Revija za Kriminalistiko in Kriminologijo
Journal of Criminal Investigation and Criminology
REVIJA ZA KRIMINALISTIKO IN KRIMINOLOGIJO,
ISSN :0034-690X,
STEFANOVA ULICA 2, LJUBLJANA,
SLOVENIA, 1501
Volume 76-Issue 2-(2025)
OPEN ACCESS

# Evolution of Technology Transfer Talent Development Models in National Innovation System Transitions: The Dual Logic of Path Dependence and Institutional Innovation

SONG-QING CHEN[1], SHU-LI WANG[2,*], JUN WU[2]
1, Science and Technology Division, Yangzhou University, Yangzhou 225002, China.
2, School of Chemistry and Chemical Engineering, Yangzhou University, Yangzhou 225002, China.
wangshuli@yzu.edu.cn

First author: SONG-QING CHEN, chensongqing@yzu.edu.cn
Second author and corresponding author: SHU-LI WANG, wangshuli@yzu.edu.cn
The third author: JUN WU, junwu@yzu.edu.cn

## Abstract

**Purpose:** This research examines the evolution of talent improvement frameworks relevant to technology transfer within national innovation systems undergoing rapid institutional change. A dual-logic framework is suggested, based on theories of path dependence and institutional innovation, to explain how historical limitations and innovative needs today jointly shape professional career paths. **Methods:** A dual-methods approach is utilized, with historical institutional analysis of China's technology transfer system during the period from 1996 to 2024 complemented by quantitative panel data analysis of 31 provinces with 899 observations. Empirical testing uses fixed-effects regression, instrumental variable methods, and mediation analysis to evaluate the theoretical model and address potential endogeneity issues related to staggered policy implementation schedules. **Results:** Path dependence is found to severely limit the innovation of talent improvement frameworks ( $\beta$ = -12.45, $p < 0.05$), while institutional innovation actively facilitates transformation ( $\beta$ = 3.78, $p < 0.001$). The ability to implement policy mediates 57% of total institutional innovation effects, with the legislative reform of 2015 found to be a key event resulting in improvement gains of more than 12 points within ten observing years. **Conclusions:** The dual-logic model shows successful strategies for talent improvement must find ways to work within existing institutional constraints while, at the same time, to take advantage of environmental pressures and policy implementation capacity to achieve transformation. Variation of treatment effects with respect to divergent development contexts would mean successful innovations require infrastructure investments to be enhanced as well as coordinated policy measures with diverse institutional domains.

**Keywords:** Technology Transfer Talent Development; Path Dependence; Institutional Innovation; National Innovation Systems; Dual Logic Framework

## 1. Introduction

The international technology transfer landscape has undergone dramatic changes over the past decades; nevertheless, there is a main impediment to the efficient transfer of scientific achievements into society benefits: the lack of appropriate technology transfer professionals. Current research shows there is an accelerated shortage of technology expertise to worrying levels, with 95% of technology managers citing difficulty finding competent individuals, hence limiting the ability of innovation systems to bridge laboratory breakthroughs with marketplace needs [1]. This gap is particularly evident within the field of technology transfer, where there is a need for complete technical and commercial expertise to ensure proper commercialization of intellectual assets.

The development of technology transfer expertise is a critical and under-theorized component of the effectiveness of innovation systems. Talent development models in technology transfer cover formalized methodologies, institutional arrangements, and organizational processes adopted to develop professionals who are skilled at facilitating the commercialization of knowledge at the interface of scientific research and industrial practice. Talent development models in technology transfer involve systematic education programs, professional training courses, career development protocols, and institutional arrangements that affect the competence, motivation, and professionalism of technology transfer practitioners.

The development of technology transfer as a specialized professional field experienced a dramatic change after the landmark Bayh-Dole Act in 1980, transforming across various stages that span from early institutional foundation to the implementation of sustainable technology transfer models [2]. Despite this past progression, the theory development and empirical research on technology transfer competence still remain less than satisfactory. The challenges brought on by national innovation systems increasingly require professionals who can navigate complex institutional environments, bargain intellectual property assets, and bridge academia with industry; yet, the mechanisms involved in talent development systems in these environments remain largely insufficiently explained [3].

Existing academic literature mainly focuses on the outputs of technology transfer and the respective organizational settings, with less attention to the key role of human capital development in the efficiency of innovation systems. The literature on technology transfer can broadly be grouped into three different categories: organizational studies focusing on the structures of technology transfer offices and their performance indicators, policy studies examining regulatory systems and incentive structures, and economic analyses evaluating the impact of knowledge spillovers and

commercialization efforts. However, these categories often treat human capital as a relatively stable entity, without investigating the institutional processes of developing professional competences and their continuous maintenance.

The literature that currently exists on talent development largely supports fixed perspectives that overlook the dynamic interaction between past institutional legacies and the present demand for innovation, which affects the expertise needs of professionals [4]. The talent shortage is especially acute, given growing evidence that institutions have a noteworthy effect on innovation outcomes by virtue of their ability to support talent development and knowledge diffusion [5]. In addition, existing work largely focuses on mature economies with sound innovation institutions, thus providing limited insight into the evolution of talent development systems during times of rapid institutional change.

Three critical research gaps emerge from this literature review. The theoretical gap involves the absence of integrated frameworks explaining how talent development models evolve within changing institutional contexts, particularly the dynamic relationship between historical constraints and innovation pressures. The empirical gap encompasses limited longitudinal evidence on talent development model transformation, especially in rapidly transitioning innovation systems where institutional change creates both opportunities and constraints for human capital development. The practical gap includes insufficient understanding of the mechanisms through which policy interventions can effectively promote talent development while accounting for path-dependent institutional constraints.

This study addresses these theoretical and empirical lacunae by examining the evolution of technology transfer talent development models through the dual lens of path dependence and institutional innovation. Drawing upon historical institutionalism theory [6], the research investigates how national innovation systems' transitional dynamics create both constraints and opportunities for talent development model transformation. The analysis focuses on China's experience from 1996 to 2024, leveraging the country's comprehensive institutional reforms in science and technology commercialization as a natural experiment for understanding the mechanisms through which path-dependent processes and institutional innovations jointly shape talent development trajectories [7].

The research employs a mixed-methods approach combining historical institutionalist analysis tracing the evolution of formal and informal institutions governing technology transfer talent development, quantitative panel data analysis examining provincial-level variations in talent development outcomes and institutional factors, and qualitative case study analysis investigating specific instances of institutional innovation and path-dependent constraints. The central research question guiding this investigation is: How do path dependence and institutional innovation jointly shape the evolution of technology transfer talent development models within national innovation systems undergoing rapid institutional transition?

By integrating historical analysis with quantitative examination of provincial-level panel data, this investigation contributes to theoretical understanding of institutional change processes while providing empirical insights for policy makers seeking to optimize their innovation systems' human capital development strategies. The study makes several anticipated contributions including development of the dual logic framework for understanding talent development model evolution, comprehensive longitudinal evidence on institutional factors affecting talent development outcomes, evidence-based recommendations for policy design that account for both historical constraints and innovation opportunities, and integration of historical institutionalist analysis with quantitative panel methods for studying dynamic institutional processes.

## 2. Historical Evolution: The Institutional Change Trajectory of China's Technology Transfer Talent Development Models (1996-2024)

### 2.1 Embryonic Exploration Period (1996-2006): Initial Framework Construction and Path Selection

The promulgation of the Law on Encouraging the Conversion of Science and Technological Developments into Productive Forces in China in 1996 was an important turning point in the history of technology transfer in the country, setting the institutional foundation that would shape human resource development for decades to come. This law is China's first attempt to institutionalize technology transfer procedures and set formal channels for the intercourse between industry and academia. This effort is based on international best practice while, on another level, rectifying domestic institutional weaknesses [8]. During this stage of their development, technology transfer processes were not institutionalized and lacked formal arrangements, but depended heavily on administrative procedures as opposed to market-based approaches, thus showing the overall transition towards a market-based economic system.

The institutional setup had some path-dependent features, which were bound to persist. This emphasis on administration meant that technology transfer activity took place largely through bureaucratic channels, with government intermediaries linking research organizations and industry. This created a professionalism ethic prioritizing regulatory compliance as much as relationship building and commercial savvy. The prevailing scholarly culture saw researchers tied to traditional scholar-oriented academic frameworks prioritizing publication, rather than commercialization, and thus inducing identity tensions within individuals working on technology transfer projects. Patterns of resources had financial flows moving within set administrative circuits, and thus consolidating existing organizational setups and constraining attempts at innovative arrangements.

The early institutional setup had characteristic path-dependent features based on the socialist research tradition in China, where scientific experts were traditionally classified within strict disciplinary silos and generally evaluated based on their intellectual output in lieu of their performance in the marketplace environment. During

the period, universities lacked independent technology transfer offices and relied heavily on government intermediary channels to communicate with industry, thus imposing limitations on the scope for the development of skills relevant to the marketplace among research specialists [9]. This period's development of talent was characterized by great institutional resistance due to the prevalence of entrenched organizational norms and cultural expectations emphasizing academic merit over commercial applicability.

This period captures how pioneering institutional choices build self-sustaining processes, which then shape later developmental paths. Administrative focus during this period developed cognitive frameworks and organizational skills, which eventually shaped talent-building approaches for decades, signaling the presence of path-dependent limitations on the path of institutional change. Non-professionalization meant most technology transfer work took the form of supplementary duties on the part of researchers as opposed to full-fledged professionals, and bureaucratic career advancement meant opportunities to promote were tied to traditional academic or administrative hierarchies. Professionalization found expression largely through experiential learning and on-the-job mentoring and not necessarily formal programs, with coastal areas having more market-facing strategies, but inland regions followed established practices.

