Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

The impact of complementary assets on university technology transfer revenues: Evidence from provincial panel data in China

Chengshuo Dong

dongcs0528@outlook.com

Yanshan University

Xianfeng Zhao

Yanshan University

Chunlin Li

Yanshan University

Research Article

Keywords: Complementary assets, University technology transfer, University technology transfer revenues, Digital infrastructure, Fixed-network access capacity, University technology transfer service personnel inputs

Posted Date: November 24th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11751814/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

University research outputs require resources matched to technology transfer tasks to generate market revenue. However, the relationships between different complementary assets and specific revenue outcomes remain insufficiently understood. Drawing on complementary assets theory, this study develops an analytical framework encompassing physical connectivity, information access, and human-mediated knowledge translation. Using panel data for 30 Chinese provincial-level regions from 2014 to 2023, we estimate two-way fixed effects models. These models examine how digital infrastructure, fixed-network access capacity, and university technology transfer service personnel inputs relate to different revenue outcomes. Digital infrastructure is significantly and positively associated with aggregate revenue-generating outcomes of university technology transfer. Fixed-network access capacity is significantly and positively associated with patent commercialization revenue. University technology transfer service personnel inputs are significantly and positively associated with technology-transfer revenue. Robustness checks using alternative variable measures, sample adjustments, and inference procedures suited to a limited number of clusters broadly support these findings. By linking asset functions to specific technology transfer tasks, this study clarifies the resource conditions supporting revenue generation in university technology transfer. The findings inform regional network development and the allocation of professional service resources within universities.

1 Introduction

University technology transfer is an important means by which universities contribute to innovation and socioeconomic development. In 2016, the State Council of the People's Republic of China issued Provisions on the Implementation of the Law of the People's Republic of China on Promoting the Transformation of Scientific and Technological Achievements. These provisions encourage universities to transfer research outputs to enterprises or other organizations through assignment, licensing, or contributions of research outputs as equity. They also require state-established universities to develop technology transfer systems and mechanisms and strengthen their professional technology transfer teams (State Council of the People's Republic of China, 2016). In recent years, China has continued reforms concerning the allocation of rights over research outputs generated in the course of employment, revenue sharing, technology transfer systems, and university–industry collaboration. These reforms have improved the institutional environment for university technology transfer. Yet growth in university research output does not fully translate into market revenue. Enabling market participants to discover technologies dispersed across university research activities and adopt them effectively remains a practical challenge for China's university innovation system. Research on university patent values and licensing revenue shows that the estimated economic value of a technology differs from the revenue universities actually realize (Hsu et al., 2021). Explaining university technology transfer therefore requires attention to the conditions that support the entry of research knowledge into the market. This study examines how these supporting conditions relate to the revenue-generating outcomes of university technology transfer.

A central question in research on university technology transfer is how knowledge generated within universities becomes an economic resource that market participants can identify, adopt, and pay for. Studies have measured commercialization activity through invention disclosures, patent licenses, and transaction counts, assessed resource utilization through input–output efficiency, and examined economic returns through licensing revenue and patent values (Rothaermel et al., 2007; Thursby & Thursby, 2002). These measures capture different aspects of university technology transfer and highlight the links among knowledge production, transaction activity, and revenue realization. In particular, the gap between the estimated economic value of university patents and actual licensing revenue indicates that commercially promising research outputs still require further market discovery, transaction coordination, and integration into practical applications before generating revenue (Hsu et al., 2021). An explanation of university technology transfer must therefore extend beyond research outputs themselves to the resources and capabilities that enable their value to be realized.

The theory of complementary assets provides an analytical foundation for this extension. Whether innovators profit from technological innovation depends on combining technology with the assets required for commercialization; technological superiority alone does not guarantee economic returns (Teece, 1986). To enter the market, research knowledge must be

connected with market information, organizational services, and other commercialization resources. Innovators' knowledge backgrounds and access to resources also shape the pathways through which they achieve commercial applications (Agarwal & Shah, 2014). The analytical value of complementary assets thus lies in explaining how particular resources support innovators in performing commercialization tasks. For universities, this perspective shifts attention from their capacity to supply research outputs to the connectivity and organizational capacity needed to support the market adoption of those outputs.

This organizational capacity is first reflected in universities' arrangements for coordinating research activities and market transactions. Faculty incentives, staffing in technology transfer offices, and informational and cultural barriers between universities and firms jointly influence how research knowledge enters the market. Commercialization activities and broader academic engagement also differ in their dependence on organizational support (Perkmann et al., 2013; Siegel et al., 2003). Together, these studies show that university technology transfer requires sustained coordination of the objectives and actions of researchers, technology transfer offices, and firms. Service personnel and organizational arrangements connect the screening of research outputs, technical explanations, communication of demand, and transaction advancement, thereby providing important support for linking research supply with market demand. Regional resource endowments and the availability of research and development personnel are closely associated with universities' technology transfer performance, indicating substantial geographical variation in the commercialization resources available to universities (Qin et al., 2017). Research integrating university dynamic capabilities with provincial environments further indicates that technology creation and licensing value need to be understood in relation to internal organizational activities and external market and institutional conditions (Yuan et al., 2018). Organizational and regional research thus offers connected explanations: the external environment shapes universities' opportunities to access and acquire resources, whereas internal organizational conditions shape how those resources are used in commercialization activities. Understanding university technology transfer therefore requires closer examination of the relationship between regional resources and universities' service inputs.

Digital development makes information flows and interorganizational connections important elements of this relationship. Research on the digital economy, open public data, and business process digitalization has incorporated digital conditions into analyses of university technology transfer at the levels of regional development, public information provision, and organizational activities, respectively (Adomako & Nguyen, 2024; He, 2024; Naerjiang·Ahai et al., 2026). University–industry cooperation, interorganizational collaboration, and patent commercialization lags help explain how digital conditions operate. Taken together, these studies indicate that the relationship between digitalization and commercialization needs to be understood through the dissemination of information about research outputs, the formation of links between suppliers and users, and the sustained advancement of transactions. However, disseminating information and enabling technology adoption involve different commercialization tasks. Research on electronic marketplaces emphasizes how the costs of acquiring and comparing information influence market participants' search and matching. Research on knowledge codification shows that the forms in which knowledge is expressed and its tacit components affect transmission methods and interaction requirements (Bakos, 1997; Cowan et al., 2000). Patent texts, technological classifications, and legal status information allow potential technology recipients to search, compare, and make preliminary assessments. Explaining technical solutions, communicating implementation requirements, and adapting technologies to applications require further interaction and coordination. Following this logic, digital infrastructure, fixed-network access capacity, and university technology transfer service personnel support physical connectivity, information access, and human-mediated knowledge translation, respectively. Distinguishing the primary tasks supported by these assets grounds research on digital environments and organizational support in the concrete processes through which university research enters the market.

