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Research on the Impact of Scientific and Technological Talent Agglomeration on Green Development

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ABSTRACT

With the intensification of the global ecological crisis, promoting green development has become a key path to achieve sustainable development. Based on the panel data of 30 provincial-level administrative regions in China from 2011 to 2022, this paper systematically examines the impact of scientific and technological talent agglomeration on regional green development and its mechanism of action. The study constructs a comprehensive evaluation index system of regional green development level, adopts location entropy to measure the degree of scientific and technological talent concentration, and empirically analyses it by using the fixed effect model, mediation effect model and moderating effect model. The study finds that (1) scientific and technological talent concentration has a significant promotion effect on green development, and this conclusion still holds after various robustness tests and endogeneity treatment; (2) from the perspective of regional heterogeneity, the green development effect of scientific and technological talent concentration is significant in the eastern region, while it is not significant in the central and western regions; from the perspective of period heterogeneity, the promotion effect of scientific and technological talent concentration is more significant after the introduction of 'The Outline of National Innovation-Driven Development Strategy'; from the perspective of Internet development, the promotion effect is more significant; from the perspective of the heterogeneity of period, the promotion effect is more significant; from the perspective of heterogeneity of the level of Internet development, scientific and technological talent agglomeration shows a stronger promotion effect in regions with a lower level of Internet development; (3) the mechanism test shows that scientific and technological talent agglomeration can promote green development through two paths of enhancing the level of public environmental concern and promoting green technological innovation, and at the same time, the level of marketisation and the government's attention to scientific and technological talent can positively regulate this kind of promotion. Based on the conclusions of the study, this paper puts forward policy suggestions to systematically improve the level of regional scientific and technological talent concentration, and to give full play to the effects of external supervision and technological innovation.

KEYWORDS

Scientific and technological talent agglomeration; Green development; Public environmental concern; Green technology innovation

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1. Introduction

With the acceleration of industrialization and urbanization, the world is facing severe challenges such as climate change, resource scarcity and declining biodiversity, which pose a major threat to the sustainable development and long-term stability of human society. The traditional economic growth model based on high resource consumption and high environmental costs is no longer sustainable, and it is urgent to explore a new development path that takes into account economic growth and ecological protection. Driven by a number of international environmental agreements such as the United Nations Framework Convention on Climate Change and the Paris Agreement, the green development agenda has received widespread global attention, and countries have successively formulated and implemented green development strategies to cope with the increasingly severe ecological crisis. China's economy has maintained a steady growth trend, and although it has made many remarkable achievements in the process, it has also produced serious environmental pollution and ecosystem degradation problems, such as increased smog, water pollution, and soil quality, which need to be solved urgently by changing the development mode. At present, China's economy is in the critical stage of structural optimization and development momentum transformation, and how to achieve a balance between economic development and ecological environmental protection has become the core issue of sustainable development. In this context, promoting a major strategy with innovation-driven and green development as the core is not only an inevitable choice to deal with environmental constraints, but also a key path to shape future economic competitiveness. As a key driver of innovation, scientific and technological talents play an irreplaceable role in leading technological breakthroughs and promoting industrial upgrading. In the process of in-depth adjustment of the economic structure, talent is the key variable, and the party and the state attach great importance to the basic role of talent in innovation and development. The Fourth Plenary Session of the 19th Central Committee of the Communist Party of China and the Fifth Plenary Session of the 19th Central Committee of the Communist Party of China successively proposed to build an institutional mechanism to promote the benign and orderly flow of talents, comprehensively stimulate the innovation vitality of all kinds of talents, and fully release the talent dividend. By establishing a sound talent flow and incentive mechanism, breaking down institutional barriers, and building a more open talent ecosystem, we can further enhance the enthusiasm and creativity of talents, so that they can realize their potential in a wider range of fields. The report of the 20th National Congress of the Communist Party of China further pointed out that education, science and technology, and talents are important foundations and strategic supports for building a modern socialist country in an all-round way, and that the coordinated development of the "trinity" must be regarded as a long-term strategy, and clearly put forward that "science and technology are the primary productive forces, talents are the first resources, and innovation is the first driving force". In the new journey of building a modern socialist country in an all-round way, by strengthening the cultivation of scientific and technological talents, we can give full play to their leading role in innovation-driven and green development strategies, and provide continuous impetus for achieving high-quality economic development. Based on this, this paper organically combines green development and the agglomeration of scientific and technological talents in a unified framework, sorts out the relevant literature and theories, clarifies the relationship between the two, analyzes the impact of scientific and technological talent agglomeration on green development and the impact path, and forms targeted and feasible countermeasures according to the research conclusions, in order to promote the reasonable agglomeration of scientific and technological talents and improve the regional green development capacity.

2. Literature review and research hypotheses

2.1. Agglomeration of scientific and technological talents on green development

Economics ultimately addresses the distribution and allocation of social resources, and therefore explains the direct impact of scientific and technological talent concentration on green development in terms of the two basic factors of production, namely, labour and capital.

From the perspective of the labour factor, the concentration of scientific and technological talents has a far-reaching impact on the production and consumption behaviours of the labour force in the region. First, the concentration of scientific and technological talents leads to the efficient circulation and sharing of knowledge (Scarrà & Piccaluga., 2022). In areas where S&T talents are concentrated, S&T talents and non-S&T workers can obtain the latest industry news, market demand and policy support through frequent exchanges. By doing so, non-technical workers have low-cost and efficient access to innovative knowledge, including environmentally friendly technologies, sustainable development policies, and resource-efficient production methods (Tuape et al., 2022). With the transfer of new knowledge, the quality skills and environmental awareness of the entire labour force are enhanced (Wang et al., 2023). Under the incentive effect, S&T talents continuously learn new theories, technologies and skills to improve their professional quality (Salas et al., 2001). Knowledge sharing and skill interoperability within the S&T talent cluster reduces the cost of acquiring new knowledge and technology, allowing the labour force to accumulate technical understanding and professionalism (Massa et al., 2023). In areas where scientific and technological talents are concentrated, interdisciplinary, cross-sectoral, and cross-industry collaborative innovation projects are frequent, and scientific and technological talents gradually develop green production and environmentally friendly work norms, which create motivation for other labourers to learn and emulate in the process of exposure (He & Zaman, 2024). As a result, labour groups pay more attention to environmental protection in the selection of raw materials, production processes, waste management, etc., and environmentally friendly work practices are promoted, reducing the environmental burden of production activities. On the other hand, labourers, as a consumer group, are influenced by the sustainable consumption habits of science and technology talents, and gradually form environmentally friendly consumption standards through workplace interactions, daily social interaction, and the dissemination of regional cultural atmosphere (Wang et al., 2014). Overall, the concentration of scientific and technological talents promotes the standardisation of green production by facilitating knowledge sharing and skill enhancement in the production field, and leads to the formation of green consumption habits, optimises the labour force structure, and injects the concept of sustainable development into the region through the demonstration effect in the consumption field.

