Can interactive platform of university science parks enhance the quality of university research outcomes? evidence from a difference-in-differences model

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This study aims to examine the effect of national-level university science parks on university research productivity and quality in China. The actions and intentions of different individuals have driven each participating department to achieve varying degrees of development. Using the Triple Helix Theory to analyze university-industry government interactions, a Difference-in-Differences model was used to evaluate the causal relationship between science park participation and university research outcomes. The analysis provided new evidence on the impact of economic policies on the research capabilities of universities. Analysis indicated that: (a) National-level university science parks significantly promoted the growth of research projects and academic publications in universities. (b) Geographically, their influence in eastern China was more pronounced on research output and paper publications. (c) Disciplinary analysis indicated a stronger effect on increasing paper publications in science and engineering universities. (e) Personnels' perceived behavioral control anticipated negative emotions, and sense of community all have direct positive effects on innovative intentions. Personnels' innovative intentions have a direct positive effect on their innovative behaviors. Personnels' age, education level, and monthly income have heterogeneous effects on innovative behaviors. By analyzing the conclusion, this study provides new empirical evidence for the practical applications of the Triple Helix Theory, highlighting the strategic role of science parks and individuals in fostering academic research. Policy recommendations are offered to optimize university-industry collaboration and enhance research performance.

KEYWORDS

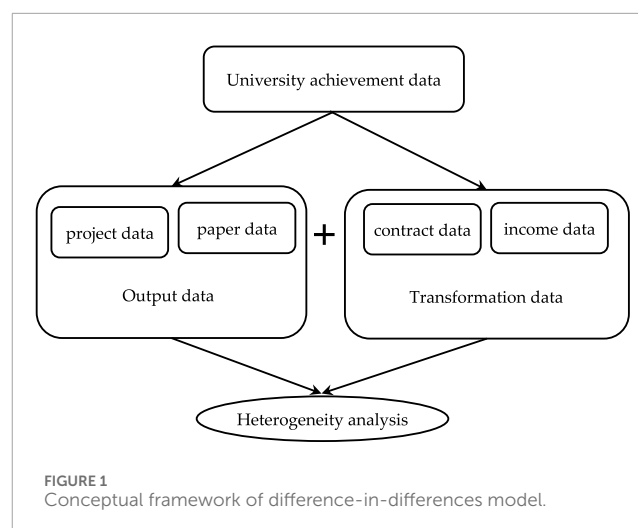university science parks, university research quality, dynamics of opinion formation, difference-in-differences model, triple helix theory, exploring human

1 Introduction

American scholar Frederick Terman pioneered the university-industry collaboration model, founding the first university research park in the world—Stanford Research Park—which later evolved into what is now known as Silicon Valley" [1].

This model has influenced similar initiatives worldwide, with various countries developing their own versions: designated as "technology research parks" in the United States [2], "science cities" in Japan, "science parks" in the United Kingdom, and "research entrepreneurship centers" in Germany. In China, university science parks operate a three-tier system—national, provincial, and municipal—that plays a significant role in economic and technological advancement. The 2021 China Torch Statistical Yearbook reports that China has established 140 national-level university science parks across all provinces and municipalities, with the total number of science parks >10,000. Data from the Torch High-Tech Industry Development Center of the Chinese Ministry of Science and Technology (2002–2020) indicate that enterprises within these parks achieved an average annual revenue growth of approximately 8%, demonstrating their role in enhancing corporate economic performance. Furthermore, the number of incubated enterprises increased from 5,000 to nearly 10,000 between 2004 and 2020, highlighting the continued support of the parks for startup development. On the other hand, In the field of social physics, research on individual behavior provides a unique perspective through which social individual reactions can be observed, such as the impact of policies on social individuals. These statistical based models provide crucial objective insights and deepen our understanding of the complex and dynamic nature of social systems. By studying individual social behavior through micro models, researchers can discover the intrinsic dynamics that govern individual social behavior. In addition, the diversity of behaviors observed in different models highlights the theoretical significance of the research. In response to the above introduction, firstly, this project attempts to discover the changes in research output of universities participating in China's national university science and technology parks. Secondly, this study also collected questionnaires to investigate the formation and dynamics of opinions among university personnel participating in university science parks, and to further explore the mechanisms of human interaction in society.

Specifically, Technological innovation has emerged as a key driver of social development. Individuals are the source of driving innovation. The mechanism provides a structural framework for individual innovation, and the quality of this structural framework will affect innovative output. National level university science and technology parks have constructed new mechanisms and provided new impetus for individual innovation output. The study will apply the mechanism of university science and technology parks and analyze it in conjunction with the output of university achievements. The core of university innovation output is researchers, and this research is conducive to discovering the relationship between macro mechanisms and individual innovation. Using Hangzhou Future Sci-Tech City as a representative case, 2 decades of development have fostered benchmark enterprises such as the company of DeepSeek AI and Unitree Robotics, generating significant industrial clustering effects. As a crucial platform for industry-university-research collaboration, university science parks facilitate knowledge transfer between academia and industry while driving adaptive reforms in academic research systems by transmitting corporate technological demands in reverse. This bidirectional interaction mechanism is transforming innovative ecosystems by establishing positive feedback loops

FIGURE 1
Conceptual framework of difference-in-differences model.

between fundamental research and applied development. Several critical questions arise: While university science parks contribute to economic growth, do they equally enhance the quality of academic research outputs? Do participating institutions experience varying effects on different research outcomes, such as fundamental research and technological commercialization? Does this institutional effect differ across regions, disciplines, and institutions? Therefore, this study aims to examine national-level university science parks, which provide an ideal research sample due to their policy significance and data availability. The research design mainly consists of two dimensions. Firstly, the different-in-different model was applied to analyze different types of scientific research outputs. This study collected data on university projects, published papers, signed contracts, and actual income. Research projects and published papers were classified as indicators of scientific research outputs, while signed contract data and annual income were used as measurement standards for research output conversion. These two types of indicators serve as key indicators for evaluating the quality of university scientific research. The study will also combine heterogeneity analysis to understand the changing effects of different regional distributions, types, and research capabilities of universities. Figure 1 represents a conceptual framework of difference-in-differences models. Secondly, the operation of university science and technology parks cannot be separated from individual interaction, especially the changes in scientific research output after universities participate in university science and technology parks, which require researchers from participating universities to continuously conduct scientific research. However, the work efficiency of these individuals may be affected by some factors. In response to this hypothesis, after difference-in-differences evaluation, the study also interviewed and obtained 408 questionnaires from university researchers participating in the university science park. Based on these questionnaires, combined with confirmatory factor analysis and structural model analysis, the study attempted to discover specific factors that affect individual work efficiency. Figure 2 represents conceptual frameworks of individual behavioral factors.

FIGURE 2
Conceptual frameworks of individual behavioral factors.
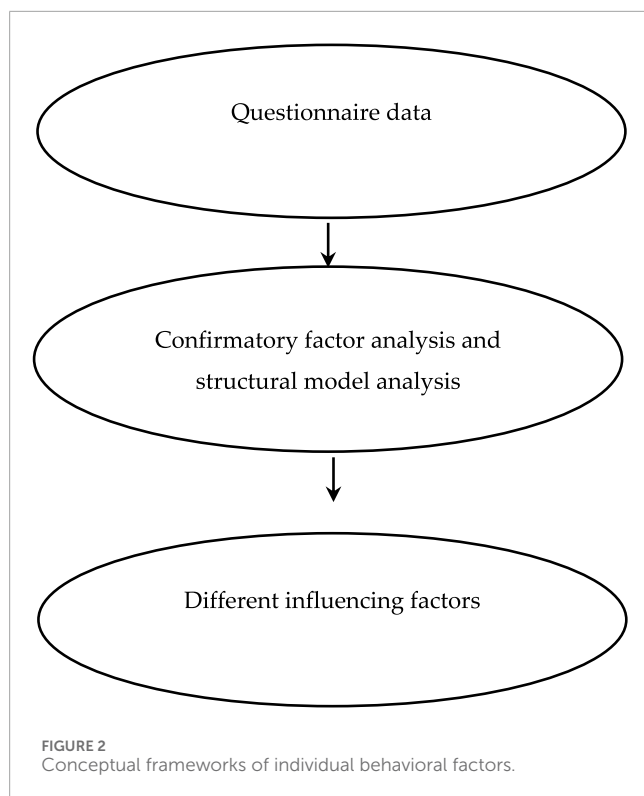
2 Literature review

2.1 Research on the correlation between university science parks and scientific research achievements in universities

Regarding international developments, Bhavem examined the enactment of the U.S. Bayh-Dole Act in the 1980s and observed a subsequent improvement in university patent quality [3]. Similarly, Stefano demonstrated that, in an analysis of approximately 600 invention reports, a higher output of university research enhances overall scientific productivity [4]. Christons identified a competitive dynamic between university science parks and other technology transfer models, suggesting that this competition ultimately improves the quality of university patents [5]. Additionally, this study highlights an inherent connection between academic research output and university science parks. University science parks play a crucial role in translating academic knowledge and technology into market-driven applications, thereby overcoming the traditionally insular nature of universities [6]. This process ultimately enhances the societal contributions of universities. Castillo et al. indicate that technology matching is a time-intensive process; however, university science parks significantly reduce this duration [7]. This efficiency is attributed to the dual nature of knowledge transmission—explicit and tacit [8]. Explicit knowledge involves codified and easily transferable information, while tacit knowledge, such as experiential insights, is difficult to articulate and requires deeper interaction for effective transfer. This distinction suggests that enterprises may face challenges in fully recognizing the technological capabilities of universities, while universities need to identify enterprises whose technological needs align with their research expertise.

University science parks address this dual-matching challenge by facilitating communication platforms [9], enhancing alignment between academic research and industry needs, and fostering mutual outcomes [10].

The emergence of university science and technology park platforms is essentially the emergence of new organizational forms. However, research has shown that driving scientific research output is not only about organizational changes, but also about individual factors and demographic characteristics [11]. An experiment based on 160 experimental interventions showed that changes in individual behavior are closely related to external contextual environments [12]. Research on individual factors has shown that factors such as communication, interaction, rewards, and job recognition can affect the output of scientific research results [13]. Meanwhile, studies have shown that factors that affect individuals mainly include childhood experiences, education level, personality, values, political attitudes, sense of responsibility, age, and gender [14]. The demographic characteristics are reflected in the individual's gender, age, and level of experience, which can also have varying degrees of impact on the output of scientific research results [15].

In the context of Chinese research, higher education policies play a crucial role in improving university research outcomes, attracting significant scholarly attention. For example, Ma Junfeng conducted an analysis of the Western and Central China Higher Education Revitalization Plan—a policy initiative that allocates financial resources to underdeveloped regions. The finding demonstrates the effectiveness of the plan in increasing research output [16]. Similarly, researchers have investigated the effect of the "Double First-Class" initiative in China on enhancing research capabilities in universities [17]. However, advancements in academic research outcomes are not solely driven by policy interventions. University-industry collaborations, particularly those facilitated by science park models, play a vital role. Guo Tianbao and Ru Ning conducted a study on National University Science Parks (NUSPs) in China, revealing that universities involved in these parks experienced a 31% increase in the number of invention patents, along with improvements in patent quality [18]. Other studies have primarily examined the developmental trajectory of NUSPs [19]. The first university science park in China was established at Northeastern University in the 1980s, followed by the involvement of Tsinghua University, Peking University, Harbin Institute of Technology, and other institutions, initially adopting experimental models [20]. A significant milestone was reached in 2006 when the Ministry of Education and the Ministry of Science and Technology jointly issued the "National University Science Park Accreditation and Management Measures." This policy established formal accreditation standards and operational guidelines, signifying the maturation phase of NUSP development in China. During this period, enhanced university-NUSP interactions facilitated greater technology transfer opportunities among participating institutions [20].

