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Research article

Patent output and patent transfer network in China universities: Moderating roles of absorptive capacity and desorptive capacity

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ABSTRACT

Although absorptive capacity and desorptive capacity has been widely present in university-industry relationships, there has been no research on their potential impact on the relationship between university patent output and university patent transfer network. We constructed datasets of patent applications and patent transfers to firms from 383 universities between 2002 and 2021 in China, and empirically demonstrated the effect of the patent output on university patent transfer network using negative binomial regression models. We also examined the moderating effects of absorptive capacity and desorptive capacity. The results reveal that university patent output positively affects the size and the connection strength of the university patent transfer network. Technology transfer offices and satellite institutions, for desorptive capacity in universities, negatively moderate the relationship between the university patent output and the university patent transfer network, respectively. For absorptive capacity in firms, research and development intensity of new products and the level of research and development personnel input, respectively, have a positively moderate effect on the relationship between the university patent output and the university patent transfer network. Our research provides insights into the dynamics of the university patent transfer network; especially against the backdrop of a sharp increase in university patent output and insufficient development of the university patent transfer network, this study provides evidence to the substitution effect of desorptive capacity in universities and the bidirectional effect of absorptive capacity in firms.

1. Introduction

Over the past few decades, universities worldwide have increasingly been dedicated to developing and transferring new technologies to firms, thus contributing to the development of society [1]. Although a few universities have been remarkably successful, the vast majority face significant challenges, especially in China, where the disparity between the high number of university patent applications and the low volume of actual patent transfers is quite prominent. As of 2021, Chinese Higher Education Institutions (HEIs) had filed 260,696 domestic invention patents, totaling 544,110 patents in force [2]. However, the implementation rate of patents in 2021 was only 13.8 % [3]. A recent study revealed one obstacle to university patent transfers is how to maintain long-term research and development (R&D) collaborations between university and industry [4], specifically in developing a stable and efficient University Patent Transfer Network (UPTN). Thus, in the context of open innovation, the macro policy objective for promoting university patent

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Abbreviations:

AC	Absorptive Capacity
DC	Desorptive Capacity
UPO	University Patent Output
UPTN	University Patent Transfer Network
UTTO	University Technology Transfer Office
USI:	University Satellite Institution
RDINP	R&D Intensity of New Products
LRDPI	Level of R&D Personnel Input
HEIs	Higher Education Institutions
CNIPA	China National Intellectual Property Administration
TISO	Technology Intermediary Service Organization

transfer in the future should be to develop a vast and robust social network, fostering prosperous and active high-quality collaborations between universities and enterprises at both national and regional levels.

In recent years, social network analysis has been extensively applied in research on university knowledge (patent) transfer network [5–9], contributing to the understanding of the formation of patent transfer networks and their impact on economic growth or the innovation performance [6], spatiotemporal distribution characteristics [7], and structural features [10]. Social connections among actors increase opportunities to acquire potentially useful learning, ideas, or resources [11], thereby increasing the likelihood and volume of organizational knowledge transfer, and playing a crucial role in facilitating resource exchange and the knowledge transfer [12]. A well-established UPTN will promote inter-regional patent transfer, thereby enhancing the innovation capabilities of less advantaged regions, helping them break free from the "lock-in" of development paths [13].

University Patent Output (UPO) does not automatically transfer to firms; this requires universities to possess DC to market patents to firms and firms to have AC to realize the value of university patents [14]. Absorptive Capacity (AC) and Desorptive Capacity (DC) commonly exists in the patent transfer networks between universities and firms, and have a linear or inverted U-shaped impact on the organizational performance of technology transfer [15]. Over the last decade, some relevant studies use AC and DC as a theoretical framework or lens to illustrate the R&D cooperation and the innovation performance of university-firm technology transfer network [14,16–18], but the empirical background is selectively developed countries [18,19].

In the university system of China, the patent transfer has become one of the key priorities beyond teaching and research. More and more universities have found dedicated technology transfer offices [20] or satellite research institutions [21]with the function of a technology transfer platform in other provinces outside the main campus, in order to discover transferable patents and transfer them to firms. In addition, more firms are also attempting to improve their absorptive capacity in the process of R&D cooperation and the technology import by increasing the investment of personnel and funds, so as to better apply technologies from universities. Despite the continuous growth in UPO, the patents transfer from universities to firms remains limited, with rarely a few regions' firms acquiring a significant number patents from universities, and the development of UPTN is uneven and inadequate [22,23]. Studying only the antecedents of the university side has inevitable limitation [24], so, how the DC in universities and the AC in firms jointly affects the relationship between UPO and UPTN, especially in developing countries like China, is an interesting gap.

Therefore, we focus on the University Technology Transfer Office (UTTO) and University Satellite Institution (USI) in China, as well as R&D Intensity of New Products (RDINP) and the Level of R&D Personnel Input (LRDPI), to test the moderating effects of AC and DC on the relationship between UPO and UPTN. Based on 71,642 patents transferred by 383 Chinese universities to 28,435 firms from 2002 to 2021, as well as 1,745,647 patents field by these universities and other relevant data representing DC in universities and AC in firms, we conduct the empirical study. The content structure as follows: Theory background and hypothesis development is conducted, and a research framework based on DC and AC is proposed in section 2. Research design is introduced in section 3, while analysis and discussion of results is presented in section 4 and 5. Finally, conclusions are summarized and their implications for theory and practice are concluded in the last section.

2. Theory background and hypothesis development

2.1. UPO and the development of UPTN

Although there are multiple elements and various measurements for understanding the third-mission of universities, the patent output remains one of the key indicators of interest to researchers, policymakers, and other stakeholders [25]. UPO serves not only as an outcome of university scientific researches but also as an input for transferring patents to industry. It signifies not just the innovative capacity of universities but also the opportunities for universities to transfer patents to external firms.

From a social network perspective, the patent transfer involves efforts where technology sources produce patents and transfer them to recipients, who subsequently acquire and exploit these patents. Patents serve as channels for transmitting technology, information, and knowledge [26]. The more patents a university produce, the greater the likelihood that the university will transfer patents to more firms, potentially leading to a larger size of UPTN. This is because an increase in UPO can enhance the credibility of the university and faculty inventors, creating a “halo effect” on external firms, thus attracting more firms to establish the patent transfer and collaborative R&D relationships [27]. Furthermore, there is a positive correlation between UPO and the number of patents licensed or assigned to firms [18,20]. UPO can also strengthen the connection strength of UPTN. Therefore, the first hypothesis proposed as follows.

Hypothesis 1a. **(H1a)**. The more patents a university produce, the larger the size of UPTN, i.e., the greater the number of companies acquiring university patents.

Hypothesis 1b. **(H1b)**. The more patents a university produce, the higher the connection strength of UPTN, i.e., the greater the number of patents transferred from the university to firms.

2.2. Moderating role of DC in universities

As the impact of open innovation on organizational R&D efforts deepens, Lichtenthaler et al. defined the capability required for the external commercialization of internal knowledge within organizations as “Desorptive Capacity” (DC) corresponding to “Absorptive Capacity” (AC) [28]. DC consists of two dimensions: (1) identifying opportunities for external application of knowledge; and (2) transferring knowledge to recipients. Universities lack the indispensable conditions for the patent implementation and cannot generate economic benefits directly through self-implementation. Therefore, universities should develop their DC based on the patent output [18]. DC not only helps maintain and strengthen existing UPTN but also explores broader external technology exploitation markets, effectively disseminating university’s intellectual properties. In this study, we measure the DC needed to develop UPTN through UTTO and USI, and examine the moderating effect of them on the relationship between UPO and UPTN. Although these two proxies may not fully represent the multi-dimensional, multi-level and dynamic characteristics of DC, under current conditions, they are the simplest and most effective measures available thus far, as their functional positioning and terms of reference can comprehensively reflect the DC in UPTN.