Existing research establishes the importance of organizational support, regional environments, and digital conditions, but does not adequately explain the functional relationships between specific assets and commercialization tasks. Discussions of resource access, organizational coordination, information flows, and interorganizational collaboration have yet to be integrated into a systematic account of the distinct roles of physical connectivity, information access, and human-mediated knowledge translation. Consequently, relationships between resources and technology transfer outcomes are often

understood in terms of general facilitating effects, leaving unclear which supporting conditions different commercialization tasks require. As digital conditions continue to improve, distinguishing the functions of regional network resources and university service inputs helps identify specific constraints on the market entry of research outputs and establish more targeted resource allocation priorities. This gap is also evident in the limited specification of links between supporting conditions and revenue outcomes. The formation of collaborative relationships, patent transactions, and the realization of market revenue capture different aspects of the commercialization process. Although existing studies have examined licensing revenue and patent values, targeted empirical evidence remains limited on which complementary assets are associated with patent commercialization revenue and technology-transfer revenue, respectively. Assessing resources through aggregate commercialization performance does not fully reveal how network access and service personnel relate to specific revenue outcomes. It is therefore necessary to connect asset functions, commercialization tasks, and revenue-generating outcomes, and to examine how different supporting conditions relate to both aggregate revenue-generating outcomes and the two component revenue measures. Doing so can deepen our understanding of the conditions under which university research outputs realize their economic value.

To address these gaps, this study adopts a complementary assets perspective and integrates digital infrastructure, fixed-network access capacity, and university technology transfer service personnel inputs into a single analytical framework. Focusing on physical connectivity, information access, and human-mediated knowledge translation, it develops an approach that links complementary assets to the tasks involved in commercializing university research. By examining how these conditions relate to overall revenue-generating outcomes of university technology transfer, patent commercialization revenue, and technology-transfer revenue, the study advances general discussions of commercialization support toward specific connections between asset functions and revenue outcomes. This approach helps refine theoretical explanations of digital environments and organizational support in university technology transfer and provides empirical insights to inform the allocation of regional network resources and university technology transfer service personnel inputs.

2 Theoretical background and hypotheses

2.1 Complementary assets theory

Teece systematically developed the theory of complementary assets within the profiting from innovation framework. Complementary assets comprise the supporting resources and capabilities required to commercialize technological innovations successfully (Teece, 1986). Technological innovation alone does not guarantee commercial success. Innovators also need access to appropriate production, organizational, transaction, and service conditions to convert technological outputs into market returns. Based on the dependence between assets and particular innovations, Teece distinguishes two broad categories of complementary assets: generic and specialized. Generic assets can support multiple innovation activities, whereas specialized assets are dependent on particular innovations (Teece, 1986). This dependence substantially influences whether innovation returns can be realized and who captures them. In university technology transfer, research outputs, market demand, and application contexts are typically dispersed across different organizations. The process involves presenting research outputs, retrieving information, matching supply and demand, explaining technologies, negotiating transactions, and adapting technologies to applications. Digital infrastructure, fixed-network access capacity, and personnel engaged in research application and science and technology services provide physical connectivity, information access, and human-mediated knowledge translation, respectively. They therefore constitute complementary assets supporting the commercialization of university research.

The technology transfer of university does not involve a uniform pattern of dependence on information. The early stages of patent commercialization rely more heavily on information that can be searched and compared. Patent texts, technological classifications, and legal status can be recorded and disseminated in relatively standardized forms. Although activities generating technology-transfer revenue may also involve codified information such as patents, they often depend more on sustained professional communication and organizational coordination. These requirements arise when explaining technical solutions, communicating implementation conditions, transferring process know-how, and adapting technologies

after transfer. Highly codified information is generally more amenable to retrieval through texts and databases and to remote matching. Technological knowledge with a greater tacit component requires more interaction and collaboration for its translation into practice (Arora et al., 2001; Cowan et al., 2000). Digital infrastructure supports multiple forms of university technology transfer and is therefore classified as a generic complementary asset. It is accordingly linked to overall revenue-generating outcomes, which combine the two revenue categories. Fixed-network access capacity primarily supports the retrieval and matching of codifiable information. Personnel engaged in research application and science and technology services primarily support the translation and implementation of tacit knowledge. These two resources are classified as specialized complementary assets and are linked to patent commercialization revenue and technology-transfer revenue, respectively.

The digital infrastructure index (DINF) itself includes fixed-network access ports as one of its components. Accordingly, H1 examines the relationship between overall network infrastructure conditions and aggregate revenue-generating outcomes of university technology transfer. H2 further identifies the conditional association between the fixed-network access dimension and patent commercialization revenue within these broader network conditions. The two hypotheses examine different levels, namely an aggregate indicator and a specific dimension; they do not imply that the variables are entirely independent. The links between the three complementary assets and different revenue outcomes are not simply pairings of indicators. They depend jointly on the processability of information about research outputs, the main frictions in technology transfer, and the functions performed by each asset. The commercialization of university research does not involve a uniform pattern of dependence on information. The early stages of patent commercialization rely more heavily on searchable and comparable information. Patent texts, technological classifications, and legal status can be recorded and disseminated in relatively standardized forms. Although technology transfer may also involve codified information such as patents, explaining technical solutions, communicating implementation conditions, transferring process know-how, and adapting technologies after transfer require sustained professional communication and organizational coordination. Highly codified information is generally more amenable to retrieval through texts and databases and to remote matching. Technological knowledge with a greater tacit component requires more interaction and collaboration for its translation into practice (Arora et al., 2001; Cowan et al., 2000). On this basis, the study maps the three complementary assets to revenue-generating outcomes according to the stages at which they primarily operate, as summarized in Table 1.

Table 1
Functional alignment between complementary assets and technology transfer outcomes

Outcome type	Predominant knowledge form	Predominant friction	Corresponding complementary asset	Asset type
Aggregate market revenue	Mixed knowledge	Accessibility friction	Digital infrastructure	Generic
Patent commercialization revenue	Codified knowledge	Information friction	Fixed-network access capacity	Specialized
Technology-transfer revenue	Tacit knowledge	Knowledge translation friction	Professional service personnel	Specialized

In summary, complementary assets can facilitate revenue generation from university research by improving the physical connectivity, information access, and personnel support required for market entry. Based on the functional alignment between assets and technology transfer stages, this study examines three relationships. These link digital infrastructure to aggregate revenue-generating outcomes, fixed-network access capacity to patent commercialization revenue, and technology transfer service personnel inputs to technology-transfer revenue.

