Indegree
1	Guangdong Gaohang Intellectual Property Operations Co., Ltd.	Guangzhou	625
2	State Grid Corporation of China	Beijing	596
3	Liyang Changda Technology Zhuanyi Center Ltd.	Changzhou	382
4	Changshu Intellectual Property Operation Center Co., Ltd.	Suzhou	355
5	Shenzhen Pengbo Information Technology Co., Ltd.	Shenzhen	352
6	Huzhou Youyan Intellectual Property Service Co., Ltd.	Huzhou	300
7	Zhejiang Pinchuang Intellectual Property Service Co., Ltd.	Huzhou	267
8	Jiangyin Zhichanghui Intellectual Property Operation Co., Ltd.	Wuxi	247
9	Zhejiang Zhiduoduo Network Technology Co., Ltd.	Hangzhou	204
10	HIT Robot Group Co., Ltd.	Harbin	201

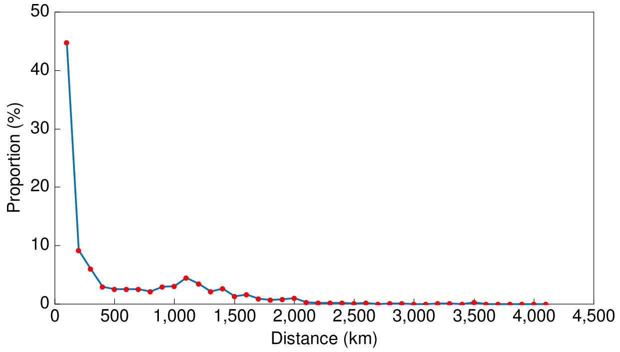

Fig. 5 Decay of UTFs with increasing distance.

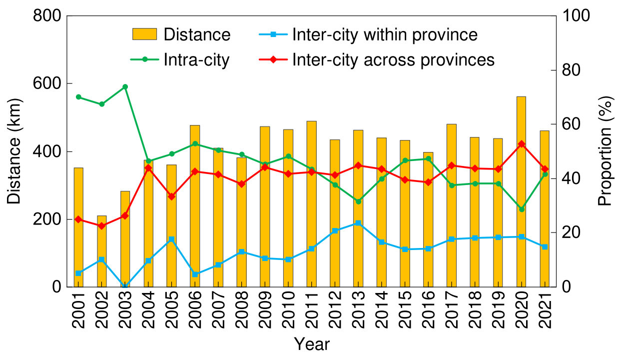

Fig. 6 Average distance and spatial scale trends.

between 2001 and 2004, after which it fluctuated around 43%. The proportion of inter-city patent assignments within the provinces increased between 2001 and 2013, after which it fluctuated between 14% and 18%. Overall, UTFs underwent a delocalization process.

Intra-regional evolution. The number of intra-regional patent transfers in China during the three periods is presented in Fig. 7. In 2001–2007, intra-regional university-enterprise patent transfers occurred in only 32 cities, most of which were provincial capitals and municipalities. Shanghai had the largest number of intra-regional UTFs at 70, followed by Beijing with 51. The numbers in the other regions were below 20.

The pattern for 2008–2014 was similar to that for 2001–2007. Intra-regional UTFs were distributed across 92 cities. Beijing and Shanghai had the highest number of intra-regional patent transfers, at 763 and 380, respectively. Provincial capitals, such as Nanjing and Wuhan, also became active. The numbers in other regions were mostly below 60.

In 2015–2021, intra-regional UTFs occurred in 188 cities, and the differences in the number of flows varied widely. Beijing, Shanghai, and Hangzhou ranked among the top three with 2287, 1472, and 1366, respectively. Moreover, local UTFs significantly increased in Wuhan, Guangzhou, Xi'an, Harbin, and other provincial capital cities with higher-education resources, as well as in Changzhou, Suzhou, Zhenjiang, Wuxi, and other cities in the Yangtze River Delta. The numbers were mostly below 200 in cities other than provincial capitals, as these cities lacked prestigious universities. Nonetheless, intra-regional technology flows were more active in coastal areas than in inland areas.