2.2.1. Moderating role of UTTO

Over the past two decades, based on the experiences of universities in the United States and European region, an increasing number of Chinese universities have founded UTTO. At present, UTTO has gradually become institutionalized and is considered the integral component of universities in China. UTTO can consolidate various resources, focus on cultivating specialized talent, and systematically carry out tasks including the invention disclosure, the patent application, value assessment, commercial marketing and negotiation, formal contracting, as well as the follow-up and maintaining of patent transfers [29,30]. Through these efforts of UTTO, universities can send a clear signal to firms in the market about the importance attached to the patent transfer.

UTTO aim at enhancing the quality of UPO and the performance of patent transfers, achieving systematic management of patent production and transfer. In practice, UTTO is increasingly focusing on promoting collaboration between universities and firms, as well as supporting broader missions related to university research [31]. On the one hand, UTTO implement graded and classified managements of patent output and establish channels of connection through technology marketing efforts to match potential objects between universities and businesses, thereby developing the first dimension of DC: identifying opportunities for universities to assign and license patents to firms. On the other hand, UTTO assist inventors in executing the management process of patent transfers and provide specialized services such as value assessment, transaction negotiation, contract drafting and signing, to reduce transaction costs, accelerate transaction processes, and develop the second dimension of DC: facilitating the transfer of patents to firms. Therefore, the second hypothesis proposed as follows.

Hypothesis 2a. **(H2a)**. If other conditions remain unchanged, UTTO have a positive moderating effect on the relationship between UPO and the size of UPTN.

Hypothesis 2b. **(H2b)**. If other conditions remain unchanged, UTTO have a positive moderating effect on the relationship between UPO and the connection strength of UPTN.

2.2.2. Moderating role of USI

With the development of the higher education system, universities worldwide are transforming from small, homogeneous institutions focused on cultivating knowledge elites to diverse, large-scale complex entities [32], with the establishment of USI across regions being a key feature. In China, prestigious universities like Harbin Institute of Technology, Tsinghua University, and Peking University had already set up USI as early as the 1990s. In recent years, an increasing number of Chinese universities have established USI in provinces outside their main campuses to undertake functions related to technology development and outcome commercialization, such as regional research institutes, dispatched research institutes, new types of R&D institutions, university-industry collaboration platforms, technology innovation platforms, and functional platforms for research and commercialization [21]. USI serves as a crucial carrier for the technology transfer and their establishment represents a significant aspect of university development. Through research innovation and patent transfer efforts, USI facilitates high-quality interactions between university and industry [32], stimulating demand for knowledge-intensive services in the regions located and contributing to regional economic growth.

USI serves as an enabler in the development of regional innovation system by coordinating and integrating resources from their main campuses, supporting the absorption and dissemination of university technologies by firms in the region [33], and helping them overcome barriers to endogenous development paths in the region [34]. On the one hand, USI can bridge the connection between main campus and regional firms, reducing cognitive, geographic, organizational, and social distances between the two [21], fostering organized proximity between universities and firms [34], and expanding the size of UPTN. On the other hand, USIs are conducive to embedding within the region's R&D networks and establishing trust with local firms, facilitating the linkage of firms' technology development needs with UPO and patent transfer opportunities [35]. They identify more long-distance transfer opportunities for UPO, enhancing the connection strength of UPTN. Thus, the following hypothesis is proposed.

Hypothesis 3a. **(H3a)**. If other conditions remain unchanged, USI has a positive moderating effect on the relationship between UPO and the size of UPTN.

Hypothesis 3b. **(H3b)**. If other conditions remain unchanged, USI has a positive moderating effect on the relationship between UPO and the connection strength of UPTN.

2.3. Moderating role of AC in firms

Cohen and Levinthal [36] formally introduced and developed the concept of AC, which refers to the organization's capacity to recognize the value of new external information, assimilate that information, and apply it for commercial purposes. AC not only assists firms in searching for, identifying relevant knowledge domains, determining sources and providers of knowledge within those domains [37,38], but also helps expand the range of latent partners for collaboration [39]. AC is of significant importance for firms in enhancing organizational performance and competitiveness.

In the context of university transferring patents to industry, firms and universities possess distinct skills, cognitive structures, and cultures [40]. The knowledge embedded in patents that needs to be transferred is often complex [41]. Patent transfer does not imply the fulfill application of technological knowledge; just those firms with sufficient AC can successfully acquire and utilize university patents. Lack of AC within a firm in the course of R&D, especially in new products, can hinder secondary development, commercialization, and industrialization of university patents, thereby adversely affecting the size and strength of UPTN. Conversely, firms with AC are better equipped to manage the flow of external knowledge [42], and utilize the inflow of external knowledge within the organization [37,43], reduce risks associated with excessive exploration of external knowledge [44], and mitigate obstacles to the patent transfer. Additionally, cultural and knowledge-sharing differences between R&D personnel and faculty inventors in the patent transfer process may be bridged by high LRDPI [40], underscoring the crucial role-played by LRDPI within firms. These two agents are frequently used to measure AC of firms in technology transfer research.

2.3.1. Moderating role of RDNIP

Based on the degree of novelty, previous research [45] has distinguished between incremental innovation and radical innovation. Incremental innovation "involves relatively small technological improvements and provides lower benefits for businesses and users". Radical innovation, on the other hand, is defined as "a new product that combines fundamentally different substantial technologies and provides more value for businesses and users compared to previous products." The development of new products is a core activity for innovative firms, and the connection between university patent transfer and corporate R&D is primarily achieved through the development of new products by firms.

From the perspective of demand-pull, technical challenges encountered in firm's new product development may lead to demands for university patent technologies, especially in fundamental technologies in which universities are skilled. Typically, the higher the expected returns on new production for businesses, the greater the investment in R&D, which will stimulate firms to actively seek patent transfer opportunities with new universities. Conversely, insufficient investment in basic R&D by firms may lead to insufficient demands for university patent technologies, thereby trigger difficulties in university patent transfer [46] or even refusal to establish patent transfer connections with universities. Furthermore, the implementation of university patent technologies in new production may give rise to new problems and a series of improvement and optimization needs, prompting firms to require more university patent technologies and strengthen the connection strength of UPTN. We can capture AC within firms by calculating the ratio of R&D investment in new products to sales revenue, known as R&D intensity of New Product (RDINP) [36]. Therefore, we hypothesize that,

Hypothesis 4a. **(H4a)**If other conditions remain unchanged, RDINP has a positive moderating effect on the relationship between UPO and the size of UPTN.

Hypothesis 4b. **(H4b)**. If other conditions remain unchanged, RDINP has a positive moderating effect on the relationship between UPO and the connection strength of UPTN.

2.3.2. Moderating role of LRDPI

The R&D personnel are crucial assets for firms to achieve technological advancements. For universities, transferring patents to firms often aims at solving practical issues, carrying greater practical value. When utilizing new technologies, firms with high LRDPI tend to achieve greater success. R&D personnel often suggest that firm collaborate with universities to acquire more solutions suited for new products and technologies, thereby maximizing the production output or diversifying product portfolios. Through this approach, R&D personnel can initiate, support, and re-initiate technology import.