In China, research on individual behavior is often associated with policy-making Li Feng's research emphasizes that the performance evaluation of scientific researchers' achievements should be based on three indicators: papers, patents, and research projects [21]. These evaluations provide reference for the establishment of incentive systems for scientific researchers.

Meanwhile, relevant studies have shown that the evaluation of scientific research performance in universities focuses on efficiency [22]. This makes it difficult for researchers to combine research results with social development needs to meet institutional requirements during the research process. Similar research not only exists in the field of scientific research, but also in other related fields. For example, if environmental policies are effective, they will also affect residents' willingness to recycle and strengthen [23]. Moreover, if the effectiveness of environmental policies is perceived by individuals at a high level, this change will also affect the strengthening of individuals' willingness to protect the environment [24].

2.2 Theory introduction

Existing research demonstrates a correlation between research outcomes and university science parks. The fundamental concept of university science parks is consistent with the Triple Helix Theory, as both emphasize the development of platforms that facilitate interactions among universities, enterprises, and governments. The Triple Helix Theory similarly emphasizes that close collaboration among these entities fosters mutual development [25]. Therefore, this study establishes its theoretical foundation by examining the evolution of the Triple Helix Theory. Initially proposed by Etzkowitz in 1995, this theory is characterized by nonlinear interactions [26] and has significantly influenced academic discourse. The theory specifically demonstrates that enterprises commission universities to develop new technologies for market applications while governments provide policy support, fostering interdependent relationships that facilitate iterative development [27]. In practice, the three helices rarely attain perfect equilibrium. Instead, their driving forces vary across regional contexts [28], while their essential structure remains intact through autonomous but interdependent operations [29]. Researchers suggest that an optimal model involves balanced contributions and mutual benefits among the three entities [29]; however, achieving perfect equilibrium remains unattainable in practice.

Within this framework, universities act as both drivers of innovation and beneficiaries, particularly through research outputs [30]. University science parks serve as specialized platforms that operationalize Triple Helix dynamics [31], facilitating knowledge commercialization and technology transfer through structured university-industry-government collaboration [32]. However, the theoretical model in Figure 3 recognizes that varying contextual factors influence the driving forces and distribution of benefits within the helix structure. This study specifically aims to examine the NUSPs in China, where distinct institutional settings may generate unique patterns of research quality outcomes. At the same time, as an important factor in interaction, the efficiency of individual interaction may also affect the operational efficiency of the triple helix framework. To be specific, The theory of planning behavior emphasizes that an individual's behavioral intention determines their behavior [33]. Personal behavioral intention depends to some extent on various factors such as personal perception, personal attitude, social environment, etc [34]. According to this theory, individual behavior plays an important role in the operation of university science parks. Therefore, individual factors have

FIGURE 3
Diagram illustrating the interactions among multiple participants within the Triple Helix framework.
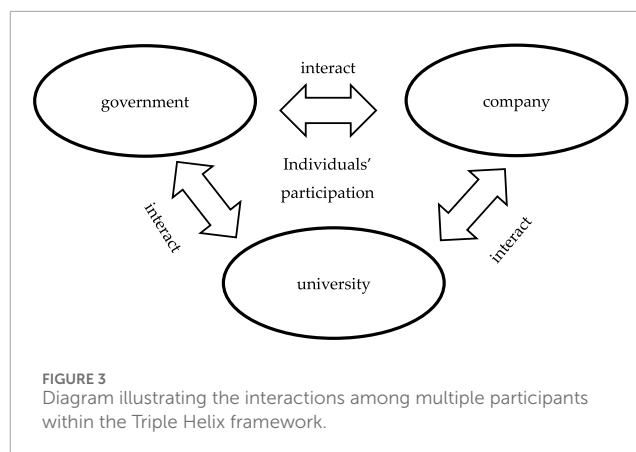
been added in Figure 3, where universities, governments, and enterprises all have individual participation in their interactions. This study focuses on individuals of scientific research in universities participating in university science parks. To address theoretical gaps, this study is based on Triple Helix Theory, using the Differences-in-Differences (DID) model combining confirmatory factor analysis and structural model analysis to analyze the effect of NUSPs on academic research performance.

Three research gaps were identified through a literature review and theoretical analysis: 1) limited investigation of the China-specific university-science park relationships, 2) insufficient assessment of research benefits within the Triple Helix framework, and 3) limited investigation of the influence of science parks from a Triple Helix perspective. This study addresses these gaps by applying the Triple Helix Theory to evaluate research quality in the context of NUSPs in China. In terms of theoretical value, in addition to the practical application of this theory in China, the research results are also conducive to revealing that universities, as participants, may also achieve in-depth development in scientific research. The core of this development also highlights the positive significance of interaction between universities and society. At the same time, in the field of research, the theoretical value lies in the innovative development of higher education, the construction of innovative systems in public management, and the cooperation between industry, academia, and research in business management, which will have positive significance in many areas.

A staggered DID approach was adopted to accommodate variations in NUSP establishment dates throughout the study period, following the application of this model by Goodman in similar policy evaluations [35]. The DID model effectively isolates policy effects by comparing treatment and control groups over time. Its established applications include analyses of historical policy shifts [36] and institutional transformations [37]. Previous studies in the education sector have effectively employed the DID approach to demonstrate the positive effect of NUSPs on university patent outputs [18], validating its suitability for this research.

Figure 4 illustrates conceptual framework for evaluating research quality in Chinese universities. The diagram depicts how NUSP participation (treatment variable) interacts with Triple Helix dynamics to influence research performance outcomes. Institutional characteristics and temporal trends are accounted for
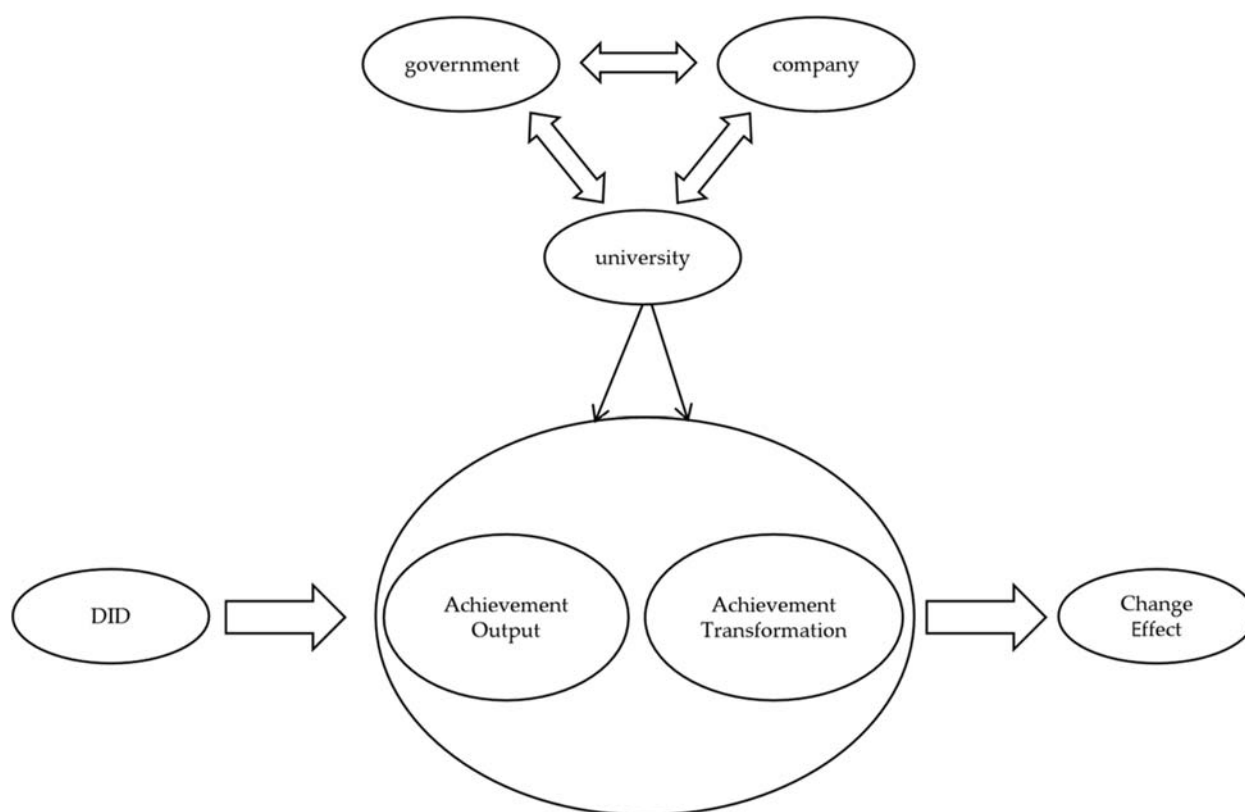
FIGURE 4
Conceptual framework for evaluating research quality in Chinese universities.

using DID specifications. This combined theoretical and empirical approach facilitates a comprehensive analysis of both institutional mechanisms and quantitative effects.

2.3 Consideration of other factors

Human behavior is a key factor determining the state of innovation. Among them, various factors that affect innovation behavior have always been the focus of scholars' research. Personal factors include childhood experiences, knowledge and education, personality and self-construction, sense of control, values, political attitudes and worldviews, goals, perceived responsibility, cognitive biases, regional attachment, age, gender, and activity choices. Meanwhile, Social factors include religion, urban-rural differences, norms, social class, proximity to innovation, as well as cultural and racial differences. The variable relationship diagram in Figure 5.

Firstly, in order to better predict and analyze innovative behavior, it is necessary to understand the various factors that influence individual innovative behavior. Research on individual innovative behavior mostly focuses on the characteristics of "people" and neglects the influence of external factors on individual innovative behavior. In many different domains of behavior, behavioral intention can predict an individual's behavior to some extent. Similarly, the implementation of innovative behavior by university researchers should also be largely predicted by their

innovation intentions. To some extent, the innovative willingness of technical personnel involved in university science parks may affect their innovative behavior.

