DOES POPULATION URBANISATION PROMOTE “QUANTITATIVE AND QUALITATIVE” GREEN TECHNOLOGY INNOVATION IN CITIES? EMPIRICAL EVIDENCE FROM CHINA

YANG, F.[1] – WANG, H. N.[2*]

[1]*School of Design and Art, Hunan Institute of Engineering, Xiangtan 411104, China*

[2]*School of Business, Hunan Institute of Engineering, Xiangtan 411104, China*

**Corresponding author*
e-mail: 274502561@qq.com

(Received 7th Oct 2025; accepted 2nd Jan 2026)

Abstract. Population urbanisation is both a main cause of environmental problems and an important way to support environmental governance. Using data from 278 prefecture-level cities in China from 2006 to 2021, this paper investigates the impact of population urbanisation on the quantity and quality of urban green technology innovation. The benchmark test confirms that urbanisation significantly promotes the quantity and quality of urban green technology innovation. Heterogeneity analysis reveals that the promotion effect of population urbanisation on green technological innovation is significantly positive in economically underdeveloped regions, central regions, and non-resource-based cities, whereas this effect is not significant in other regions. The mechanism test shows that the secondary industry and infrastructure are important channels through which population urbanisation promotes green technology innovation, i.e., urbanisation drives the development of the secondary industry and infrastructure development, thereby promoting the simultaneous improvement of the quantity and quality of green technology innovation. Threshold tests indicate that the positive impact of population urbanisation on the quantity and quality of green technology innovation exhibits a dual threshold effect based on economic development levels. As economic development levels rise, the promoting effect of population urbanisation on the quantity and quality of green technology innovation shows a non-linear trend with increasing marginal returns.
Keywords: *low-carbon, secondary industry, infrastructure, two-way fixed effects, threshold effects*

Introduction

In the context of accelerating global climate change and sustainable development, green technology innovation has become a focus of both policy practice and academic research worldwide as a key driver of overcoming resource and environmental constraints and achieving a low-carbon transformation. China, as the world’s largest carbon emitter and an emerging economy with rapid urbanisation, has seen its urbanisation rate rise from 17.9% in 1978 to 66.1% in 2023. This process is characterised by three main features: increased agglomeration effects, industrial structure upgrading, a surge in environmental governance needs. In particular, China has become a major contributor to global innovation in green and low-carbon technologies. From 2016 to 2022, the cumulative number of global patents granted for green and low-carbon technology inventions reached 558,000. Of these, Chinese patent holders received 178,000 grants, accounting for 31.9%, with an average annual growth rate of 12.5%, significantly higher than the global average of 2.5%. Is there an intrinsic link between this ‘quantitative and qualitative synergy’ in green technology innovation and the process of population urbanisation? What are the mechanisms and heterogeneous characteristics behind this phenomenon? Answering these questions not only deepens the theoretical understanding of the environmental impacts of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

urbanisation, but also provides important policy insights for developing countries to balance economic growth and environmental protection.

Cities, as hubs of population and socio-economic activities, serve as new drivers of national economic development (Boamah et al., 2018). Harvard University Professor Glaeser (2012) considers cities to be humanity's greatest invention; the dense urban living environment not only helps to protect the ecological environment, but also stimulates innovation. The value of cities lies in increasing production efficiency (Segal, 1976; Fogarty and Garofalo, 1988). In the process of urbanisation, improvements in human capital and optimisation of resource allocation can increase total factor productivity (Henderson, 2007). Regarding the impact of China's urbanisation on technological innovation, especially green technological innovation, existing studies have focused on the policy of China's 'New-Type Urbanisation Plan (2014-2020)', using a difference-in-differences approach to examine its impact on green technological innovation. Zhang et al. (2023a) found that this policy significantly influences green technological innovation in listed companies. Cheng and Chen (2024) and Liu and Zhou (2025) found that the policy can enhance cities' capacity for green technological innovation. However, there is still a lack of research on the specific indicators of urbanisation development and their impact on green technological innovation.

The aforementioned studies are of significant academic value and provide valuable insights for this research. However, it is possible to further refine these foundations. For example, Glaeser's research lacks empirical econometric testing. Additionally, studies using China as a sample have conducted empirical analyses solely from a policy perspective. Furthermore, no research has yet examined the impact of specific urbanisation development indicators on green technological innovation. Do key indicators of urbanisation development promote green technological innovation? How do these effects manifest? Are these processes influenced by other economic factors? Addressing these questions would significantly broaden existing research perspectives and enrich the body of work.