From the perspective of capital factors, the concentration of scientific and technological talents promotes regional green development by enhancing the efficiency and quality of capital flows. Firstly, as a signal of the soundness of the regional environmental support system, the concentration of scientific and technological talents enhances capital's trust in the regional investment environment (Zhang et al., 2024). The concentration of scientific and technological talents indicates that the region has strong innovation ability and industrial development potential, which enhances the capital market's expectation of regional investment returns (Li et al., 2022). In the context of green financial development, green bonds, green funds and other financial instruments provide more investment channels for capital, providing financial security for regional green development (Yang, X, 2023). Secondly, the accelerated information flow in the environment of scientific and technological talent concentration improves the capital's response speed to market changes and the ability to identify investment opportunities. Capital can capture market dynamics in a more timely manner, reducing decision uncertainty and waiting costs (Yanore et al., 2023). In a transparent environment, capital can quickly identify potential projects through accurate market judgement and risk assessment (Radulescu et al., 2024). With their professional knowledge and insights into environmental needs, S&T talents assist capitalists in conducting scientific and comprehensive project assessments to reduce the loss of blind investment (Gallagher et al., 2023). As a result, scientific and technological talents guide capital flow to environmentally friendly production, clean energy procurement, and eco-friendly

logistics through professional knowledge and information sharing mechanisms, forming a green capital chain that runs from production to consumption. Regional environmental protection culture and market reputation are continuously strengthened, providing a credible investment environment for long-term capital. Overall, the concentration of scientific and technological talents promotes the concentration of regional capital, provides efficient, transparent and scientific decision-making support for capital flows, and enhances the level of regional green development. Based on the above analyses, this paper proposes research hypotheses:

H1: Science and technology talent concentration can enhance the level of regional green development.

2.2. Influencing mechanism of scientific and technological talent agglomeration on green development

2.2.1. Analysis of mediating mechanism

Public environmental concern refers to the degree of public concern, attitude and action towards environmental issues, which is reflected in the continuous concern and expression of topics such as ecological protection, pollution prevention and resource management, and is presented through social behaviour, consumption choices, and policy support. Economics considers information as a key public resource, and its low-cost dissemination can effectively reduce the threshold of information and knowledge acquisition (Sheba et al., 2023). Scientific and technological talents are able to keep abreast of the latest environmental science knowledge, environmental policy dynamics and related technological advances due to their high professionalism and information acquisition capabilities (Benvenuti et al., 2023). The concentration of scientific and technological talent increases information density in the region and reduces the marginal cost of public access to environmental protection information, allowing the public to increase their exposure to environmental knowledge without specialised training or additional economic expenditure (Guo & Xu, 2024). This information can be transmitted through formal occasions such as community activities, environmental lectures, and company environmental training, as well as through informal means such as daily social interactions, social media communication, and neighbourhood exchanges, allowing for wider acceptance and dissemination of environmental information among the public. With the knowledge spillover effect of scientific and technological talents, the public's environmental knowledge level is gradually improved and their concern for environmental issues is enhanced (Zhang et al., 2024). At the same time, the participation of S&T talents in public education activities related to environmental protection deepens the public's understanding of and concern for environmental issues. According to public choice theory, individuals' perceptions and preferences are often influenced by other groups' behaviours and deepen their impressions and sense of identity in interaction (Jing et al., 2023). In the environment of scientific and technological talent concentration, the public not only receives environmental information but also asks questions or gives feedback during the participation activities, deepening their understanding of environmental issues through interaction (Jamil et al., 2023). In addition, the popularity of social media accelerates the information feedback mechanism, the public can express their views on environmental issues at any time on the network platform, and scientific and technological personnel can disseminate more information accordingly to promote the public's attention to environmental issues, forming an effective two-way communication mechanism.

Green technological innovation refers to technological innovation that reduces resource consumption, lowers environmental pollution, protects ecosystems and promotes sustainable development through technological means in economic activities. From research and development to application popularisation, green technology innovation goes through a complete chain of basic research and development, technology validation, industrialisation, market application, technology diffusion and popularisation. Endogenous growth theory suggests that technological progress comes from knowledge accumulation and innovation, and scientific and technological talent is the core element of knowledge creation (Moughari & Daim, 2023). In the basic R&D stage, the concentration of S&T talent

promotes multidisciplinary knowledge integration and accelerates technology conceptualisation (Oduro et al., 2024). For the core bottlenecks of green technologies, groups of S&T talents in the clustering area can break through through joint research. The clustering of scientific and technological talents promotes the establishment of technology testing platforms, such as shared laboratories, whose expertise can accurately assess the feasibility of the technology, identify potential risks, and optimise the design and parameters. Based on the theory of economy of scale, the concentration of scientific and technological talents reduces the unit cost and improves the production efficiency through the scale effect, which guarantees the engineering and process optimisation of green technologies, promotes the large-scale production and commercialisation of the technologies, and improves the overall efficiency of the industry (Liu & He, 2024). At this stage, the area of scientific and technological talent concentration forms a complete industrial chain structure and promotes the collaborative innovation of upstream and downstream enterprises. At the same time, the concentration of scientific and technological talents attracts more capital inflow, providing financial support for equipment upgrading and process improvement, and this two-way interaction between capital and talents accelerates the commercialisation process of green technologies (Song et al., 2023). Based on the theory of diffusion of innovation, scientific and technological talent is an important medium for the diffusion of technology from the core region to the periphery (Yang et al., 2024). The mobility of S&T talents enables the knowledge and skills of green technologies to spread rapidly to other regions. In addition, S&T talent plays an important role in the development of green technology standards, which further enhances the diffusion efficiency of technological innovation through standardisation. Based on the above analyses, this paper proposes the research hypothesis:

H2: The concentration of scientific and technological talents can enhance the level of regional green development by increasing the level of public environmental concern and promoting green technological innovation.