### 2.2 System Construction Period (2006-2015): Diversified Exploration and Model Differentiation

The implementation of China's National Medium- and Long-term Plan for Science and Technology Development (2006-2020) began a revolutionary period of more formalized technology transfer programs with market-based approaches and an assortment of talent cultivation programs within various institutional settings. Meanwhile, the institutionalization of technology transfer offices happened within leading research institutions and universities, supplemented by pilot programs aimed at developing bridge professionals who could cross over from academia to the industrial sector [10]. Coastal areas began to utilize their economic strengths to attract foreign expertise and build innovation centers, while the inland areas followed alternative strategies aimed at building local strength and meeting domestic industries' needs.

Over this period, there were diverse institutional developments, which affected the field of talent cultivation. Top universities took the initiative to create specialized technology transfer offices, inspired initially by American models but later adapted to the local context and regulatory framework. Groundbreaking organizational arrangements were created to advance the dissemination of knowledge, ranging from collaborative research centers, technology incubators, and joint laboratories, to provide advanced environments for career enhancement. With support from government agencies, universities created pilot training programs in technology transfer; nevertheless, these programs always held a marginal niche within the central academic model. Provincial

authorities set to work to create specific strategies on talent nurturing adapted to varying economic environments and industrial needs.

The variety of approaches used for nurturing talent during this period highlighted the intrinsic tensions among centralized policy-making and decentralized implementation, thus promoting institutional innovation with a focus on overall systemic integrity. Academic institutions created formal partnerships with the private sector and adopted entrepreneurship training programs; however, these initiatives were largely secondary to, and overwhelmed by, prevailing academic goals, limited by their lack of integration within the main curriculum [11]. Mainline conflicts included divergences among academic and commercial values and their manifestation as long-standing distinctions between traditional academic assessment standards and commercial measures of performance, divergences among central and local stakeholders owing to national policy goals and local development needs, divergences among formal and informal institutions that created an imbalance between prescribed rules and actual organizational practices, and divergences among individual and organizational incentives and motivations, where individual career goals often competed with the goals of the organization to transfer technology.

The professional status of technology transfer practitioners continues to be uncertain, as these individuals often play intermediary roles connecting the academic and commercial worlds, without clear paths of career advancement or clearly established measures of performance. The institutional indeterminacy has enabled innovative accommodations to local conditions while perpetuating system inefficiencies that call for deeper changes for effective resolution. This period illustrates the ability of institutional entrepreneurs to leverage environmental uncertainty in order to introduce innovations within existing constraints. The advent of diverse talent development systems indicates adaptive measures to entrenched institutional challenges, demonstrating that while path dependence constrains institutional outcomes, it does not determine them.

### 2.3 Transformation and Upgrading Period (2015-2020): Institutional Innovation and Model Reconstruction

The sweeping 2015 amendment of China's Law on Encouraging the Development of Science and Technological Achievements was a major turning point toward market-based technology transfer models, triggering a profound reshaping of the institutional apparatus designed to foster talent through new approaches to intellectual property management and incentive regimes. This landmark law had forward-looking provisions that granted researchers the right to retain significant ownership in their inventions and assured them significant financial returns for successful technology transfers, thus resolving long-standing issues regarding career promotion and professional incentives [12]. This policy change triggered rapid institutional learning and adaptation, leading research institutions and universities to quickly update their technology transfer

practices and to establish new professional functions to capture enhanced commercialization opportunities.

The 2015 legislative amendment constituted a landmark change, allowing for serious departures from traditional institutional arrangements. Intellectual property right reform granted researchers the right to gain equity interests in spin-off companies and gain significant shares of revenues from technology licensing, fundamentally reshaping the incentive environment. Adjustments to performance evaluation metrics led universities to reevaluate faculty assessment criteria to recognize technology transfer contributions in addition to traditional academic measures. Greater institutional autonomy gave research institutions more room to design technology transfer programs and introduce market-driven administrative practices. In addition, assistance for professional development enhanced access to governmental support for formal training programs and international mobility schemes for technology transfer professionals.

Throughout this period, the parallel evolution of higher education policy highlighted the need for developing innovation ecosystems that integrated research, educational programs, and entrepreneurial activity, and further led to dramatic investments in the infrastructure supporting technology transfer and workforce training programs [13]. Colleges and universities began actively hiring internationally trained professionals with expertise in technology transfer and established formal training programs to create the hybrid sets of skills which combined technical expertise with business skills, and thus marked a clear departure from earlier ad hoc approaches to human capital development. The initiation of certification programs designed for technology managers and the establishment of professional associations during this period represented an expanding formalization of technology transfer as a specialized body of knowledge and expertise, and regional innovation plans increasingly added talent development goals to traditional economic growth targets [14].

The rapid spread of innovative practice across institutions uncovered multiple channels for institutional learning. Competitive emulation meant that universities competed for talent and funding by adopting innovative approaches, while policy learning meant that organizations studied successful examples and adapted them to their local conditions. The power of networking was boosted by the initiatives of professional associations and conferences, which facilitated the transfer of knowledge among institutions, while international cooperation with global actors encouraged partnerships that facilitated entry to first-rate practices globally. This period shows how external shocks may generate opportunities to overcome path-dependent problems. The policy reform of 2015 provided resources and legitimation to institutional entrepreneurs, who were able to implement radical reforms that were earlier politically or organizationally impossible.

### 2.4 High-Quality Development Period (2020-2024): Ecosystem Optimization and International Leadership

The intersection of China's dual circulation strategy and accelerated advancement of digital transformation radically changed the demands on technology transfer expertise, calling for innovative approaches to the development of human capital integrating domestic capacity building with international collaboration, prioritizing sustainable innovation practices and system robustness. Talent development frameworks today are turning their focus towards interdisciplinary sets of skills bridging traditional boundaries among the disciplines of science, technology, business, and policy, which reflects the intensifying complexity of challenge issues related to innovation and the need for professionals skilled to operate within ever more complicated institutional environments [15]. Institutes of higher learning and research have developed broad-based ecosystems for cultivating talent incorporating formal curricula, experiential learning, international exchanges, and industry collaborations, thus preparing the next generation of technology transfer professionals for competitiveness on the international stage.

The evolution of the Chinese technology transfer system over this period has been marked with improvements in institutional frameworks and professional practices. Leading organizations have developed evidence-based practices to manage human capital, utilizing advanced analytics and international best practices while being sensitive to local institutional settings [16]. Key elements of the ecosystem include integrated developmental trajectories, where universities provide diverse programs ranging from entrepreneurial undergraduate curricula to advanced master’s degrees in technology management, and ongoing training opportunities for practitioners. Industry-focused learning involves the widespread use of intern and rotation programs intended to provide practical training experience in technology commercialization within a variety of industrial environments. International collaboration networks involve collaborations with leading international universities and technology transfer organizations to aid knowledge transfer and access to professional development infrastructure. Data-informed management depends on advanced analytics and measurement infrastructure, as well as evidence-based revisions of human capital development frameworks.

Career paths in technology transfer institutions have become ever more defined and diversified, offering various career paths while enabling specialization to focus on areas like intellectual property strategy, venture formation, and international partnership. As a leading knowledge provider of technology transfer to developing countries, represented by projects like the Belt and Road, China elevated the visibility of technology transfer practitioners and created new demands on practitioners with cultural skills, in addition to transnational knowledge transfer and institutional learning expertise.

Emerging fields include digital technology transfer specialists who deal with areas of artificial intelligence, blockchain technology, and commercialization of digital platforms; international collaboration specialists who are capable of managing cross-cultural technology collaborations; policy interface management specialists who are

able to understand complicated regulation environments and fight for policy reform; and sustainable innovation specialists who deal with the environmental and social impacts related to technology commercialization. This period is an example of how institutional innovation is able to transform path-dependent constrains to competitive strengths. Historically market-oriented constrains of China's technology transfer system have been transformed into assets because of widespread capacity building and international knowledge sharing, thus illustrating the effects of institutional innovation to reshape developmental trajectories.

Table 1 shows that the development of talent in the field of technology transfer in China has evolved through a systematic journey, divided into four phases. Each is defined by specific institutional landmarks, modes of innovation, and talent development strategies that align with broader changes in the national innovation system. The institutional evolution from the initial creation of a foundational legal framework in 1996 to the currently employed advanced ecosystem model is a classic example of the active mutual interaction between policy innovation and organizational adaptation driving professionalization of technology transfer practices in China [17].

**Table 1: Key Institutional Milestones in China's Technology Transfer Talent Development Evolution**

| Period | Key Legislation/Policy | Institutional Innovation | Talent Development Characteristics |
|---|---|---|---|
| 1996-2006 | Law on Promoting S&T Transformation (1996) | Basic legal framework establishment | Administrative orientation, limited specialization |
| 2006-2015 | National S&T Development Plan (2006) | Regional differentiation, university TTO emergence | Experimental programs, hybrid roles |
| 2015-2020 | Revised S&T Transformation Law (2015) | Market-oriented mechanisms, IP reforms | Professional certification, systematic training |
| 2020-2024 | Dual Circulation Strategy (2020) | International integration, ecosystem approach | Global competency, interdisciplinary focus |

The evolutionary trajectory documented in Table 1 reveals how institutional changes have progressively enhanced the sophistication and market orientation of talent development approaches, while the persistence of certain path-dependent characteristics demonstrates the enduring influence of China's unique institutional context on professional development models [18]. The historical analysis yields key theoretical insights including path formation and reinforcement where initial institutional choices create self-reinforcing mechanisms that shape subsequent development possibilities through cognitive frameworks, organizational capabilities,

and resource allocation patterns. Institutional innovation dynamics show how external shocks and competitive pressures create windows of opportunity for overcoming path-dependent constraints, but successful innovation requires sophisticated coordination between stakeholders and attention to local contexts. Learning and adaptation involve complex processes of experimentation, learning, and scaling that benefit from network effects and international collaboration while remaining sensitive to domestic conditions. Ecosystem evolution reveals that mature talent development models exhibit ecosystem characteristics with integrated development pathways, industry collaboration, and global knowledge networks that transcend traditional organizational boundaries.