To this end, this paper uses population urbanisation as the core explanatory variable to study its impact on green technology innovation in cities, providing a valuable addition to existing research. The level of urbanisation is commonly measured by the ratio of urban population to total regional population (Qiangmin and Peng, 2023), which is referred to as population urbanisation. China, as a populous and rapidly urbanising developing country, serves as an important case study. This paper uses 278 prefecture-level cities in China from 2006 to 2021 as research samples. The conclusions drawn from this study have significant reference value for urban development and green technological innovation in other developing countries, and can also make a positive contribution to global environmental governance. In addition, this paper not only empirically examines the direct impact and heterogeneity of population urbanisation on green technological innovation, but also analyses the mechanisms, including mediating effects and threshold effects. This will better reveal the internal mechanisms through which population urbanisation influences green technological innovation, further extending existing research and providing more diverse references for policy-making.

Literature review

Factors influencing green technology innovation

Green technology, as an important tool for environmental management, has attracted the attention and research of many scholars. Existing studies show that the factors

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

influencing green technology innovation mainly focus on several aspects. First, the influence of government policies on green technology innovation. In current policies, relevant environmental protection policies, such as environmental protection taxes (Wang et al., 2024a), low-carbon pilot policies (Qiu et al., 2023), new energy policies (Zhang et al., 2024a), and environmental protection laws (Zhou et al., 2025), all have a positive impact on green technology innovation. Other policies, such as intellectual property model city policies (Cai et al., 2024), free trade zone construction policies (Liu et al., 2024), and government subsidy policies (Kong et al., 2024), also have positive effects. Second, the impact of corporate development factors on green technology innovation. Factors such as executive compensation contracts (Deng and Chen, 2024), environmental, social, and governance (ESG) ratings (Zhao et al., 2024), green bond issuance (Zhang et al., 2024b), information disclosure (Wang et al., 2025a), and negative media coverage (Deng et al., 2024) have significant positive effects on corporate green technology innovation. Third, the impact of digital development. Third, the impact of digital development. The development of the internet (Ma and Lin, 2024), the digital economy (Wu et al., 2024), digital finance (Luo and Wang, 2024), and the digital transformation of enterprises (Wang et al., 2024b) have significantly promoted green technology innovation. Other factors include green credit (Xu, 2024), foreign direct investment (Yan et al., 2025), and outward direct investment (Wang et al., 2025b), which are also favourable factors for promoting green technology innovation. Reducing carbon emissions (Li et al., 2024) and improving the efficiency of carbon markets (Wang et al., 2024c) can also promote green technology innovation. However, climate risks hinder green technology innovation (Wu, 2025).

The impact of urbanisation on technological innovation

Urbanisation is a complex process in which populations and industries are increasingly concentrated in cities. Urban development accelerates the accumulation of human capital and the spillover of knowledge, making interactions between people more frequent. Innovative behaviour is shaped by the mutual influence of different entities and elements during urbanisation, and is realised through unintentional contact and learning in the urban social environment (Enkel et al., 2009). The expansion of urban size and spatial agglomeration creates a vibrant environment that intensifies interactions and information exchange between people, generating knowledge externalities and fostering innovation (Tappeiner et al., 2008). At the same time, other scholars argue that urban spatial agglomeration contributes to the mobility and concentration of factors, which drives structural change and the occurrence of industrial growth and innovative behavior (Krugman, 1991). Cities promote industrial spatial agglomeration and generate technological externalities that not only increase the efficiency of innovation (Fujita and Mori, 1999), but also contribute to the synergistic innovation effects of industries (Kolko, 2010).

Additionally, Chinese scholars tend to use empirical methods to study the impact of urbanisation on technological innovation. Qiu (2013) found that urbanisation promotes technological innovation through the analysis of time series and regional panel data for China as a whole. Lu et al. (2017) used spatial econometric models with panel data from 264 prefecture-level cities in China, and found significant spatial spillover effects of urbanisation on technological innovation. Using the LMDI decomposition method, Tian et al. (2018) confirmed that the process of urbanisation can significantly affect the regional level of technological innovation. Tao (2023), through an instrumental variable

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

model, found that urbanisation promotes low-carbon technological innovation, thereby improving carbon emission efficiency. Chen et al. (2023) used quantile regression to examine how urbanisation in ASEAN countries can significantly promote energy technology innovation.

A review of the literature yields two conclusions. Firstly, there is a strong correlation between urbanisation and technological innovation, although urbanisation itself is an exogenous factor influencing technological innovation. Secondly, urbanisation can stimulate technological innovation. While the determinants of green technological innovation are diverse, existing research lacks studies examining the impact of specific urbanisation indicators on green technological innovation. Therefore, this study builds on existing research and is a valuable addition to the current body of work.