2.2.2. Analysis of moderating mechanism

The level of marketisation measures the degree of resource allocation through the market mechanism, which mainly includes four dimensions: the degree of government intervention, the degree of product market development, the degree of factor market development and the degree of improvement of the rule of law environment. A lower level of government intervention implies that market players are given more autonomy (Anjos et al., 2022). By reducing administrative approval procedures and lowering administrative regulation, the government significantly reduces the systemic cost of innovation for scientific and technological talents, enabling them to freely allocate resources according to market demand and innovation logic (Liu et al., 2024). At the same time, the government's reform of decentralisation has shifted its functions from direct control to optimising the construction of the innovation ecosystem, such as building open innovation platforms, providing precise policy guidance, providing high-quality public services for scientific and technological talents and enterprises, and creating a vibrant institutional space (Xu et al., 2024). Sound product and factor markets provide a broad market space and efficient resource allocation mechanism for the impact of scientific and technological talent concentration on green development. Mature product markets enable green technology innovations to obtain abundant market application scenarios and commercialisation paths, and scientific and technological talents can quickly identify needs and carry out technology iteration through market feedback (Wenger et al., 2024). In a highly marketised factor market, innovation factors can flow more freely and accurately, and provide diversified financing channels and risk diversification mechanisms for scientific and technological talents (Ge et al., 2024). Through tools such as equity financing, technology shareholding and venture capital, scientific and technological talents can obtain continuous financial support. A perfect rule of law environment is the key institutional guarantee for the regulating effect of marketisation level. A sound intellectual property protection system clearly defines the boundaries of the property rights of innovative achievements and reduces the systemic risk of scientific and technological talents

(Mariani & Dwivedi, 2024). Such protection not only ensures that innovation subjects receive matching economic returns, but also promotes the diffusion and application of innovations through mechanisms such as patent licensing and technology transfer. Fair and transparent market rules effectively inhibit unfair competition, and a perfect rule of law environment enhances the willingness of scientific and technological talents to invest, forming a long-term incentive mechanism for sustained innovation.

Attention theory was first proposed by Simon (1947), who believed that attention is a scarce resource that needs to be allocated among different goals. William Ocasio developed the theory of organisational attention on this basis, pointing out that organisational attention is the extent to which decision makers pay attention to particular problems, opportunities and threats. Due to attention scarcity, in the face of limited and asymmetric decision-making information, the government allocates attention resources from the perspective of public goals and benefit maximisation. The attention of government S&T talents originates from the strategy of strengthening the country with talents, which reflects the government's policy strength in cultivating, introducing, and supporting S&T talents (Zhang et al., 2023). As a pressure transfer mechanism, it can strengthen the promotion effect of S&T talent concentration on green development. First of all, the government's high attention to scientific and technological talents improves the talent policy system, creates a good development environment through the formulation of targeted talent programmes, and enhances the agglomeration effect. The scientific talent evaluation system and effective incentives stimulate the creativity of scientific and technological talents, promote the output of breakthrough innovations, and provide intellectual support for regional green development (Ma & Yang, 2024). Secondly, the government's attention to scientific and technological talents has optimised the allocation of resources, providing adequate protection for scientific and technological talents' research by increasing research investment, improving infrastructure and providing supporting services (Yu & Du, 2023). This moderating effect is also reflected in the construction of industry-university-research collaborative innovation system. Through the construction of innovation platforms and the establishment of synergistic mechanisms, talent exchange and cooperation networks are formed to promote the efficient flow and integration of innovation factors and improve the innovation and entrepreneurship ecosystem. Scientific and technological talents and industrial needs to achieve accurate docking, accelerate the transformation of technological innovation results, and enhance the kinetic energy of regional green development. Based on this, this paper proposes research hypotheses:

H3: The marketisation level and government attention to scientific and technological talents can positively regulate the promotion effect of scientific and technological talent agglomeration on green development. Specifically, the higher the level of marketisation and the government's attention to scientific and technological talent, the more significant the positive impact of scientific and technological talent concentration on green development.

3. Research design

3.1. Sample selection and data sources

3.1.1. Explanatory variable

Green development level (Gre) is the dependent variable of this study, because green development covers multiple dimensions such as economic benefits and environmental protection, therefore, this paper constructs a comprehensive evaluation index system of green development through the entropy value method. This comprehensive indicator can reflect the actual progress of each region in promoting sustainable development and environmental protection in a multi-dimensional and systematic way, and ensure that the level of green development is evaluated as comprehensively as possible, as detailed in Section 3.2.1 for specific measurement methods.

3.1.2. Core explanatory variable

Science and Technology Talent Agglomeration (Agg) is the core explanatory variable of this study, which refers to the concentration of scientific and technological personnel, especially those engaged in research and development (R&D) activities in a specific region. The location entropy can be measured by the method of location entropy, which can reflect the relative degree of scientific and technological talent concentration in a region.

3.1.3. Control variables

In this paper, the level of government financial support (Gov), the level of transportation infrastructure (Tra), the degree of openness to the outside world (Open), the level of urbanization (Urb) and the level of human capital (Edu) were selected as the control variables. This paper uses the ratio of general budget expenditure to GDP to characterize the level of government financial support, the logarithm of the national highway mileage to characterize the level of transportation infrastructure, the proportion of the actual total import and export volume to the gross regional product to characterize the degree of opening to the outside world, the ratio of the permanent population to the total population at the end of the year to characterize the level of urbanization, and the level of human capital uses the average number of years of education, that is, the population over 6 years old, primary and secondary school, junior high school, high school, secondary vocational, college and above to give 6, 9, 12, 16 years of schooling, which is represented by the weighted sum divided by the total population over 6 years of age.

3.1.4. Mediating variables

According to the above theoretical analysis, the agglomeration of scientific and technological talents can improve the level of regional green development by improving the level of public environmental concern and promoting green technology innovation. Public environmental concern is an informal means of environmental regulation, and referring to the practice of Wu Libo et al., this study uses the Baidu search index of "environmental pollution" as a proxy variable for public environmental concern. At the same time, compared with traditional innovation, green technology innovation can more effectively reduce the adverse impact of production behavior on ecology, which plays a key role in the process of achieving regional green development. Referring to the practice of Li Qingyuan et al., this study uses the logarithm of the number of green patent applications in each region as a proxy variable for green technology innovation. The reason for choosing the number of applications is that many green patents are usually applied at the time of patent application, which can more timely and directly reflect the green innovation activities of the region, and thus have an impact on environmental governance.