2.2 Hypothesis development

This study measures the market outcomes of university technology transfer in terms of revenue. Overall market-based outcomes (MARKET) combine real patent commercialization revenue and real technology-transfer revenue. Patent

commercialization revenue (PATENT) and technology-transfer revenue (TECH) capture the revenue performance of the two commercialization channels, respectively.

2.2.1 Digital infrastructure and revenue-generating outcomes of university technology transfer

University technology transfer outcomes are the realized results of activities through which research outputs are transferred and applied. This study focuses on economic outcomes measured by market revenue. Specifically, it uses patent commercialization revenue and technology-transfer revenue, with their sum serving as the aggregate indicator. University research outputs do not automatically generate market revenue. Technology transfer begins when technology suppliers communicate information about research outputs to potential users, who then recognize their application value. University research outputs are often dispersed across disciplinary teams, departments, and technology transfer stages. Firms' needs, in contrast, are embedded in particular products, production processes, and market contexts. Without reliable infrastructure, the set of research outputs that market participants can discover is restricted. Well-developed infrastructure expands opportunities for university research outputs to enter technology markets. As a key complementary asset, digital infrastructure reduces the time costs and spatial constraints of interorganizational communication. It thereby enables sustained transaction negotiations among a broader range of participants. Improved infrastructure allows technology transactions to extend beyond geographically proximate areas and existing personal networks, substantially expanding the reach of interorganizational collaboration and technology transfer (Adomako & Nguyen, 2024). Although the activities underlying PATENT and TECH differ in transaction content and implementation, both require information dissemination, contact between suppliers and users, and the advancement of transaction relationships. Digital infrastructure is not specific to any single form of university technology transfer. Instead, it provides shared network connectivity for different commercialization activities. Improvements in digital infrastructure may therefore increase both patent commercialization revenue and technology-transfer revenue, raising aggregate revenue-generating outcomes.

Taken together, these arguments suggest that digital infrastructure provides favorable conditions for the direct contribution of complementary assets to university technology transfer outcomes. Accordingly, this study proposes the first hypothesis:

H1: Improvements in digital infrastructure increase the revenue-generating outcomes of university technology transfer.

2.2.2 Fixed-network access capacity and university patent commercialization revenue

The early stages of patent commercialization depend more heavily on standardized information that can be searched and compared. Potential recipients use this information to assess whether a technology fits their research and development priorities, product portfolios, or intellectual property strategies. Information frictions are particularly pronounced at this stage (Bakos, 1997; Malone et al., 1987). Fixed-network access capacity is a specialized complementary asset that addresses these frictions. It provides suppliers and users with sustained access to patent databases, trading platforms, and technical documentation. This makes searching, comparison, and feedback routine activities, reducing search and matching costs before patent transactions (Bakos, 1997). Professional service personnel also contribute to patent transactions, but their role primarily emerges after substantive negotiations begin. Their marginal contribution to the early bottleneck of discovery and matching is weaker than that of fixed-network access. The net association with patent commercialization revenue should therefore be attributed primarily to fixed-network access capacity. Moreover, compared with one-off offline promotional events, stable access enables universities to update descriptions of research outputs, rights status, and technical documentation continuously. Potential recipients can then search and compare repeatedly before developing a definite intention to purchase. When bandwidth, reliability, or convenience constrains access to information, transaction opportunities may be lost before formal negotiations begin (Bakos, 1997). Overall, fixed-network access capacity brings more potentially tradable patents into screening and matching and extends their market reach to recipients in other

locations. It may therefore have a crucial influence on university patent commercialization revenue. On this basis, the study proposes the second hypothesis:

H2: Greater fixed-network access capacity increases university patent commercialization revenue.

2.2.3 Professional technology transfer service personnel and technology-transfer revenue

Compared with activities generating patent commercialization revenue, those generating technology-transfer revenue depend more heavily on sustained professional communication and implementation support throughout the process, although it may also involve codified knowledge such as patents. These activities often involve process know-how, experimental procedures, parameter adjustments, and post-transfer adaptation that cannot be fully codified. Such tacit knowledge is difficult to transmit over distance through documentation alone. Its explanation, negotiation, and practical implementation require substantial interaction and collaboration (Arora, 1995; Aydogan & Lyon, 2004; Nonaka, 1994). Fixed-network access capacity cannot substitute for the on-site explanation and adaptation of tacit knowledge (Aydogan & Lyon, 2004). University personnel engaged in research application and science and technology services are specialized complementary assets that support these tasks. During screening, they help research teams organize their outputs and communicate firms' needs to technology suppliers. As transactions advance, they coordinate technical explanations, valuation, intellectual property matters, and contractual arrangements. After technology delivery, they facilitate communication between university researchers and firms' technical staff on adaptation, training, and problem-solving. These activities integrate scientific language, market needs, and transaction rules into a shared context for sustained negotiation. Whether technological outputs generate commercial returns depends on their combination with appropriate complementary resources (Teece, 1986). Professional service personnel are the core organizational resource through which universities coordinate and support such collaboration.

University inputs into technology transfer service personnel are therefore a key determinant of technology-transfer revenue. Based on these arguments, the study proposes the third hypothesis:

H3: Greater university inputs into technology transfer service personnel increase university technology-transfer revenue.

3 Research methodology

3.1 Sample selection and data sources

The empirical analysis uses provincial panel data for 30 provincial-level regions in China from 2014 to 2023. The sample excludes Tibet, Hong Kong, Macao, and Taiwan. Data were obtained primarily from the *China Statistical Yearbook*, the *Compilation of Science and Technology Statistics of Higher Education Institutions*, and the Qichacha and Tianyancha databases. Three procedures were applied to improve data quality and consistency. First, gaps for provinces with substantial missing data in particular years were filled primarily through interpolation. Second, observations with apparent anomalies or logical inconsistencies were carefully checked and corrected. Third, variables were winsorized to reduce the influence of extreme observations. These procedures yielded a balanced panel of 300 province-year observations covering 30 provinces over 10 years.