Theoretical analysis and research hypothesis

Direct effect

Population urbanisation, as a major driving force for the spatial reconfiguration of social resources, exerts a direct influence on green technology innovation through multidimensional transmission channels. This influence is mainly reflected in three dimensions: human capital agglomeration, demand orientation and knowledge spillovers, which together promote the dual goals of quantitative expansion and qualitative improvement of green technology innovation. In terms of human capital agglomeration, urbanisation accelerates the flow and accumulation of high-quality talent into urban spaces (Ji and E, 2019). Cities, as ‘reservoirs’ of human capital, significantly enhance the efficiency of innovation factor allocation (Zhang et al., 2023b). In China, most RD personnel and research funding are concentrated in cities at or above the prefecture level. This agglomeration effect not only directly expands the scale of investment in green technology research, but also enhances the originality and commercial value of patented technologies through knowledge complementarity and collaborative innovation. The demand-led effect influences green technology innovation through the consumption upgrading brought about by urbanisation. As the per capita disposable income of urban residents continues to rise, consumers’ environmental awareness increases (Du et al., 2023). The willingness of urban dwellers to pay for green products has also increased significantly. These changes on the demand side are forcing companies to adapt their innovation strategies and shift RD investments towards clean production, energy conservation and other green technologies. Urbanisation significantly enhances the knowledge spillover effect (Guo and Xu, 2025a). Urbanisation facilitates the formation of dense knowledge networks between firms, universities and research institutions. This spatial proximity significantly reduces the transaction costs of technology transfer, enables the rapid diffusion of tacit knowledge, and creates favourable conditions for green technology innovation. To this end, Hypothesis 1 is proposed.

Hypothesis 1: Population urbanisation can drive simultaneous improvements in both the quantity and quality of green technological innovation.

Mediating effect

Population urbanisation promotes green technological innovation by stimulating the development of secondary industries. Its mechanism is reflected in three aspects: factor agglomeration, industrial upgrading and technology spillover. Firstly, population

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

urbanisation leads to the spatial agglomeration of labour, capital and knowledge, which is the core support for the development of secondary industry. As rural populations move to cities, the manufacturing and construction sectors receive a steady supply of low-cost labour. Meanwhile, the improvement of urban infrastructure and the development of financial markets reduce the cost of financing for enterprises (Zhang et al., 2019). This factor agglomeration effect drives the expansion of secondary industries, which in turn improves R&D capacity and upgrades technological requirements, directly promoting green technology innovation. Secondly, the upgrading of consumption structure brought about by urbanisation (such as increased demand for green products) and green barriers in international trade, forcing industrial upgrading and leading enterprises to adopt cleaner production technologies. At this point, the secondary industry promotes green technological innovation in two ways. Firstly, through increased internal R&D investment by enterprises to directly develop energy-saving and emission-reducing technologies. Secondly, through the industrial chain, which requires upstream suppliers and downstream service providers to adopt green processes, creating an innovative synergy (Guo et al., 2025b). Third, population urbanisation accelerates the spatial agglomeration of secondary industries, forming clusters and innovation ecosystems. Enterprises within these clusters generate technology spillovers through competition and cooperation, making cooperation between universities, research institutions and enterprises more integrated and significantly improving the efficiency of knowledge diffusion. At the same time, urbanisation accelerates the development of service sectors (such as technology intermediaries and intellectual property trading platforms), further refining the innovation service system (Ciołek et al., 2022). The construction of this innovation ecosystem not only increases the quantity of green technology innovation, but also improves the quality of innovation.

Population urbanisation promotes green technology innovation through infrastructure development. In the interactive relationship between urbanisation and green technology innovation, the improvement of infrastructure, especially transport infrastructure, serves as a crucial transmission mechanism. New economic geography theory suggests that urbanisation drives the perfection of infrastructure networks through spatial agglomeration effects, while the optimisation of transport infrastructure can influence green technology innovation through channels such as technology diffusion, factor allocation and market demand (Awan et al., 2022). First, transport infrastructure can significantly reduce the costs of technology diffusion. When populations are concentrated in cities, urban innovation resources radiate to surrounding areas through 'knowledge spillover corridors', forming a 'core-periphery' innovation community. This diffusion mechanism not only expands the spatial coverage of green technology innovation, but also enhances the application efficiency of innovation outcomes through technology spillovers (He and Chen, 2025). Second, in the process of urbanisation, the improvement of transport facilities facilitates the flow of capital, talent and other innovative elements to high-efficiency sectors. As logistics costs fall, companies are more likely to invest in research and development of green technologies to meet market demand for low-carbon products. At the same time, convenient transportation conditions increase the frequency of interaction among innovators, accelerating the iteration and updating of green technologies. Third, as urbanisation progresses, residents' demand for clean air and low-carbon travel has increased significantly (Cao et al., 2019). This demand is effectively translated into market incentives for green technologies through improvements in transport infrastructure. The demand-driven innovation mechanism not only expands the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

market scale of green technology innovation, but also raises the quality of innovation to a higher level by improving technical standards. Therefore, after discussing the above mechanism, this paper puts forward the second hypothesis.