3.1.5. Moderating variables

According to the above theoretical analysis, the level of marketization and the attention of government scientific and technological talents were selected as the two moderator variables in this study. Among them, the level of marketization is comprehensively measured from five indicators: the relationship between the government and the market, the development of the non-state-owned economy, the development of the product market, the development of the factor market, the development of the market intermediary organization and the legal system. The attention of government science and technology talents is to learn from the practice of Su Taoyong and others, and take the frequency of keywords of science and technology talents in the government work report as the indicator of the attention of government science and technology talents, which mainly includes human resources, talent team construction, scientific research personnel, scientific and technological innovation, etc.

3.2. Modelling setting

In order to clarify the impact of scientific and technological talent agglomeration on green development, the

level of green development (Gre) was taken as the dependent variable and the scientific and technological talent agglomeration (Agg) was taken as the core explanatory variable. At the same time, in order to alleviate the influence of endogeneity on the estimation results, this paper uses the two-way fixed effect of individual and time to analyze the impact of scientific and technological talent agglomeration on green development. The specific model setting is as follows:

$$Gre_{it} = \alpha_0 + \alpha_1 Agg_{it} + \sum \alpha_j Controls_{it} + \mu_i + v_t + \varepsilon_{it} \quad (1)$$

In the above equation, i and t represent time and region respectively. Gre_{it} is the explanatory variable, which indicates the green development level of region i in year t. Agg_{it} is the core explanatory variable, which represents the concentration of scientific and technological talents in the tth year of region i, and Controls represents a series of control variables. αare the parameters to be estimated for each variable, μ_i and $v_t$are temporal dummy variables and regional dummy variables, respectively, which are used to control the two−way fixed effect, ε_{it} represent the random perturbation term.

Based on the above theoretical analysis, this paper deeply analyzes the transmission mechanism of scientific and technological talent agglomeration on green development from the perspective of environmental concern and technological innovation. In order to avoid the estimation error caused by the traditional stepwise regression mediation effect test, this paper adopts the two-step mediation test proposed by Jiang Boat to test the impact of scientific and technological talent agglomeration on public environmental concern and green technology innovation in the empirical part. The specific model setting is as follows:

$$M_{it} = \beta_0 + \beta_1 Agg_{it} + \sum \beta_j Controls_{it} + \mu_i + v_t + \varepsilon_{it} \quad (2)$$

M_{it} are public environmental concern and green technology innovation, on the basis of α_1 is positive and passes the significance test,if β_1 is significantly positive, public environmental concern and green technology innovation can become a powerful transmission path, thereby improving the level of green development.

In order to further verify the moderating role of marketization level and government attention of scientific and technological talents in the impact of scientific and technological talent agglomeration on green development, the moderating variables were introduced into the model, and the interaction terms of scientific and technological talent agglomeration were introduced into the model. The specific model setting is as follows:

$$Gre_{it} = \gamma_0 + \gamma_1 Agg_{it} + \gamma_2 Adj_{it} + \gamma_3 Agg_{it} * Adj_{it} + \sum \gamma_j Controls_{it} + \mu_i + v_t + \varepsilon_{it} \quad (3)$$

Adj_{it} are the level of marketization and the attention of government scientific and technological talents, On the basis of α_1 being positive and passing the significance test, if the interaction term γ_3 is significantly positive, the level of marketization and the attention of government scientific and technological talents can positively regulate the promotion of scientific and technological talent agglomeration on green development.

4. Empirical analysis

4.1. Benchmark regression

Firstly, the two-way fixed effect model is used to estimate the impact of scientific and technological talent agglomeration on green development. Considering the stepwise addition of control variables can reveal the effect of the core explanatory variable on the dependent variable under different variable conditions, resulting in more

robust results. In order to observe the coefficients of the core explanatory variables, the control variables such as government financial support (Gov), transportation infrastructure level (Tra), openness to the outside world (Open), urbanization level (Urb) and human capital level (Edu), the control variables were gradually increased. As shown in columns (1) to (6) of the Table 1, when the control variables such as government financial support (Gov), transportation infrastructure level (Tra), openness to the outside world (Open), urbanization level (Urb) and human capital level (Edu) are gradually added, the coefficients of scientific and technological talent agglomeration are statistically significant at the significance level of 1%, and the coefficients are always positive, which can be concluded that the concentration of scientific and technological talents can improve the level of regional green development.

Table 1. Benchmark regression analysis.

VARIABLES	(1) y	(2) y	(3) y	(4) y	(5) y	(6) y
Agg	0.0244***	0.0247***	0.0266***	0.0340***	0.0331***	0.0302***
	(0.0085)	(0.0088)	(0.0093)	(0.0099)	(0.0103)	(0.0102)
Gov		0.0071	0.0005	0.0302	0.0329	0.0453
		(0.0594)	(0.0603)	(0.0615)	(0.0621)	(0.0615)
Tra			-0.0163	-0.0067	-0.0073	-0.0112
			(0.0252)	(0.0254)	(0.0255)	(0.0252)
Open				-0.0447**	-0.0463**	-0.0539**
				(0.0205)	(0.0211)	(0.0210)
Urb					0.0224	0.0838
					(0.0679)	(0.0703)
Edu						0.0141***
						(0.0048)
Constant	0.2768***	0.2750***	0.4630	0.3519	0.3478	0.2379
	(0.0101)	(0.0187)	(0.2910)	(0.2937)	(0.2944)	(0.2933)
Observations	360	360	360	360	360	360
R-squared	0.090	0.090	0.091	0.105	0.105	0.129
id FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

*Notes: ***, **, and * denote statistical significance at the 0.1%, 1%, and 5% levels, respectively.*

4.2. Analysis of mechanisms

4.2.1. Mediating analysis

The benchmark regression results in the above paper show that the concentration of scientific and technological talents significantly promotes the level of regional green development. The concentration of scientific and technological talents may affect the level of green development through external supervision effects and technical effects.