3.2 Variable definitions and measurement

3.2.1 Dependent variables

The dependent variables measure revenue-generating outcomes of university technology transfer. Aggregate revenue-generating outcomes (MARKET) combine real patent commercialization revenue and real technology-transfer revenue. Their sum is increased by one and transformed using the natural logarithm. This measure captures the revenue realized when university research outputs within a province enter technology markets. The two component outcomes, PATENT and TECH,

measure patent commercialization revenue and technology-transfer revenue, respectively. PATENT is used to examine the association between fixed-network access capacity and the retrieval and matching of codified research outputs. TECH is used to examine the association of service personnel inputs with tacit knowledge transfer and technological implementation. All three outcome measures use the natural logarithm of real revenue plus one to accommodate zeros and reduce right-skewness.

For compact notation, R_{it}^{P} and R_{it}^{T} denote real patent commercialization revenue and real technology-transfer revenue, respectively. The subscript i identifies the province, and t identifies the year. The outcome measures are defined as follows:

$$MARKET_{it} = ln(R_{it}^{P} + R_{it}^{T} + 1)$$

$$PATENT_{it} = ln(R_{it}^{P} + 1)$$

$$TECH_{it} = ln(R_{it}^{T} + 1)$$

University technology transfer often involves a substantial lag after the initial research investment (Wang et al., 2020). We therefore also collected input data for 2013 to construct lagged variables. Patent commercialization revenue, technology-transfer revenue, research expenditure, and gross domestic product (GDP) per capita were deflated to constant 2013 prices using the GDP deflator.

3.2.2 Core explanatory variables

Three indicators capture digital infrastructure (DINF). They comprise broadband Internet access ports per resident, fiber-optic cable route length per unit of land area, and mobile communication base stations per resident. Each component is winsorized at the 1st and 99th percentiles and z-standardized. Their equally weighted average forms DINF, which is then standardized again. Higher values indicate a higher overall provision of digital infrastructure. Consistent with H1, DINF is expected to have a positive coefficient after controlling for other factors.

Fixed-network access capacity (PORT) is measured by broadband Internet access ports per resident. It undergoes the same winsorization and standardization as the DINF components. The H2 model also includes fiber-optic cable density (CABLE) and mobile base station density (BASE). This specification identifies the net association of fixed-network access capacity conditional on other network conditions. Higher PORT values indicate greater potential capacity to accommodate fixed-network access within a region. Under H2, PORT is expected to be positively associated with university patent commercialization revenue, controlling for CABLE, BASE, and other factors.

University technology transfer service personnel inputs (TSP) capture human resource inputs within the university system. TSP uses the number of full-time personnel engaged in research application and science and technology services. One is added to this count before the natural logarithm is taken, and the resulting variable is standardized. Higher TSP values indicate greater full-time personnel inputs into these activities within a province's university system. Under H3, TSP is expected to have a positive association with technology-transfer revenue after controlling for digital infrastructure and other factors.

3.2.3 Control variables

We control for the regional environment in five respects. These comprise digital and artificial intelligence (AI) applications, economic development, industrial structure, fiscal support for science and technology, and openness. The regional digital and AI application environment (DAI) is constructed from four indicators. Two capture software business revenue as a share of GDP and the employment share of information transmission, software, and information technology services. The other two are AI invention patent density and the share of AI enterprises. The indicators are aligned in direction, winsorized at the 1st and 99th percentiles, standardized, and combined using equal weights. Higher values indicate greater development of regional digital and AI applications as captured by these indicators.

Two additional controls capture the resource conditions of universities within each province. These are student enrollment density at regular higher education institutions and real research expenditure. Student enrollment density captures the relative concentration of regional higher education resources. Real research expenditure captures the scale of university research funding. The two variables thus reflect resource concentration and the funding base for research activities, respectively.

The allocation of network infrastructure and service personnel variables is adjusted for each hypothesis. The H1 and H2 models include personnel engaged in research application and science and technology services to control for differences in university human resource inputs. The H2 model includes both CABLE and BASE to condition on other network infrastructure. TSP is the focal explanatory variable in the H3 model, which also controls for DINF. All explanatory and control variables enter the regressions with a one-year lag. Table 2 summarizes the definitions and treatment of the principal variables.

Table 2
Definitions and measurement of the principal variables

Variable role	Variable	Symbol	Measurement and treatment
Aggregate outcome	Revenue-generating outcomes	MARKET	$ln(R_{it}^{P} + R_{it}^{T} + 1)$
Component outcome	Patent commercialization revenue	PATENT	$ln(R_{it}^{P} + 1)$
Component outcome	Technology-transfer revenue	TECH	$ln(R_{it}^{T} + 1)$ after interpolation of missing revenue observations.
H1 core variable	Digital infrastructure	DINF	PORT, CABLE, and BASE are winsorized at the 1st and 99th percentiles and z-standardized. Their equal-weight average is standardized again.
H2 core variable	Fixed-network access capacity	PORT	Broadband Internet access ports per resident, winsorized at the 1st and 99th percentiles and z-standardized.
H3 core variable	Technology transfer service personnel inputs	TSP	Add one to the full-time personnel count for research application and science and technology services; take the natural logarithm, then z-standardize.
Application environment control	Digital and AI application environment	DAI	Standardized index of software business revenue/GDP, the employment share of information services, AI invention patent density, and the share of AI enterprises.
Other controls	Regional and university resource conditions	X / Z	Real GDP per capita; tertiary sector share; fiscal science and technology expenditure share; openness; university student enrollment density; real research expenditure.

3.3 Econometric model specification

3.3.1 Model for testing H1

To examine the association between digital infrastructure and aggregate revenue-generating outcomes of university technology transfer, we specify the following two-way fixed effects model:

$$MARKET_{it} = \alpha + \beta_1 DINF_{i,t-1} + \theta\, DAI_{i,t-1} + \gamma\, X_{i,t-1} + \mu_i + \lambda_t + \epsilon_{it}$$

1

In Eq. (1), $MARKET_{it}$ denotes revenue-generating outcomes of university technology transfer in province i in year t. $DINF_{i,t-1}$ is the one-year-lagged digital infrastructure index. $DAI_{i,t-1}$ represents the lagged regional digital and AI application environment, and $X_{i,t-1}$ is a vector of lagged control variables. Province fixed effects, μ_i, absorb time-invariant characteristics such as location, historical endowments, and the existing stock of universities. Year fixed effects, λ_t, absorb common shocks, including macroeconomic cycles, national policies, and common technological trends. The parameter of interest is β_1. A significantly positive β_1 indicates a positive association between digital infrastructure and aggregate revenue-generating outcomes, conditional on observed covariates and both fixed effects.