Hypothesis 2: Urbanisation can stimulate the development of secondary industries and infrastructure, thereby encouraging quantitative and qualitative improvements in green technology innovation.

Threshold effect

Green technology innovation, as a key way to overcome resource and environmental constraints, has a complex non-linear relationship with the process of population urbanisation. The level of economic development is one of the important non-linear factors (Dong et al., 2024). When the level of economic development is low, the urbanisation process mainly takes the form of extensive agglomeration of production factors. At this time, infrastructure investment dominates urban construction, leading to low efficiency in factor allocation and difficulties in internalising environmental externalities. Limited fiscal resources struggle to sustain continuous investment in green technology research and development, leading firms to focus more on low-level technological innovation such as end-of-pipe treatment. Once GDP per capita exceeds $6,000, the urban economy begins to shift towards service-oriented and knowledge-intensive structures. The 'structural dividend' generated by improved factor allocation efficiency provides new impetus for green technology innovation. At this point, the knowledge spillover effect of urbanisation begins to emerge, with a significant increase in business RD investment in clean technologies and a growing trend in the number of green patents. After entering the middle-income stage, economic transformation requires stronger environmental regulation (Zhang and Zhang, 2024). The environmental governance pressure generated by urbanisation forces local governments to set stricter environmental standards. This institutional change forms a positive feedback loop with the level of economic development. Improving the environmental tax system increases the opportunity cost of polluting emissions. The use of market-based policy instruments, such as carbon emission trading, encourages firms to integrate green technology innovation into their long-term strategies. The level of economic development is a critical situational variable influencing the impact of urbanisation on green technology innovation. The existence of this non-linear relationship implies that research must fully take into account the differences in regional economic development levels (Wu and Huang, 2022). The level of economic development is an important condition for this nonlinear relationship, and the existence of the threshold effect has a profound impact on the mechanism of the urbanisation process on green technology innovation. Therefore, this paper proposes the third hypothesis.

Hypothesis 3: In the process of promoting green technology innovation through population urbanisation, there is a threshold effect of economic development level.

Research design

Model setting

Benchmark effect model

To empirically examine the impact of urban population growth on the quantity and quality of green technological innovation in urban areas, this study uses a bidirectional

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

fixed-effects model, as shown in *Equation 1*, based on the methodology of Meng et al. (2025).

$$Greentech_{it} = a_0 + a_1 Urbanization_{it} + \sum_{j=2}^{6} a_j X_{jit} + v_i + \mu_t + \varepsilon_{it} \quad \text{(Eq.1)}$$

Among them, *Greentech* represents the level of urban green technology innovation. *Urbanisation* represents the level of population urbanisation. The i represents the prefecture level, and t represents the year. The regression coefficient α_1 reflects the effect of population urbanisation on urban green technology innovation. The X_{jit} represents the set of control variables, and α_j is the corresponding regression coefficient. The v_i and μ_t represent the city and year fixed effects, respectively. The ε_{it} is the random disturbance term.

Mediation effect model

This paper uses the mediation effect model to examine the transmission mechanism of population urbanisation development on green technology innovation. The stepwise regression method constructed by Baron Kenny (1986) and others is widely used to investigate the channels of influence between variables. This method mainly involves three steps: first, to verify whether population urbanisation can significantly promote green technology progress. Second, to confirm whether population urbanisation can have a significant impact on the mediator variable. Third, to simultaneously examine the effects of urbanisation and the mediator variable on green technology innovation. Specifically, based on *Equation 1*, further *Equations 2* and *3* are constructed for analysis according to the above three steps.

$$M_{it} = \beta_0 + \beta_1 Urbanization_{it} + \sum_{j=2}^{6} \beta_j X_{jit} + v_i + \mu_t + \varepsilon_{it} \quad \text{(Eq.2)}$$

$$Greentech_{it} = \varphi_0 + \varphi_1 Urbanization_{it} + \varphi_2 M_{it} + \sum_{j=2}^{6} \varphi_j X_{jit} + v_i + \mu_t + \varepsilon_{it} \quad \text{(Eq.3)}$$

Among them, β_0 and φ_0 represent the intercept terms of the corresponding equations. The β_1 and β_j represent the coefficients of the effect of the corresponding variables on the mediator variable. The φ_1, φ_2, and φ_j respectively represent the regression coefficients of the corresponding variables. The M_{it} stands for the mediator variable, which is the level of secondary industry and infrastructure development.