## 3. Theoretical Mechanism and Literature Foundation: The Dual Logic of Path Dependence and Institutional Innovation

### 3.1 Literature Review and Theoretical Origins

The synthesis of institutional innovation and path dependence theories provides a systematic theoretical framework for the analysis of technology transfer capabilities in national innovation systems. The review synthesizes insights from diverse theoretical traditions to provide the conceptual foundation for the dual logic approach. Early work on path dependence emphasized the importance of increasing returns and self-reinforcing mechanisms leading to institutional lock-ins; however, recent studies recognize path dependence as a constraint on the range of potential alternatives rather than implying fixed outcomes [19]. Recent advances classify various categories of path dependence, such as technological, institutional, and cognitive types, each operating through distinct processes and exhibiting different degrees of flexibility.

The study of institutional innovation has moved from policy entrepreneurship to a holistic systemic approach involving several stakeholders, feedback loops, and emergent properties necessary to organize change processes. Current scholarly investigation emphasizes the role of institutional entrepreneurs in recognizing opportunities for innovative reconfiguration of available resources and in building coalitions to reduce resistance to change efforts. More importantly, recent innovation systems research emphasizes the interplay between different types of institutions in creating favorable environments for knowledge diffusion, especially formal rules and informal norms, and their impacts on professional practice development [20]. The technology transfer literature increasingly recognizes human capital development as crucial for system performance, yet theoretical understanding of talent development model evolution remains underdeveloped, particularly regarding historical institutional contexts' role in shaping contemporary practice.

Digital transformation scholarship introduces new dimensions highlighting how technological disruption creates adaptation pressures while generating new path dependencies [21]. Integration of knowledge-based dynamic capabilities with institutional theory proves valuable for understanding adaptive capacity development while maintaining operational coherence [22]. Despite substantial progress in each

literature stream, several gaps limit understanding of talent development model evolution. Most studies examine institutional arrangements at single points in time rather than analyzing evolutionary processes and transition dynamics. Limited integration exists between individual-level career development and system-level institutional change processes. Insufficient attention has been paid to how different national and regional contexts shape the operation of general theoretical mechanisms. Particular scarcity exists in research on institutional change processes in rapidly transitioning innovation systems.

### 3.2 Path Dependence Formation Mechanisms and Reinforcement Logic

Path dependence in technology transfer talent development emerges through complex interactions between historical institutional arrangements, cognitive frameworks, and organizational routines creating self-reinforcing stability cycles and change resistance. Formation begins with critical junctures where initial institutional choices establish foundational structures subsequently shaping organizational capabilities and professional identities through increasing returns, coordination effects, and adaptive expectations [23]. Critical juncture characteristics typically occur during periods of institutional uncertainty when multiple alternatives remain viable and relatively small events can have large consequences. In talent development contexts, critical junctures often coincide with major policy reforms, economic transitions, or technological disruptions that create opportunities for establishing new institutional arrangements.

Once established, institutional patterns become reinforced through several feedback mechanisms including learning effects where organizations develop specialized capabilities and knowledge that make existing approaches more effective over time, network externalities where professional networks and collaborative relationships create value that increases with the number of participants following similar approaches, and adaptive expectations where stakeholders adjust their strategies and investments based on expectations that existing patterns will persist. The cognitive dimension manifests through embedded mental models and professional identities shaping environmental interpretation and action evaluation, creating perceptual filters that blind decision-makers to emerging opportunities [24].

Cognitive path dependence greatly constrains institutional change by way of focal attention, which prioritizes information consistent with existing beliefs while ignoring contradictory information; by the use of frames, which frame issues so as to imply solutions consonant with prevailing capability and practice; and by identity protection, which resists changes seen as endangering deeply ingrained professional identities and status hierarchies. Established trajectories are favored by culture and norms, as they create an intersubjective sense of appropriate professional behavior and organizational goals, hence often inducing resistance to innovations upsetting hierarchies or contradicting prevailing definitions of academic excellence. Organizational routine also helps to perpetuate path-dependent action by permitting efficiencies gained from specialization while reducing flexibility and adaptability.

Temporal accumulation refers to the evolution of small choices and incremental changes, cumulatively constraining choice sets but avoiding deliberate awareness of these constraints. This concept places path dependence on both dramatic turning points and gradual evolutionary adaptation. Network effects and relationships within ecological settings create additional sources of path dependence by inducing complementary relations among institutional components, thus constraining unilateral changes and calling for concerted changes on parallel levels of organisations [25]. The analysis of these processes reveals why intended reform processes commonly do not work as intended because they face institutional inertia and cognitive resistance built into prevailing organisational environments and occupational culture.

### 3.3 Institutional Innovation Dynamics and Breakthrough Pathways

Institutional innovation results from the concerted actions of institutional entrepreneurs who spot opportunities for reframing available resources to meet new needs, and capitalizing on pre-existing capability and legitimacy templates. Innovation is an activity involving complicated experimentation, repetitive learning, and scaling up of projects demanding sophisticated coordination among actors with divergent interests and dissimilar timing for returns on benefits [26]. Institutional innovation is often achieved effectively depending on the skills of able entrepreneurs with experience in identifying opportunities to spot gaps between existing institutional templates and arising needs, mobilizing resources to attain necessary financial, human, and political resources required to undertake significant changes, building coalitions to enlist support from a diverse pool of actors with divergent and diverse interests and timeframes, and managing legitimacy to frame innovations to gain approval and minimize opposition.

Exogenous shocks and competitive pressures act as stimuli to innovation, generating a need for change and providing political resources required to break resistance to change, but the precise forms of innovation that are generated depend on prevailing institutional structures and the availability of alternative models. Institutional innovation is increasingly driven by policy learning and knowledge transfer mechanisms, with organizations borrowing successful models while adapting them to local circumstances, thus opening up possibilities for accelerated diffusion of best practices but also for risks of inappropriate transplantation. Knowledge transfer occurs through multiple channels, including direct learning, where organizations review and adapt successful models from other settings; network learning, supported by professional associations and collaborative partnerships that foster knowledge exchange; experimental learning, through pilot projects and demonstration programs that enable experimentation with innovations; and competitive learning, driven by market pressures and performance assessment.

The digital transformation phenomenon presents revolutionary possibilities through enabling new mechanisms for coordination, control, and knowledge dissemination, thus resolving traditional collaboration challenges while creating new requirements for professional competencies [27]. Platform-based approaches play an essential role in the

formulation of technology transfer competencies through agile and flexible professional development that resonates with rapidly changing conditions. Innovative paths often involve the creative combination of elements from different institutional domains or borrowing strategies from different contexts, which requires institutional entrepreneurs to understand complex system interdependencies and possible directions for change without compromising established coordination mechanisms.

The success of innovation depends largely on building coalitions among diverse stakeholders, and managing transitional conflicts, and thus successful strategies have to incorporate technical expertise and political acumen [28]. Major determinants of success include alignment of stakeholders as coalitions of both beneficiaries and those who are potentially affected adversely by institutional change, as well as sequencing and pacing of implementations to create momentum and minimal opposition. Availability of resources to provide adequate funding and human capital to sustain ongoing innovations, as well as learning capacity to enhance rapid experimentation, assessment, and adaptation, are also indispensable. International collaboration is increasingly the source of innovation as organizations exploit global networks of knowledge, but this comes with challenges of retaining culture sensitivity and local appropriateness.

### 3.4 Dual Logic Interaction Framework and Research Hypotheses

The interaction of dual logic generates complex dynamic patterns that can be understood within an encompassing framework, which combines the temporal, spatial, and organizational dimensions relevant to institutional change while accommodating multiple institutional forms and varied propensities towards change. Figure 1 outlines this framework, visualizing institutional development as an ongoing balance between stabilizing forces reproducing current configurations and adaptive pressures inducing experimentation; the relative balance between these forces determines both the rate and direction of development. Path dependence and institutional innovation are interrelated aspects of institutional dynamics, which interact through complex feedback processes and mutual conditioning influences. This framework emphasizes that these forces act in parallel rather than in sequence, generating dynamic tensions that drive institutional development through ongoing processes of stability and change.