Inter-regional evolution. Figure 8 illustrates the spatial patterns of inter-regional UTFs. In 2001–2007, the inter-regional network was sparse. A total of 73 cities joined the UTFN, of which 61 received university technology from outside the region. Shanghai and Beijing received the most university patents, with 41 and 34, respectively, whereas the other cities received less than ten. At this stage, inter-regional technology flows were mainly between the provincial capital and municipalities, indicating that the network was dominated by hierarchical diffusion.

In 2008–2014, 276 cities joined the network, of which 272 received university technology from 101 cities. Nantong, Beijing, Suzhou, and Shenzhen had the largest number of technology inflows, at 912, 547, 415, and 217, respectively. Although inflows to other cities have improved to some extent, most did not exceed 100. At this stage, inter-regional technology transfer remained dominated by hierarchical diffusion, and contagion diffusion was not evident. University technology was mainly transferred to the Yangtze and Pearl River Deltas from Beijing and Xi'an. Beijing is a higher education and national administrative center that diffuses a large amount of academic knowledge to other regions and absorbs academic knowledge from the entire country.

In 2015–2021, the inter-regional network became dense. A total of 340 cities joined the network and obtained university technology from 207 cities. Inter-regional UTFs were highly geographically concentrated and presented a trapezoid structure anchored by five megalopolises: the Beijing-Tianjin region in North China, Yangtze River Delta megalopolis in East China, Pearl River Delta megalopolis in South China, Chengdu-Chongqing region in West China, and Harbin-Changchun-Shenyang region in Northeast China. Academic knowledge was mainly transferred from west to east and from north to south. Beijing and other major cities in the Pearl and Yangtze River Deltas became the main destinations for inter-regional UTFs. As the knowledge and economy center in China, the Yangtze River Delta played an important role in the national UTFN, same as Beijing, and exchanged knowledge within the region, indicating that contagion diffusion began to become noticeable. While the Pearl River Delta is an economic core, it is a knowledge-peripheral region. Therefore, it absorbed numerous academic technologies from external areas but rarely spread academic knowledge to external areas. The other cities with trapezoidal structures mainly served as knowledge exporters.

To further clarify the positions of cities within the UTFN, the roles of cities were identified based on the normalized indegree (the ratio of the weighted indegree of each city to the maximum weighted indegree in all cities) and normalized outdegree (the ratio of the weighted outdegree of each city to the maximum weighted outdegree in all cities). This indegree-outdegree dichotomy effectively reflects the impact of cities within a network (Wang et al., 2015). If a city has high normalized indegree and outdegree within the network, it acts as a national hub owing to its strong influence on other cities. If a city has a high normalized indegree but a low normalized outdegree within the network, it acts as a technology importer because it depends mainly on academic knowledge outside the region. If a city has a low normalized indegree but a high normalized outdegree within the network, it may act as a knowledge exporter because it usually has academic strength that exceeds its needs. If a city has low normalized indegree and outdegree within the network, it is at the periphery of the network because of its insignificant impact on other cities. Between 2001 and 2007, the number of inter-regional UTFs was small; therefore, this study focuses on two periods: 2008–2014 and 2015–2021.

As shown in Fig. 9, Beijing was the only national hub during both periods. Nantong was a technology importer in both periods, whereas Shenzhen, Suzhou, and Guangzhou shifted from the periphery to being technology importers. Shanghai, which was located in the exporter quadrant in 2008–2014, acted as a technology importer in 2015–2021. Xi'an and Nanjing were