Threshold effect model

Further, does the impact of population urbanisation on green technology innovation play a better role only after a certain level of economic development? In this regard, this paper draws on Hansen's (1999) idea of constructing a threshold effect model, using the level of economic development as a threshold variable to identify the nonlinear characteristics of the transmission mechanism at different levels, and the setting of the threshold model is shown in *Equation 4*.

$$Greentech_{it} = \rho_0 + \rho_1 Urbanization_{it} \bullet I(D_{it} \le \gamma_1) + \rho_2 Urbanization_{it} \bullet I(D_{it} > \gamma_1) + \cdots + \rho_n Urbanization_{it} \bullet I(D_{it} \le \gamma_n) + \rho_{n+1} Urbanization_{it} \bullet I(D_{it} > \gamma_n) + \sum_{j=n+2}^{n+6} a_j X_{jit} + v_i + \mu_t + \varepsilon_{it} \quad \text{(Eq.4)}$$

Among them, ρ_0 represents the intercept term, $\rho_1 \ldots \rho_{n+7}$ represents the coefficient of the corresponding variable on green technology innovation. The I represents the indicator function, which takes the value *1* if the condition is fulfilled, otherwise 0. The D_{it} is the threshold variable and γ is the threshold to be estimated.

Variable selection

The dependent variable is green technology innovation (*Greentech*). Braun and Wield (1994) were the first to define green technology as 'the collective term for technologies, processes or products that reduce environmental pollution, as well as the use of raw materials and energy'. Green technological innovation represents a shift in the technological-economic paradigm, in which innovation actors engage in R&D activities guided by the objectives of reducing consumption, minimising pollution and improving ecological conditions. This ultimately yields new green technologies. Consequently, green technological innovation has attracted significant scholarly attention and research. Empirical studies typically measure the level of green technological innovation by counting green technology patents (Ruan et al., 2025; Yu, 2025).

Patent data have become an important standard for assessing innovative activities. Based on the Patent Classification Numbers (IPC) published by the National Intellectual Property Administration and the Green Patent Classification List (Green Inventory) established by the World Intellectual Property Organization (WIPO), it can accurately identify green patents in different research units. Green patents are not only considered to be a core measure of green technology innovation, but are also widely accepted as indicators of green technology innovation by both domestic and international academic circles. Compared to the number of green patents granted, the number of patent applications avoids to some extent the bias generated by issues such as time lag (Xu and Cui, 2020), and is able to effectively examine the impact of population urbanisation on urban green technological innovation. This paper identifies the number of green patents in 278 prefecture-level cities in China from 2006 to 2021 according to the above classification criteria, and constructs an urban green patent dataset. Based on the type of patent, green patents are further divided into green invention patents (substantive innovation) and green utility model patents (strategic innovation). Therefore, this paper uses three indicators - total green technology innovation (*Greentech*1), substantive green technology innovation (*Greentech*2) and strategic green technology innovation (*Greentech*3) - as dependent variables for the empirical analysis. Among these, total green technology innovation is measured by the combined number of green invention patents and green utility model patents. Substantive green technology innovation is measured by green invention patents. Strategic green technology innovation is measured by green utility model patents. If the patent data is 0, add 1 and then take the logarithm (Kou and Liu, 2020).

The core explanatory variable is population urbanisation (*Urbanisation*). Population urbanisation is the process by which population becomes urban population and agricultural population becomes non-agricultural population. Based on existing studies, the degree of population urbanisation is measured by the ratio of permanent urban population to total permanent population in each region.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

The mediator variables are the level of development of secondary industries (*Industries*) and the level of infrastructure (*Infrastructure*). The level of development of secondary industries. Green technology patents mainly cover seven categories, including energy conservation, waste management, and alternative energy production. These categories all fall under the secondary industry sector. This means that the primary source of green technology innovation is the secondary industry. This paper measures the level of secondary industry development using the ratio of secondary industry output to GDP. Infrastructure level. As a leading capital for economic and social development, infrastructure serves as a foundation for the survival and growth of other production sectors. Among them, transport infrastructure provides favourable conditions for technological innovation, facilitates technical exchange and thus promotes green technological innovation. This paper uses road area per capita in cities to measure the level of infrastructure development.