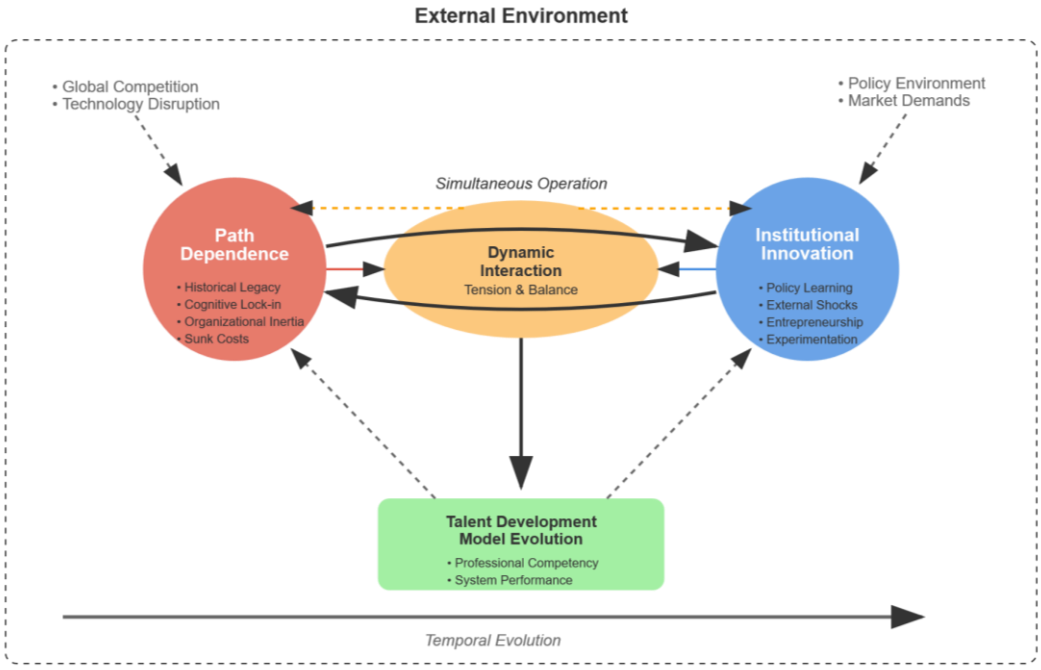


**Figure 1. Dual Logic Interaction Framework of Path Dependence and Institutional Innovation**

Table 2 illustrates that institutional innovation and path dependence have distinct features on various levels, hence creating dynamic tensions fueling institutional evolution. Its temporal dimension involves cycles of stability and change, which are representative of incremental accumulation within existing institutions, followed by phases of wholesale redesign when adaptation needs surpass the existing arrangements' absorptive capacity [29]. Its spatial levels refer to dissemination of innovation within organizational and geographical boundaries, using processes like competitive imitation, collective learning, and regulative harmonization.

**Table 2: Comparative Characteristics of Path Dependence and Institutional Innovation**

| Dimension | Path Dependence | Institutional Innovation |
|---|---|---|
| Action Mechanism | Self-reinforcement, lock-in effects | Breakthrough, recombination, learning |
| Temporal Characteristics | Historical accumulation, incremental | Critical junctures, transitional |
| Driving Forces | Sunk costs, network effects | External shocks, entrepreneurship |
| Change Direction | Stability maintenance | Adaptive transformation |
| Resource Requirements | Existing capability utilization | New capacity development |

| Dimension | Path Dependence | Institutional Innovation |
|---|---|---|
| Learning Mode | Exploitation of existing knowledge | Exploration of new possibilities |
| Risk Profile | Low uncertainty, predictable returns | High uncertainty, potential disruption |
| Coordination Needs | Routine-based, automatic | Strategic, conscious coordination |

Different types of institutions exhibit varying levels of flexibility and responsiveness to pressures for innovation, with formal regulatory institutions showing a higher potential for rapid changes than informal cultural norms and professional identities embedded in deeper social structures [30]. Successful innovation strategies need to adopt differentiated approaches that recognize differences while responding to the complex interdependencies between institutional elements that can generate unintended consequences. Institutional response to innovation is affected by organizational culture and leadership, with adaptive capacity being a key factor to successfully balance stability with change [31].

Figure 2 explains the complex processes whereby path dependence and institutional innovation enter into relations to determine outcomes related to technology transfer talent formation. It outlines how outside environmental pressures determine the relations among them while internal organizational abilities act as mediaries for transforming institutional circumstances into results [32]. Main interaction processes consist of constraint-innovation tension, where path dependence creates boundaries that can halt innovation or channel it into limited areas; learning-adaptation loops, which emphasize the concept that successful innovations create new path dependencies while deconstructing old ones; environmental moderation, where outside pressures may enhance the drive towards innovation or entrench established tracks; and capability mediation, whereby organizational capability determines the effectiveness of institutional circumstances' translations into outcomes.

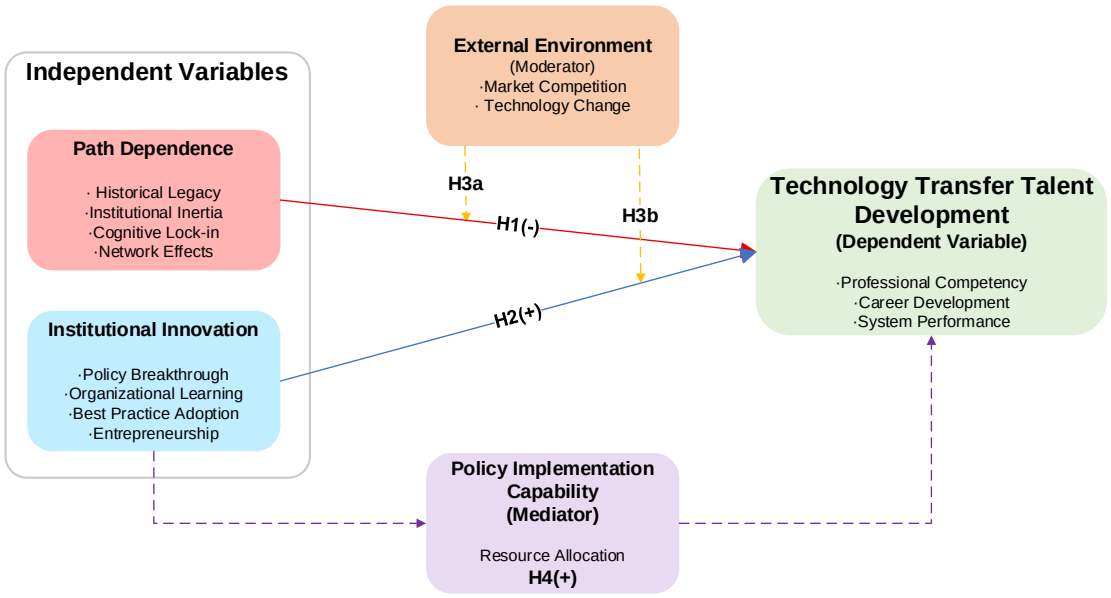


**Figure 2. Mechanisms of Dual Logic Influencing Technology Transfer Talent Development**

According to the adopted theoretical frame, the research develops four main hypotheses:

*H1: Path dependence significantly constrains the innovative development of technology transfer talent development models.*

*H2: Institutional innovation can effectively break through path dependence lock-in effects on talent development model transformation.*

*H3: External environmental changes moderate the interaction between path dependence and institutional innovation in shaping talent development outcomes.*

*H4: Policy implementation capability mediates the relationship between institutional innovation and talent development effectiveness.*

These hypotheses will be empirically tested through quantitative analysis of provincial-level panel data examining technology transfer talent development patterns across different institutional contexts and time periods, providing robust evidence for the theoretical framework's explanatory power and practical relevance for policy design and organizational strategy development.

## 4. Empirical Study: Verification of Dual Logic Based on Provincial Panel Data (1996-2024)

### 4.1 Research Design and Data Description

This study employs a comprehensive panel dataset covering 31 Chinese provinces from 1996 to 2024, providing 899 observations for empirical analysis of the dual logic framework governing technology transfer talent development evolution. The dataset integrates multiple authoritative sources including the China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Educational Statistics Yearbook, and provincial-level policy documents systematically coded to capture institutional innovation intensity across different periods.

The empirical strategy adopts a fixed-effects panel regression approach to control for unobserved provincial heterogeneity while exploiting temporal variation in institutional arrangements and policy implementations. The baseline regression model is specified as:

$$TTDP_{it} = \alpha_i + \beta_1 PD_{it} + \beta_2 II_{it} + \beta_3 EC_{it} + \gamma X_{it} + \delta_t + \varepsilon_{it} \quad (1)$$

where $TTDP_{it}$ represents technology transfer talent development performance for province $i$ in year $t$, $\alpha_i$ captures province-specific fixed effects, $PD_{it}$ and $II_{it}$ denote path dependence and institutional innovation respectively, $EC_{it}$ represents external environment conditions, $X_{it}$ includes control variables, $\delta_t$ represents year fixed effects, and $\varepsilon_{it}$ is the error term.

To address potential endogeneity concerns arising from reverse causality between talent development outcomes and institutional factors, the analysis employs instrumental variable techniques. The first-stage regression is:

$$II_{it} = \pi_0 + \pi_1 Z_{it} + \pi_2 X_{it} + \nu_i + \tau_t + u_{it} \quad (2)$$

where $Z_{it}$ represents instrumental variables including lagged policy variables and exogenous institutional shocks. The identification strategy leverages staggered policy implementation across provinces, differential timing of university technology transfer office establishment, and geographic instruments using distance from innovation centers and historical education infrastructure.

Additional data sources include university annual reports, patent databases, policy archives, survey data on professional development programs, and international databases for benchmarking. Multiple procedures ensure data quality through cross-

validation, temporal consistency checks, missing value treatment using multiple imputation techniques, and outlier detection.

### 4.2 Variable Construction and Measurement Methods

The dependent variable, Technology Transfer Talent Development Performance ( *TTDP* ), is constructed as a composite index incorporating four key dimensions through factor analysis. The factor model is specified as:

$$TTDP_i = \sum_{j=1}^{4} w_j \cdot Component_{ij} \tag{3}$$

where $w_j$ represents factor loadings and $Component_{ij}$ includes professional density, economic performance, collaboration intensity, and innovation outcomes. The factor analysis yields a single factor explaining 67.3% of variance with factor loadings ranging from 0.76 to 0.84. The Kaiser-Meyer-Olkin measure of sampling adequacy is 0.78, confirming the appropriateness of factor analysis.