3.3.2 Model for testing H2

The H2 specification examines the functional alignment between fixed-network access capacity and patent commercialization. It therefore uses PORT in place of the composite DINF index. CABLE and BASE are included alongside PORT to control for backbone transmission infrastructure and mobile connectivity:

$$PATENT_{it} = \alpha + \beta_2 PORT_{i,t-1} + \delta_1 CABLE_{i,t-1} + \delta_2 BASE_{i,t-1} + \theta\, DAI_{i,t-1} + \gamma\, X_{i,t-1} + \mu_i + \lambda_t + \epsilon_{it}$$

2

The coefficient β_2 captures the association between fixed-network access capacity and university patent commercialization revenue, conditional on CABLE, BASE, DAI, and other controls. A significantly positive β_2 indicates a positive association between fixed-network access capacity and patent commercialization revenue.

3.3.3 Model for testing H3

The H3 specification uses technology transfer service personnel inputs as the focal explanatory variable. DINF is retained as a control for the regional network environment. This distinguishes external connectivity from the internal organizational capacity of universities to support technology transfer:

$$TECH_{it} = \alpha + \beta_3 TSP_{i,t-1} + \delta\, DINF_{i,t-1} + \theta\, DAI_{i,t-1} + \gamma\, Z_{i,t-1} + \mu_i + \lambda_t + \epsilon_{it}$$

3

In Eq. (3), $TECH_{it}$ denotes technology-transfer revenue, and $TSP_{i,t-1}$ is the one-year-lagged measure of technology transfer service personnel inputs. $Z_{i,t-1}$ comprises the remaining control variables and excludes TSP. A significantly positive β_3 indicates that the scale of service personnel inputs is positively associated with technology-transfer revenue. This association is conditional on comparable regional connectivity, application environments, and other provincial characteristics.

4 Results

4.1 Descriptive statistics

Table 3 reports descriptive statistics for the principal variables. The three outcome measures—aggregate revenue-generating outcomes of university technology transfer (MARKET), university patent commercialization revenue (PATENT), and technology-transfer revenue (TECH)—have means of 8.4238, 7.0744, and 8.0278, respectively. Their standard deviations are 2.3536, 2.5484, and 2.3380, indicating substantial differences in revenue performance across provincial university systems. The digital infrastructure index (DINF) and its three network components—fixed-network access capacity (PORT), fiber-optic cable density (CABLE), and mobile base station density (BASE)—have means close to zero and standard deviations close to one, as expected after standardization. The maximum values of CABLE and the regional digital and artificial intelligence (AI) application environment index (DAI) are 5.6148 and 5.5547, respectively, indicating that a few provinces are well above the overall distribution. Technology transfer service personnel inputs (TSP) have a median of

0.2149 and a minimum of − 3.7018, suggesting pronounced interprovincial disparities in personnel engaged in research application and science and technology services.

The control variables also exhibit substantial variation across provinces and years. Log real gross domestic product (GDP) per capita has a standard deviation of 0.4366, the tertiary sector share ranges from 0.3864 to 0.8408, and openness reaches a maximum of 1.0828. These differences reflect considerable regional variation in economic development, the service orientation of industrial activity, and external economic linkages.

Table 3
Descriptive statistics for the principal variables

Variable	N	Mean	SD	Median	Minimum	Maximum
MARKET	300	8.4238	2.3536	8.9083	1.4044	11.7230
PATENT	300	7.0744	2.5484	7.4155	0.0000	10.9697
TECH	300	8.0278	2.3380	8.6251	1.4044	11.3225
DINF	300	0.0000	1.0017	-0.0561	-1.5806	3.8432
PORT	300	0.0000	1.0017	0.0275	-1.8628	2.1376
CABLE	300	0.0000	1.0017	-0.2806	-0.6812	5.6148
BASE	300	0.0000	1.0017	-0.0575	-1.6493	2.4032
TSP	300	0.0000	1.0017	0.2149	-3.7018	1.7270
DAI	300	0.0000	1.0017	-0.2690	-0.8850	5.5547
*ln*PGDP	300	10.9357	0.4366	10.8815	10.0890	12.0934
TERT	300	0.5206	0.0835	0.5095	0.3864	0.8408
FISCAL	300	0.0224	0.0153	0.0162	0.0055	0.0625
OPEN	300	0.2518	0.2448	0.1419	0.0124	1.0828
EDU	300	0.0216	0.0055	0.0210	0.0106	0.0390
lnRD	300	9.8909	1.3239	10.1745	5.9940	12.3151

Note. Variable definitions are provided in Table 2. N = number of observations; SD = standard deviation. DINF, PORT, CABLE, BASE, TSP, and DAI are standardized. Explanatory and control variables are lagged by one year. lnPGDP = log real GDP per capita; TERT = tertiary sector share; FISCAL = fiscal support for science and technology; OPEN = openness; EDU = university student enrollment density; lnRD = log real research expenditure.

4.2 Baseline regression results

Table 4 presents the baseline estimates for the three models and the corresponding multiple-testing results. All models include province and year fixed effects, and conventional standard errors are clustered by province. The core explanatory variables are standardized, and the dependent variables are in logarithmic form.

Table 4
Baseline regression estimates and multiple-testing results

Hypothesis	Coefficient (clustered SE)	Clustered *p* value	Wild *p* value	Holm *p* value	R^2
H1	1.004** (0.426)	0.0255	0.0202	0.0404	0.915
H2	0.907** (0.324)	0.0090	0.0234	0.0404	0.885
H3	0.460*** (0.149)	0.0043	0.0058	0.0174	0.909

Note. Significance stars are based on the wild bootstrap *p* values: * $p < .10$, ** $p < .05$, and *** $p < .01$.

In the H1 model, the coefficient on DINF is 1.004, with a province-clustered *p* value of .0255 and a wild bootstrap *p* value of .0202. The coefficient is therefore positive and significant at the 5% level under both inference procedures. This finding indicates a positive association between digital infrastructure and aggregate revenue-generating outcomes of university technology transfer. Better digital infrastructure can extend the potential reach of information dissemination and interorganizational connections, supporting the generation of revenue from university research. H1 is supported.

In the H2 model, the coefficient on PORT is 0.907, with a province-clustered *p* value of .0090 and a wild bootstrap *p* value of .0234. The positive association is significant at the 1% level using province-clustered inference and at the 5% level using the wild bootstrap. The result indicates that greater fixed-network access capacity is associated with higher university patent commercialization revenue. Stable fixed-network access helps potential recipients retrieve, compare, and make preliminary assessments of relatively codified patent information, thereby supporting patent commercialization. H2 is supported.