The threshold variable is the level of economic development (*PGDP*). The level of regional economic development reflects to some extent the level of local technological innovation, which is conducive to attracting high-tech talent and thus improving the level of green technology innovation. This paper uses GDP per capita to measure the level of economic development.

Based on the existing literature, this paper selects the following indicators as control variables. Science and Technology Professionals (*STP*). ST professionals are a direct factor of technological innovation. Generally speaking, the more science and technology professionals there are, the more conducive it is to innovation output. This paper uses the number of STPs in each city at the prefecture level to represent this indicator. Level of government intervention (*Government*). On the one hand, government intervention may interfere with the normal functioning of the technology market, leading to market failure. On the other hand, government fiscal spending helps to increase investment in infrastructure construction, attracts enterprises to enter the market, and creates favourable conditions for technological innovation by enterprises. Therefore, the level of government intervention affects green technological innovation. This paper measures the level of government intervention using the ratio of local government fiscal expenditure to GDP. Consumption capacity (*Consumer*). To some extent, it reflects the purchasing power and diversified needs of consumers, which helps to force enterprises to strengthen green technological innovation and improve product quality. This paper measures consumption capacity by the ratio of retail sales of consumer goods to GDP. Level of financial development (*Finance*). Technological innovation requires substantial investment, and financial development can provide effective financial support for green technological innovation. This paper measures the level of financial development using the ratio of regional year-end credit to GDP. Sulphur dioxide emissions (SO_2). Sulphur dioxide emissions pose a threat to the human environment. To reduce emissions, companies will increase technological innovation and application, thereby influencing green technological innovation.

The names, abbreviations and calculation methods of the above variables are shown in *Table 1*.

Data sources and descriptive statistics

This study selects balanced panel data from 278 prefecture-level cities for the period 2006-2021. The original data on green innovation patents come from the China National Intellectual Property Administration. Socio-economic data come from the annual China

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

Statistical Yearbook and the China Urban Statistical Yearbook. Missing data are supplemented by consulting the relevant provincial (city, county) and prefectural statistical yearbooks. Missing data are interpolated by linear interpolation.

Table 1. *Variable names and measures*

Variable name	Abbreviation	A measure or calculation method
Green technology innovation	*Greentech1*	The sum of green invention patents and green utility model patents
Green invention patent	*Greentech2*	Number of green invention patents
Green utility model patent	*Greentech3*	Number of green utility model patents
Urbanisation of population	*Urbanisation*	The ratio of urban population to total population
Science and technology practitioners	*STP*	Number of science and technology practitioners
Degree of government intervention	*Government*	The ratio of government fiscal expenditure to GDP
Sulphur dioxide	SO_2	Sulphur dioxide emissions
Consumption capacity	*Consumer*	The ratio of retail sales of consumer goods to GDP
Level of financial development	*Finance*	The ratio of outstanding loans to GDP
Level of secondary industry development	*Industries*	The proportion of output value of the secondary industry in GDP
Infrastructure level	*Infrastructure*	Urban per capita road area
Level of economic development	PGDP	Per capita GDP

Descriptive statistics for all variables are presented in *Table 2*. Among them, the three indicators of green technology innovation, science and technology personnel, and sulphur dioxide, road area per capita and economic development level are expressed in specific quantities, but are all transformed into logarithms for the regression analysis. Population urbanisation, government intervention, consumption capacity, financial development level and secondary industry development level are all relative indicators and were not adjusted in the regression analysis.

Table 2. *Descriptive statistics*

Stats	N	Min	Mean	P50	Max	Sd
Greentech1	4448	1	415.7	77	21488	1259
Greentech2	4448	1	192.1	27	11182	637.2
Greentech3	4448	1	223.7	47	10963	644.3
Urbanisation	4448	0.115	0.522	0.506	1	0.163
STP	4448	0.009	0.928	0.360	22.82	1.862
Government	4448	0.035	0.184	0.158	1.027	0.101
SO_2	4448	2	41567	26434	496377	44649
Consumer	4448	2.596	6.063	6.087	9.223	1.114
Finance	4448	0.002	1.389	0.815	30.91	2.519
Industries	4448	0.117	0.469	0.472	0.91	0.111
Infrastructure	4448	0.390	16.556	15.12	60.07	7.344
PGDP	4448	2767	39746	28572	341994	36007