Columns (1) and (2) in the Table 2 show that the coefficient of scientific and technological talent agglomeration for green development is 0.03 and passes the 1% significant level test, and the coefficient of public environmental concern is also significantly positive. This means that the concentration of scientific and technological talents has promoted the level of green development in the region by raising public environmental concern. On the one hand, the gathering of scientific and technological talents is often accompanied by high-quality knowledge dissemination and information sharing, and scientific and technological talents can deepen the public's understanding of environmental issues through various channels such as academic exchanges and scientific research activities. On the other hand, the gathering of scientific and technological talents will directly bring about the application of new local technologies, such as the popularization of clean energy, the promotion of intelligent transportation systems,

and the extensive use of environmental protection equipment. The application of these new technologies allows the public to directly experience the benefits of environmental improvement, which not only enhances the public's confidence in environmental protection technologies, but also prompts them to pay more attention to environment-related issues. Therefore, the Science and Technology Talent Cluster promotes green development at a broader level by raising public awareness of the environment.

The results of columns (1) and (3) in the Table 2 show that the coefficients of scientific and technological talent agglomeration on green development and scientific and technological talent agglomeration on green technology innovation are significantly positive, revealing the potential impact mechanism of scientific and technological talent agglomeration on the level of green development through green technology innovation. On the one hand, as the most active element of the innovation system, scientific and technological talents can trigger a chain reaction through their own agglomeration effect, thereby promoting the agglomeration of other innovation elements such as capital and technology, and promoting green technology innovation. On the other hand, the agglomeration of scientific and technological talents can build an innovation ecological network within the region and between industries, break the traditional barriers to technology research and development, and greatly improve the systematic, collaborative and open nature of green technology innovation.

Table 2. Mediating analysis.

VARIABLES	(1) y	(2) PEC	(3) GTI
Agg	0.0302***	0.1142***	0.1736**
	(0.0102)	(0.0320)	(0.0797)
Gov	0.0453	-0.4693**	0.6608
	(0.0615)	(0.1923)	(0.4785)
Tra	-0.0112	-0.0583	1.2801***
	(0.0252)	(0.0789)	(0.1964)
Open	-0.0539**	-0.1470**	-0.2849*
	(0.0210)	(0.0656)	(0.1631)
Urb	0.0838	-0.2236	0.5479
	(0.0703)	(0.2197)	(0.5469)
Edu	0.0141***	-0.0093	0.0252
	(0.0048)	(0.0150)	(0.0374)
Constant	0.2379	1.6227*	-8.7978***
	(0.2933)	(0.9168)	(2.2816)
Observations	360	360	360
R-squared	0.129	0.879	0.929
id FE	YES	YES	YES
year FE	YES	YES	YES

*Notes: ***, **, and * denote statistical significance at the 0.1%, 1%, and 5% levels, respectively.*

4.2.2. Moderating analysis

In order to explore whether the level of marketization and the attention level of government scientific and technological talents can play a moderating role in the impact of scientific and technological talent agglomeration on green development, this paper uses the moderating effect to test, and the test results are as shown in the Table 3. In column (1) of the Table 3, the coefficient of Market*Agg is 0.047, which passes the significance level test of 1%. This means that there is a significant positive interaction between the level of marketization and the agglomeration of scientific and technological talents, that is, when the level of marketization increases, the positive effect of the agglomeration of scientific and technological talents on green development is more obvious. A higher level of marketization can guide the flow of various production factors to a better market by amplifying the agglomeration effect of scientific and technological talents, improve the utilization efficiency of factors, and also promote market

competition and innovation incentives, thereby promoting the improvement of green development level.

In column (2) of the Table 3, the coefficient of Attention*Agg is 0.008, which passes the significance level test of 5%. These results indicate that the interaction term Attention*Agg, between the attention of government science and technology talents and the concentration of science and technology talents, has a significant positive moderating effect. This means that when the government's attention to scientific and technological talents increases, the positive impact of scientific and technological talent agglomeration on green development is significantly enhanced. This is because the government's attention to the cultivation of scientific and technological talents can often ensure that the role of scientific and technological talents in promoting regional green development is maximized through direct pressure transmission mechanisms such as institutional design and regulatory measures

Table 3. Mediating analysis.

VARIABLES	(1) y	(2) y
Agg	0.0258**	0.0164
	(0.0101)	(0.0119)
Market	0.0102***	
	(0.0031)	
Market*Agg	0.0475***	
	(0.0150)	
Attention		0.0003
		(0.0045)
Attention*Agg		0.0079**
		(0.0040)
Gov	0.0544	0.0317
	(0.0609)	(0.0609)
Tra	-0.0031	-0.0191
	(0.0251)	(0.0251)
Open	-0.0412**	-0.0407*
	(0.0207)	(0.0217)
Urb	0.0634	0.1109
	(0.0689)	(0.0702)
Edu	0.0104**	0.0125***
	(0.0047)	(0.0048)
Constant	0.1172	0.3322
	(0.2941)	(0.2919)
Observations	360	360
R-squared	0.192	0.157
id FE	YES	YES
year FE	YES	YES

*Notes: ***, **, and * denote statistical significance at the 0.1%, 1%, and 5% levels, respectively.*

4.3. Endogeneity test

In the previous paper, we conclude that the concentration of scientific and technological talents has a significant positive impact on regional green development, but the benchmark regression results may be affected by endogeneity, resulting in errors in the estimation results. First of all, there is a reverse causal problem, with the promotion of local environmental policies, the rise of green industries, etc., the level of green development has improved, and it will also attract more scientific and technological talents. This two-way causal relationship makes it difficult to discern the net effect of scientific and technological talent agglomeration on green development. On the other hand, this study cannot control all the variables related to the concentration of scientific and technological talents and green development. If these factors are not included in the model, they may cause the error terms in the

model to be associated with explanatory variables, which in turn can affect the accuracy of the estimates. Therefore, by using the instrumental variable method, we try to alleviate the interference of endogeneity on the net effect of scientific and technological talent agglomeration on green development.