Innovative firms typically have higher LRDPI; enabling them to resolve more issues that are technical, generate more demands for the technology transfer, especially for radical innovation. If a firm with high LRDPI, it has a positive impact on both university and firm. During the exploitation of university patents, support from high LRDPI in firms can facilitate better integration of university technologies with existed technologies, preventing business disruptions and reducing coordination costs in R&D efforts. In the process of secondary development, through effective communication and collaboration with R&D personnel, faculty inventors can gain a more comprehensive and exact understanding of technical issues, making university patent technologies more closely aligned with industry needs [40]. In conclusion, for successful commercialization of technology, firm's high LRDPI will support the acquisition and assimilation of university patent technologies. Therefore, we propose the following hypothesis,

Hypothesis 5a. **(H5a).** If other conditions remain unchanged, LRDPI has a positive moderating effect on the relationship between UPO and the size of UPTN.

Hypothesis 5a. **(H5b).** If other conditions remain unchanged, LRDPI has a positive moderating effect on the relationship between UPO and the connection strength of UPTN.

Establishing the patent transfer relationships between universities and firms are not merely about firms absorbing university patent technologies, as they also constitute formal collaborative relationships with the explicit goal of creating innovative outcomes [40,41]. At the inter organizational level, if universities lack DC to support the technology transfer, and firms lack AC to utilize university technology, they will hinder the establishment of patent transfer connections and the quantity of patents transferred. Therefore, both DC in universities and AC in firms can influence the development of UPTN. Despite existing research on AC and DC in university-industry collaboration [14,47], to our learning, there has been no empirical analysis studying their impacts in UPTN simultaneously, particularly within the context of universities in developing countries. Drawing from literature on open innovation and the technology transfer [18,28,47], we present the research framework shown as Fig. 1, to assist in analyzing the moderating effects of DC in universities and AC in firms on the relationship between UPO and UPTN.

3. Research design

3.1. Definition the scope of empirical research

Our research background is in China. Universities represent a crucial component of the China national innovation system. Compared to other countries and regions in East Asia, universities have played a more prominent role in the process of technological catch-up in China [48]. Due to China's unique national conditions, within macro management studies related to education, science and technology, and intellectual property rights, universities are often categorized under HEIs or used synonymously with them in academic research, rarely being studied as a distinct research topic. In an academic sense, for facilitating comparison and reference with counterpart research findings from other countries, it is necessary to clarify the university first. According to the "Higher Education Law of PRC", HEIs include university, independent college, higher vocational institution, adult HEIs, and others. University refers to one category of HEIs engaged in undergraduate education and above, with at least three or more disciplinary, and is fundamentally different from other HEIs as to target, level, and size. According to the list of colleges and universities released by ministry of education, as of May 31, 2022, there were a total of 3013 HEIs in mainland China (including 2759 regular HEIs and 254 adult HEIs). Among these, regular HEIs consist of 1270 undergraduate institutions and 1489 junior colleges (higher vocational institutions). Within undergraduate institutions, strictly defined universities are only 444, which bear the three missions of teaching and education, scientific research, and social service, serving as the key actors in patent output and patent transfer efforts.

Furthermore, research on the patent transfer in Chinese universities is often placed under the agenda of the transformation of scientific and technological achievements, technology transfer, or knowledge flow in HEIs. However, the patent transfer differs significantly from the technology transfer, technology commercialization, and knowledge dissemination. Patent transfer emphasizes the utilization of patented technology and changes in legal rights, serving as a formal form of technology transfer, technology commercialization, and knowledge dissemination. Empirical studies on UPTN have utilized various patent data and its combination, such as the patent citation [8], patent Co-ownership [6,13,49], patent licensing [5,22,50,51], patent assignment [7,10], both patent licensing and assignment [9,52]. We believe that patent citation data may be used to study the transfer of technology and knowledge between universities and firms but may not reflect the transfer of patent rights and implementations. Patent Co-ownership data are employed to explore knowledge flow and the technology transfer between universities and firms but may not reveal the orientation of

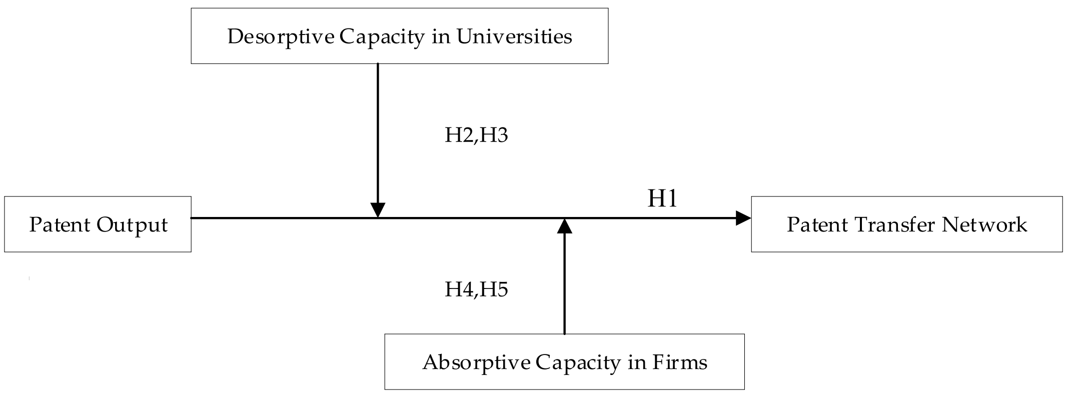

Fig. 1. Research framework.

such flow or transfer. Patents are products of legal systems. Even though patents contain technology and knowledge, research on the patent transfer should emphasize the essential attributes of patent transfer. Licensing and assignment data represent formal transfer paths generated by patent legal procedures and contracts. By tracking changes in patent assignees, one can comprehensively monitor the multiple and directed flows of technology, knowledge, and rights.

Moreover, within Chinese patent legal system, patents include inventions, utility models, and industrial designs. Invention is widely regarded as one of the significant indicators for measuring university research strength and the innovation capability and has been extensively used in relevant empirical studies [5,51]. Therefore, in our study, the patent transfer specifically refers to the transfer of application rights and patent rights for invention patents.

Finally, the firms in our study refer to domestic enterprises in China, excluding enterprises whose registered and business location are located outside mainland China. Therefore, in empirical research, we define university patent transfer as the legal action where universities from mainland China license and assign their invention patent (application) rights to domestic firms.

3.2. Variable selection

3.2.1. Dependent variable

We conceptualize UPTN as a social network that represents two groups of heterogeneous nodes (actors) – universities and firms. UPTN is formed based on UPO, with each patent transferred from a university to a firm representing a form of patent transfer connection. The UPTN in our study is a directed and weighted social network. We select network size (N_{Size}) and the connection strength of network (N_{CS}) as two dependent variables to measure the development level of UPTN. The number of nodes can reflect N_{Size}, while the frequency of connections between nodes reflects N_{CS}.

In the empirical analysis, N_{Size} is measured by the number of firm nodes connected to each university through the patent transfer; a higher value indicates a larger size of UPTN and involvement of more firms obtaining university patents. N_{CS} is quantified by the number of patents transferred from each university to firms; a higher value indicates a greater number of patents transferred from universities to firms or a larger number of patents acquired by firms from universities. To mitigate frequent and substantial fluctuations in single-year values, N_{Size} and N_{CS} are summed in various periods at the provincial region level. The magnitude of these values represents differences in the development level of UPTN.