Secondly, In the field of innovation, attitude is an important assessment of an individual's perception of innovative targets. Many research results have also confirmed this statement, that is, attitude towards innovative behavior is an important determinant of an individual's intention to engage in innovative behavior. Innovative identification captures an individual's perception of social pressure towards specific behaviors. In other words, innovative identification is the opinion of others who are important to an individual and can influence their decision-making. Most of an individual's behavior is controlled by will, and perceived behavioral control is one of the important influencing factors of behavioral intention. Behavioral control and motivation determine behavior. Perceived behavioral control enables individuals to effectively evaluate their ability to achieve expected behavior, which not only includes self-efficacy, but also considers people's grasp or control of external non motivational factors such as resources, opportunities, and facilitating factors. If people believe that they have the necessary resources and opportunities, and that their behavior is controllable, they may have positive behavioral intentions. Otherwise, people will also evaluate the likelihood of overcoming specific situations to act. Innovation perception behavior can indirectly influence behavior through the mediating effect of behavioral intention or directly influence behavior. Engaging in innovation requires individuals

FIGURE 5
Variable relationship diagram.
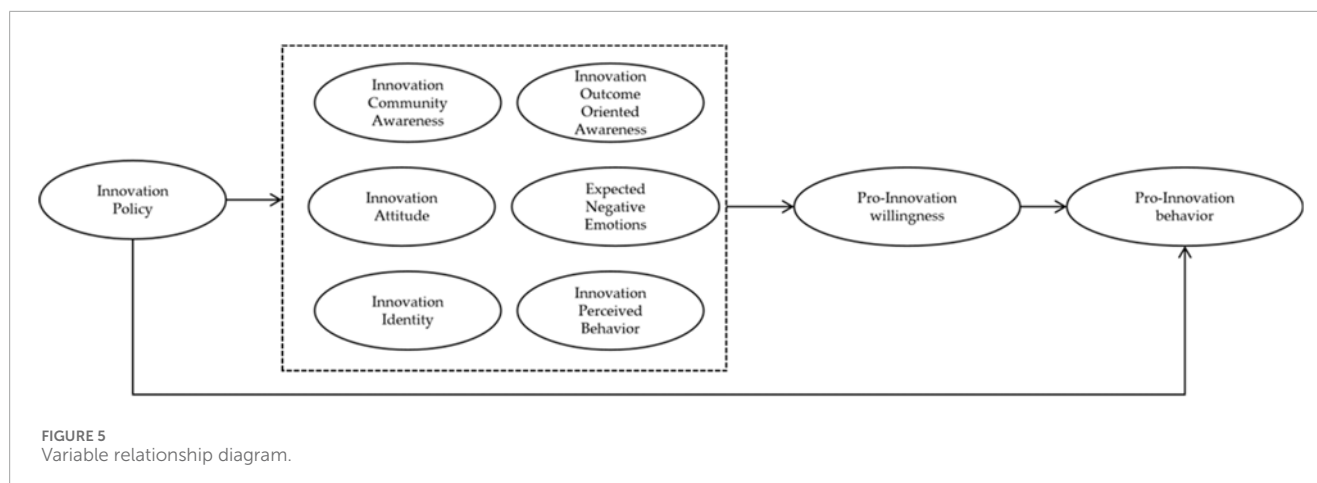
to cope with certain limitations, obstacles, or inconveniences. People who can highly control such obstacles or inconveniences have stronger innovative intentions and behaviors. Meanwhile, Innovative behavior is likely to affect the positive interrelationships between attitudes, subjective norms, and perceived behavioral control. Therefore, this article assumes that if science and technology personnel participating in university science and technology parks hold a positive attitude towards innovative behavior, or perceive that others expect and support them to do so, and they believe they can meet their behavioral expectations, then science and technology personnel participating in university science and technology parks may have a strong intention to engage in innovative behavior and adopt such behavior.

Thirdly, Behavioral intention depends on an individual's emotions towards a certain behavior, external factors in the social environment, and the perceived potential consequences of a particular behavior. Emotions refer to the emotions that individuals experience or feel when they think about engaging in or not engaging in a certain behavior. Considering that the manifestation of specific behaviors can evoke individual emotions, which may be positive or negative. Individual behavior is not simply rational decision-making, and non-cognitive or emotional factors play a role in the process of people's action. Community consciousness is a manifestation of an individual's sense of belonging. The interaction between an individual and those around them, or their identification with a social group, can align their feelings, thoughts, and behaviors with group norms. And correspondingly, individuals' self-awareness and behavior also remain consistent, so that they can act according to group goals. In real-world innovation, innovative community consciousness is a social based perceptual measure to demonstrate individual responsible behavior towards society. It can be said that the awareness of innovative communities increases individuals' behavioral intentions or actual participation in social responsibility actions. Understanding of the consequences of behavior may also be one of the predictive factors for individual behavior. Before engaging in specific behavior, individuals can roughly anticipate what kind of results this behavior may produce. Consequence awareness refers to the degree to which an individual values the consequences of a certain behavior. And individuals will largely consider whether to engage in this behavior based on their own understanding

of the outcome of the behavior. An individual's perception or understanding of the expected outcome of a certain behavior may evoke moral obligations and trigger corresponding behavioral intentions. If a person believes that the outcome of performing a certain behavior is positive, meaningful, and valuable, then they are likely to exhibit a positive or strong behavioral intention towards that behavior. Based on the negative emotions, innovation community awareness, and innovation outcome-oriented awareness expected by technology personnel participating in university science parks. Hence, the innovation willingness of technical personnel participating in university science parks can also be influenced by various factors.

Fourthly, in general, after government agencies issue or implement certain policies or regulations, people's reactions to them to some extent indicate what kind of intentions and actions they will take next, and most of these "reactions" will first have an impact on some social and psychological factors. Innovation policies, as one of the external contextual factors, whether command and control, market incentives, or public participation, may have a certain impact on the cognitive, emotional, or non-cognitive psychological factors of science and technology personnel participating in university science parks. Favorable situational factors should have a positive impact on an individual's behavioral attitude. Through discussion, understanding, and implementation of innovative policies by those around them, individuals may feel the constraints, pressures, and expectations of institutional or social innovation, and their subjective norms may be influenced to some extent. Innovation policies, as an external contextual factor, may also affect people's perception of their level of control over the execution of specific behaviors and the difficulty of executing those behaviors. If innovation policies provide clear guidance for technology personnel participating in university science parks to engage in innovation behavior, people will feel that they have relatively greater control over the performance of innovation behavior, and there will not be too many obstacles or difficulties in engaging in this behavior. The guiding and regulatory functions of innovation policies may cause individuals to experience negative emotions such as guilt, disappointment, and anxiety if they do not act. Moreover, the introduction of innovation policies may trigger a sense of community among technology personnel participating in university

science parks, and everyone will gradually reach this consensus. At the same time, in the process of understanding the relevant content of innovation policies and implementing innovation policies, scientific and technological personnel participating in university science parks in universities will consider the benefits of engaging in innovative behavior and the consequences of not engaging in it due to the impact of innovative policies. Hence, Innovation policy is also a key variable.

It should be noted that some control variables are contemporaneous policies, which were introduced at different time points. However, during the COVID-19 period, some control variables for contemporaneous policies were not introduced, which limited the impact of special events in this study.

3 Research design

3.1 Data collection

The research should ensure the timeliness of research, due to that, data collect from 2014 to 2024. It should be noted that although the receipt collection time is from 2014 to 2024, due to the 1-year lag in data collection, the actual time reflected in the data should be from 2013 to 2023. The data collection process in this section comprised two components: (1) university research output and technology transfer outcomes and (2) university research inputs. Integrating the market-oriented framework proposed by Macho-Stadler, which evaluated research quality based on both output (e.g., publications, patents) and commercialization (e.g., technology transfers) [38], a similar approach was adopted to define and collect data on university research performance. Research output was evaluated using four indicators: patents, academic papers, research projects, and monographs. Technology transfer was measured based on the number of technology transfer contracts and the revenue generated from technology transfers [16]. Data was collected on undergraduate universities from the Compilation of Science and Technology Statistics for Higher Education Institutions, published by the Ministry of Education in China. Meanwhile, some of the missing data is collected through web crawling methods on the official websites of universities. The data setting included the following indicators: "Total Research Projects" (count), "Academic Papers" (number of articles), "Technology Transfer Contracts" (count), and "Annual Actual Income" (thousand yuan) from technology transfers. Chinese higher education institutions are classified into three categories: (1) undergraduate universities (integrating research, teaching, and societal service); (2) adult continuing education institutions; and (3) higher vocational colleges (both primarily teaching-focused) [39]. Because the latter two types of institutions do not involve research and development, the research did not collect relevant data from the latter two types of institutions. to account for other factors influencing annual variations in university research outcomes—such as faculty capacity, industry-academia R&D collaborations, and research-oriented human resource allocation, all of which significantly affect research quality [16]—additional data were collected from the Compilation of Science and Technology Statistics for Higher Education Institutions, and crawling way on university official websites. Specifically, three continuous control variables were

included: (1) "Teaching and Research Staff" (headcount) to measure faculty investment, (2) "Enterprise-Commissioned Projects" (institutional revenue) to reflect external R&D funding, and (3) "Annual Research Personnel" (headcount) to quantify workforce commitment to research activities. In the organization of panel data, due to the presence of zero values in some data, the research processed the data by logarithmic plus one. These variables were designed to isolate the effects of institutional and collaborative dynamics on research performance.

3.2 Model specification

This study collected data on the output of achievements from 1,051 universities involved from 2014 to 2024. To achieve these objectives, this section outlines the rationale for selecting the DID model. First, the staggered DID approach was employed because the NUSPs in China are accredited in multiple batches. This model effectively isolated the causal effects of NUSP accreditation over time. Meanwhile, the research will apply method of ordinary least squares, it also applied in research of Guo Tianbao and Ru Ning [18]. Second, building on previous research [18], the part of heterogeneity analysis was conducted to examine differences in outcomes based on regional disparities (e.g., eastern vs. western China), discipline focus (e.g., humanities vs. STEM), and institutional tier (e.g., "Double First-Class" universities vs. regional institutions). Third, the empirical model was formalized as follows Equation 1:

$$INNOVATION_{ny} = \beta a + \beta b \times X_{ny} + F_{ny} + M_n + T_y + O_{ny} \quad (1)$$

where the $INNOVATION_{ny}$ represents research output metrics (e.g., patents, academic papers) for university n in year y, the coefficient βb estimates the effect of participation in NUSPs on research outcomes, and X_{ny} is a binary variable indicating whether university n joined a NUSP in year y. The term F_{ny} represents a set of control variables (e.g., faculty size, industry-academia collaboration funding), while M and T denote university-specific and year-specific fixed effects, respectively, to account for institutional heterogeneity and temporal trends. Finally, O_{ny} represents the idiosyncratic error term, reflecting unobserved stochastic factors. This specification ensures a rigorous estimation of NUSP influences by isolating institutional and temporal variations while controlling potential confounding factors.

3.3 Variable specifications

This section highlights the rationale for variable specification, focusing on data characteristics, dependent variables, explanatory variables, and control variables.

First, upon data collection, the panel data revealed the presence of zero values. Ma encountered a similar issue in their DID model and addressed it by applying a logarithmic transformation with a constant of 1 added to zero values [16]. The same approach was adopted for the logarithmic transformation of panel data in this study.

Second, the dependent variables include four categories of data used to assess university research output performance: total

number of research projects (items), number of academic papers (articles), number of signed contracts (items), and actual annual income (in thousands of yuan). In previous studies, university research outputs have been combined with technology transfer capabilities to develop innovation performance indicators for evaluating research capacity [40]. For university research outputs, previous studies have commonly used paper publications and research project data as key indicators [41]. Consequently, this study adopts the total number of research projects and academic papers as dependent variables representing research outputs. Regarding technology transfer, Macho-Stadler analyzes university technology transfer data [38]. The number of contracts signed with external partners and actual annual income from collaborations were used in this study as dependent variables for technology transfer outcomes.

Third, following Angrist's use of external shock events as explanatory variables in DID models [42], the recognition of a university's science park as a National University Science Park (NUSP) was employed in this study as the explanatory variable.