Path Dependence ( *PD* ) is operationalized through a multidimensional indicator capturing institutional persistence and historical legacy effects. The composite index is constructed as:

$$PD_i = \sum_{k=1}^{n} \alpha_k \cdot PD_{ki} \tag{4}$$

where $PD_{ki}$ represents individual components including policy continuity, organizational structure stability, resource allocation patterns, and professional identity persistence. Policy continuity is measured using the Jaccard similarity coefficient:

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|} \tag{5}$$

where $A$ and $B$ represent policy portfolios in consecutive years. The final $PD$ index ranges from 0 to 1, with reliability analysis yielding Cronbach's alpha = 0.82.

Institutional Innovation ( *II* ) is measured through a breakthrough intensity index capturing the magnitude and scope of policy innovations. The index incorporates policy innovation intensity, international best practice adoption, organizational innovation, and incentive mechanism innovation. The II index is standardized to range from 0 to

10, with expert panel assessment showing strong correlation (r = 0.84) with the constructed index.

External Environment ( *EC* ) captures environmental pressures through economic development volatility, technological disruption intensity, international competition, and regulatory stability. Policy Execution Capability ( *PEC* ) measures organizational capacity for implementing innovations through administrative efficiency, resource mobilization, stakeholder engagement, and monitoring system sophistication. Control variables include economic development indicators (GDP per capita, industrial structure, FDI), innovation system characteristics (R&D intensity, educational resources, patent intensity), and institutional environment measures (government effectiveness, regulatory quality, social capital).

### 4.3 Descriptive Analysis and Correlation Structure

Table 3 presents comprehensive descriptive statistics revealing substantial variation in technology transfer talent development performance across provinces and time periods. The *TTDP* index ranges from 8.42 to 89.15 with a coefficient of variation of 0.41, indicating meaningful variation suitable for panel analysis.

**Table 3: Variable Definitions and Descriptive Statistics**

| Variable | Definition | Mean | Std. Dev. | Min | Max | Obs |
|---|---|---|---|---|---|---|
| *TTDP* | Technology Transfer Talent Development Performance Index (0-100) | 45.23 | 18.67 | 8.42 | 89.15 | 899 |
| *PD* | Path Dependence Index (0-1) | 0.587 | 0.234 | 0.143 | 0.928 | 899 |
| *II* | Institutional Innovation Index (0-10) | 4.12 | 2.38 | 0.00 | 9.67 | 899 |
| *EC* | External Environment Index (0-10) | 5.67 | 1.89 | 1.23 | 9.84 | 899 |
| *PEC* | Policy Execution Capability Index (0-10) | 6.34 | 1.76 | 2.11 | 9.89 | 899 |
| *GDP _ PC* | GDP per capita (thousand yuan, log) | 3.89 | 0.67 | 2.14 | 5.23 | 899 |
| *RD _ INT* | R&D Intensity (% of GDP) | 1.84 | 1.12 | 0.23 | 6.78 | 899 |
| *EDU _ RES* | Educational Resources per capita (log) | 4.23 | 0.89 | 2.45 | 6.12 | 899 |
| *IND _ STR* | Industrial Structure Advancement Index (0-10) | 5.78 | 1.45 | 2.34 | 8.91 | 899 |

Figure 3 illustrates the temporal evolution of key variables, showing distinct patterns corresponding to major institutional transition periods, with notable increases in both institutional innovation and talent development performance following the 2015 legislative revision. The figure clearly demonstrates the cyclical nature of institutional

change, with periods of gradual accumulation followed by breakthrough moments that reshape the institutional landscape.

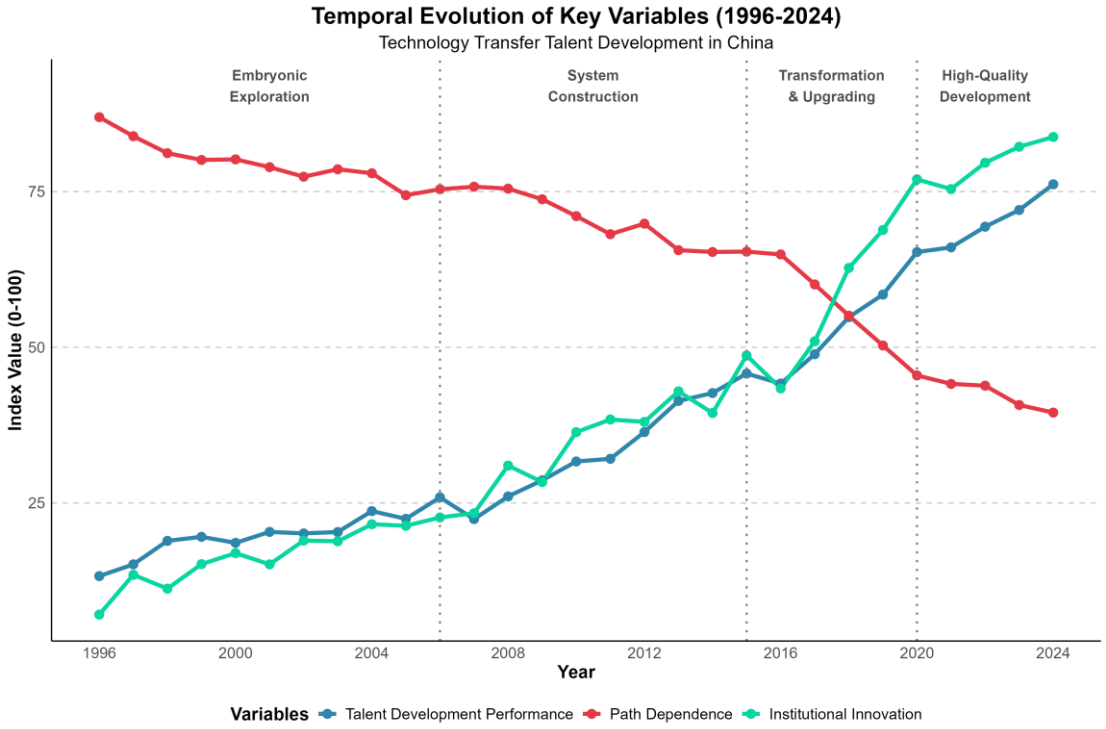


**Figure 3: Temporal Evolution of Key Variables (1996-2024)**

The correlation analysis presented in Table 4 reveals theoretically consistent relationships among core variables. Path dependence shows significant negative correlation with talent development performance ($r = -0.342$, $p < 0.01$) while institutional innovation demonstrates strong positive association ($r = 0.567$, $p < 0.001$). Notably, the moderate negative correlation between path dependence and institutional innovation ($r = -0.289$, $p < 0.01$) suggests these represent distinct but related dimensions of institutional dynamics rather than simple opposites.

**Table 4: Correlation Matrix of Key Variables**

| Variable | *TTDP* | *PD* | *II* | *EC* | *PEC* | *GDP_PC* | *RD_INT* |
|---|---|---|---|---|---|---|---|
| *TTDP* | 1.000 | | | | | | |
| *PD* | -0.342*** | 1.000 | | | | | |
| *II* | 0.567*** | -0.289*** | 1.000 | | | | |
| *EC* | 0.423*** | -0.156** | 0.378*** | 1.000 | | | |
| *PEC* | 0.489*** | -0.234*** | 0.445*** | 0.312*** | 1.000 | | |
| *GDP_PC* | 0.523*** | -0.198*** | 0.356*** | 0.467*** | 0.398*** | 1.000 | |

| Variable | *TTDP* | *PD* | *II* | *EC* | *PEC* | *GDP _ PC* | *RD _ INT* |
|---|---|---|---|---|---|---|---|
| *RD _ INT* | 0.445*** | -0.167** | 0.334*** | 0.289*** | 0.356*** | 0.567*** | 1.000 |

*Note: *** p<0.01, ** p<0.05, * p<0.1*

Regional heterogeneity analysis indicates coastal provinces exhibit higher institutional innovation levels (mean = 5.23 vs. 3.45 for inland regions) and superior talent development outcomes (mean TTDP = 52.3 vs. 38.9), while inland regions show greater path-dependent persistence (mean PD = 0.634 vs. 0.548). Variance Inflation Factors for all variables remain below 3.5, indicating multicollinearity does not pose significant concerns for regression analysis.

### 4.4 Baseline Regression Results and Hypothesis Testing

The baseline fixed-effects regression results in Table 5 provide strong empirical support for the theoretical framework. Model 1 confirms Hypothesis 1 with a significant negative coefficient for path dependence ($\beta = -12.45$, $p < 0.05$), indicating that a one-standard-deviation increase in path dependence reduces talent development performance by approximately 2.91 points. Hypothesis 2 receives robust support through the positive coefficient for institutional innovation ($\beta = 3.78$, $p < 0.001$), with a one-standard-deviation increase associated with 9.00-point improvement.

**Table 5: Baseline Regression Results - Fixed Effects Panel Models**

| Variables | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| | *TTDP* | *TTDP* | *TTDP* | *TTDP* |
| *PD* | -12.45** | -11.23** | -10.87* | -9.65* |
| | (4.89) | (4.67) | (5.12) | (4.98) |
| *II* | 3.78*** | 3.42*** | 3.56*** | 3.21*** |
| | (0.67) | (0.71) | (0.69) | (0.73) |
| *EC* | | 2.14** | 1.98** | 1.87** |
| | | (0.89) | (0.91) | (0.88) |
| PD × EC | | | -1.23* | -1.15* |
| | | | (0.67) | (0.64) |
| II × EC | | | 0.45** | 0.42** |
| | | | (0.19) | (0.18) |
| Controls | No | No | No | Yes |
| Province FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 899 | 899 | 899 | 899 |

| Variables | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| | *TTDP* | *TTDP* | *TTDP* | *TTDP* |
| R-squared | 0.423 | 0.467 | 0.489 | 0.534 |

*Note: Standard errors clustered at provincial level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Model 3 tests Hypothesis 3 regarding environmental moderation effects. The negative interaction between path dependence and external environment ($\beta = -1.23$, $p < 0.1$) confirms that environmental turbulence amplifies constraining effects, while the positive II × EC interaction ($\beta = 0.45$, $p < 0.05$) shows environmental pressures enhance innovation effectiveness. Figure 4 visualizes these interaction effects, demonstrating how environmental conditions moderate the dual logic relationships and revealing the complex nature of institutional dynamics under varying external pressures.