3.2.2. Independent variable

We use the total number of domestic invention patents filed by each university during every observation period to construct the independent variable, UPO (U_{PatO}), in which we take the square root in the empirical analysis. Following the study by Shen et al. [53], for robustness testing, we also introduce the level of U_{PatO} as another variable. Specifically, based on UPO, we divide all universities into five categories: universities in the top five quintiles are assigned a value of 5, while those in the bottom five quintiles are assigned a value of 1, with values of 4, 3, and 2 corresponding to universities in the second, third, and fourth quintiles, respectively. In other words, the higher the level of U_{PatO}, the greater the quantity of patents produced by such universities.

Next are the four moderating variables that reflect DC in universities and AC in firms, examining their moderating effects on the relationship between UPO and UPTN.

(a) Based on the organizational characteristics of the university, we selected UTTO (U_{TTO}) and USI (U_{SI}) to measure DC in universities. U_{TTO} is measured by whether each university had an independent secondary technology transfer department during the observation period, with 1 indicating presence and 0 indicating absence. U_{SI} is measured by whether each university had a USI in other provinces undertaking the function of transforming scientific and technological achievements during the observation period, with 1 indicating presence and 0 indicating absence. In empirical analysis, 1 represents high DC, while 0 represents low DC in universities.
(b) Based on the continuity, comparability, and availability of panel data, we selected RDNIP (F_{RDINP}) and LRDPI (F_{LRDPI}) to measure AC in firms. At the provincial region level, F_{RDINP} was measured by the ratio of R&D investment to sales revenue (percentage) in new products, while F_{LRDPI} was measured by the full-time equivalent of R&D personnel (thousand person-years) in up-scale enterprises. In empirical analysis, the annual average values of these two variables within the observation period are obtained first and then subjected to centering processing. Values above the average are coded as 1, representing high AC; and values below the average are coded as 0, representing low AC in firms.

3.2.3. Control variable

According to prior research, university characteristics are first controlled. The first is university prestige (U_{Pre}). In UPTN, firms tend to establish patent transfer relationships with universities of higher prestige [27]. Higher prestige not only facilitate universities to collaborate with a broader range of firms across a larger spatial scope and transfer more patents to firms [23,54], but also improves the reputation of faulty inventors ans positively regulates the pricing of patent transactions [55]. Therefore, assigning 1 to "Project 985" universities (U_{985}), 2 to "Project 211" universities (U_{211}), and 3 to general universities (U_{Gen}).

The second is the type of university (U_{Type}). Different types of universities possess different endowments with regard to patent output and transfer. For instance, disciplines such as communication, mechanical engineering, and chemical engineering in technological universities are more likely to generate practical innovative technologies applicable to production. However, research outcomes in other types of universities, such as those focusing on liberal arts, finance, law, and languages; generally consist of new theories, methods, or viewpoints, which do not easily transform to economically valuable technical solutions. Consequently, the quantity and scope of knowledge transfer vary among different types of universities [23]; with technological and comprehensive universities demonstrating more prominent patent transfers [10]. Hence, assigning 1 to comprehensive universities (U_{Com}), 2 to technological universities (U_{Tech}), and 3 to other universities (U_{Other}).

The third is to control the geographical spatial characteristics of universities and firms. Previous literature has examined the geographic distance between the firms and the cities where universities are located [56,57], commonly finding that geographic distance hinders the patent transfer, but lacks examination of the geographic distance between universities and firms. We searched for the latitude and longitude of universities and firms in bulk based on their addresses, then calculated the spherical distance between them using the Haversine formula [54,58]. Taking the square root in empirical analysis. Furthermore, the spatial location relationship between university and firm (UF_{SL}) also needs to be controlled. Previous studies have found that patents licensing from universities to firms in the same province is the mainstream [22], while cross-regional patent transfer is relatively less [56]. Assign 1 to universities and firms are located in the same provincial region, while 0 signifies they are not.

The next is the location of firms (F_{Loc}). Due to uneven economic development, the innovation capabilities, R&D resources, and technology transfer performance vary across different regions in China [59]. According to the criterion of division of the National Bureau of Statistics of China, the 31 provincial-level regions in the mainland of China are divided into eastern, western, central and northeastern regions. Firms located in the eastern region (F_{Est}) are denoted as 1, those in the western region (F_{Wst}) as 2, those in the central region (F_{Cen}) as 3, and those in the northeastern region (F_{NEst}) as 4.

Lastly, controlling the observation periods (OP) [54] to mitigate the influence of time trends on the study results. Based on the distinction of OP as illustrated in Fig. 2 below, four time dummy variables, P1, P2, P3, and P4 are set where assigned 1, 2, 3, and 4, to represent the periods of 2002–2007, 2008–2015, 2016–2018, and 2019–2021, respectively.

3.3. Data collection

Patent data on transfer and output are retrieved and collected through the Incopat original database (https://www.incopat.com/), its data originate from the official database of CNIPA, updated daily. The software interface and the operating language are in Chinese and widely used in relevant studies [10,23]. Since the enforcement of the "regulation on the filing and administration of patent implementation license contracts" on January 1, 2002, the construction of the patent contract filing database by the CNIPA has been completed and made available for public inquiry. So, the search range was from 2002 to 2021 in order to maintain timeliness. Patent publication number, legal status, filing date of license contracts, the execution date of assignment, as well as applicant, licensee, and assignee names, types, and address information was exported to Excel.

After the initial results were manually processed, we eventually collected 71,642 records of 383 universities in mainland China transferring invention patents to 28,435 domestic firms between 2002 and 2021, involving 68,460 invention patents. Among these, 54,803 patents were assigned, and 14,750 patents were licensed, with some inventions undergoing both licensing and assignment

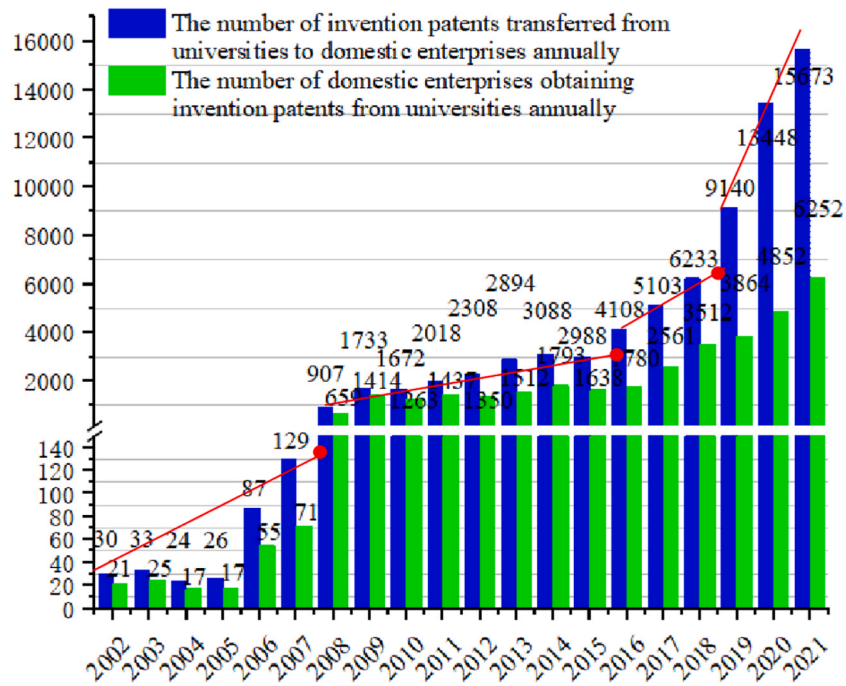

Fig. 2. The annual trend in the number of inventions transferred from universities to firms and the number of firms acquired universities patents in Mainland China from 2002 to 2021.

simultaneously. Subsequently, based on the patent transfer datasets of the identified 383 universities, their total number of domestic inventions (including applications) filed between 2002 and 2021 was retrieved from the Incopat also, totaling 1,745,647 inventions, thus establishing a data set of university patent output.