University research outputs may be influenced by various factors, including internal changes in dependent variables and external policy interventions, as identified in DID model studies [43]. Building on Ma's approach, which considers changes in university researchers and investment data as determinants of research capabilities [16], this study incorporates internal control variables, including changes in teaching and research personnel, annual commissioned projects from enterprises/institutions, and annual investment in research staff. Externally, Chinese universities receive significant policy support affecting research outputs. For example, higher education policies including the Characteristic Key Discipline Program (which funds over 1 million RMB to develop world-class disciplines), University Discipline Innovation and Talent Introduction Plan (which recruits foreign experts to enhance academic standards), and Midwest Higher Education Infrastructure Project (which addresses regional disparities through financial investments in underdeveloped provinces) influence research outputs by providing funding and attracting talent. During the research period, these policies were promulgated at different time periods. In order to avoid interference caused by contemporaneous policies, these higher education policies are set as control variables. Additionally, economic policies such as High-Tech Industrial Development Zones (HIDZs), which provide tax incentives for frontier technology R&D, and Economic and Technological Development Zones (ETDZs), which promote technology-intensive manufacturing through tax exemptions, stimulate industry-university-research collaboration and knowledge commercialization. These policy factors are represented as dummy variables that indicate university participation in higher education programs or placement within HIDZ/ETDZ regions. Descriptive statistics and variable relationship diagrams are presented in the following table and figure. The "Discipline Innovation and Talent Recruitment Program for Higher Education Institutions" also aims to elevate Chinese universities to world-class status or support high-level disciplines in becoming world-class. To achieve this, the Chinese government attracts experts from leading foreign universities or research institutions to integrate into the research system of China, thereby advancing academic disciplines in the country. The "Project for Strengthening Basic Capabilities of Universities in Central and Western China" is a regulatory

policy introduced by the Chinese government to address regional disparities in higher education development. This policy focuses on providing financial investments to universities in provinces with less-developed higher education systems, aiming to strengthen their academic capabilities. The policies described above are designed primarily to improve higher education through financial support and talent development, which may have influenced university research output during the study period. Therefore, university participation in these policies was included as a control variable to account for the influence of higher education policies. Economic policies may also promote collaboration between regional industries, universities, and research institutions, potentially increasing university research outputs [44]. In China, HIDZs and ETDZs are key policy tools designed to stimulate regional technological advancement and economic growth. HIDZs are designated zones where the Chinese government encourages enterprises to conduct innovative research in frontier technologies. Once a region is approved as a HIDZ, the central government provides preferential tax policies and financial support, while local governing authorities provide additional incentives such as bonuses or special tax exemptions to qualifying enterprises. ETDZs are designated areas that focus on technology-intensive industrial and manufacturing processes. These zones aim to enhance industrial efficiency and reduce costs by fostering industrial agglomeration. ETDZs are mainly supported through tax incentives, such as exemptions on tariffs and import duties. Both ETDZs and HIDZs prioritize technological innovation as a driver of regional economic growth. This emphasis on innovation enhances the potential for universities to translate academic knowledge into economic applications. Consequently, this study uses the presence of HIDZs and ETDZs in the host regions of the university as control variables to account for the influence of economic policy factors.

Table 1 and Figure 6 present descriptive statistics tables and variable relationship between the national university science park and participating universities in China based on the variables established through the above analysis.

4 Empirical analyses of the influence of national university science parks on university research output and technology transfer

4.1 Empirical result

Table 2 presents the empirical results of the study. The findings indicate that technology transfer contracts and corresponding revenues had no significant effects. However, total research projects and academic publications demonstrated significant growth. This result has two key implications: first, universities in designated National University Science Parks experienced significant post-designation growth; second, universities participating in these parks outperformed non-participating institutions in terms of growth. These results show the positive effect of National University Science Park participation on research output. The number of contracts and actual income had no significant effects, suggesting that the capacity for technology commercialization remains underdeveloped, highlighting the need for improvements

TABLE 1 Descriptive statistics of the influence of national university science parks of China on the quality of scientific research achievements of universities.

	Variables	Observed quantity	Average value	Standard deviation	Minimum	Maximum
Explained variable	Total number of research projects	11,561	304.463	758.340	0	9,684.4
	Academic papers	11,561	160.955	577.879	0	9,135
	Number of contracts signed	11,561	8.354	43.759	0	1,030
	Actual income for the year	11,561	2092.435	16,924.08	0	613,524
Control variable	High-tech Industrial Development Zones (HIDZs)	11,561	0.697	0.460	0	1
	Economic and Technological Development Zones (ETDZs)	11,561	0.682	0.466	0	1
	Characteristic key discipline programs	11,561	0.038	0.192	0	1
	Discipline Innovation and Talent Recruitment Program for Higher Education Institutions	11,561	0.078	0.268	0	1
	Project for Strengthening Basic Capabilities of Universities in Central and Western China	11,561	0.047	0.211	0	1
	Teaching and research staff at universities	11,561	604.065	1,381.655	0	22,783
	Commissioned by enterprises and public institutions	11,561	58,121.49	236,607.1	0	5078989
	Commissioned by enterprises and public institutions, number of personnel invested in the year	11,561	200.157	490.352	0	7,793

in research quality. According to the Triple Helix theory [27], universities have capitalized on park opportunities for research output growth but lag in achieving translational outcomes, reflecting systemic imbalances among the key innovation stakeholders.

To account for the characteristics of the DID model, additional parallel trend assumptions must be validated based on the regression results. The DID model requires that the treatment and control groups demonstrate similar pre-event trends. Therefore, this study must specifically verify whether no significant difference was found in research outcomes between universities before they were designated as National University Science Parks. After a university

is successfully designated as a National University Science Park, it is important to confirm whether this external event has a short-term influence on the research outcomes of the university. To assess this, the negative period was used as the baseline, and parallel trend charts were generated. The trend analysis results show that the parallel trend test was successful. Figures 7, 8 show a clear upward trend in the total number of projects and academic papers during the designated period for the National University Science Park, meanwhile, the statistical tests of parallel trends formed in Table 3. Additionally, the trend results for each period fell within the confidence interval.
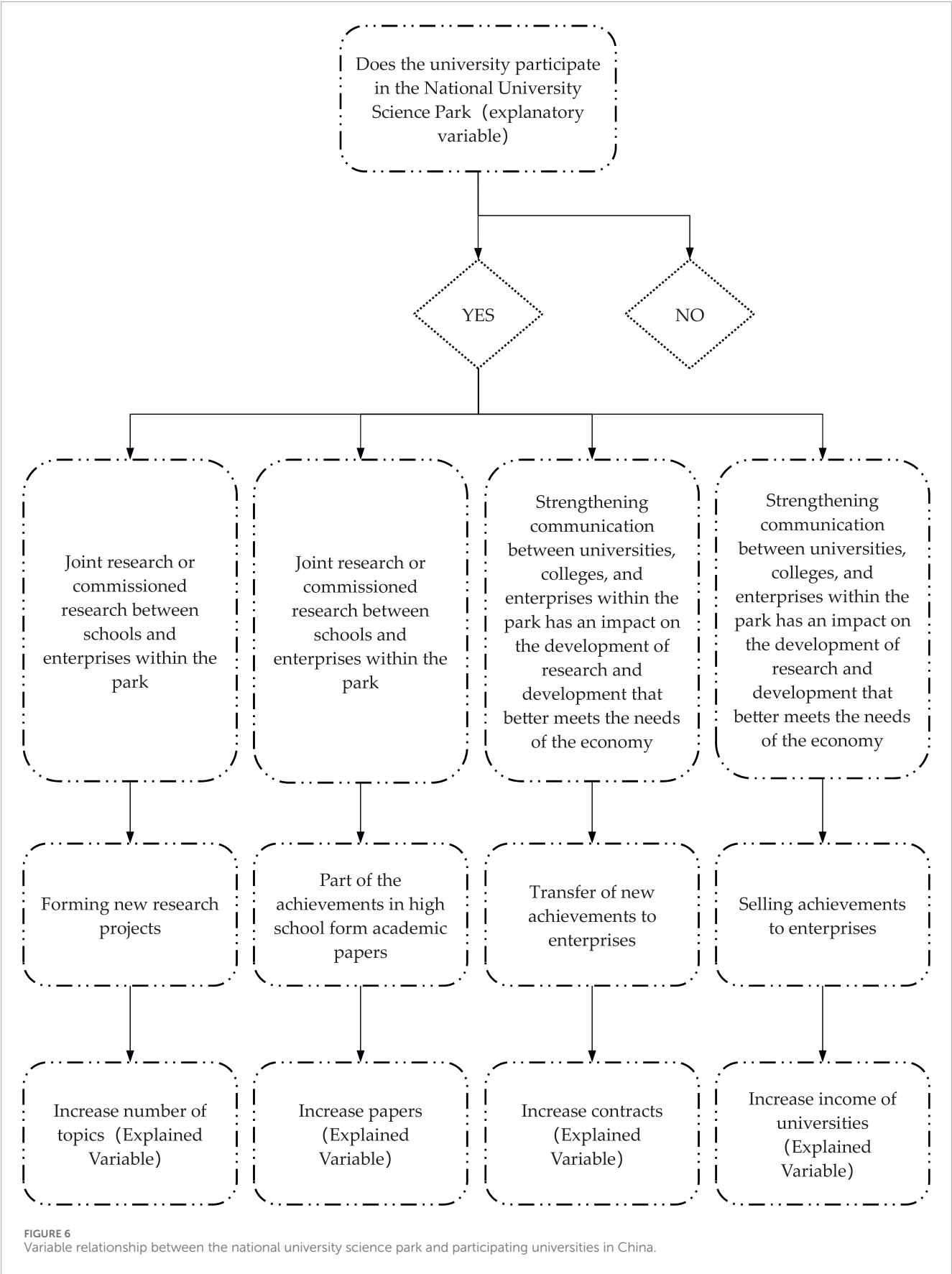
FIGURE 6
Variable relationship between the national university science park and participating universities in China.

TABLE 2 Benchmark test results of different achievements of participating universities by China National University Science Park.

Variables	Total number of projects	Academic paper	Number of contracts signed	Actual income
National University Science Park	0.0803*	0.345***	0.215	0.454
	(0.0465)	(0.116)	(0.155)	(0.403)
High-tech industrial development zone	−0.0525**	0.0669	0.0330	0.0432
	(0.0211)	(0.0568)	(0.0397)	(0.116)
Economic and technological development zone	−0.0168	0.0965	−0.0182	0.0581
	(0.0276)	(0.0600)	(0.0417)	(0.111)
Key discipline projects with distinctive features	0.0285	0.411***	0.175	0.203
	(0.0307)	(0.0773)	(0.109)	(0.217)
Innovation and Intelligence Introduction Program for University Departments of Higher Education	0.124***	0.356***	0.0824	−0.138
	(0.0384)	(0.0808)	(0.116)	(0.227)
Project to build basic capacity of universities in the central and western regions	0.166***	0.393***	0.0338	−0.174
	(0.0343)	(0.0677)	(0.0737)	(0.174)
College teaching and research personnel	0.166***	0.0483*	−0.0497***	−0.171***
	(0.0198)	(0.0267)	(0.0127)	(0.0381)
Entrusted by enterprises and institutions	0.0329***	0.0600***	0.0121***	0.0450***
	(0.00288)	(0.00566)	(0.00391)	(0.0107)
Number of people invested in that year	0.729***	0.428***	0.147***	0.493***
	(0.0290)	(0.0378)	(0.0229)	(0.0638)
Observation numbers	11,561	11,561	11,561	11,561
R-squared	0.992	0.943	0.828	0.842
School FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Note: The standard error of robustness is shown in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