This paper uses the number of jinshi in each province during the Ming and Qing dynasties as an instrumental variable. An effective variable needs to meet the requirements of both relevance and exclusivity. On the one hand, during the Ming and Qing dynasties, areas with a large number of Jinshi usually had a deeper Confucian cultural tradition and an atmosphere that attached importance to education. This kind of cultural heritage that attaches great importance to education may affect the cultivation and agglomeration of modern scientific and technological talents through intergenerational inheritance, family education, local culture and other ways, so the number of Jinshi data in the Ming and Qing dynasties in the region is selected to meet the relevance. On the other hand, the imperial examination system was abolished in 1905, and the level of modern green development is often not directly constrained by the historical factor of the imperial examination system or the distribution of jinshi hundreds of years ago, and meets the requirement of exclusivity. Therefore, this study suggests that the number of Jinshi in each province in the Ming and Qing dynasties may be a suitable instrumental variable, and at the same time, the data on the number of Jinshi in the Ming and Qing dynasties in each province are collected based on the CNRDS Confucian culture database to characterize the concentration level of modern scientific and technological talents. However, since this data is a cross-sectional data, we multiply it by the year to obtain a tool variable in the form of a panel, considering that it needs to be extended to panel data. As can be seen from the Table 4, the p-value of the LM statistic of the instrumental variable in the non-recognizable test is 0.000, which passes the unrecognizable test, and at the same time, the Wald F statistic is greater than the critical value of the Stock-Yogo weak ID test critical values at the 10% level in the weak instrumental variable test, which passes the weak instrumental variable test, indicating that the instrumental variable is valid. In the first stage of regression, the coefficient of the instrumental variable is significantly positive, which is in line with the theoretical expectation. In the second stage of regression, the coefficient of scientific and technological talent agglomeration was 0.0413, which passed the significance test of 5% significance. This result shows that the benchmark conclusion of this paper is still valid after the introduction of instrumental variables to mitigate the intervention of reverse causality.

Table 4. Endogeneity test.

VARIABLES	(1) Agg	(2) y
JinshiIV	0.0005***	
	(0.0001)	
Agg		0.0413**
		(0.0182)
Gov	-0.4761	0.1081***
	(0.3549)	(0.0415)
Tra	-0.2232***	0.0078
	(0.0429)	(0.0057)
Open	1.7138***	0.0731**
	(0.1257)	(0.0365)
Urb	-0.1059	0.1931***
	(0.3638)	(0.0376)
Edu	0.3198***	0.0027
	(0.0000)	(0.0063)
Under identification test		30.738
		<0.000>
Weak identification test		31.927
		[16.38]

Constant	0.2274	-0.0061
	(0.8596)	(0.0891)
Observations	360	360
R-squared	0.690	0.709

Notes: The p-value of the LM statistic is in angle brackets; Inside the square brackets are the cut-off values of the Stock-Yogo weak ID test critical values at the 10% significance level.

4.4. Robustness tests

In order to further test whether the above conclusions are robust and valid, the robustness test was carried out by adding control variables, shrinking the tail, replacing the model, and excluding the special year.

4.4.1. Add important control variables

Although the relevant variables affecting green development are controlled in the benchmark regression, such as the level of government financial support (Gov), the level of transportation infrastructure (Tra), the degree of openness to the outside world (Open), the level of urbanization (Urb) and the level of human capital (Edu), considering that there may still be some important related variables, the level of fixed asset investment, foreign direct investment, financial development level and informatization level are continued to be controlled in this part. The ratio of the sum of deposits and loans of financial institutions and the total volume of post and telecommunications business to GDP is characterized. After increasing the four control variables, namely fixed asset investment (FAI), foreign direct investment (FDI), financial development level (Fin) and informatization level (Inf), as shown in the column (1) of the Table 5 the regression coefficient for scientific and technological talent pooling remains significantly positive.

4.4.2. Tail the data

Since the regression results of the model are usually affected by a few extreme data, in order to exclude this effect, all continuous variables were tested after 1% tailing on both sides. In the column (2) of the Table 5, the regression coefficient of scientific and technological talent agglomeration was 0.036, and it was significant at the 1% significance level. This proves that the benchmark regression results are robust.

4.4.3. Replace the model

The Tobit model is usually used to deal with situations where the dependent variable is truncated or restricted, and is suitable for scenarios where the value of the dependent variable is limited, such as an upper or lower bound. In this paper, the value of the explanatory variable green development level calculated by the entropy weight method ranges from 0 to 1, that is, the value of the dependent variable is limited, which meets the conditions for the use of the Tobit model. In the column (3) of the Table 5, the regression coefficient of the concentration of scientific and technological talents was 0.041, and it was significant at the 1% significance level. This indicates that the positive impact of the concentration of scientific and technological talents on green development is still significant in the case of the Tobit model. This also proves that the benchmark regression results are robust.

4.4.4. Exclude special years

At the beginning of 2020, the new crown epidemic occurred, and all aspects of domestic society were temporarily impacted. In the early days of the pandemic, provinces adopted strict border control measures, which led to some restrictions on the movement of talent. At the same time, the epidemic has also sprouted the exploration of new education and scientific research models, which makes the agglomeration ecology of scientific and technological talents no longer limited to geographical agglomeration, and the way has become more flexible and

diversified. At the same time, the epidemic has also had an impact on the allocation of economic resources, which will inevitably have an impact on the level of regional green development. Based on this, the samples of 2020, 2021, and 2022 were deleted and re-entered. The coefficient of scientific and technological talent agglomeration In the column (4) of the Table 5 is positive, and it still passes the significance test at the 10% level. It can be seen that the results of benchmark regression are still robust and valid.

Table 5. Robustness tests.

VARIABLES	(1)	(2)	(3)	(4)
	y	y	y	y
Agg	0.0204**	0.0382***	0.0409***	0.0199*
	(0.0103)	(0.0114)	(0.0082)	(0.0109)
Gov	0.0538	0.0604	-0.0137	0.0391
	(0.0687)	(0.0603)	(0.0482)	(0.0687)
Tra	-0.0320	-0.0632***	-0.0290***	-0.0593*
	(0.0250)	(0.0243)	(0.0092)	(0.0310)
Open	-0.0239	-0.0330	-0.0105	-0.0948***
	(0.0215)	(0.0265)	(0.0186)	(0.0205)
Urb	0.0183	0.3718***	-0.0160	0.0798
	(0.0697)	(0.0960)	(0.0319)	(0.0736)
Edu	0.0112**	0.0085	-0.0001	0.0296***
	(0.0047)	(0.0055)	(0.0021)	(0.0088)
Fai	-0.0235**			
	(0.0113)			
Fdi	0.6464***			
	(0.1392)			
Fin	-0.0061			
	(0.0067)			
Inf	-0.0137			
	(0.0101)			
Constant	0.5543*	0.7280***	0.6120***	0.6836*
	(0.2938)	(0.2807)	(0.1098)	(0.3517)
Observations	360	360	360	270
R-squared	0.196	0.208		0.202
id FE	YES	YES		YES
Year FE	YES	YES		YES