Furthermore, for research purposes, other data were also collected:

- The missing addresses were supplemented through searching for Tianyancha database (www.tianyancha.com).
- Information about UTTO and USI was compiled by accessing each university's official website and relevant online news.
- Annual provincial data on full-time equivalent of R&D personnel, R&D expenditure and sales revenue of new product of up-scale enterprises from 2002 to 2021 was gathered via the National Bureau of Statistics (https://data.stats.gov.cn/).

4. Data analysis and results

4.1. Descriptive statistics

Not all universities transfer patents to firms. The 383 universities are distributed across 30 provincial regions in mainland China (excluding Tibet), accounting for 86.26 % of all universities. As to the university prestige, 37 "Project 985" universities (excluding National University of Defense Technology and Minzu University of China), the remaining 63 "Project 211" universities (excluding 13 universities, such as: Communication University of China, Central University of Finance and Economics, etc), and 283 general universities are included. In terms of university types, these universities include 137 technological universities, 101 comprehensive universities, and 145 universities in other categories (agriculture and forestry, normal education, medicine, finance and economics etc, are included). Apart from the Sino-foreign cooperative institutions Kunshan Duke University, Xi'an Jiaotong-Liverpool University, Ningbo Nottingham University, and the private university Westlake University, the other 379 universities are public institutions. There are 28,435 firms spread across 31 provincial regions in mainland China, with 68.56 % of the firms located in the eastern region, while the central, western, and northeastern regions account for 15.03 %, 11.33 %, and 5.08 % of firms, respectively.

Overall, the number of patents transferred from universities to firms shows a periodical upward trend over time, as shown in Fig. 2. The period from 2002 to 2007 marks the initial stage. Despite the Chinese government establishing a technology market in 1993 and implementing economic and tax measures to incentivize universities to commercialize patents, during this period, the domestic technology market had not fully developed, and the immediate effects of patent transfers from universities to firms were not significant. Starting from 2002, the Chinese government began promoting the establishment of dedicated technology transfer institutions within universities and decentralizing the intellectual property rights of research project outcomes to universities, allowing them to decide on licensing or assign to others independently. During this period, the number of patents transferred from universities to firms increased from 30 in 2002 to 129 in 2007, with only dozens of companies acquiring university patents.

In 2008, the Chinese government identified intellectual property rights as a national strategy, explicitly propose to promote the transfer of patents from universities to firms. That year marked the first turning point, with the number of patents transferred from universities to firms (907) growing by 603.10 % compared to 2007 (129). Subsequently, from then until 2015, this number consistently remained within the range of 1650 to 3,100, maintaining relative stability overall. This trend aligns with the research conclusions on the patent licensing trends in Chinese universities during this period by Yin et al. [22]. Concurrently, the total number of firms acquiring university patents generally ranged between 650 and 1800.

In 2016, a second turning point occurred, reaching 4188 patents transferred, and continued to exceed 5000 and 6000 in 2017 and 2018 consecutively, showing significant growth. This outcome may be related to the first revision of the "Law of the PRC on Promoting the Transformation of Scientific and Technological Achievements" in 2015, which encouraged the establishment of technology intermediary service organization (TISO). From patent transfer records, we observe that the majority of TISOs obtained their first patent license or assignment from universities after 2016. These TISOs typically operate under names such as "Technology Transfer Center," "Intellectual Property Operation Company," "Intellectual Property Service Company," or "Network Technology Company," concentrating mainly in a few provinces like Jiangsu, Zhejiang, Guangdong, Beijing, Shaanxi, and Anhui, etc. Therefore, after 2016, there was another increase in the number of firms obtaining university patents.

In 2019, marking the third turning point, the number of patents transferred from universities to enterprises reached 9,140, jumping to 13,448 in 2020 and further increasing to 15,673 in 2021. The number of firms acquiring university patents increased from 3864 to 6,252, with significant growth observed in the size and the connection strength of UPTN. It is evident that from 2002 to 2021, UPTN has been significantly guided and driven by major policies, experiencing four distinct periods: 2002–2007, 2008–2015, 2016–2018, and 2019–2021. Based on this, our study divides into four observation periods, serving as one of the solid bases for the research design is supplemented here.

Table 1 describes the variables of the empirical analysis and presents the results of the correlation analysis. The observed values of the dependent variables N_{Size} and N_{CS} have a relatively large range, indicating significant variations in the size and connection strength. The median values tend towards the lower end, suggesting that the development level of the majority UPTNs is relatively low. There are considerable differences in the independent variable UPatO. In terms of correlation, the correlation coefficient between N_{Size} and N_{CS} is 0.846, indicating a strong inherent connection between them, which can jointly characterize the development level of UPTN. The absolute values of the correlation coefficients between the independent and dependent variables are all less than 0.4, and the absolute values of the correlation coefficients between any two independent variables included in the regression model are all less than 0.7. The Variance Inflation Factor (VIF) analysis results shows that the VIF values of all variables range from 1.01 to 2.48, which is below the acceptable criterion of 10 suggested by Hair et al. [60], indicating that concerns about multi-collinearity between variables

Table 1
Results of the descriptive statistics and correlation analysis for variables.

Variable	Range	Med	Mean	Std	1	2	3	4	5	6	7	8	9	10	11	12
1. NSize	1–343	1	4.63	12.76	1											
2. NCS	1–1139	2	10.04	36.96	0.868	1										
3. UPatO	5–18467	1794	2837.09	2956.10	0.164	0.154	1									
4. UTTO	0–1	1	0.55	0.50	0.005	0.013	0.254	1								
5. USI	0–1	0	0.21	0.41	0.105	0.111	0.438	0.255	1							
6. FRDINP	1.54-16.39	7.59	7.59	1.33	−0.002	0.006	0.014	−0.046	0.015	1						
7. FLRDPI	0.11–683.88	81.9	164.97	181.98	0.167	0.156	−0.079	0.001	−0.035	0.012	1					
8. UPre	1–3	3	2.34	0.81	−0.074	−0.059	−0.667	−0.417	−0.354	0.047	0.088	1				
9. UType	1–3	2	1.83	0.74	−0.069	−0.055	−0.361	−0.145	−0.208	0.038	0.035	0.307	1			
10. UFDst	0.01–3656.00	853.54	899.98	645.43	−0.225	−0.184	0.116	0.074	0.042	0.184	0.026	−0.092	−0.032	1		
11. UFSL	0–1	0	0.14	0.35	0.387	0.323	−0.160	−0.063	−0.139	−0.017	−0.069	0.099	0.081	−0.520	1	
12. FLoc	1–4	1	1.82	1.00	−0.097	−0.086	0.047	0.005	0.022	−0.026	−0.455	−0.017	0.001	−0.015	0.081	1
13. OP	1–4	3	3.11	0.88	0.009	0.052	−0.029	0.050	0.081	0.263	0.205	0.068	0.048	0.147	0.017	−0.084

are not present.

4.2. Empirical results

The dependent variables are count variables that are positive integers, and Poisson regression is commonly used for modeling count data. However, both dependent variables exhibit a strong over-dispersion characteristic (see Table 1), the standard deviation is much larger than the mean, rejecting the hypothesis of equal mean and variance, indicating that the Poisson model is not suitable. Since the Negative Binomial model allows for over-dispersion, this study employs it to predict the impact of UPO on UPTN. To test H1a and H1b, Models 1 and 6 only include the U_{PatO} and all control variables. To examine moderation effects, Models 2–5 and 7–10 sequentially introduces interaction terms between U_{TTO}, U_{SI}, F_{RDINP}, and F_{LRDPI} with U_{PatO}.