4.2 Robustness test

First, during the research period, six batches of National University Science Parks were designated, totaling 66 parks. Beijing and Shanghai host 13 National University Science Parks in China. As a political center and an economic hub, these two regions hold significant geopolitical and financial advantages. Additionally, most universities affiliated with National University Science Parks in these regions are part of the Double First-Class Universities initiative, which further strengthens their financial and talent resources. To ensure the results reflect a broader impact, we excluded samples from universities in these regions, as suggested by previous studies, and conducted the regression analysis again [18]. The total number of projects (item 1) and academic papers (article 1) in Table 3

show statistically significant results. Second, to verify the robustness of these empirical results, we applied a replacement regression model based on previous research methodologies [45]. A zero-inflated negative binomial regression model was employed for robustness testing. The results for the total number of projects (item 2) and academic papers (article 2) in Table 4 show significant effects. Third, the effect of policy spillover may also influence the changes in university research outcomes. To examine this, a placebo test was conducted using 500 random treatments, and the results were plotted as point trends. Figures 9, 10 show the results. Both figures show that the test results fall within the statistical threshold, confirming that the observed increase in the total number of projects and academic papers at universities is unlikely to be coincidental.
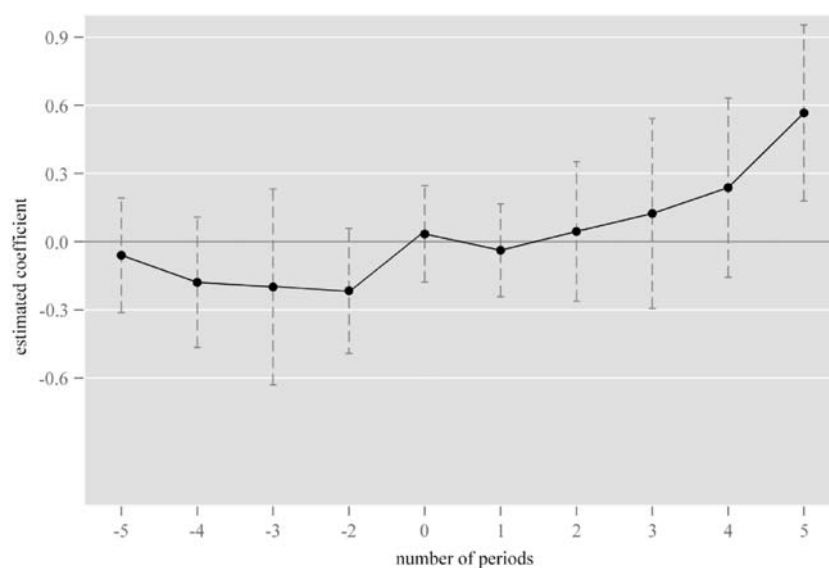
FIGURE 7
Parallel trend test of the output effect of the total number of participants in Chinese universities.
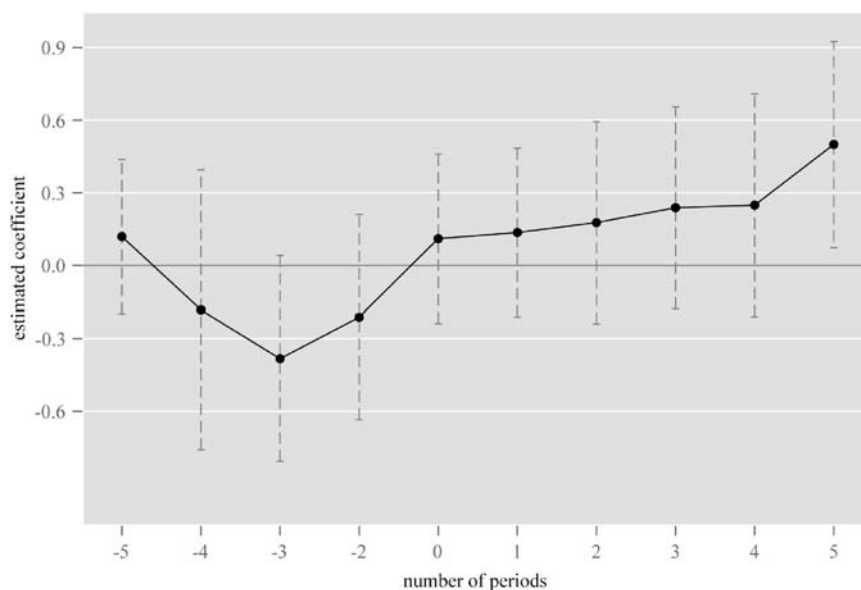
FIGURE 8
Parallel trend test of the output effect of academic papers in Chinese universities.

5 Heterogeneity analysis

Heterogeneity analysis will be divided into four sections. To be specific. Firstly, research will analyze classification of economic zones based on the locations of colleges and universities. Secondly, classification of university types will be analyzed. Thirdly, research also analyzes classification of capabilities in universities. Fourthly, individuals' factors should be researched, which are more important sections for heterogeneity analysis. This section will be named classification of innovative behavior.

5.1 Classification of economic zones based on the locations of colleges and universities

The economic development of China exhibits distinct regional characteristics, with the eastern region being more economically and educationally advanced, while the central and western regions demonstrate comparatively slower progress in these areas. This disparity may be owing to the greater economic prosperity of eastern cities, which enables them to provide more financial

TABLE 3 Statistical tests of parallel trends.

Variables	Total number of projects	Academic paper
DID_{t-5}	−0.720	0.119
	(0.172)	(0.123)
DID_{t-4}	−0.199	−0.182
	(0.167)	(0.224)
DID_{t-3}	−0.179	−0.383
	(0.111)	(0.268)
DID_{t-2}	−0.199	−0.212
	(0.0978)	(0.164)
DID_t	0.0338	0.111
	(0.0824)	(0.135)
DID_{t+1}	−0.0379	0.136
	(0.0791)	(0.135)
DID_{t+2}	0.0450	0.177
	(0.119)	(0.161)
DID_{t+3}	0.124	0.239
	(0.162)	(0.162)
DID_{t+4}	0.238	0.249
	(0.153)	(0.178)
DID_{t+5}	0.566***	0.500**
	(0.150)	(0.212)
High-tech industrial development zone	0.537***	−1.033***
	(0.0922)	(0.0687)
Economic and technological development zone	0.0645	−0.0661**
	(0.0603)	(0.0335)
Key discipline projects with distinctive features	0.0849	0.0156
	(0.0612)	(0.0402)
Innovation and Intelligence Introduction Program for University Departments of Higher Education	0.450***	−0.0185
	(0.0754)	(0.0466)
Project to build basic capacity of universities in the central and western regions	0.0397	0.00450
	(0.0407)	(0.0303)
College teaching and research personnel	0.293***	0.562***
	(0.0167)	(0.0143)

TABLE 3 (*Continued*) Statistical tests of parallel trends.

Variables	Total number of projects	Academic paper
Entrusted by enterprises and institutions	0.0799***	0.0885***
	(0.00600)	(0.00577)
Number of people invested in that year	0.0550***	0.0860***
	(0.00983)	(0.00867)
Observations	11,561	11,561
R-squared	0.940	0.967
School FE	Yes	Yes
Year FE	Yes	Yes

Note: The standard error of robustness is shown in parentheses in the table;***$p < 0.01$,**$p < 0.05$, *$p < 0.1$.

subsidies or additional policy support to university science parks. This phenomenon may reduce the efficiency of industry-academia-research collaboration within these parks, potentially altering university research outcomes. Higher education development in China also shows a clear pattern: the eastern region is more advanced, while the central and western regions are developing at a slow pace [46]. To explore this, the study categorizes universities into eastern, central, and western regions and further examines the effects on research outcomes in each area. Table 5 presents regression results for two variables: the total number of university projects (Variable 1) and academic papers (Variable 2). The eastern region demonstrates significant effects on both types of research output. In the central region, only the total number of university projects has a significant effect. The Western region performs relatively poorly in terms of university research outputs.

The results show that regional disparities in economic and educational capabilities across China may also influence university research outcomes within the framework of the triple helix theory. This influence may arise from variations in the strength of governments, enterprises, and universities across different regions of China. Weaknesses in any of the universities, enterprises, or government can hinder university research output. In particular, the central and western regions of China experience slower economic growth and less developed higher education systems. Consequently, after national university science parks are recognized, the governments in these regions may lack the economic resources needed to support park development, thereby reducing their operational efficiency. The uneven development of higher education weakens university R&D capabilities, preventing institutions in the central and western regions from providing sufficient R&D support when joining national university science parks. Additionally, slow regional economic growth limits the ability of local enterprises to access better development opportunities. Consequently, companies struggle to generate substantial revenue from technological advancements [47], reducing the likelihood of university-enterprise collaboration.

5.2 Classification of university types

Chinese universities vary by specialization, including comprehensive, science and engineering, medical, agricultural, sports, art, language, ethnic, and teacher education institutions. These universities focus on different academic areas, which may result in distinct research outcomes. Based on previous research [18], universities can be broadly categorized into two types: humanities-oriented and science and engineering-oriented universities. Comprehensive, science and engineering, and medical universities fall under the science and engineering category, while sports, art, language, ethnic, and teacher education universities are considered humanities-oriented universities. The subsequent analysis will include regression to examine these classifications. Table 6 presents the regression results for humanities- and science-oriented universities, labeled as Humanities University 1 and Science University 1. The remaining columns display regression results for the number of published papers. No significant regression result was found for changes in university projects between humanities and science universities, suggesting that the number of university projects is unrelated to whether a university is humanities- or science-oriented. However, the regression results for published papers show a significant growth effect for both humanities and science universities.

These regression results show that the triple helix theory influences research outcomes differently across various types of universities. This variation is primarily driven by two factors. First, applying for research projects often requires substantial financial investment. However, most companies within university science parks are startups with limited financial resources [48]. Consequently, these companies are more likely to opt for low-investment, high-impact strategies, such as collaborating with universities to publish papers that highlight their achievements or technologies, rather than pursuing costly project applications. Second, as the interaction between universities and enterprises within the park increases, companies are more likely to propose technologies aligned with economic markets [49]. Although this exchange is less likely to lead to cooperation and project applications,

TABLE 4 Robust test of different achievements of participating universities by China National University Science Park.