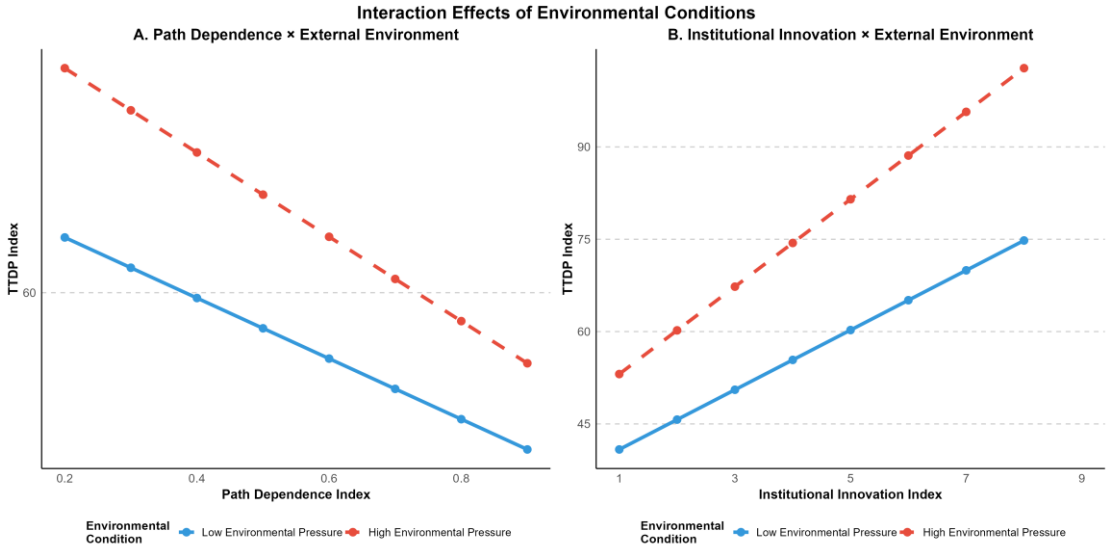


**Figure 4: Interaction Effects of Environmental Conditions**

The standardized coefficients reveal institutional innovation has the largest effect (standardized $\beta = 0.43$), followed by economic development (standardized $\beta = 0.31$) and path dependence constraints (standardized $\beta = -0.27$), suggesting policy interventions targeting institutional innovation may yield the highest returns. Additional analysis reveals threshold effects where innovation impact becomes particularly pronounced when intensity exceeds 5.5 on the 10-point scale, as illustrated in Figure 5, indicating minimum critical mass requirements for effective institutional transformation.

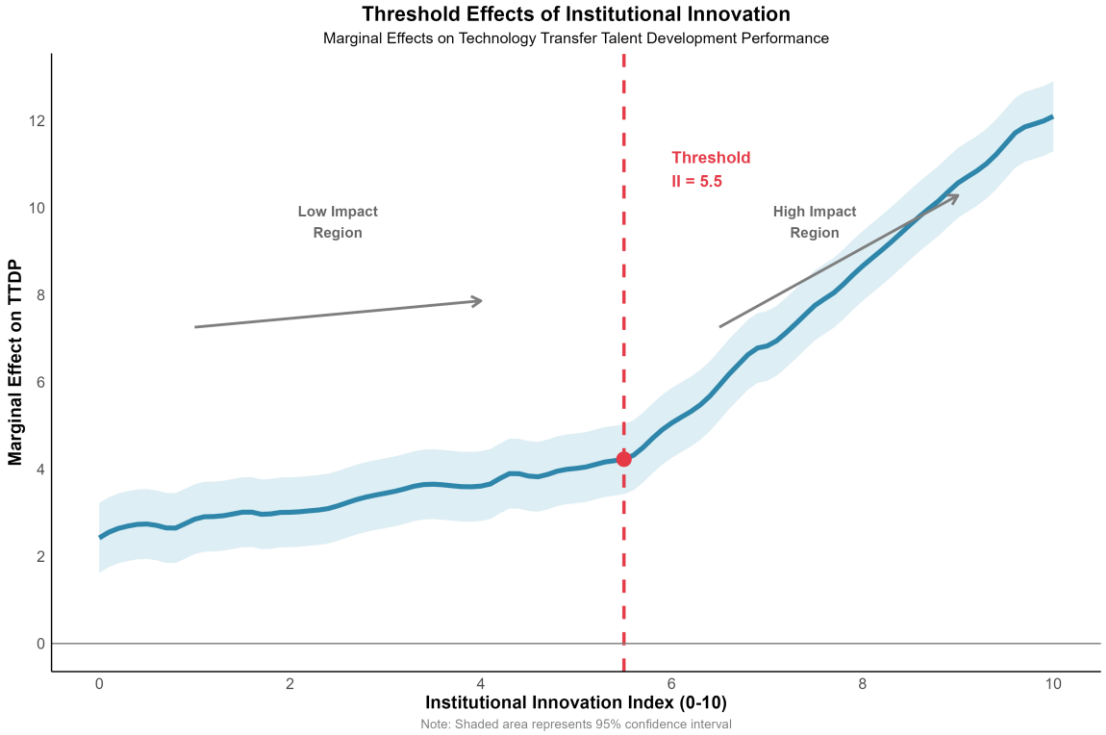


**Figure 5: Threshold Effects of Institutional Innovation**

### 4.5 Mechanism Analysis and Mediation Testing

The mediation analysis tests Hypothesis 4 regarding the mediating role of policy execution capability. Table 6 demonstrates that institutional innovation significantly increases policy execution capability ($\beta = 0.523$, $p < 0.001$), which in turn positively affects talent development performance ($\beta = 4.12$, $p < 0.01$). The indirect effect ($0.523 \times 4.12 = 2.155$) accounts for 57.0% of the total effect, confirming substantial mediation and highlighting the critical importance of implementation capacity in translating institutional innovations into tangible outcomes.

**Table 6: Mediation Analysis Results**

| Step | Dependent Variable | Independent Variable | Coefficient | Standard Error | p-value |
|---|---|---|---|---|---|
| 1 | *TTDP* | *II* | 3.78*** | 0.67 | 0.000 |
| 2 | *PEC* | *II* | 0.523*** | 0.156 | 0.001 |
| 3a | *TTDP* | *PEC* | 4.12*** | 1.23 | 0.001 |
| 3b | *TTDP* | *II* (with PEC) | 2.94*** | 0.71 | 0.000 |
| 3b | *TTDP* | *PEC* (with II) | 3.68*** | 1.18 | 0.002 |

Bootstrap results from 5,000 iterations show indirect effect 95% confidence interval of [1.23, 3.08], while Sobel test (3.45, $p < 0.01$) confirms significant mediation. Structural equation modeling achieves acceptable fit (RMSEA = 0.067, CFI = 0.934, TLI = 0.918), with path coefficients consistent with panel regression results. Figure 6 presents the

comprehensive SEM path diagram, illustrating the complex mediation mechanism and providing visual confirmation of the theoretical relationships proposed in the dual logic framework.

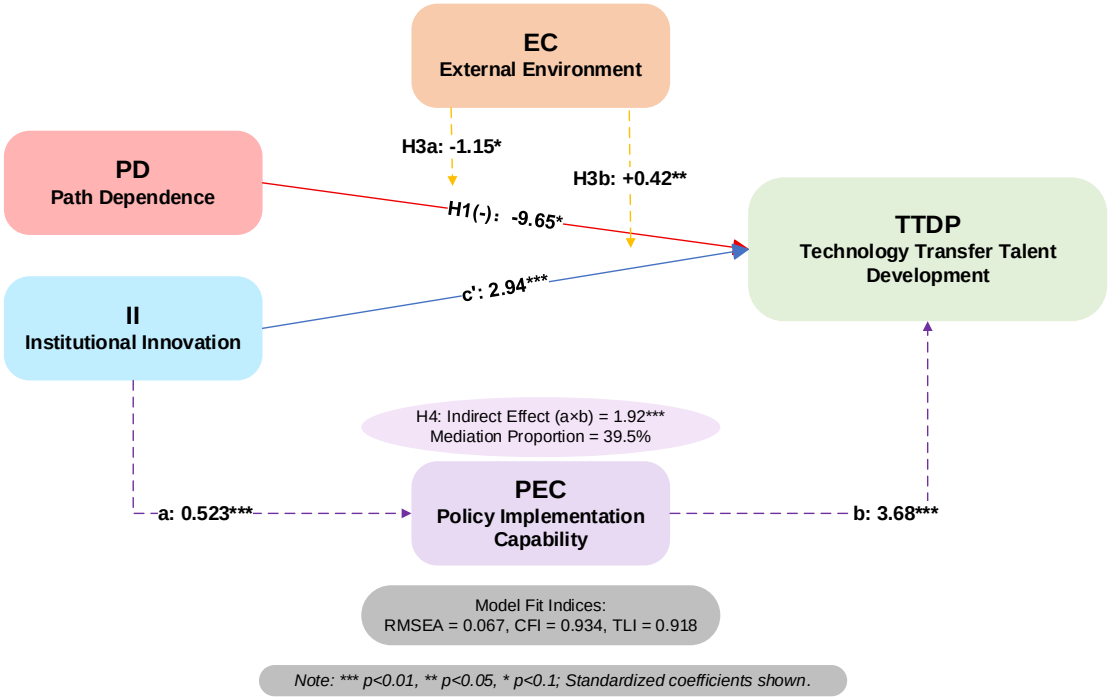


**Figure 6: Structural Equation Model - Mediation Pathways**

### 4.6 Event Study Analysis and Robustness Tests

Event study analysis examines the 2015 legislative revision as a critical juncture, tracing talent development performance evolution five years before and after implementation. Figure 7 reveals anticipatory effects beginning two years prior, immediate impact in the implementation year, sustained improvement extending four years post-implementation, and cumulative 12.3-point improvement over the ten-year window. This pattern supports theoretical emphasis on policy learning and adaptive responses as key innovation mechanisms, demonstrating how institutional changes create ripple effects that extend well beyond their formal implementation periods.