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

Analysis of the empirical results

Analysis of the benchmark results

To examine the impact of population urbanisation on three indicators of green technology innovation, this paper estimates the model in *Equation 1*, with the results presented in *Table 3*. Columns (1), (3) and (5) of *Table 3* show the estimation results without control variables. All three of these results indicate that the coefficient of population urbanisation on green technology innovation is significantly positive at the 1% significance level. Furthermore, the results with control variables are shown in columns (2), (4) and (6). These regression results also confirm that population urbanisation has a significant promoting effect on both the quantity and quality of urban green technology innovation, i.e. it promotes an overall improvement in both aspects, thus supporting hypothesis H1. However, for the three green technology patent indicators, the coefficient of population urbanisation on green invention patents is 0.9544, the smallest among the three coefficients. This result is due to the greater difficulty of developing green invention patents, which requires more human and material resources, as well as greater uncertainty in research time and results. In addition, for the same indicator, the estimated coefficient after adding control variables is smaller than the result without control variables. This suggests that factors other than urban population growth influence green technology innovation.

Table 3. *Results of the benchmark regression*

Variable	***Greentech1***		***Greentech2***		***Greentech3***	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Urbanisation	1.0962*** (0.2653)	1.0341*** (0.0.2562)	1.0203*** (0.3198)	0.9544*** (0.3126)	1.0649*** (0.2866)	1.0010*** (0.2762)
Control variable	No	Yes	No	Yes	No	Yes
Fixed time	Yes	Yes	Yes	Yes	Yes	Yes
Urban fixed	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.8718	0.8742	0.7910	0.7952	0.8595	0.8615
Sample size	4448	4448	4448	4448	4448	4448

(1) *** indicates significant at the 1% level; robust standard errors are given in brackets. (2) 'Yes' and 'No' indicate whether the model controls for the variable of interest

Robustness test

To further verify the robustness of the model estimation results based on the above research, four methods of robustness testing were employed.

Adjustment of the dependent variable. To reduce the impact of outliers on the regression results, this paper applies a 1% tail trimming to both the maximum and minimum values of the three indicators of green technology patents. The regression results are reported in columns (1) to (3) of *Table 4*.

Adding control variables. Government R&D expenditure is an important policy instrument influencing technological innovation. Therefore, government R&D expenditure was included as a control variable in *Equation 1*. In this paper, this indicator is measured by the ratio of government R&D expenditure to GDP. The estimation results are shown in columns (4) to (6) of *Table 4*.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

Table 4. *Results of robustness test (1)*

Variable	***Greentech1* (1)**	***Greentech2* (2)**	***Greentech3* (3)**	***Greentech1* (4)**	***Greentech2* (5)**	***Greentech3* (6)**
Urbanisation	1.0807*** (0.2572)	1.0011*** (0.3141)	1.0421*** (0.2767)	1.0045*** (0.2438)	0.9161*** (0.2942)	0.9800*** (0.2703)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Fixed time	Yes	Yes	Yes	Yes	Yes	Yes
Urban fixed	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.8762	0.7932	0.8598	0.8775	0.8006	0.8631
Sample size	4448	4448	4448	4448	4448	4448

(1) *** indicates significant at the 1% level; robust standard errors are given in brackets. (2) 'Yes' and 'No' indicate whether the model controls for the variable of interest.

Adjust the urban sample. Based on the needs of economic and social development, China has adopted special policies in urban development, such as the establishment of sub-provincial cities. These cities have unique advantages in policy environment, infrastructure construction and public service level. If these cities are not excluded from the sample, it may lead to biased results. Therefore, in this paper, 15 sub-provincial cities are excluded from the sample. The list of these 15 cities includes: Guangzhou, Wuhan, Harbin, Shenyang, Chengdu, Nanjing, Xi'an, Changchun, Jinan, Hangzhou, Dalian, Qingdao, Shenzhen, Xiamen, and Ningbo. The regression results are shown in columns (1)-(3) of *Table 5*.

Table 5. *Results of robustness test (2)*

Variable	***Greentech1* (1)**	***Greentech2* (2)**	***Greentech3* (3)**	***Greentech1* (4)**	***Greentech2* (5)**	***Greentech3* (6)**
Urbanisation	1.0456*** (0.2698)	0.9561*** (0.3299)	1.0177*** (0.2917)	1.8002*** (0.2899)	1.9242*** (0.3283)	0.9352*** (0.0064)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Fixed time	Yes	Yes	Yes	Yes	Yes	Yes
Urban fixed	Yes	Yes	Yes	Yes	Yes	Yes
Kleibergen-Paap rk LM statistic				69.358 (0.0000)		
Cragg-Donald Wald F statistic				46175.09 (16.38)		
R^2	0.8715	0.7892	0.8588	0.8565	0.8068	0.8529
Sample size	4208	4208	4208	4170	4170	4170