In the H3 model, the coefficient on TSP is 0.460, with a province-clustered *p* value of .0043 and a wild bootstrap *p* value of .0058, both significant at the 1% level. Greater university inputs into technology transfer service personnel are thus associated with higher technology-transfer revenue. The activities underlying TECH involve not only contract signing but also technical evaluation, communication about technical solutions, and post-transfer adaptation. Service personnel provide the organizational capacity needed to support these knowledge transfer activities. H3 is supported.

4.3 Robustness checks

We conduct five sets of robustness checks to assess whether the baseline results depend on particular variable treatments, sample compositions, or inference procedures. Following the baseline specifications, these checks examine outcome transformations and extreme observations, inference with a limited number of clusters, the construction of core variables and treatment of missing values, sample windows and influential observations, and dynamic specifications with stronger controls for common shocks.

4.3.1 Alternative outcome transformations and treatment of extreme observations

To assess sensitivity to functional form and extreme observations, we replace the logarithmic transformation with the inverse hyperbolic sine transformation and, separately, winsorize each of the three logged dependent variables at the 1st and 99th percentiles. As shown in Table 5, all three core coefficients remain positive under both treatments. The wild bootstrap *p* values indicate significance at the 5% level for H1 and H2 and at the 1% level for H3, consistent with the baseline results.

Table 5
Alternative outcome transformations and treatment of extreme observations

Test	H1 coefficient (Wild *p* value)	H2 coefficient (Wild *p* value)	H3 coefficient (Wild *p* value)	Maximum Holm *p* value
Inverse hyperbolic sine transformation	1.024** (0.0197)	0.996** (0.0227)	0.473*** (0.0046)	0.0394
Dependent variables winsorized at the 1st and 99th percentiles	1.009** (0.0200)	0.912** (0.0230)	0.460*** (0.0058)	0.0400

Note. Wild bootstrap *p* values are reported in parentheses. Maximum Holm *p* value denotes the largest Holm-adjusted *p* value across H1–H3. * $p < .10$, ** $p < .05$, and *** $p < .01$.

4.3.2 Inference with a limited number of clusters

We further assess inference using a wild bootstrap with Webb's six-point weights and the leverage-adjusted CR2 cluster-robust variance estimator. Table 6 shows that all three unadjusted *p* values are below .05 under both procedures. The largest Holm-adjusted *p* values are .0422 and .0267, respectively. The baseline conclusions therefore remain supported under alternative procedures that account for the limited number of clusters.

Table 6
Inference with a limited number of clusters

Inference procedure	H1 *p* value	H2 *p* value	H3 *p* value	Maximum Holm *p* value
CR1 standard errors clustered by province	0.0255	0.0090	0.0043	0.0255
Wild bootstrap with Rademacher weights	0.0202	0.0234	0.0058	0.0404
Wild bootstrap with Webb's six-point weights	0.0211	0.0214	0.0062	0.0422
Leverage-adjusted CR2 with t(29)	0.0267	0.0105	0.0072	0.0267

Note. All *p* values are two-sided. CR1 and CR2 denote the conventional and leverage-adjusted cluster-robust variance estimators, respectively; t(29) denotes a t distribution with 29 degrees of freedom. The Webb and CR2 procedures account for the limited number of clusters.

4.3.3 Construction of core variables and treatment of missing values

This check examines whether the baseline associations are driven by a particular index construction, combination of network controls, or treatment of missing technology-transfer revenue. For H1, the alternative specifications using a principal-component version of DINF and fiber-optic cable length per resident yield wild bootstrap *p* values of .0160 and .0166, respectively. A two-component index excluding the cable component also remains significant. For H2, the wild bootstrap *p* values are .0339 when PORT enters without the other network components, .0260 when PORT enters with CABLE, and .0271 when it enters with BASE. The positive association between fixed-network access capacity and patent commercialization revenue therefore does not depend on a particular combination of network controls.

For the treatment of missing revenue observations, excluding observations with originally blank technology-transfer revenue yields wild bootstrap *p* values of .0257 for H1 and .0600 for H3. Treating those blanks as zeros yields *p* values of .0088 and .0050, respectively. The core coefficients remain positive under both treatments; H3 is significant at the 10% level when observations with missing revenue are excluded.

4.3.4 Sample windows and influential observations

To assess whether the baseline results are driven by a few distinctive regions, particular years, or temporary shocks, we vary the sample window and examine influential observations. Excluding the four centrally administered municipalities yields wild bootstrap *p* values of .0331 for H1, .0846 for H2, and .0021 for H3. Excluding 2023 yields *p* values of .0267, .0556, and .0560, respectively. Thus, H2 is significant at the 10% level when the municipalities are excluded, and H2 and H3 meet the 10% threshold when 2023 is excluded. In the leave-one-province-out analyses, H1, H2, and H3 remain significant at the 5% level. These checks broadly support the baseline findings across alternative sample compositions.

4.3.5 Dynamic specifications and stronger controls for common shocks

To reduce the influence of common contemporaneous changes and examine lagged associations, we extend the baseline two-way fixed effects specifications in three ways. We add region-by-year fixed effects, lag all explanatory variables by two years, and estimate the cumulative effects of a distributed lag specification covering one- and two-year lags.

Table 7
Dynamic specifications and stronger fixed effects controls

Specification	**H1 coefficient (Wild *p* value)**	**H2 coefficient (Wild *p* value)**	**H3 coefficient (Wild *p* value)**
Region-by-year fixed effects	0.870 (0.1107)	0.906** (0.0364)	0.348 (0.1640)
All explanatory variables lagged by two years	0.932** (0.0479)	0.729** (0.0417)	0.490* (0.0502)
Cumulative effects of one- and two-year distributed lags	1.168** (0.0157)	1.096** (0.0204)	0.475* (0.0986)

Note. Wild bootstrap *p* values are reported in parentheses. * $p < .10$, ** $p < .05$, and *** $p < .01$.

Table 7 shows that, with region-by-year fixed effects, H2 has an unadjusted wild bootstrap *p* value of .0364, but the results for the three hypotheses do not all remain significant after joint adjustment. When all explanatory variables are lagged by two years, the unadjusted *p* values are .0479 for H1, .0417 for H2, and .0502 for H3. For the cumulative effects of one- and two-year distributed lags, H1 and H2 remain significant at the 5% level, while H3 is marginally significant at the 10% level. Taken together, the five sets of robustness checks broadly support the reliability of the core findings.