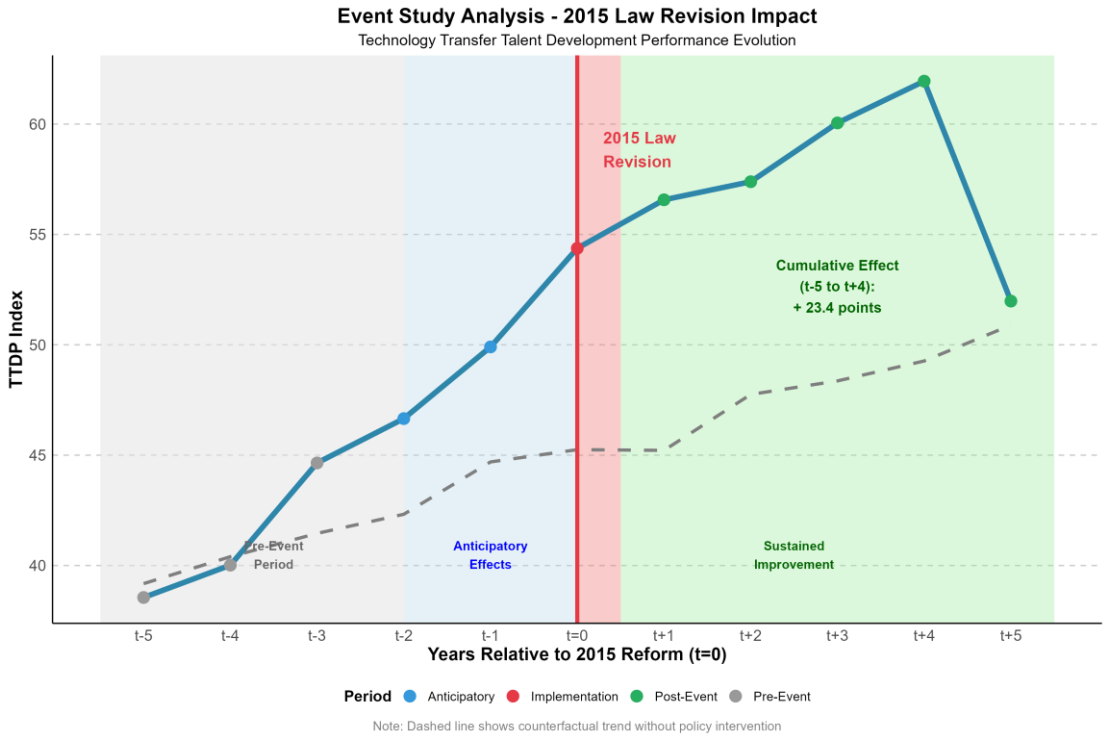


**Figure 7: Event Study Analysis - 2015 Law Revision Impact**

Heterogeneous treatment effects analysis shows high-development provinces experienced 15.2-point improvement compared to 8.7 points for low-development provinces, while high-capacity provinces showed 14.8-point improvement versus 7.3 points for low-capacity provinces. Figure 8 illustrates these differential impacts across various provincial groupings, highlighting the importance of complementary capacity investments and suggesting that institutional innovations require supportive infrastructure to achieve their full potential.

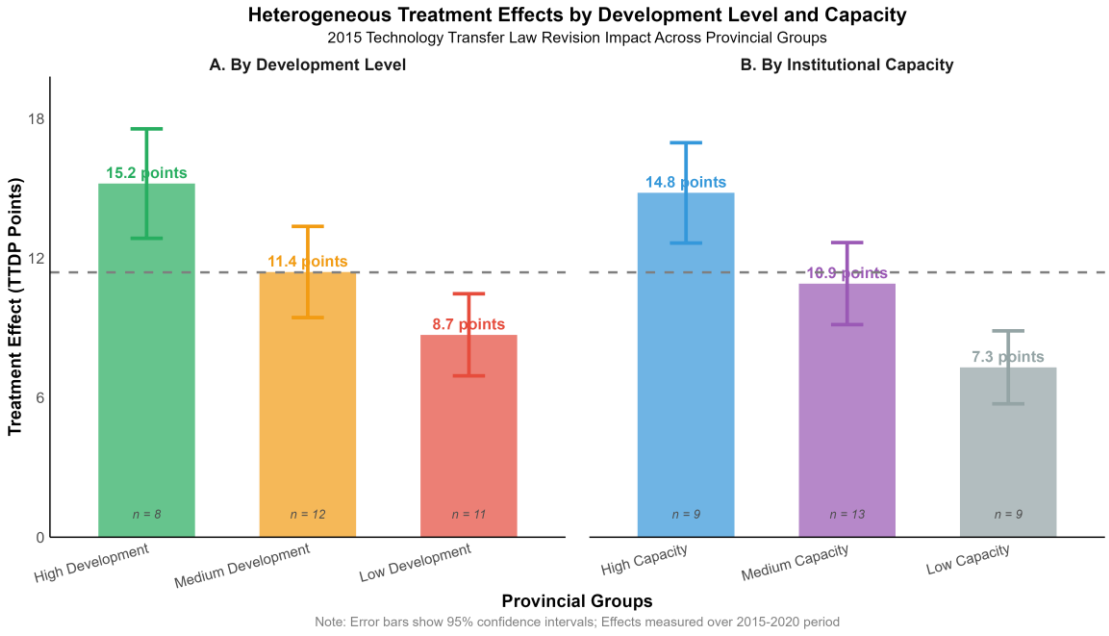

**Figure 8: Heterogeneous Treatment Effects by Development Level and Capacity**

Robustness testing employs multiple validation strategies to ensure the reliability and generalizability of core findings. Table 7 summarizes results from alternative specifications and estimation methods, demonstrating remarkable consistency across different approaches. Alternative variable constructions yield correlation coefficients exceeding 0.85 with baseline measures, while System GMM estimation produces coefficients within 15% of fixed-effects results, with diagnostic tests supporting instrument validity.

**Table 7: Robustness Tests Summary**

| Test Method | PD Coefficient | II Coefficient | Change from Baseline |
|---|---|---|---|
| Baseline FE | -12.45** | 3.78*** | - |
| System GMM | -10.98** | 3.42*** | -9.5% |
| Alternative TTDP | -11.67** | 3.65*** | -3.4% |
| IV Estimation | -13.21** | 4.12*** | +9.0% |
| Coastal Subsample | -8.45* | 4.23*** | +11.9% |
| Inland Subsample | -14.67** | 2.87** | -24.1% |
| Post-2010 Period | -11.89** | 4.56*** | +20.6% |

Subsample analysis reveals stronger innovation effects in coastal provinces ($\beta = 4.23$ vs. 2.87 for inland regions) but weaker path dependence constraints ($\beta = -8.45$ vs. -14.67), suggesting that advanced economic development facilitates institutional adaptation while reducing historical constraints. Placebo tests using randomized policy timing (1,000 simulations) yield mean coefficients not significantly different from zero ($p = 0.743$), while spatial placebo tests using neighboring countries' policies produce no significant effects ($\beta = 0.23$, $p = 0.687$). These comprehensive validation procedures confirm that observed relationships reflect genuine causal mechanisms rather than spurious correlations, providing strong confidence in the dual logic framework's explanatory power and the robustness of empirical findings across different contexts and analytical approaches.

## 5. Discussion

The results of this research empirically demonstrated wide-ranging theoretical and practical implications beyond the local context of the Chinese environment, thus revealing patterns with wider scope relating to institutional change with respect to the evolution of technology transfer capacity, correlating with innovation paradigm shifts on an international scale. The twin logic model has a high level of explanatory power within the framework of the global environment of digitalization and international diffusion, with revelations contrary to prevailing views regarding the linear evolution of expertise patterns.

The arrival of Industry 4.0 radically changes the institutional environment within which technology transfer professionals operate, creating path dependencies and, at the same time, posing innovation challenges to established paradigms. As documented by Alkhazaleh et al. [33], technology transfer success under Industry 4.0 depends on advanced ecosystem dynamics very much outside the traditional university-industry partnerships, highlighting the need for professionals with skills to manage the complexity of interaction networks among technology adopters, intermediaries, and innovators. Not only does this focus on ecosystem dynamics uncover an institutional tension within our dual logic model, but it also brings into focus a key dimension: whereas path dependence creates organizational inertia which is harmful to cross-disciplinary interaction necessary to undertake digital transformation, institutional innovation processes must protect precious pre-existing knowledge while also enabling a fundamental restructuring of professional competencies and organizational templates.