The estimation results for the size of the UPTN (N_{Size}) are presented in Table 2. In Models 1–5, the coefficient of U_{PatO} is positive and significant, indicating that UPO positively influences the size of UPTN. H1a is supported. In Models 2 and 3, the coefficients of U_{TTO} and U_{SI} are positive and significant ($\beta = 0.372$, $P < 0.01$; $\beta = 0.420$, $P < 0.01$), suggesting that UTTO and USI both positively affects the size of UPTN. However, the coefficients of $U_{TTO} \times U_{PatO}$ and $U_{SI} \times U_{PatO}$ are negative and significant ($\beta = -0.005$, $P < 0.01$; $\beta = -0.008$, $P < 0.01$), indicating that the joint effect of UTTO and USI with UPO negatively moderates the relationship between UPO and the size of the UPTN. H2a and H3a are rejected. In Model 4, the coefficient of F_{RDINP} is negative and significant ($\beta = -0.095$, $P < 0.1$), implying that FRDINP negatively affects the size of NPTN. However, the coefficient of $F_{RDINP} \times U_{PatO}$ ($\beta = 0.003$, $P < 0.1$) is positive and significant, showing that when both UPO and RDINP increase simultaneously, they jointly have a positive impact on the size of UPTN. H4a is supported. In Model 5, the coefficient of FLRDPI is positive and significant ($\beta = 0.126$, $P < 0.1$), illustrating that LRPDI positively influences the size of UPTN. The coefficient of $F_{LRDPI} \times U_{PatO}$ ($\beta = 0.012$, $P < 0.1$) is also positive and significant, indicating that when both UPO and LRDPI increase simultaneously, they jointly have a positive impact on the size of UPTN. H5a is supported.

Table 3 presents the regression results for the connection strength of UPTN (N_{CS}). Among models 6–10, the coefficients for U_{PatO} are consistently positive and significant, indicating a positive impact of UPO on the connection strength of UPTN. H1b is supported. In models 7 and 8, both UTTO and USI have positive and significant coefficients ($\beta = 0.326$, $P < 0.01$; $\beta = 0.471$, $P < 0.01$), suggesting that both UTTO and USI positively influence the connection strength of UPTN. However, the coefficients for $U_{TTO} \times U_{PatO}$ and $U_{SI} \times U_{PatO}$ are negative and significant ($\beta = -0.003$, $P < 0.1$; $\beta = -0.008$, $P < 0.01$), indicating that the joint effect of UTTO and USI with UPO negatively moderates the relationship between UPO and the connection strength of UPTN. H2b and H3b are not supported. In model 9, the coefficient for F_{RDINP} is negative and significant ($\beta = -0.133$, $P < 0.05$), implying that the RDINP negatively affects the connectivity strength of UPTN. However, the coefficient for $F_{RDINP} \times U_{PatO}$ ($\beta = 0.003$, $P < 0.1$) is positive and significant, indicating that when both UPO and RDINP increase simultaneously, they jointly have a positive impact on the connection strength of UPTN. H4b is supported. In model 10, the coefficient for F_{LRDPI} is positive but not significant, suggesting that LRDPI does not have a significant positive impact on the connection strength of UPTN. However, the coefficient for $F_{LRDPI} \times U_{PatO}$ ($\beta = 0.013$, $P < 0.1$) is positive and significant, indicating that when both UPO and LRDPI increase simultaneously, they jointly have a positive impact on the connection

Table 2
Results of the regression for N_{Size} (the number of firms acquiring universities' patents).

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
UPatOUUPato UPatOcd UTTOUU$_{PatO}$	0.021*** [a] (0.066e-2)	0.023*** (0.104e-2)	0.023*** (0.071e-2)	0.020*** (0.077e-2)	0.016*** (0.069e-2)
U_{TTO}		0.372*** (0.054)			
U_{SI}			0.420*** (0.071)		
F_{RDINP}				−0.095* (0.047)	
F_{LRDPI}					0.126* (0.051)
$U_{TTO} \times U_{PatO}$		−0.005*** (0.001)			
$U_{SI} \times U_{PatO}$			−0.008*** (0.001)		
$F_{RDINP} \times U_{PatO}$				0.003*** (0.082e-2)	
$F_{LRDPI} \times U_{PatO}$					0.012*** (0.085e-2)
U_{985}	−0.301*** (0.040)	−0.299*** (0.039)	−0.276*** (0.042)	−0.298*** (0.040)	−0.259*** (0.038)
U_{211}	−0.059* (0.029)	−0.084** (0.029)	−0.074* (0.030)	−0.059* (0.029)	−0.040 (0.028)
U_{Com}	0.127*** (0.034)	0.119*** (0.034)	0.097** (0.034)	0.128*** (0.034)	0.126*** (0.033)
U_{Tech}	0.112*** (0.033)	0.075* (0.033)	0.104** (0.033)	0.113*** (0.033)	0.117*** (0.031)
U_{FDst}	−0.010*** (0.001)	−0.009*** (0.001)	−0.009*** (0.001)	−0.010*** (0.001)	−0.012*** (0.001)
U_{FSL}	1.825*** (0.041)	1.837*** (0.041)	1.844*** (0.041)	1.821*** (0.041)	1.751*** (0.039)
F_{Est}	0.920*** (0.045)	0.910*** (0.045)	0.905*** (0.045)	0.915*** (0.045)	0.463*** (0.046)
F_{Wst}	0.052 (0.051)	0.044 (0.050)	0.029 (0.050)	0.042 (0.051)	0.073 (0.048)
F_{Cen}	0.287*** (0.050)	0.279*** (0.050)	0.274*** (0.050)	0.294*** (0.050)	0.294*** (0.048)
P2	1.178*** (0.099)	1.146*** (0.099)	1.180*** (0.099)	1.172*** (0.099)	1.180*** (0.095)
P3	1.033*** (0.099)	0.987*** (0.099)	1.03*** (0.099)	1.028*** (0.099)	1.034*** (0.095)
P4	1.310*** (0.099)	1.266*** (0.099)	1.317*** (0.099)	1.314*** (0.099)	1.320*** (0.095)
Intercept	−1.710*** (0.117)	−1.800*** (0.119)	−1.789*** (0.118)	−1.655*** (0.119)	−1.439*** (0.113)
Theta	2.326	2.370	2.350	2.332	2.795
ALC	30574	30525	30522	30564	29711
2 LL	−30544.2	−30490.6	−30488.4	−30529.9	−29677.1
Pseudo R^2	0.652	0.661	0.661	0.658	0.709

[a] * means $p < 0.1$, ** means $p < 0.05$, ** means $p < 0.01$. $N = 7133$.

Table 3
Results of the regression for NCS (the number of patents transferred from universities).