5 Conclusions and discussion

5.1 Main conclusions and contributions

Drawing on complementary assets theory, this study examines how three types of complementary assets—digital infrastructure, fixed-network access capacity, and university technology transfer service personnel inputs—relate to revenue-generating outcomes of university technology transfer. The empirical analysis uses panel data for 30 Chinese provinces from 2014 to 2023. The findings indicate that the commercialization of university research is not an automatic extension of research production, but depends on the combined contribution of external conditions and internal capabilities. Three main conclusions emerge.

First, digital infrastructure is significantly and positively associated with aggregate revenue-generating outcomes of university technology transfer. Better infrastructure, comprising broadband access ports, fiber-optic cable networks, and mobile communication base stations, enables university research outputs to reach beyond geographical boundaries and enter wider networks of information dissemination, supply–demand matching, and interorganizational collaboration. Digital infrastructure extends the reach of information about research outputs and reduces the basic costs of online presentation, remote communication, and sustained collaboration between universities and firms.

Second, greater fixed-network access capacity is positively associated with university patent commercialization revenue. Its contribution to patent commercialization lies in providing reliable access through which standardized information about research outputs can enter market matching processes. Patent texts, technological classifications, legal status, and the scope of patent rights are relatively highly codified. Stable fixed-network access helps universities, firms, and technology intermediaries access patent databases and technology trading platforms to search, screen, and compare information.

Third, greater university inputs into technology transfer service personnel are positively associated with higher technology-transfer revenue. Generating this revenue requires personnel who can continually explain tacit knowledge and provide organizational support throughout the transfer process. Expanding the reach of information dissemination alone cannot replace the technical services provided by professionals. Personnel engaged in research application and science and technology services thus constitute specialized organizational assets in the commercialization of university research. They translate scientific language into solutions that firms can understand, evaluate, and implement.

This study makes three contributions. First, it distinguishes revenue-generating outcomes of university technology transfer from input–output efficiency. By using patent commercialization revenue and technology-transfer revenue to measure revenue outcomes, it avoids interpreting an expansion in market activity directly as an improvement in resource allocation efficiency. Second, it applies complementary assets theory to the commercialization of university research and develops a three-layer framework of physical connectivity, information access, and human-mediated knowledge translation. The framework explains how digital infrastructure, fixed-network access capacity, and technology transfer service personnel inputs support connections to research outputs, information discovery, and technological implementation, respectively. Third, using panel data for 30 provinces from 2014 to 2023, the study differentiates its empirical tests by knowledge characteristics and technology transfer tasks. It thereby provides provincial evidence on the functional alignment between different complementary assets and technology transfer channels.

5.2 Policy and managerial implications

First, align infrastructure upgrades with actual technology transfer needs. Local governments should treat broadband access, fiber-optic cable networks, and mobile communication base stations as public connectivity infrastructure that supports the circulation of innovation resources. They should continue to improve network coverage, transmission reliability, and interregional connectivity, with particular attention to links among university clusters, technology transfer hubs, and regions where transferred technologies are applied. Provincial authorities can work with university technology transfer organizations to assess requirements for publishing information about research outputs, accessing patent databases, communicating remotely about technologies, and transmitting documentation. These assessments should distinguish inadequate network connectivity from restricted access to resources and poor coordination between operational processes. Where connectivity barriers exist, upgrade responsibilities should be assigned to specific service nodes, and access availability, transmission reliability, and actual usage should be recorded before and after the upgrades.

Second, establish procedures for updating information about research outputs and responding to firms' needs. University technology transfer organizations can use existing research output repositories to prioritize technologies that are ready for engagement with potential users. Each project should specify a contact person, the date of the latest information update, and the information that can be disclosed publicly. In addition to patent titles, rights status, and technological classifications, project descriptions should identify application scenarios, available testing and validation conditions, unresolved issues, and proposed forms of collaboration. This information enables firms to decide whether to proceed to

substantive evaluation. Once a firm expresses a need, the organization should identify the staff member responsible for handling the inquiry, the relevant research team, and the feedback procedure. Reasons why a project does not advance should be recorded continuously and used to refine project descriptions or engagement arrangements. Technology platforms should also provide research output evaluation, demand posting, valuation advice, and transaction matching services alongside their websites and data repositories. These services help turn network access into market information that potential technology recipients can use.

Third, build a professional and stable university technology transfer service workforce. Universities should appoint a coordinator for each project entering the transfer process and define the responsibilities of research teams, technology transfer organizations, and external service professionals in accordance with the requirements of the full transfer process. For technologically complex projects with lengthy adaptation periods, service tasks and their completion can be recorded at milestones such as confirmation of technical solutions, experimental validation, and delivery and acceptance. This provides a clear channel for addressing technical issues after a contract has been signed. Staffing decisions should go beyond expanding personnel numbers. Differentiated training, career development, performance evaluation, and incentives linked to revenue sharing should strengthen staff members' understanding of technologies, ability to communicate with industry, and capacity to identify risks. For technologies involving substantial complexity and long transfer cycles, professionals should be able to remain involved in post-transfer adaptation and feedback, rather than treating contract signing as the completion of technology transfer.

Fourth, align the three types of complementary assets with specific tasks and coordinate their governance. Local governments should improve regional connectivity and the public environment for technology transactions. Universities should strengthen the governance of information about research outputs and the organization of professional services, while firms should actively communicate their application needs, provide testing scenarios, and offer technical feedback. Policy evaluation can incorporate network infrastructure, the quality of information about research outputs, professional service capacity, and realized market outcomes into a single governance process. However, it should not reduce all technology transfer activities to one revenue indicator or equate network infrastructure construction with the effectiveness of intelligent technology applications. Clear coordination of responsibilities among governments, universities, firms, and technology transfer organizations can connect physical infrastructure, information access, and human-mediated knowledge translation, creating a complete service environment from the presentation of research outputs to technological implementation.

5.3 Limitations and future research

The study has two limitations that suggest directions for future research.

First, the analysis needs to extend to the university level. Provincial panel data inevitably obscure heterogeneity among individual universities. Within the same province, centrally administered and locally administered universities, as well as comprehensive and sector-specialized universities, differ systematically in their technology transfer capabilities and approaches. Future research could use university-level panel data or multilevel data linking provinces and universities to identify differences in technology maturity, technological fields, types of recipients, and the capabilities of technology transfer organizations. Measures of complementary assets could also be refined from provincial indicators to more direct university-level dimensions, such as the development of technology transfer offices, incentives for researchers, and the degree to which university–industry collaboration is institutionalized.