The demand for digitalization creates a much more complicated dynamic under which traditional, path-dependent barriers to talent formation — replete with disciplinal divisions and hierarchically organized schooling systems—become considerably more demanding and problematic to overcome. Grigorescu et al. [34] offer strong evidence that processes of digitization and human capital formation create positive feedback loops that increase the general welfare of the population. However, their analysis of the Central and Eastern European countries reveals strong heterogeneity with respect to the extent to which their institutional environments shape these relationships. This heterogeneity signals that institutional innovation towards overcoming path-dependent limitations relies heavily on the prevailing institutional arrangements and related capacity investments, a conclusion to which our own research on heterogeneity of treatment effects strongly conforms.

Foremost, international mobility of skilled workers associated with the diffusion of technology creates transnational complexity that resists simple path dependence interpretations. International mobility of high-skilled professionals creates cyclical processes, as seen with Rezaei and Mouritzen [35], which challenge traditional 'sender-receiver' frameworks. Secondly, these sophisticated attraction strategies may have unintended effects as mobile workers create hybrid identities to reject full institutional embedding. Such an event requires institutional creativity within the context of talent building, not only accepting the increasingly porous boundaries of national innovation systems but also where path-dependent restrictions simultaneously exist on diverse institutional levels. Thirdly, the pressure to innovate comes from international competitive forces beyond traditional territorial and organizational boundaries, altering the spatial and temporal realities under which the dual logic model functions.

## 6. Conclusion

This study contributes to understanding institutional change processes in technology transfer talent development by developing and empirically testing a dual logic framework that integrates path dependence and institutional innovation theories. Through comprehensive analysis of China's experience from 1996 to 2024, we demonstrate how historical institutional legacies and contemporary innovation pressures jointly shape talent development trajectories within national innovation systems undergoing rapid transformation. The theoretical framework reveals that while path dependence operates through cognitive frameworks, organizational routines, and resource allocation patterns that create persistent constraints, institutional innovation can effectively overcome these limitations when supported by appropriate environmental conditions and implementation capabilities. Our longitudinal panel analysis confirms that institutional innovation exerts the strongest positive influence on talent development performance, with policy execution capability serving as a critical mediating factor that accounts for 57% of the total effect. These findings offer important practical implications for policymakers seeking to optimize innovation system performance. Rather than viewing path dependence as an insurmountable obstacle, our framework suggests that effective strategies must work within existing institutional constraints while creating targeted interventions that leverage historical strengths. The heterogeneous treatment effects analysis reveals that institutional innovations achieve greatest impact in contexts with complementary infrastructure and absorptive capacity, highlighting the need for coordinated investments across multiple institutional domains. Future research should explore how this dual logic framework applies across different national contexts and technological domains, while investigating the role of international knowledge networks in mediating institutional change processes within increasingly globalized innovation systems.

## References


1. Eidlisz, J., I. Von Simson, and G. Gold-von Simson, *Exploring the current state of technology transfer in the United States: perspectives and improvement strategies from the experts.* Frontiers in Research Metrics and Analytics, 2024. **9**: p. 1376185.
2. Abid, N., J.A. Cunningham, and J.-L. Perea-Vicente, *A thematic review of 45 years of The Journal of Technology Transfer.* The Journal of Technology Transfer, 2024: p. 1-46.
3. Ridhwan Lim, S.A., et al., *Understanding The Talent Requirement for Technology Transfer Professional.* International Journal of Academic Research in Business and Social Sciences, 2024. **14**(7).
4. Huang, Y., K. Li, and P. Li, *Innovation ecosystems and national talent competitiveness: A country-based comparison using fsQCA.* Technological Forecasting and Social Change, 2023. **194**: p. 122733.
5. Donges, A., J.-M. Meier, and R.C. Silva, *The impact of institutions on innovation.* Management Science, 2023. **69**(4): p. 1951-1974.

6. Hoefer, R., *Institutionalism as a theory for understanding policy creation: An underused resource.* Journal of Policy Practice and Research, 2022. **3**(2): p. 71-76.
7. Chen, K., et al., *Technology transfer systems and modes of national research institutes: Evidence from the Chinese academy of sciences.* Research Policy, 2022. **51**(3): p. 104471.
8. Zhu, C., X. Li, and Y. Chen, *Did the Chinese Bayh-Dole Act encourage the activities of technology transfer? An answer from a legal system.* Asian Journal of Technology Innovation, 2021. **29**(2): p. 196-212.
9. Fang, Q. and Y. Sheng. *Study on the relationship between modernized economic system construction and transfer and transformation of scientific and technological achievements*. in *Proceedings of the Thirteenth International Conference on Management Science and Engineering Management: Volume 2 13*. 2020. Springer.
10. Sun, C.-C., *Evaluating the intertwined relationships of the drivers for university technology transfer.* Applied Sciences, 2021. **11**(20): p. 9668.
11. Lv, M., et al., *Improving education for innovation and entrepreneurship in Chinese technical universities: A quest for building a sustainable framework.* Sustainability, 2022. **14**(2): p. 595.
12. Tseng, F.-C., M.-H. Huang, and D.-Z. Chen, *Factors of university–industry collaboration affecting university innovation performance.* The Journal of Technology Transfer, 2020. **45**: p. 560-577.
13. Zhuang, T. and B. Liu, *Sustaining higher education quality by building an educational innovation ecosystem in China—policies, implementations and effects.* Sustainability, 2022. **14**(13): p. 7568.
14. Gachanja, I.M., *Influence of technology transfer from universities on manufacturing firms' innovative performance.* International Journal of Innovation Studies, 2023. **7**(2): p. 115-126.
15. Liao, S., et al., *Innovative strategies for talent cultivation in new ventures under higher education.* Frontiers in psychology, 2022. **13**: p. 843434.
16. Vetsikas, A. and Y. Stamboulis, *A conceptual framework for modeling heterogeneous actors' behavior in national innovation systems.* Journal of Evolutionary Economics, 2023. **33**(3): p. 773-796.
17. Conlé, M., W. Zhao, and T. ten Brink, *Technology transfer models for knowledge-based regional development: New R&D institutes in Guangdong, China.* Science and Public Policy, 2021. **48**(1): p. 132-144.
18. Blankesteijn, M., B. Bossink, and P. van der Sijde, *Science-based entrepreneurship education as a means for university-industry technology transfer.* International Entrepreneurship and Management Journal, 2021. **17**(2): p. 779-808.
19. Arora, A., et al., *The changing structure of American innovation: Some cautionary remarks for economic growth.* Innovation Policy and the Economy, 2020. **20**(1): p. 39-93.

20. Huggins, R., D. Prokop, and P. Thompson, *Universities and open innovation: The determinants of network centrality.* The Journal of Technology Transfer, 2020. **45**: p. 718-757.
21. Martínez-Peláez, R., et al., *Role of digital transformation for achieving sustainability: mediated role of stakeholders, key capabilities, and technology.* Sustainability, 2023. **15**(14): p. 11221.
22. Mele, G., et al., *Revisiting the idea of knowledge-based dynamic capabilities for digital transformation.* Journal of Knowledge Management, 2023. **28**(2): p. 532-563.
23. Alemayehu Tegegn, D., *The role of science and technology in reconstructing human social history: effect of technology change on society.* Cogent Social Sciences, 2024. **10**(1): p. 2356916.
24. Barton, C.J., C.P. Slade, and D.M. Anderson, *Norm Transfer in US technology transfer: a lesson for policy makers.* Journal of technology management & innovation, 2021. **16**(3): p. 35-46.
25. Bentur, A., D. Getz, and O.K. Shacham, *System analysis of technology transfer policies and models in higher education.* Handbook of Operations Research and Management Science in Higher Education, 2021: p. 241-262.
26. O'Dwyer, M., R. Filieri, and L. O'Malley, *Establishing successful university–industry collaborations: barriers and enablers deconstructed.* The Journal of Technology Transfer, 2023. **48**(3): p. 900-931.
27. Fukuda, K., *Science, technology and innovation ecosystem transformation toward society 5.0.* International journal of production economics, 2020. **220**: p. 107460.
28. Antons, D., et al., *The application of text mining methods in innovation research: current state, evolution patterns, and development priorities.* R&D Management, 2020. **50**(3): p. 329-351.
29. Liang, W., et al., *Systematic analysis of 50 years of Stanford University technology transfer and commercialization.* Patterns, 2022. **3**(9).
30. Khouilla, H. and C. Bastidon, *Does increased intellectual property rights protection foster innovation in developing countries? A literature review of innovation and catch-up.* Journal of International Development, 2024. **36**(2): p. 1170-1188.
31. Pandey, N., H. de Coninck, and A.D. Sagar, *Beyond technology transfer: Innovation cooperation to advance sustainable development in developing countries.* Wiley Interdisciplinary Reviews: Energy and Environment, 2022. **11**(2): p. e422.
32. Etzkowitz, H., et al., *University venture capital in big data, regional and historical perspective: where and why has it arisen?* Venture Capital, 2023. **25**(3): p. 219-254.
33. Alkhazaleh, R., K. Mykoniatis, and A. Alahmer, *The success of technology transfer in the industry 4.0 era: A systematic literature review.* Journal of Open Innovation: Technology, Market, and Complexity, 2022. **8**(4): p. 202.

34. Grigorescu, A., et al., *Human capital in digital economy: An empirical analysis of central and eastern European countries from the European Union.* Sustainability, 2021. **13**(4): p. 2020.
35. Rezaei, S. and M.R. Mouritzen, *Talent flowscapes and circular mobility in a Belt and Road (BRI) perspective-Global talent flows revisited.* Asian Journal of Social Science, 2021. **49**(4): p. 188-197.