Variables	Model 6	Model 7	Model 8	Model 9	Model 10
U_{PatO}	0.025*** (0.001)	0.025*** (0.001)	0.027*** (0.084e-2)	0.023*** (0.091e-2)	0.020*** (0.081e-2)
U_{TTO}		0.326*** (0.063)			
U_{SI}			0.471*** (0.082)		
F_{RDINP}				−0.133** (0.055)	
F_{LRDPI}					0.052 (0.060)
$U_{TTO} \times U_{PatO}$		−0.003*** (0.001)			
$U_{SI} \times U_{PatO}$			−0.008*** (0.001)		
$F_{RDINP} \times U_{PatO}$				0.003*** (0.098e-2)	
$F_{LRDPI} \times U_{PatO}$					0.013*** (0.001)
U_{985}	−0.339*** (0.046)	−0.333*** (0.046)	−0.337*** (0.049)	−0.340*** (0.046)	−0.299*** (0.045)
U_{211}	−0.155*** (0.034)	−0.170*** (0.034)	−0.183*** (0.035)	−0.157*** (0.034)	−0.131*** (0.033)
U_{Com}	0.152*** (0.039)	0.154*** (0.039)	0.112** (0.039)	0.153*** (0.039)	0.153*** (0.038)
U_{Tech}	0.146*** (0.037)	0.120** (0.038)	0.124** (0.038)	0.146*** (0.037)	0.137*** (0.036)
UF_{Dst}	−0.010*** (0.001)	−0.009*** (0.001)	−0.009*** (0.001)	−0.010*** (0.001)	−0.012*** (0.001)
UF_{SL}	1.936*** (0.049)	1.952*** (0.049)	1.958*** (0.049)	1.933*** (0.049)	1.857*** (0.047)
F_{Est}	1.066*** (0.052)	1.058*** (0.052)	1.053*** (0.052)	1.063*** (0.052)	0.627*** (0.054)
F_{Wst}	0.172** (0.057)	0.162** (0.057)	0.152** (0.057)	0.166** (0.058)	0.189*** (0.055)
F_{Cen}	0.348*** (0.057)	0.345*** (0.057)	0.337*** (0.057)	0.352*** (0.057)	0.345*** (0.055)
P2	0.850*** (0.107)	0.834*** (0.1074)	0.842*** (0.107)	0.840*** (0.107)	0.858*** (0.104)
P3	0.927*** (0.107)	0.892*** (0.107)	0.910*** (0.107)	0.920*** (0.107)	0.947*** (0.104)
P4	1.334*** (0.107)	1.294*** (0.107)	1.323*** (0.107)	1.332*** (0.107)	1.340*** (0.104)
Intercept	−1.291*** (0.128)	−1.348*** (0.130)	−1.370*** (0.129)	−1.220*** (0.130)	−1.007*** (0.125)
Theta	1.172	1.184	1.178	1.174	1.278
ALC	39458	39410	39421	39451	38888
2 LL	−39427.9	−39375.9	−39387.4	−39417.2	−38853.5
Pseudo R_2	0.581	0.585	0.584	0.582	0.617

strength of UPTN. H5b is supported.

Based on the exclusion of multi-collinearity risk, we further examined the robustness of the model. Specifically, we replaced the independent variable U_{PatO} with the level of U_{PatO}, and the estimated results were found to be consistent with those reported in Tables 2 and 3

Our control variables remained highly consistent across all models. Among them, the coefficients for U_{985} and U_{211} were significantly negative, indicating that the size and connection strength of UPTN of "Project 985" universities and "Project 211" universities decreased compared to general universities. Possible explanations include the tendency of patents from "Project 985" universities and "Project 211" universities to focus more on cutting-edge technology or basic research, the greater diversification of other technological achievements channels apart from patent transfers, or the establishment of stricter cooperation conditions when establishing patent transfer relationships with firms. Meanwhile, the patent transfer of general universities might be more flexible and open, attracting more firms to develop and expand UPTN. The coefficient for the geographic distance between universities and firms (UF_{Dst}) was significantly negative, suggesting that the size and connection strength of UPTN (NCS) decrease with an increase in the geographical distance between universities and firms.

Additionally, the positive and significant coefficients for the university type (U_{Type}), location of firms (F_{LOC}), spatial relationship between universities and firms (UF_{SL}), as well as time dummy variables were observed in all models, indicating that: (a) Comprehensive universities and technological universities have larger-size and stronger connection strength of UPTN compared to other types of universities. (b) UPTN formed by universities and firms within the same provincial region is dominant. (c) Firms located in the eastern region obtain more patents from a larger number of universities compared to the northeastern, central, and western regions. (d) The coefficients of the time dummy variables in Table 2 show a V-shaped upward trend, suggesting that the overall size of UPTNs continues to expand over time, but with relatively slower growth during 2016–2018 (P3). The coefficients of the time dummy variables in Table 3 show a continuous upward trend, indicating that the connection strength of UPTN increases over time.

5. Discussion

UPO is the foundation for the formation and development of UPTN, which positively influences the network size and the connection strength of UPTN. This provides a legitimate reason for the growth of UPO in China. Chang et al. [61] found that UPO in China continues to increase due to factors such as internal R&D investment, research project management, performance evaluation, and regional economic development. According to CNIPA [2], the number of invention patents annually filed by HEIs, including universities, increased from 4677 in 2002 to 220,640 in 2021, representing a growth of approximately 4585.9 % with an average annual growth rate exceeding 30 %. According to our study, only 3.9 % of the inventions have been transferred. In addition, the average maintenance period of invention patents in Chinese universities is only 4.6 years, lower than the overall average of 6.9 years [3]. Although the relationship between the quantity and quality of UPO is beyond the scope of our study, it is worth considering that the increasing UPO in China may pose a serious challenge to organizational implementation and management ability in university patent transfers. Therefore, developing DC to exploit the transfer potential of UPO and promote high-quality development of UPTN become an urgent task.

For DC in universities, both UTTO and USI play a promoting role in the development of UPTN. However, when they coexist with UPO, their interaction effect has a negative moderating effect on the size and the connection strength of UPTN, namely substitution effect [45]. This might imply that, in some cases, UPO has some conflicts or competitions with UTTO and USI in the development of UPTN, which leads to insufficient DC in universities. We believe that the substitution effect may be due to the following reasons.

Firstly, regarding UTTO. On the one hand, the rapid growth in UPO may have dispersed the resources and attention of UTTO, thereby affecting its effective operation. When the invention disposal capacity of UTTO is insufficient to meet the marketing demands of UPO, UTTO may become passive "management organizations," relying on firms to approach them. In such cases where employees and budgets are lacking, the focus of UTTO may shift from invention marketing to prioritizing the submission of patent applications and obtaining patent right [62], aiming at legitimize their efforts through increased UPO. On the other hand, the pathways and objectives of UPO may conflict with the operational strategies of UTTO, leading to adverse effects. UPO is driven by the academic reputation of the faculty inventors or the evaluation systems of the university. Establishing spin-offs or transferring patents to firms to obtain monetary income rarely becomes the direct motivation for patent applications [63].

In practice, the work of UTTO primarily focuses on managing processes such as the invention disclosure and application evaluation, patent maintenance, and performance metric, rather than actively seeking patent transfer opportunities to firms. Currently, the level of specialization of UTTO in China is still low, and the patent transfer service system remains imperfect [61]. Additionally, there may be other factors or mechanisms that have not been considered in our empirical study, such as the age, experience, and staff of UTTO [29, 64], which may prevent UPO and UTTO from playing a positive reinforcing effect. Therefore, the development of UPTN not only requires appropriate UPO as a guarantee, but also requires UTTO to play a role in the whole process from thpatent creation to enforcement in firms, and promote the development of UPTN through a comprehensive service system, rich work experience, and high-quality staff.