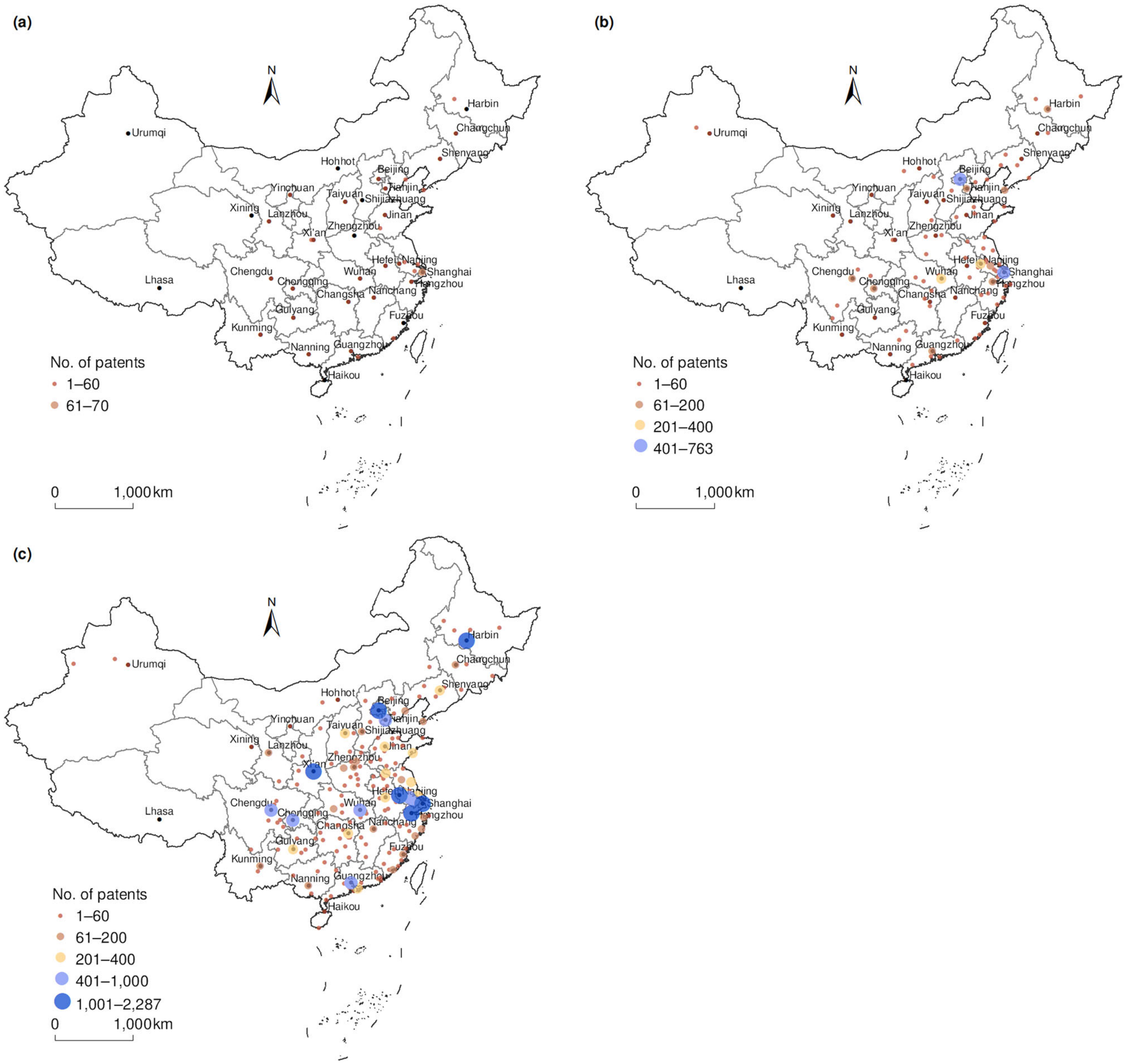

Fig. 7 Evolution of intra-regional UTFN. Map **a** shows the spatial pattern of intra-regional UTFN in 2001–2007. Map **b** shows the same content in 2008–2014. Map **c** shows the same content in 2015–2021. The nodes represent the cities. Node size indicates the number of university patents.

technology exporters during both periods, whereas Hangzhou shifted from the network periphery to the technology importer quadrant. Other cities with low normalized indegree and outdegree had a limited influence on cities within the network, indicating that they were on the periphery of the network. In the future, Huzhou and Jiaxing, two economy-core but knowledge-peripheral cities in the Yangtze River Delta, may move toward the importer quadrant. Shanghai and Nanjing, developed cities with rich higher-education resources, may become national hubs. Wuhan, Chengdu, and Chongqing may become technology exporters.