Second, the two-way fixed effects models with one-year-lagged explanatory variables, together with alternative inference procedures for a limited number of clusters and sample checks, provide empirical support for a positive relationship between complementary assets and revenue-generating outcomes. Nevertheless, reverse causality and the influence of unobserved factors cannot be fully excluded. Future research could exploit exogenous policy shocks, such as broadband infrastructure pilots and the development of technology trading platforms. Analyses of spatial spillovers, event studies, and

more finely specified dynamic models could further identify the long-term effects of network connectivity and university organizational capacity, as well as the conditions under which these effects arise.

Declarations

Author Contribution

C.D. curated the data, performed the statistical analyses, and wrote the initial draft. X.Z. designed the study and provided methodological guidance. C.L. interpreted the results and reviewed and revised the manuscript. All authors reviewed the manuscript.

References

1. Adomako, S., & Nguyen, N. P. (2024). Digitalization, inter-organizational collaboration, and technology transfer. *The Journal of Technology Transfer*, *49*(4), 1176–1202. https://doi.org/10.1007/s10961-023-10031-z
2. Agarwal, R., & Shah, S. K. (2014). Knowledge sources of entrepreneurship: Firm formation by academic, user and employee innovators. *Research Policy*, *43*(7), 1109–1133. https://doi.org/10.1016/j.respol.2014.04.012
3. Arora, A. (1995). Licensing tacit knowledge: Intellectual property rights and the market for know-how. *Economics of Innovation and New Technology*, *4*(1), 41–60. https://doi.org/10.1080/10438599500000013
4. Arora, A., Fosfuri, A., & Gambardella, A. (2001). *Markets for technology: The economics of innovation and corporate strategy*. MIT Press. https://doi.org/10.7551/mitpress/4451.001.0001
5. Aydogan, N., & Lyon, T. P. (2004). Spatial proximity and complementarities in the trading of tacit knowledge. *International Journal of Industrial Organization*, *22*(8–9), 1115–1135. https://doi.org/10.1016/j.ijindorg.2004.09.003
6. Bakos, J. Y. (1997). Reducing buyer search costs: Implications for electronic marketplaces. *Management Science*, *43*(12), 1676–1692. https://doi.org/10.1287/mnsc.43.12.1676
7. Cowan, R., David, P. A., & Foray, D. (2000). The explicit economics of knowledge codification and tacitness. *Industrial and Corporate Change*, *9*(2), 211–253. https://doi.org/10.1093/icc/9.2.211
8. He, J. (2024). Shuzi jingji dui gaoxiao keji chengguo zhuanhua xiaolü de yingxiang [The impact of the digital economy on the efficiency of university technology transfer]. *Hebei Daxue Xuebao (Zhexue Shehui Kexue Ban)*, *49*(1), 134–146.
9. Hsu, D. H., Hsu, P. H., Zhou, T., & Ziedonis, A. A. (2021). Benchmarking U.S. university patent value and commercialization efforts: A new approach. *Research Policy*, *50*(1). Article 104076. https://doi.org/10.1016/j.respol.2020.104076
10. Malone, T. W., Yates, J., & Benjamin, R. I. (1987). Electronic markets and electronic hierarchies. *Communications of the ACM*, *30*(6), 484–497. https://doi.org/10.1145/214762.214766
11. Naerjiang·Ahai, Dong, B. W., & Ding, M. L. (2026). Gonggong shuju kaifang nengfou cujin gaoxiao keji chengguo zhuanhua: Jiyu zhengfu shuju pingtai shangxian de zhun ziran shiyan [Does public data openness promote technology transfer in higher education institutions? Based on a quasi-natural experiment of government data platform access]. *Kexuexue Yanjiu*, *44*(6), 1276–1287. https://doi.org/10.16192/j.cnki.1003-2053.20250711.001
12. Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization Science*, *5*(1), 14–37. https://doi.org/10.1287/orsc.5.1.14
13. Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., Fini, R., Geuna, A., Grimaldi, R., Hughes, A., Krabel, S., Kitson, M., Llerena, P., Lissoni, F., Salter, A., & Sobrero, M. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relations. *Research Policy*, *42*(2), 423–442. https://doi.org/10.1016/j.respol.2012.09.007
14. Qin, X., Du, D., Liu, S., & Fan, F. (2017). Zhongguo shengji gaoxiao keyan chengguo zhuanhua xiaolü shikong geju yu yingxiang yinsu: Jiyu wangluo SBM moxing de pingjia [Spatiotemporal patterns and determinants of university

technology transfer efficiency across Chinese provinces: An evaluation based on a network SBM model]. *Dili Yanjiu*, *36*(9), 1641–1652. https://doi.org/10.11821/dlyj201709004

15. Rothaermel, F. T., Agung, S. D., & Jiang, L. (2007). University entrepreneurship: A taxonomy of the literature. *Industrial and Corporate Change*, *16*(4), 691–791. https://doi.org/10.1093/icc/dtm023
16. Siegel, D. S., Waldman, D., & Link, A. (2003). Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: An exploratory study. *Research Policy*, *32*(1), 27–48. https://doi.org/10.1016/S0048-7333(01)00196-2
17. State Council of the People's Republic of China (2016). *Guowuyuan guanyu yinfa shishi Zhonghua Renmin Gongheguo cujin keji chengguo zhuanhua fa ruogan guiding de tongzhi [Notice of the State Council on issuing provisions for implementing the Law of the People's Republic of China on Promoting the Transformation of Scientific and Technological Achievements]*(Guo Fa [2016] No. 16). https://www.gov.cn/zhengce/content/2016-03/02/content_5048192.htm
18. Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, *15*(6), 285–305. https://doi.org/10.1016/0048-7333(86)90027-2
19. Thursby, J. G., & Thursby, M. C. (2002). Who is selling the ivory tower? Sources of growth in university licensing. *Management Science*, *48*(1), 90–104. https://doi.org/10.1287/mnsc.48.1.90.14271
20. Wang, Z., Zhang, C., & Dong, H. (2020). 24 suo bushu gaoxiao keji chengguo zhuanhua xiaolü de DEA fenxi [DEA evaluation of the S&T achievements transformation efficiency: A study of 24 universities under the Ministry of Education]. *Science Research Management, 41*(4), 280–288. https://www.kygl.net.cn/CN/Y2020/V41/I4/280
21. Yuan, C., Li, Y., Vlas, C. O., & Peng, M. W. (2018). Dynamic capabilities, subnational environment, and university technology transfer. *Strategic Organization*, *16*(1), 35–60. https://doi.org/10.1177/1476127016667969