*Notes: ***, **, and * denote statistical significance at the 0.1%, 1%, and 5% levels, respectively.*

4.5. Heterogeneity test

4.5.1. Regional heterogeneity

China has a vast geographical area, and there is significant heterogeneity among different regions in terms of geographical endowment and policy environment. The intricacies and diversity of these regional factors have a profound impact on the concentration of scientific and technological talents and the level of regional green development. Therefore, the whole sample is divided into the eastern and central regions to test the heterogeneous effect of scientific and technological talent agglomeration on green development. Column (1) in the Table 6 shows that the coefficient of scientific and technological talent agglomeration in the eastern region is 0.035, which is significantly positive, which means that the agglomeration of scientific and technological talents promotes the green development level of the eastern region. (2) The coefficient of scientific and technological talent agglomeration is positive but not significant, which means that the impact of scientific and technological talent agglomeration on the green development of central and western regions has not been fully released. This may be due to the fact that the

east, as an economically developed region, has attracted a nationwide gathering of scientific and technological talents, forming a spillover effect of innovative knowledge and improving the overall innovation ability. However, due to the low attractiveness of the central and western regions, the inflow of scientific and technological talents is limited, and it is difficult to form a sufficient agglomeration effect, which makes the driving force of scientific and technological innovation for green development weak. First of all, the eastern region has a stronger economic base, with a large concentration of high-tech enterprises, scientific research institutions and universities, which provides vast research and cooperation opportunities for scientific and technological talents, as well as good infrastructure and living conditions, allowing them to carry out innovative work more effectively. However, the scientific research and industrial foundation in the central and western regions is relatively weak, and the innovation environment and supporting facilities are not perfect, making it difficult for scientific and technological talents to fully display their talents. Second, the industrial structure of the eastern region is more suitable for the needs of green development. The industries in the eastern part of the country are more inclined to high-tech, service and advanced manufacturing, facing greater pressure from industrial upgrading and green transformation, and there is an urgent demand for clean technology and energy conservation and emission reduction, so they are more willing to introduce scientific and technological talents to promote green technology innovation and application. However, the central and western regions are dominated by traditional energy, mining and heavy industry, and the cost of green transformation of industries is high, even if scientific and technological talents are concentrated, it is difficult to see significant results in the short term.

4.5.2. Temporal heterogeneity test based on central policy guidance

The Outline of the National Innovation-Driven Development Strategy (hereinafter referred to as the "Outline") is a programmatic document issued by the Chinese government in 2016 to promote China's transition from a factor-driven and investment-driven growth model to an innovation-driven sustainable development model. The outline regards scientific and technological talents as a core element in the implementation of the innovation-driven development strategy, so 2016 is an important node. The period from 2011 to 2022 was divided into two sample intervals, namely pre-outline (2011-2015) and post-outline (2016-2022). Before the introduction of the outline, the impact of scientific and technological talent agglomeration on green development was 0.015 but not significant, but after the introduction of the outline, the coefficient of scientific and technological talent agglomeration was significantly positive. The reason for this difference is that this outline emphasizes "creating an institutional environment conducive to the development of innovative talents", so whether it is from financial support or from the construction of innovation platforms, scientific and technological talents can get greater support and R&D efficiency has been greatly improved. At the same time, the incentive mechanism of scientific and technological talents has also improved the marginal utility of scientific and technological talents. In short, the increase in the matching degree between the supply of scientific and technological talents and the demand for green development driven by the policy means that the innovative achievements of scientific and technological talents can better meet the market demand, so that the effect of the agglomeration of scientific and technological talents is significantly amplified after the policy is introduced.

4.5.3. The level of Internet development heterogeneity

There are significant differences in the level of Internet development in different regions of China, reflecting the regional imbalance in information infrastructure construction, economic development model, and technological innovation capabilities. In the era of digital economy, the flow of information and the diffusion of technology depend on the development and popularization of the Internet. In this study, we used the Internet broadband access users in each province to characterize the level of Internet development, and divided the whole sample into regions with

high Internet development level and low Internet development level, so as to test the heterogeneous effect of scientific and technological talent agglomeration on green development. Column (3) in the Table 6 shows that the coefficient of scientific and technological talent agglomeration is positive but not significant in areas with high Internet development level, indicating that the promotion effect of scientific and technological talent agglomeration on green development in these regions is not significant. Column (2) shows that the coefficient of scientific and technological talent agglomeration is positive and significant in areas with low Internet development level, which means that the role of scientific and technological talent agglomeration in promoting green development is more significant in these regions. One possible explanation is that, first, regions with a high level of Internet development tend to have advanced infrastructure and relatively complete technological innovation systems. The green development of these areas has been improved through various channels, so although the concentration of scientific and technological talents is conducive to the improvement of green development, the marginal effect is not significant. On the contrary, in areas with a low level of Internet development, the degree of informatization is low, the infrastructure and technical conditions are relatively backward, and the demand for green development is more urgent. In this environment, the agglomeration of scientific and technological talents can significantly improve the technical level, bring about innovation effects, and play a more prominent role in promoting green development. Second, in areas with a high level of Internet development, technical exchanges between enterprises and scientific research institutions are more frequent, and innovation networks are more mature, so the role of scientific and technological talents may tend to be saturated, and it is difficult to further improve green development through agglomeration. In areas with a low level of Internet development, information dissemination and technology diffusion are relatively slow, and the introduction of scientific and technological talents can make up for these shortcomings, play a greater leading role, and promote the transformation and upgrading of regional green development. Therefore, the concentration of scientific and technological talents in areas with a low level of Internet development can produce a more significant green development effect.