Discussion

Compared with previous studies, this study provides a more comprehensive and detailed understanding of the development process and current situation of UTFs in China. This study uses patent assignment data and adopts technological, organizational, and regional perspectives. The findings of this study differ from those of the existing literature. First, previous studies on the quality of university patents have shown that patent quality does not increase with patent quantity and that innovation policies to promote high-quality patents should focus on increasing university R&D rather than reducing the cost of university patenting (Fisch et al., 2016). From the perspective of patent assignments, this study shows that G06F (electric digital data processing), H04L (transmission of digital information), and C07D (heterocyclic compounds), as well as other technologies, are the most popular domains. Second, at the initiative of policymakers, many universities worldwide have taken action to develop a third mission by fostering links with enterprises and promoting the commercialization of technology (Perkmann et al., 2013). However, our study found that universities are not homogeneous regarding patent transfers and only prestigious universities with a focus on science and engineering disciplines occupy central positions in the UTFN. This implies that these universities should receive attention and resource investments in the future. Third, the conventional wisdom based on conceptual frameworks,

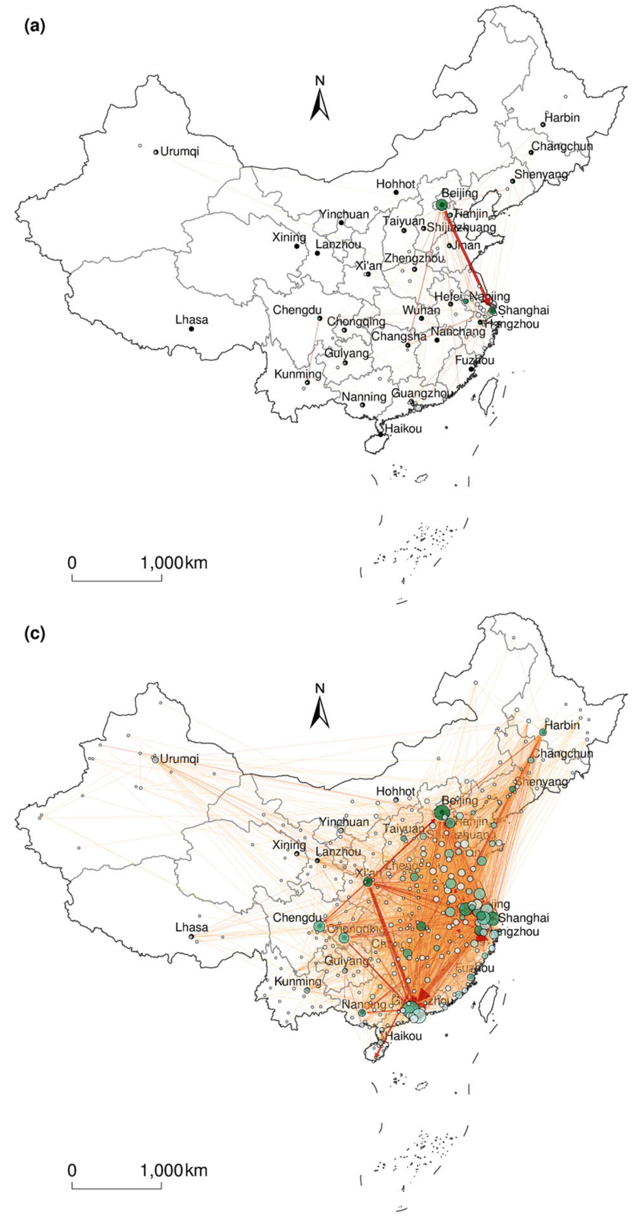

Fig. 8 Evolution of inter-regional UTFN. Map **a** shows the spatial pattern of inter-regional UTFN at the city level in 2001–2007. Map **b** shows the same content in 2008–2014. Map **c** shows the same content in 2015–2021. The nodes represent the cities. Node size indicates the number of incoming edges incident on it. The depth of the node color indicates the number of edges stemming from the node. A directed connection between two cities indicates UTFs and the thickness of the directed connection indicates the frequency of flows between the two cities.

such as the triple helix, the regional innovation system, and the engaged university, emphasizes that knowledge spillovers are geographically localized (Uyarra, 2010) and argues that universities serve local development and local investment in university research (Mukherji and Silberman, 2021). Nonetheless, this study shows that while UTFs are highly localized, they are undergoing a process of delocalization. This is likely due to the spatial mismatch between knowledge supply and demand and the presence of divergent technological development trajectories between universities and industry in the same region. This leads to varying university-region relationships in terms of patent transfers.