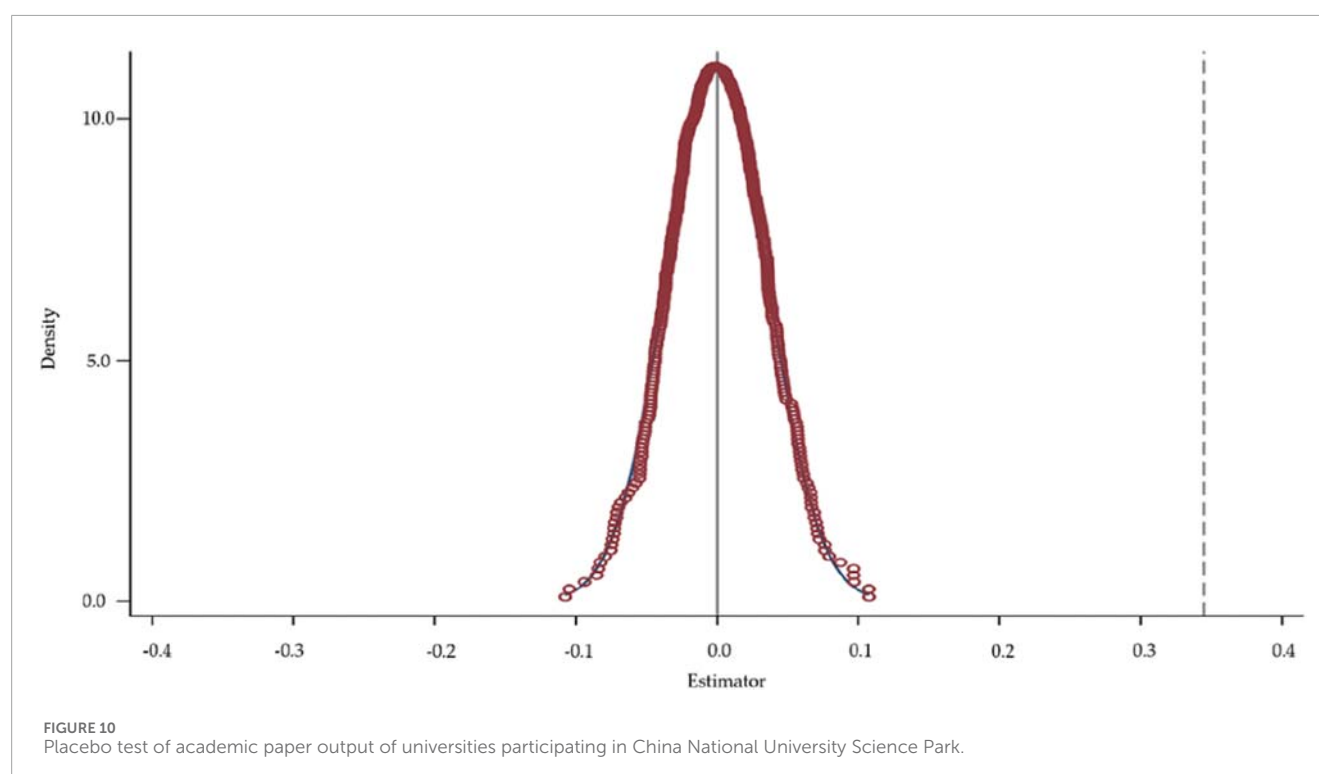| Variables	Total number of projects 1	Academic paper 1	Total number of projects 2	Academic paper 2
National University Science Park	0.104**	0.279**	0.0808*	0.334***
	(0.0509)	(0.128)	(0.0467)	(0.116)
High-tech industrial development zone	−0.0525**	0.0316	−0.0527**	0.0833
	(0.0259)	(0.0590)	(0.0229)	(0.0616)
and economic and technological development zones	−0.0245	0.0705	−0.0149	0.0910
	(0.0291)	(0.0590)	(0.0278)	(0.0605)
Key discipline projects with distinctive features	0.0541	0.390***	0.0314	0.472***
	(0.0372)	(0.0794)	(0.0331)	(0.0815)
Innovative Intelligence Program for University Departments	0.191***	0.193**	0.133***	0.392***
	(0.0457)	(0.0808)	(0.0447)	(0.0937)
Project to build basic capacity of universities in the central and western regions	0.184***	0.360***	0.168***	0.381***
	(0.0352)	(0.0690)	(0.0346)	(0.0684)
College teaching and research personnel	0.0734***	−0.0164	0.165***	0.0464*
	(0.0117)	(0.0206)	(0.0199)	(0.0268)
Entrusted by enterprises and institutions	0.0336***	0.0291***	0.0321***	0.0596***
	(0.00279)	(0.00609)	(0.00291)	(0.00573)
Number of people invested in that year	0.867***	0.606***	0.731***	0.430***
	(0.0145)	(0.0253)	(0.0293)	(0.0382)
Observation numbers	10,604	10,604	10,978	10,978
R-squared	0.892	0.890	0.991	0.940
School FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Note: The standard error of robustness is shown in parentheses in the table; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

it shapes the research approach of universities and generates new research outcomes, such as the publication of papers [1]. Therefore, the triple helix theory can have varying effects across different types of universities.

5.3 Classification of capabilities in universities

In industry, academia, and research collaboration, universities contribute their technical expertise. The level of a university can also affects the extent of changes in research outcomes. Therefore, classifying universities by level helps assess their influence on national university science parks. Drawing on previous studies and the "Double First-Class" policy of China—which primarily strengthens university research through funding—this study classifies first-class universities and disciplines as high-level institutions, while all others are categorized as general universities [18]. Table 7 shows the regression results after classification. The regression results for university projects correspond to general institutions1 and high-level institutions1, while the remaining data pertain to university paper publications. The findings indicate no significant effect of the university level on the number of projects, suggesting that the recognition of national university science parks has not contributed to project growth at either general or high-level institutions. However, the regression results for university publications show a significant growth effect for general institutions, whereas no significant effect is observed for high-level institutions.

FIGURE 9
Placebo test of total output of university projects in China National University Science and Technology Parks.

FIGURE 10
Placebo test of academic paper output of universities participating in China National University Science Park.
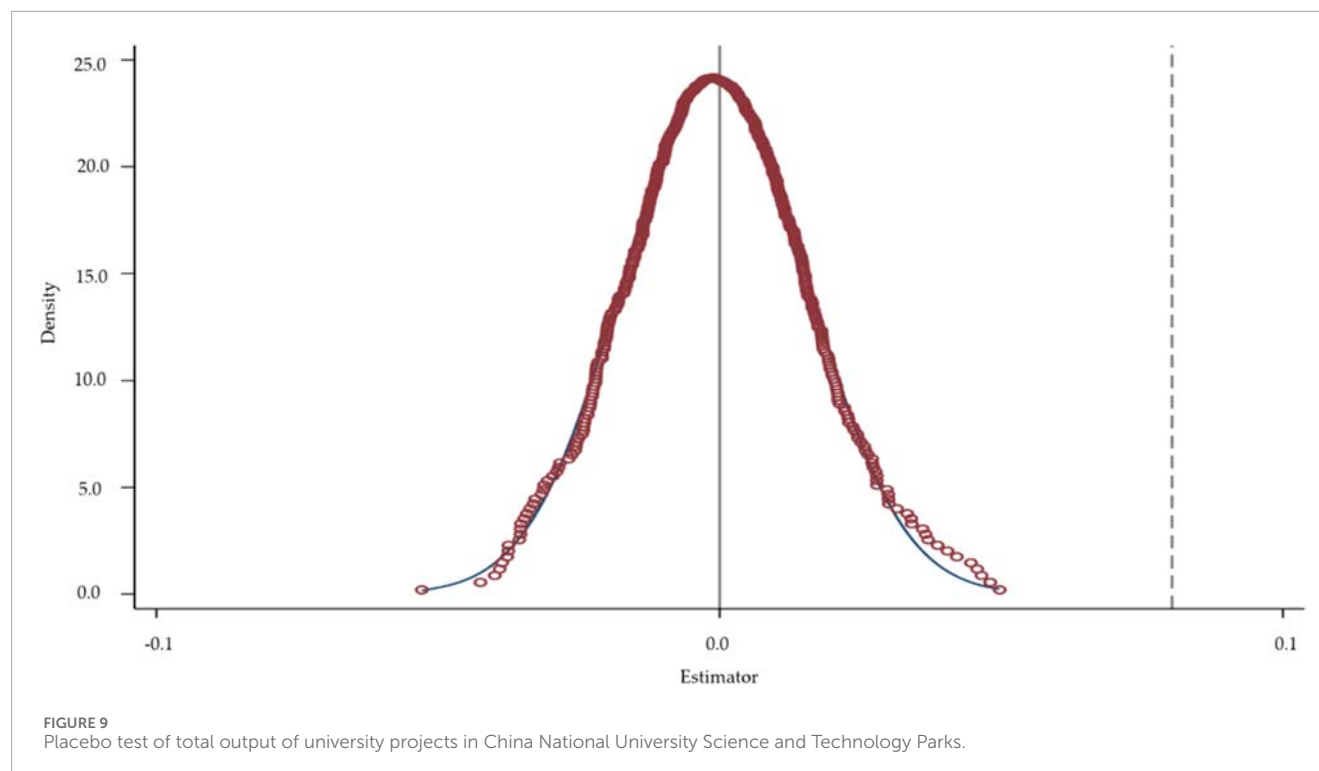
These findings further highlight how disparities in university strength within the three-tier model influence their ability to benefit from collaboration. First, general universities have fewer opportunities to participate in industry-university-research activities. However, by engaging in such collaborations through the National University Science Park model, they can leverage its platform effect to foster continuous interaction with enterprises, leading to new ideas and research outputs. Despite this advantage, their limited R&D capabilities make it difficult to achieve significant growth in research activities that require strong R&D technological foundations. Second, high-level institutions have not experienced a significant increase in research output through this process. This

TABLE 5 Heterogeneity analysis of different regions in China.

Variables	Eastern region 1	Central region 1	Western region 1	Eastern region 2	Central region 2	Western region 2
National University Science Park	0.102**	0.115	−0.0521	0.258*	0.634***	0.345
	(0.0504)	(0.134)	(0.133)	(0.152)	(0.224)	(0.233)
High-tech industrial development zone	−0.00310	−0.0791*	−0.140***	0.0668	0.193	0.0631
	(0.0271)	(0.0414)	(0.0486)	(0.0692)	(0.117)	(0.188)
and economic and technological development zones	−0.0438	0.0574	−0.0621	−0.0833	0.228**	0.437*
	(0.0390)	(0.0437)	(0.0856)	(0.0781)	(0.0957)	(0.225)
Key discipline projects with distinctive features	0.0559	−0.0332	0.0363	0.451***	0.186	0.622***
	(0.0357)	(0.0747)	(0.0941)	(0.0951)	(0.136)	(0.223)
Innovation and Intelligence Introduction Program for University Departments	0.0652	0.264***	0.181***	0.422***	0.260	0.233
	(0.0487)	(0.0848)	(0.0674)	(0.104)	(0.166)	(0.186)
Project to build basic capacity of universities in the central and western regions	0.140	0.159***	0.180***	0.669***	0.456***	0.143
	(0.0970)	(0.0493)	(0.0631)	(0.181)	(0.0975)	(0.117)
College teaching and research personnel	0.144***	0.179***	0.171***	−0.0144	0.126***	0.0333
	(0.0411)	(0.0225)	(0.0301)	(0.0459)	(0.0456)	(0.0422)
Entrusted by enterprises and institutions	0.0345***	0.0335***	0.0291***	0.0679***	0.0532***	0.0566***
	(0.00519)	(0.00406)	(0.00524)	(0.00881)	(0.00874)	(0.0130)
Number of people employed in that year	0.755***	0.682***	0.769***	0.539***	0.340***	0.345***
	(0.0582)	(0.0310)	(0.0441)	(0.0579)	(0.0659)	(0.0653)
Observation numbers	5,819	3,509	2,233	5,819	3,509	2,233
R-squared	0.993	0.991	0.990	0.957	0.928	0.928
School FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: The standard error of robustness is shown in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

study shows that China places particular emphasis on the scientific research development plans of its stronger universities. In 2015, the State Council of China issued the "General Plan for Coordinating the Construction of World-Class Universities and Disciplines," which states that the development of world-class universities and disciplines should be aligned with economic growth. This requirement underscores the crucial role of these institutions in industry-university-research cooperation. However, university-enterprise partnerships extend beyond the National University Science Park model. Universities also collaborate directly with

enterprises through technology development agreements, direct transfer of research outcomes, and joint laboratory initiatives. These diverse collaboration models suggest that high-level institutions engage with the market in multiple ways. Furthermore, the strong research capabilities of high-level institutions generate a higher demand for collaboration. Alternative cooperation models enable direct and targeted communication between high-level institutions and potential partners, facilitating technical exchanges. However, enterprises within university science parks must engage with universities to explore collaborative project opportunities. This

TABLE 6 Heterogeneity analysis of different types of universities in China.