Table 6. Heterogeneity tests.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Eastern part	Central and western part	Pre-policy	Post-policy	High Internet development	Low Internet development
Agg	0.0345***	0.0263	0.0151	0.0378**	0.0131	0.0622***
	(0.0092)	(0.0215)	(0.0160)	(0.0175)	(0.0151)	(0.0184)
Gov	0.6187***	-0.0325	0.0573	0.0454	-0.0495	0.1404*
	(0.1124)	(0.0808)	(0.1600)	(0.1039)	(0.1098)	(0.0829)
Tra	0.0307	-0.1308***	0.0304	0.0546	-0.0115	-0.0158
	(0.0315)	(0.0324)	(0.0634)	(0.0428)	(0.0291)	(0.0451)
Open	-0.1164***	-0.1054*	-0.1150***	0.0274	-0.0117	-0.0809**
	(0.0207)	(0.0623)	(0.0357)	(0.0681)	(0.0280)	(0.0346)
Urb	-0.0318	0.4263*	-0.0149	-0.0970	0.3654***	0.0675
	(0.0626)	(0.2230)	(0.0778)	(0.1250)	(0.0943)	(0.1164)
Edu	0.0102**	0.0111	0.0221*	0.0100*	-0.0069	0.0209***
	(0.0046)	(0.0091)	(0.0124)	(0.0058)	(0.0075)	(0.0068)
Constant	-0.1352	1.5254***	-0.2302	-0.4592	0.3071	0.1804
	(0.3385)	(0.4247)	(0.7428)	(0.5205)	(0.3659)	(0.4949)
Observations	132	228	150	210	180	180
R-squared	0.606	0.197	0.166	0.106	0.253	0.245
id FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

*Notes: ***, **, and * denote statistical significance at the 0.1%, 1%, and 5% levels, respectively.*

5. Conclusion and policy implications

This study first reviews the relevant literature at home and abroad, theoretically defines the concept of scientific and technological talent agglomeration and green development, and further puts forward the influence mechanism of scientific and technological talent agglomeration on green development based on the relevant theoretical basis. On this basis, relying on a number of statistical yearbooks and authoritative databases, the panel data of 30 provinces, municipalities and autonomous regions in China from 2011 to 2022 were collected and

collated, the concentration of scientific and technological talents was measured by the method of location entropy, and the index system of green development level was constructed by using the entropy method, and the current situation of scientific and technological talent agglomeration and green development was investigated. Furthermore, through the empirical analysis of the benchmark regression model, the mediating effect model, the moderating effect model and the spatial econometric model, and the robustness test, endogeneity test and heterogeneity test are used to verify the accuracy of the results, the following conclusions are obtained: from the perspective of the whole country, the agglomeration of scientific and technological talents has a significant positive impact on green development, that is, the agglomeration of scientific and technological talents can promote regional green development. This conclusion is still valid after adding control variables, tailing the data, replacing the model, eliminating the robustness tests such as special years, and using endogenous processing such as tool variables. Based on the analysis of regional heterogeneity, the agglomeration of scientific and technological talents in the eastern region can promote its green development, while the promotion effect in the central and western regions has not reached a significant level. Based on the analysis of heterogeneity over time, the impact of scientific and technological talent agglomeration on green development is more significant after 2016, which is related to the introduction and gradual implementation of the Outline of the National Innovation-Driven Development Strategy by the central government. Based on the heterogeneity analysis of Internet development level, the green development effect of scientific and technological talent agglomeration is more significant in areas with low Internet development level. From the perspective of the influencing mechanism, the agglomeration of scientific and technological talents can promote the improvement of the level of green development through the external supervision effect, that is, the public environmental concern and the technological innovation effect, that is, the green technology innovation effect, and the marketization level and the attention level of government scientific and technological talents can positively adjust the promotion effect of scientific and technological talent agglomeration on green development, indicating that the green development effect of scientific and technological talent agglomeration is stronger in the environment of higher marketization level and higher attention of government scientific and technological talents. Based on the above conclusions, the following policy recommendations are made:

First of all, systematic policies are implemented to improve the level of regional scientific and technological talent agglomeration. The first is to establish and improve a long-term mechanism for the cultivation and introduction of scientific and technological talents. Strengthen the capacity building of institutions of higher learning and scientific research institutes to cultivate high-quality scientific and technological innovation talents by optimizing discipline settings, innovating training models, and strengthening the integration of industry and education. Improve the talent introduction mechanism and establish diversified introduction channels. Through talent recruitment fairs, international exchanges and cooperation, etc., differentiated introduction policies are formulated for talents at different levels and in different fields, and an evaluation system oriented by innovation ability and results is established. Strengthen the cultivation of international talents, support scientific and technological talents to participate in international exchanges and cooperation, and attract overseas high-level talents through project cooperation and technical consultation. The second is to build a multi-level talent incentive guarantee system. Improve the salary distribution mechanism, and establish an income distribution system that is closely linked to the value of the post and the contribution of innovation. Support enterprises to implement medium and long-term incentives such as equity incentives and option incentives, so that talents can share the fruits of development. Strengthen incentives for the transformation of scientific and technological achievements, improve the income distribution mechanism for the transformation of achievements, and increase the proportion of income of scientific research personnel. Establish a service platform for the transformation of achievements and provide full-process services. Improve the talent security system, and provide guarantees in housing, medical care,

children's education, etc. The third is to create an environment conducive to innovation and entrepreneurship. Strengthen the construction of platforms, and provide good conditions for scientific research through the construction of key laboratories and engineering technology research centers. Create an atmosphere of innovation culture, carry forward the spirit of science and craftsmanship, and establish a value orientation that advocates innovation and tolerates failure. Through innovation and entrepreneurship competitions, scientific and technological achievements exhibitions and other activities, the innovation achievements are displayed. Strengthen the protection of intellectual property rights, improve protection mechanisms, and crack down on infringements. The second is to give full play to the dual effects of external supervision and technological innovation. In terms of strengthening the effect of external supervision, the first is to improve the environmental information disclosure system, improve the mandatory disclosure mechanism of enterprise environmental information, establish a unified environmental information publicity platform, and regularly publish environmental quality reports. Include information disclosure in enterprise environmental credit assessments. The second is to build a public participation platform, use "Internet +" to build an environmental supervision platform, establish an environmental protection reporting reward mechanism, and improve the institutional guarantee for public participation in environmental decision-making. The third is to carry out environmental education and publicity, and enhance public awareness of environmental protection through various channels. In terms of improving the level of green technology innovation, the first is to set up a green technology innovation fund, focusing on supporting innovation in the fields of energy conservation and environmental protection, cleaner production, and resource recycling. Establish a project selection mechanism and implement whole-process supervision. The second is to improve the innovation incentive mechanism, implement differentiated preferential tax policies, and increase financial support. The third is to establish an innovation reward system to commend and reward teams that have made major breakthroughs.

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Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Author contributions

Yunqian Hu: Conceptualization, Methodology, Supervision, Formal analysis, Writing - review & editing. Pu Hao: Software, Visualization, Funding acquisition, Writing – original draft, Writing - review & editing, Formal analysis.

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