A growing body of research has shown that an organization's role in regional innovation depends largely on the network in which it is embedded. For universities, a previous study has theoretically identified five major functions that characterize the geographical scale and scope of technology flows in universities and their role in the multiscale network of technology flows (Fromhold-Eisebith and Werker, 2013). Our research empirically focuses on the geography of UTFs, which reveals the role of universities in local, regional, and national innovation systems. This study extends the theory of regional innovation systems and expands the research field of university-industry interaction. Practically, this study is significant for improving the efficiency of university technology transfer, promoting university-enterprise interaction, and enhancing regional competitiveness.

Our research uses patent assignment data that reflect the economic value of technology flows as well as explicit and implicit knowledge sharing. However, the channels of UTFs are diversified, including satellite institutes, contract research, and patent licensing. Therefore, future research should compare university patent transfers with other technology flow channels, expand the research contents of UTFs, and promote an in-depth analysis of

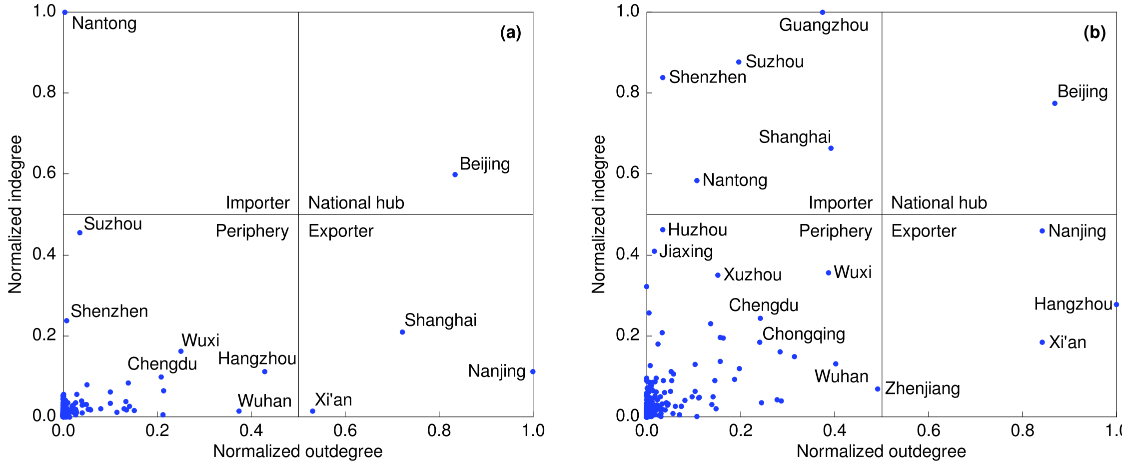

Fig. 9 Position of cities in UTFN. Figure **a** shows the position of cities in UTFN in 2008–2014. Figure **b** shows the same content in 2015–2021.

the spatial mechanism of UTFs. Moreover, UTFs may differ across technology domains, and such nuances should be addressed in the future.

Conclusions

This study investigated UTFs in China from technological, organizational, and regional perspectives. The results revealed a close relationship between the number of university patent transfers and increased support from national incentive policies. The number of patent assignments showed a clear upward trend between 2001 and 2021, indicating the growing transfer of academic patents to enterprises. Before 2007, the number of patent assignments increased gradually, as universities had no right to dispose of patents. Between 2008 and 2014, the number increased but remained at a relatively low level, as the revised Science and Technology Progress Law enacted in 2007 authorized universities to dispose of academic patents, while the patent income was retained by the central government. However, with the revision of the Law of Promoting Scientific and Technological Achievements Transformation of the People's Republic of China in 2015, a surge in university and enterprise participation within the UTFN was witnessed, leading to a substantial increase in patent assignments.

Additionally, UTFs are highly heterogeneous in terms of technology fields and organizations involved in patent transfers. While an increasing number of universities and enterprises have joined the network, significant differences are observed in patent transfer behaviors between universities and enterprises. Academic patents are sold primarily by prestigious universities that focus on science, engineering, and comprehensive disciplines. Intellectual property services and technology-based enterprises run by universities occupy central positions in the network. University-transferred patents are primarily concentrated in Categories C (chemistry, metallurgy) and G (physics), followed by Categories A (human necessities), B (performing operations, transporting), and H (electricity). Few patents are related to Categories D (textiles, paper), E (fixed constructions), and F (mechanical engineering, lighting, heating, weapons, blasting), which is consistent with the popular technology areas of national knowledge flows. The most active technology fields are chemistry, metallurgy, and physics.