Variables	Liberal arts and science colleges 1	Science and technology university 1	Liberal arts and science colleges 2	Science and technology university 2
National University Science Park	0.132	0.0721	0.411*	0.324**
	(0.0926)	(0.0502)	(0.240)	(0.128)
High-tech industrial development zone	−0.105**	−0.0418*	−0.0582	0.0967
	(0.0471)	(0.0236)	(0.132)	(0.0627)
and economic and technological development zones	−0.0517	−0.00444	0.117	0.0957
	(0.0440)	(0.0333)	(0.150)	(0.0636)
Key discipline projects with distinctive features	0.0388	0.0348	0.124	0.465***
	(0.0744)	(0.0334)	(0.145)	(0.0868)
Innovation and Intelligence Introduction Program for University Departments of Higher Education	0.107	0.128***	0.187	0.381***
	(0.103)	(0.0421)	(0.114)	(0.0926)
Project to build basic capacity of universities in central and western China	0.253***	0.142***	0.318**	0.399***
	(0.0924)	(0.0354)	(0.134)	(0.0782)
College teaching and research personnel	0.205***	0.155***	0.172***	0.0178
	(0.0338)	(0.0228)	(0.0481)	(0.0302)
Entrusted by enterprises and institutions	0.0308***	0.0342***	0.0700***	0.0585***
	(0.00452)	(0.00344)	(0.0112)	(0.00655)
Number of people invested in that year	0.713***	0.734***	0.355***	0.448***
	(0.0397)	(0.0340)	(0.0663)	(0.0426)
Observation numbers	2,255	9,306	2,255	9,306
R-squared	0.989	0.992	0.934	0.945
School FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Note: The standard error of robustness is shown in parentheses.***$p < 0.01$,**$p < 0.05$, *$p < 0.1$.

process requires considerable effort from high-level institutions, making full participation in national university science parks challenging. Therefore, these institutions derive fewer benefits in terms of research publication output. Consequently, within the framework of the triple helix theory, universities at different levels in China exhibit distinct patterns of theoretical integration.

5.4 Classification of innovative behavior

Personal behavior reflects whether an individual can put in effort to engage in a certain activity. In order to explore the impact of national level university science and technology parks

on the behavior of science and technology personnel participating in university science and technology parks, this study further analyzed the individual gender and age of science and technology personnel participating in university science and technology parks in universities, and attempted to discover the mechanism of gender and age on the output of university projects and papers. The measurement model, structural model, and mediation effect are mainly tested and estimated through confirmatory factor analysis and structural model analysis to verify the influence of gender and age. Among them, in estimating the measurement model, this study adopts Maximum Likelihood, ML. This section is mainly divided into confirmatory factor analysis, hypothesis testing, the impact effect of differentiation, three parts.

TABLE 7 Analysis of heterogeneity of different levels of universities in China.

Variables	General institutions 1	High-level institutions 1	General institutions 2	High-level institutions 2
National University Science Park	0.0595	0.0693	0.396**	0.126
	(0.0617)	(0.0738)	(0.163)	(0.172)
High-tech industrial development zone	−0.0419*	−0.126***	0.0877	−0.144
	(0.0228)	(0.0371)	(0.0608)	(0.143)
and economic and technological development zones	−0.00184	0.133***	0.115*	0.678***
	(0.0280)	(0.0380)	(0.0610)	(0.142)
Key discipline projects with distinctive features	0.0304	−0.0611	0.341***	0.519**
	(0.0335)	(0.0742)	(0.0761)	(0.210)
Innovation and Intelligence Introduction Program for University Departments	0.0417	−0.000631	0.252	0.0713
	(0.0788)	(0.0445)	(0.175)	(0.0943)
Project to build basic capacity of universities in the central and western regions	0.184***	0.0230	0.447***	0.0357
	(0.0363)	(0.0833)	(0.0726)	(0.177)
College teaching and research personnel	0.159***	0.482***	0.0476*	0.282**
	(0.0196)	(0.0811)	(0.0273)	(0.123)
Entrusted by enterprises and institutions	0.0322***	0.0321***	0.0630***	0.0145
	(0.00300)	(0.00929)	(0.00579)	(0.0214)
Number of people invested that year	0.743***	0.360***	0.426***	0.346***
	(0.0293)	(0.0811)	(0.0393)	(0.122)
Observation numbers	10,142	1,419	10,142	1,419
R-squared	0.990	0.993	0.919	0.967
School FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Note: The standard error of robustness is shown in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

A total of 408 valid questionnaires were collected for the survey on the university science park. Specifically, all respondents are researchers from universities participating in the university science park, these personnels are important human resources for the research and development process of universities and university science parks, and their behavior will be able to affect the output of scientific research results in universities. Because samples are collected in two ways, the issue of sampling bias needs to be considered. The analysis based on chi square contingency table shows that there is no significant difference between the two samples in terms of demographic variable distribution or key variable structure, therefore, the sampling bias issue is not significant. After sorting and analyzing the data collected from the valid questionnaires, the descriptive statistics of the demographic characteristics of the sample of 408 survey subjects are shown in Table 8.

Firstly, In confirmatory factor analysis. Confirmatory Factor Analysis is mainly used to study the properties and relationships of potential structural surfaces. Unlike exploratory factor analysis, confirmatory factor analysis explicitly tests hypotheses about the relationship between latent variables and their corresponding observed variables or indicators. Confirmatory factor analysis can provide direct and quantitative evidence of external and internal consistency between architectural indicators, playing a crucial role in validating measurement models used for path or structural analysis. Evaluating the measurement model and verifying whether the measured variables accurately reflect the required constructs or factors is a necessary step before evaluating the structural model to

TABLE 8 Sample description.

Variables	Category	Sample size	Percentage
Gender	Male	176	43.1%
	Famele	232	58.9%
Age	≤25	117	28.7%
	26–35	140	34.3%
	36–45	68	16.7%
	46–60	39	9.6%
	>60	44	10.8%

test hypotheses. The results of confirmatory factor analysis on the measurement model are shown in Table 9.

Standardized estimates measure how much of the variance in observed indicators is explained by the corresponding latent variables. According to Table 8, the standardized factor loadings for almost all latent variable questions are above 0.6, with only a few questions having standardized estimates less than 0.6 but greater than 0.5, all within an acceptable range, indicating that the questions have a certain level of reliability. The Z-values obtained by dividing the standardized estimation coefficient by the standard error are all greater than 1.96, and all P-values are less than 0.001, indicating that the estimates for all questions are significant.

Square Multiple Correlation (SMC) refers to the R-square of the measurement model, which is numerically equal to the square of the standardized factor loading. It also represents the explanatory power of the latent variable dimension on the problem, that is, the reliability of the problem. According to Table 8, almost all questions have SMC values greater than 0.36, which are within an acceptable range, indicating good question reliability.

Composite Reliability is the combination of the reliability of all observed indicators, numerically equal to the sum of the standardized factor loadings of a latent variable divided by the sum of the factor loadings plus the error variance, reflecting the internal consistency of the problem in each dimension. The calculation results show that the reliability values of each dimension are greater than 0.7, indicating a high internal consistency of the latent variable dimension and a certain level of reliability.

Cronbach's alpha measures the degree to which observed indicators are simultaneously loaded as latent variables increase. The Cronbach's alpha coefficient of each latent variable is above 0.7, indicating that the scale used in this study has considerable reliability.

The Average of Variance Extracted represents the average explanatory power of each latent variable dimension on the topic. The higher the AVE, the higher the convergent validity of the dimension. An AVE greater than 0.3 is acceptable, while an AVE greater than 0.5 indicates good explanatory power. According to Table 10, the AVE of each latent variable in this study is greater than 0.5, indicating that the model variables have generally converged well.

The lower triangle of Table 9 is the Pearson correlation matrix, and the results on the diagonal of the correlation matrix are the square roots of the AVE for each latent variable dimension. The data results show that the square roots of all AVE values are greater than the Pearson correlation coefficient between latent variables, indicating that there are sufficient differences among the variables in the model and good discriminant validity.

Based on the analysis of the above data results, it can be concluded that the measurement model or questionnaire scale of this study passed the internal consistency reliability test and has good convergent validity and discriminant validity.

Secondly, in the hypothesis testing section. This study proposes an integrated theoretical model to empirically investigate the relationship between innovative policies and Personnels' innovative behavior. By conducting confirmatory factor analysis on the measurement model and comparing the theoretical model with alternative models, the proposed model has been proven to be reasonable and useful for further research.

This study used Mplus7.4 software to estimate the structural model using structural equation modeling. The data results are shown in Table 11.

Regarding the goodness of fit index of the model, the relevant data has been reported and analyzed in the previous section, as shown in Table 10. The relevant results indicate that the integrated model proposed in this study to test the research hypothesis has an acceptable fitting effect and meets the adaptation criteria.

Regarding the standardized path coefficients between variables in the structural model, as shown in Table 10, the standardized path coefficient between innovative policies and Personnels' innovative behavior is 0.351, and the P-value is less than 0.001, indicating that innovative policy has a positive impact on innovative behavior. The standardized path coefficient between innovative willingness and innovative behavior is 0.394, and the P-value is less than 0.001, indicating that innovative willingness can have a positive impact on innovative behavior. The path coefficient between innovative perception behavior control (P > 0.1) and innovative behavior is not significant.

The standardized path coefficient between innovative perception behavior control and innovative willingness is 0.379, with a P-value less than 0.001; The path coefficient between expected negative emotions and innovative willingness is 0221, with a P-value less than 0.001; The path coefficient between innovative community awareness and innovative willingness is 0.169, with a P-value less than 0.01; The path coefficient between innovative outcome oriented awareness and innovative willingness is 0.109, with a P-value less than 0.1. The above data indicates that innovative perception behavior, expected negative emotions, innovative community awareness, and innovative outcome-oriented awareness all have a positive impact on innovative willingness. However, attitude (P > 0.1) and innovative identification (P > 0.1) have no significant impact on innovative willingness.

The standardized path coefficient between innovative policy and attitude is 0.570, with a P-value less than 0.001; The standardized path coefficient between innovative identification is 0.630, with a P-value less than 0.001; The standardized path coefficient between innovative perception behavior and innovative perception behavior is 0.635, with a P-value less than 0.001; The standardized path

TABLE 9 Reliability analysis.