Secondly, universities can expand their third mission by establishing satellite institutions and promoting the development of cross-regional UPTN. USI can help overcome the problem of low DC for external knowledge in the region and thus overcome obstacles in endogenous path development [36]. However, our research did not find that USI strengthens the positive impact of UPO on UPTN. There may be various explanations for this. On the one hand, USI may facilitate new firms in acquiring university patent technology through non-patent transfer pathways such as face-to-face technical consultation, technical services, and collaborative research, thereby inhibiting the development of UPTN. On the other hand, over time, USI will require a higher degree of coordination and mobilization of resources from the main campus, as well as sustained support from the regional government, in order to develop their DC and expand UPTN. According to empirical evidence, USIs would encounter several challenges when establishing the patent transfer network between universities and local firms. These challenges involve not only addressing potential resource competition with the main campus but also necessitate strategic organizational coordination at the whole university level. The objective of this coordination is to foster organized proximity [36] and cultivate DC within the context of UPTN. By doing so, USIs can enhance their adaptability to the innovation ecosystem in the local region.

For AC in firms, when both RDINP and UPO are high, their joint effect has a positive impact on the development of UPTN. RDINP in firms is an important indicator for evaluating R&D strength and the innovation level. Firms with higher R&D strength are more likely to collaborate with universities [44], and in regions where firms have higher R&D strength, licensing activities of university patents are also more frequent [65]. However, consistent with the findings of Kobarg et al. [45], our study also found that AC represented by RDINP within firms cannot be considered to have a completely positive impact on UPTN, especially in environments characterized by radical innovation represented by new product development. As RDINP increases, Firm's capability of independent innovation also improves. Firms become more capable of retaining the R&D process internalized, reducing the demand for university patent technologies, thus inhibiting the development of UPTN. In this case, the increase in university patent output bridges the decrease in demand caused by the high level of RDINP.

Furthermore, the joint effect of high LRDPI in firms and UPO also has a positive impact on the development of UPTN. High LRDPI means that firms may allocate more resources to technological and product innovation, increasing the demand for UPO and creating potential opportunities for establishing patent transfer connections with universities, although we did not find that high LRDPI increases the connection strength of UPTN. The higher complexity and learning difficulty of university patent technologies requires R&D personnel in firms to possess certain cognitive abilities for absorption [43], and the knowledge and skills of R&D personnel facilitate the formation of trust between firms and universities [36,43]. Therefore, we believe that communication between R&D personnel in firms and faculty inventors in universities plays an important role in facilitating the establishment of patent transfer relationships.

6. Conclusions and further research agenda

6.1. Conclusions and implications

Our study aim at providing a deeper understanding of the dynamics of UPTN by focusing on the moderating role of AC and DC on the relationship between UPO and UPTN. Through the research framework, we treat UPO as a function of the development level of UPTN and investigate the moderating effects of UTTO and USI, RDINP, LRDPI on the relationship between UPO and UPTN. The joint effect of UTTO and UPO, of USI and UPO negatively moderates the development of UPTN, respectively, revealing the potential substitution effect of DC. RDINP negatively affects the development of UPTN, while LRDPI positively influences the size of UPTN. In the context of university-industry patent transfer, there is empirical support for the bidirectional effect of AC. Additionally, the joint effect of LRDPI and UPO has a strengthening effect on UPTN.

Our study has three main academic implications. Firstly, by employing social network theory and two fundamental indicators of network: the size and the connection strength, this study addresses the research gap in university patent transfer for public value, responding to the call from Bozeman et al. [66]. While most studies focus on the economic returns of university patent transfers, it remains crucial to emphasize that the patent output and transfer are natural extensions of the core research activities of universities [41]. Additionally, emphasize private and economic values, achieving social and public values should not be overlooked [66], especially for public and non-profit universities.

Secondly, we propose a research framework that combines DC and AC and: (a) examines the competency of UTTO and USI in developing UPTN under rapid UPO, providing empirical evidence of inadequate DC in Chinese university patent transfers; (b) reveals the bidirectional impact of RDINP and LRDPI on the size of UPTN in the context of radical innovation, uncovering the strengthening effect of AC and UPO on the development of UPTN. This expands our understanding of the dynamics of UPTN. Moreover, by conducting the investigation in China, our study provides important empirical evidence addressing the lack of research on developing countries' patent transfer networks.

Out study provides insights into the management of patent output, the development of patent transfer networks in universities, and the optimization of technology innovation and the management of human resource in firms. The research findings indicate that while UPO positively affects the development of UPTN, it also imposes higher requirements on the DC of universities. It is important to be cautious of the potential long-term negative impacts that may arise from mismatched growth rates between UPO and DC.

Firstly, we suggest that policymakers and university administrators take the next steps to stimulate the transfer potential of existing UPO while implementing strict review criteria and procedures for incremental outputs. The objective should be achieving "less but high-quality" growth in UPO. Secondly, we propose that UTTO and USI should undergo strategic transformation and upgrading. They should transition from administrative entities that facilitate cross-border collaborations and university-industry cooperation to comprehensive service entities embedded within regional and cross-regional innovation ecosystems. The focus of resources allocation should shift from managing the patent output to developing service-oriented patent transfer networks.

Furthermore, enhancing the DC of patent transfer within the university strategy requires the establishment of effective workflow and organizational practices that enable effective collaboration among UTTO, USI, faculties, research projects management, state-owned asset management, legal, and financial departments. Mobilizing and coordinating resources across the entire university will promote the development of UPTN. Moreover, it may also be beneficial to consider diversifying approaches such as outsourcing and partnerships [16] to flexibly utilize external resources and compensate for any deficiencies in internal technological specialization and service capabilities.

Our research results also indicate that the AC in new product R&D has a dual effect on the development of UPTN. We recommend that firms should remain vigilant of declining openness in university-industry collaborations and avoid the potential negative effects of "lock-in" caused by radical innovation. Additionally, AC in firms, in terms of LRDPI, enhances the size of UPTN. We suggest that firms hire more R&D personnel with backgrounds in STEM (Science, Technology, Engineering, and Mathematics) disciplines. Establishing close cooperative relationships between employees through personal mentor-student relationships and alumni networks with the main campus and its satellite institutions should be prioritized.

6.2. Limitations and future research opportunities

Despite the contributions of this study, it is subject to certain limitations. Firstly, we investigated the relationship between university patent output and patent transfer networks based on formal legal channels such as licensing and assignment. However, it is important to acknowledge that there are patent transfer networks formed through other avenues, such as contract research, equity participation, and the establishment of university spin-offs. In practice, patent transfers through these channels often occur more frequently but tend to be more secretive and informal, making accurate data tracking and capturing challenging. Future research could conduct supplementary studies using available data.

Secondly, our manipulation of control variables may have been overly simplistic. Although in the context of this study, variable manipulations were grounded in literature and experiential evidence, and we considered temporal changes during data collection and empirical analysis while controlling for the influence of other spatiotemporal factors, it may still fail to fully reflect the dynamic nature of AC and DC, particularly their multidimensional and multilevel characteristics. Despite the fact that AC and DC can be measured using different approaches, and that no single method is universally superior in all circumstances [42], we recommend future research to utilize more detailed operations by combining survey scales and interview surveys, among other methods, to measure AC and DC.

Lastly, both the investigation of the relationship between university patent output and patent transfer networks and the examination of the moderating effects of AC and DC were preliminary in nature, and therefore, future research can expand upon our findings. Although we have already established that UPO positively influences the size and the connection strength of UPTN, it is reasonable to suspect that this influence may be nonlinear, and the mechanisms through which AC and DC play a moderating role may be more complex. Hence, further exploration is required in future research.

Data availability statement

Data will be made available on request.

Ethical statement

Because the data in this research is not collected from human subjects and is not involving Human Participants and/or Animals, EA is no needed in this research.

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CRediT authorship contribution statement

Hongjun Jia: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis. **Jing Zhou:** Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jing Zhou reports financial support was provided by National Natural Science Foundation of China. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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