Furthermore, regions occupy varying positions within the network, as some degree of spatial mismatch is observed between university knowledge supply and regional knowledge demand. Prestige universities in China are primarily distributed in economically developed provincial capitals and municipalities. Therefore, UTFs are highly geographically localized, as the supply and demand overlap in space. Nonetheless, geographical distance has no substantial restrictions on cross-regional flows, which are gradually delocalized. The indegree-outdegree matrix shows that Beijing and Shanghai are national hubs in the cross-regional network because of their high influence on other regions. Economy-core and knowledge-peripheral cities, such as Shenzhen, Guangzhou, and Suzhou, are knowledge importers owing to their high dependence on outside academic knowledge. Conversely, cities with academic strength that exceeds their needs, such as Nanjing, Hangzhou, and Xi'an, are knowledge exporters. Other cities are located at the periphery of the network.

Policy implications. These findings have some important implications.

First, this study reveals the detailed trends in popular technology fields over time, which could guide universities in future R&D activities by helping them understand technology demand. The results indicate that universities should prioritize R&D in popular technology fields, such as G06F (electric digital data processing), H04L (transmission of digital information), and C07D (heterocyclic compounds), which reflect the high demand from enterprises toward universities. Furthermore, the results provide governments with valuable information on emerging technologies. The emphasis on academic technology development and transfer activities is often related to governmental innovation strategies, especially in the early stages of research (Chang, 2022). Therefore, governments can allocate R&D resources based on technology trends.

Second, the network constructed in this study can identify universities that are key players in the local, regional, and national innovation systems. Many universities in China have positioned themselves as important participants in the national technology transfer system to acquire financial support when responding to national policies (Yu et al., 2022). To promote technology flows, the government encourages most universities to establish technology transfer institutions and uses this factor as an important reference for university evaluation, which may lead to a waste of resources. Our analysis of key organizations shows that the position difference of universities in the network is closely related to their halo effect and discipline structure. The government should prioritize guiding universities that occupy central positions in the network to improve their technological innovation commercialization. For other universities, policies could emphasize functions such as teaching, basic research, and cultural development.

Third, the blind increase in university R&D by local governments may not contribute to regional development. The spatial-level analysis of the UTFN shows that university technology is not evenly distributed and that UTFs are undergoing a process of delocalization, characterized by self-absorption within host regions and interaction with developed regions. Therefore, a one-size-fits-all approach to university innovation policies is not feasible. Regions should formulate their university policy based on patenting, absorptive capability, and network position. Policies in Beijing, Shanghai, and other cities with intensive university resources and strong absorptive capabilities should focus on increasing university R&D to strengthen the supply of efficient technology. In Shenzhen, Suzhou, and other cities with weak university resources but strong absorptive capabilities, governments should actively build a national technology transfer network to obtain more university technology. Finally, in regions with abundant university technology that cannot fully absorb it owing to a weak industrial base or poor innovation environment, policies should focus on actively exploring the technology transfer mode in line with regional industrial characteristics.

Data availability

The datasets generated during and/or analyzed during the current study are available in the Harvard Dataverse repository: https://doi.org/10.7910/DVN/MOHXB5.

Received: 12 December 2023; Accepted: 21 March 2024;
Published online: 02 April 2024

Notes

1 https://www.incopat.com/login?locale=en.
2 https://www.gov.cn/xinwen/2021-10/31/content_5648029.htm.
3 https://www.qcc.com/.
4 see https://www.wipo.int/publications/en/.

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Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant nos. 42201192, 42130510, 42171184), the Youth Project of Chief Research Base of Humanities and Social Sciences of MOE (Grant no. 22JJDZS790302), and the Key Scientific Research Project of Education Department of Anhui Province (Grant no. SK2021A0090).

Author contributions

LY: conceptualization, methodology, data curation, visualization, writing—original draft, writing—review and editing, funding acquisition. TZ: conceptualization, data curation, writing—review and editing. XC: writing—review and editing, supervision, funding acquisition. SH: conceptualization, writing—review and editing. GZ: supervision, funding acquisition.

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

Informed consent was not required as the study did not involve human participants.

Additional information

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