Variable	Subject	Parameter significance estimation				Question reliability	Composite reliability	Cronbach's alpha
		Std. Est	S.E.	Est./S.E.	P-value	SMC	CR	
PBC	PBC1	0.782	0.037	21.014	***	0.612	0.762	0.887
	PBC2	0.651	0.039	16.710	***	0.424		
	PBC3	0.720	0.038	19.030	***	0.518		
ANE	ANE1	0.841	0.021	39.830	***	0.707	0.878	0.867
	ANE2	0.973	0.018	54.116	***	0.947		
	ANE3	0.688	0.029	23.743	***	0.473		
SOC	SOC1	0.741	0.029	25.338	***	0.549	0.835	0.834
	SOC2	0.843	0.026	32.612	***	0.711		
	SOC3	0.791	0.027	28.888	***	0.626		
AOC	AOC1	0.846	0.019	45.659	***	0.716	0.900	0.898
	AOC2	0.819	0.020	41.143	***	0.671		
	AOC3	0.889	0.016	56.385	***	0.790		
	AOC4	0.769	0.023	32.814	***	0.591		
PEI	PEI1	0.848	0.017	50.514	***	0.719	0.920	0.911
	PEI2	0.930	0.012	75.369	***	0.865		
	PEI3	0.891	0.014	62.744	***	0.794		
PEB	PEB1	0.576	0.039	14.836	***	0.332	0.786	0.779
	PEB2	0.521	0.042	12.502	***	0.271		
	PEB3	0.821	0.027	30.032	***	0.674		
	PEB4	0.823	0.027	30.14	***	0.677		

Note: ***P < 0.001.
EP, innovation policy; ATT, innovation attitude; SN, innovation identity; PBC, innovation perceived behavior; ANE, expected negative emotions; SOC, innovation community awareness; AOC, innovation outcome oriented awareness; PEI, innovation willingness; PEB, innovation behavior.

coefficient between expected negative emotions is 0.389, with a P-value less than 0.001; The standardized path coefficient between innovative community awareness and innovation community consciousness is 0.552, with a P-value less than 0.001; The standardized path coefficient between innovative result oriented consciousness and innovation is 0.566, with a P-value less than 0.001.

The R-squared in structural models is used to measure the explanatory variance of a latent variable relative to its total variance. According to the data results, it has a certain explanatory power for most of the dependent variables. Among them, for the most important dependent variable in this study, innovative behavior can explain 55.1% of its variance.

Third, in the impact effect of differentiation. Human behavior largely guides the output of university achievements. To verify this behavior, this study introduced two sociodemographic variables, gender and age, to investigate the correlation between these two variables and the output of university achievements. The data results are shown in Table 12.

According to the table, the standardized path coefficients between the gender of science and technology personnel participating in university science and technology parks and university innovation behavior are 0.025, but the P-values are all greater than 0.1, indicating that the gender of science and technology personnel participating in university science and technology parks has a certain impact on university innovation behavior, but not significant. The standardized path coefficient between the age

TABLE 10 Convergence validity and discriminant validity analysis.

Variables	Convergent validity	Discriminant validity								
	AVE	EP	ATT	SN	PBC	ANE	SOC	AOC	PEI	PEB
PBC	0.518	0.341**	0.531**	0.582**	0.720					
ANE	0.709	0.216**	0.195**	0.313**	0.329**	0.842				
SOC	0.628	0.368**	0.282**	0.369**	0.395**	0.397**	0.792			
AOC	0.692	0.339**	0.586**	0.438**	0.488**	0.249**	0.380**	0.832		
PEI	0.793	0.228**	0.401**	0.428**	0.558**	0.434**	0.442**	0.427**	0.891	
PEB	0.489	0.417**	0.319**	0.479**	0.469**	0.346**	0.390**	0.385**	0.544**	0.699

Note: **$p < 0.01$.

The lower triangle in the table represents the Pearson correlation matrix, and the result on the diagonal of the correlation matrix is the square root of the AVE, of each facet.

EP, innovation policy; ATT, innovation attitude; SN, innovation identity; PBC, innovation perceived behavior; ANE, expected negative emotions; SOC, innovation community awareness; AOC, innovation outcome oriented awareness; PEI, innovation willingness; PEB, innovation behavior.

TABLE 11 Effects of innovative policies on personnels' innovative behavior.

Dependent variables	Independent variable	Std. Est	S.E.	Est./S.E.	P-value	R^2	Hypothesis testing
FEB	PEI	0.394	0.056	7.024	***		SUP H1
	PBC	0.096	0.083	1.161	0.246		NOT SUP H3
PEI	ATT	0.032	0.064	0.504	0.614	0.443	NOT SUP H2a
	SN	0.044	0.062	0.710	0.478		NOT SUP H2b
	PBC	0.379	0.072	5.242	***		SUP H2c
	ANE	0.221	0.051	4.359	***		SUP H4a
	SOC	0.169	0.056	3.009	0.003		SUP H4b
	AOC	0.109	0.060	1.804	0.071		SUP H4c
ATT	EP	0.570	0.046	12.494	***	0.325	SUP H5a
SN	EP	0.630	0.040	15.869	***	0.397	SUP H5b
PBC	EP	0.635	0.046	13.807	***	0.404	SUP H5c
ANE	EP	0.389	0.048	8.046	***	0.152	SUP H6a
SOC	EP	0.552	0.044	12.427	***	0.305	SUP H6b
AOC	EP	0.566	0.043	13.183	***	0.320	SUP H6c

Note:a. ***$P < 0.001$.

EP, innovation policy; ATT, innovation attitude; SN, innovation identity; PBC, innovation perceived behavior; ANE, expected negative emotions; SOC, innovation community awareness; AOC, innovation outcome oriented awareness; PEI, innovation willingness; PEB, innovation behavior.

of science and technology personnel participating in university science parks and the innovation behavior of universities is −0.014, but the P-values are all greater than 0.1, indicating a certain negative correlation between age and innovation behavior, but not significant.

The standardized coefficient between the age of science and technology personnel participating in university science and technology parks and the innovation willingness of universities is 0.133, and the P-value is less than 0.01, indicating a significant positive correlation between age and innovation willingness. However, the standardized path coefficient between the gender of technology personnel participating in university science parks and the innovation willingness of universities is 0.036, but the P-value is greater than 0.1, indicating that gender has a certain impact on the innovation willingness of universities, but not significant.

TABLE 12 Differentiated impact effect.

Dependent variables	Independent variable	Std. Est.	S.E.	Est./S.E.	P-value
PEI	Gd	0.025	0.042	0.603	0.547
	Age	−0.014	0.049	−0.274	0.784
PEB	Gd	0.036	0.042	0.855	0.393
	Age	0.133	0.049	2.720	0.007

BEH, innovation behavior in universities; WIS, innovation willingness in universities; Gd, Gender; Age, Age.

6 summary

6.1 Conclusions

National University Science Parks of China provides new opportunities for universities to enhance their research output. University science and technology parks play an important role in promoting innovative output among university researchers. These parks provide institutions with a platform for development. However, studies show that the ability of universities to translate research into practical applications has not significantly improved after joining the National University Science Parks, highlighting the need for higher-quality research. This study presents the following key findings: First, universities that gain recognition as part of the National University Science Park experience significant growth in both research projects and publications. Second, regional differences influence research output. Only universities in eastern China show a significant increase in the number of research projects. Both the eastern and central regions show a significant increase in the number of published papers. Third, when universities are classified into humanities and sciences, only science-oriented universities experience a significant increase in publications. Fourth, when universities are categorized by level, only general institutions show a significant increase in the number of published papers. These findings indicate that the triple helix theory has varying effects depending on contextual factors, providing new evidence for further research on its application.

Classification of innovative behavior analysis emphasizes that the behavior, willingness, and actions of personnel involved in the research and development of university science parks in universities to some extent involve Innovative Policy, Innovative Attitude, Innovative Identity, Innovative Perceived Behavior, Expected Negative Emotions, Innovative Community Awareness, Innovative Outcome Oriented Awareness. The results of further analysis emphasize that individual behavioral factors play an important role in the positive impact of Chinese university science and technology parks on the quality of scientific research achievements in universities. Individual behavior with positive motivation improves the operational efficiency of the university science and technology park model. While enterprises and governments in the university science and technology park actively play their respective roles, the research tasks of universities in this role become more arduous. The enthusiasm of researchers needs to be better stimulated, so that the process of scientific research from research and development to output can be efficiently operated. This

output is not only beneficial to the development of the university's own research capabilities but may also be conducive to the high probability of university achievements serving the university science and technology park. Therefore, individual behavioral factors play a decisive role in the innovation capability of China's national university science and technology parks. Results also expanded the theory of triple helix. Analysis incorporates individual factors of universities participating in university science parks into the triple helix theory, emphasizing the importance of individuals. Specifically, the main participants of the triple helix theory are enterprises, universities, and governments, which interact and achieve their own new developments. However, the interaction of multiple participants in the triple helix theory cannot be separated from human behavior. In the previous theoretical construction, individual factors were included in the triple helix theory. The focus of this study on individual behavior is on researchers participating in national university science parks. Through research, it was found that the individual behavior of researchers to some extent affects the scientific research output of universities. So, in the triple helix theory, university researchers can provide efficient motivation for the benefit of the university side. This result to some extent reveals new factors that affect the operational efficiency of multiple participants in the triple helix theory, which also provides new reference significance for the in-depth study of the theory.

As the data in this study is limited to 2023, it should be noted that new national university science parks in China continued to be approved for construction after this period, which may have introduced limitations regarding the timeliness of the research. Consequently, obtaining data from subsequent years would help address the limitations of the study in timeliness and provide real-time insights into the latest developments and trends of national university science parks in China.

6.2 Policy recommendations

Based on the main research findings and heterogeneity analysis, this paper recommends focusing on five key areas—parks, universities, enterprises, government and individuals. First, national university science parks have not significantly improved the transfer of research outcomes or increased revenue for universities. This suggests that universities need to enhance their technology transfer capabilities and focus on developing high-end products that align with market demands. Second, universities should recognize the importance of national university science parks. The park model

serves as a key avenue for external collaboration, and universities must prioritize such partnerships to better align their research outcomes with market needs. Third, enterprises within the park should actively engage with universities, aligning collaborations with their own development needs to harness academic expertise and strengthen their competitiveness. Fourth, local governments should provide targeted policy support to enhance the operation of national university science parks. Given regional economic disparities, governments in economically weaker areas should maximize their policy advantages. For example, they can implement tailored incentives for national university science parks, universities, and enterprises. Publicly recognizing and promoting significant achievements within these parks can not only enhance the sense of achievement of participants but also increase their visibility and influence. Fifth, the enthusiasm of individuals to participate in research and development is also influenced by multiple factors. In response to this situation, enterprises and universities in national level university science and technology parks should encourage the research and development enthusiasm of researchers, which can be enhanced through various methods such as bonus rewards, publicity, promotion rewards, etc. Specifically, in terms of universities and enterprises, universities and enterprises that cooperate within university science parks can jointly establish incentive mechanisms to help participants in scientific research achieve efficient output of results. The formulation of these strategies also needs to be combined with the factors that affect individuals in the research conclusions of this article, so that new strategies can produce more positive results. As far as universities themselves are concerned, they should introduce a new mechanism for evaluating research personnel and include the research achievements of their external cooperation in the assessment mechanism. The university science and technology park model is a collaborative model between universities and external society, in which universities participate extensively. On the one hand, it is conducive to enhancing the functions of universities in serving society, and on the other hand, it is also conducive to universities' scientific research achievements serving social development as much as possible. Therefore, it is necessary for universities to promote extensive communication and efficient research and development among individuals through performance evaluation. As far as enterprises are concerned, they can establish additional reward mechanisms for breakthrough technologies completed by university research teams, which also enables university research teams to better serve society and retain some of their achievements in universities, resulting in mutual benefits for both universities and enterprises.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

The studies involving human participants were reviewed and approved by the Biomedical Ethics Committee of Nankai University. The patients/participants provided their written informed consent to participate in this study. The studies were conducted in accordance with the local legislation and institutional requirements.

Author contributions

TG: Methodology, Conceptualization, Writing – review and editing, Software, Writing – original draft. AH: Writing – original draft, Investigation, Validation. LZ: Visualization, Writing – review and editing. SY: Writing – review and editing.

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