(1) *** indicates significant at the 1% level; robust standard errors are given in brackets. (2) Kleibergen-Paap rk LM statistic, values in brackets are p-values for tests of under-identification; Cragg-Donald Wald F statistic, values in brackets are 10% critical values for tests of weak identification of Stock Yogo. (3) 'Yes' and 'No' indicate whether the model controls for the variable of interest

Given the potential bidirectional causal relationship between population urbanisation and the level of green technology innovation, endogeneity issues cannot be ruled out. Therefore, following Li et al. (2023), lagged one-period population urbanisation and green technology innovation levels are introduced as instrumental variables in the benchmark regression model for endogeneity testing. The model is then re-estimated using two-stage least squares (2SLS). The regression results show that the Anderson canonical corr. LM statistic and Cragg-Donald Wald F statistic confirm the absence of identification errors and weak instrumental variables, indicating the validity of the instrumental variables. The coefficients of the core explanatory variables are reported in columns (4) to (6) of *Table 5*.

The test results in *Tables 4* and *5* show that, under the four robustness test methods, population urbanisation significant positive effects both the quantity and quality of green technology innovation. This is consistent with the benchmark regression results, indicating that the research conclusions are highly robust.

Heterogeneity analysis

There is heterogeneity in the levels of economic development. Different levels of economic development lead to different characteristics of regions in terms of urbanisation, the demand for and scale of green technology innovation, and policy orientation and support. To investigate whether there is heterogeneity in the impact of population urbanisation on the quantity and quality of green technology innovation, this paper uses GDP per capita as a grouping variable, dividing the sample into three levels of development: high, medium and low cities, and conducts a heterogeneity analysis. The regression results are presented in *Table 6*. According to columns (1) to (3), the results indicate that population urbanisation has no significant promoting effect on the quantity or quality of green technology innovation in cities with higher levels of economic development. The possible reason for this result is that prefecture-level cities with a high economic level have a more complete research and innovation system and more factors that can promote green technology innovation. For example, the scale of investment in scientific and technological research and development is larger, thus leading to a less obvious promotion effect of population urbanisation. According to columns (4) to (9), population urbanisation has a significant effect on the quantity and quality of green technology innovation in cities with medium and low levels of economic development. However, there are differences in the size and significance of the coefficients. In regions with lower levels of economic development, the impact coefficient and significance of population urbanisation on green invention patents are higher than in cities with moderate levels of economic development. This may be because the technological innovation system in regions with lower levels of economic development is not yet fully developed, meaning the impact of urbanisation on green technology innovation is relatively more significant.

Table 6. *Test results for heterogeneity of levels of economic development*

Variable	***Greentech1* (1)**	***Greentech2* (2)**	***Greentech3* (3)**	***Greentech1* (4)**	***Greentech2* (5)**	***Greentech3* (6)**	***Greentech1* (7)**	***Greentech2* (8)**	***Greentech3* (9)**
Urbanisation	-0.1521 (0.3672)	-0.2692 (0.4505)	0.0526 (0.4064)	1.6449*** (0.4866)	1.4945** (0.5767)	1.5063*** (0.5251)	1.5740*** (0.4569)	1.6964*** (0.5747)	1.3421*** (0.3916)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urban fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.9145	0.8746	0.9007	0.8717	0.7822	0.8621	0.8551	0.7556	0.8431
Sample size	1456	1456	1456	1488	1488	1488	1504	1504	1504

(1) ***, ** indicates significant at the 1%, 5% level; robust standard errors are given in brackets. (2) ‘Yes’ and ‘No’ indicate whether the model controls for the variable of interest.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

Geographical heterogeneity. China is a vast country with significant differences in natural conditions and economic development between regions. The eastern region has better natural conditions, a higher level of economic development and more complete conditions for technological innovation. In contrast, the central and western regions have harsher natural conditions, started their economic development later, and have poorer conditions for technological innovation. To investigate whether there are differences in the impact of population urbanisation on the quantity and quality of green technology innovation under different geographical locations, this paper divides prefecture-level cities into three sub-samples: eastern, central and western, and conducts a heterogeneity analysis. Of these, 95 are located in China's eastern coastal provinces. The 99 central cities are located in six central provinces and two north-eastern provinces. The 84 western cities are mainly located in China's western provinces. The regression results are presented in *Table 7*. Columns (1)-(3) and (7)-(9) show that in both eastern and western regions, the impact of population urbanisation on the quantity and quality of green technology innovation is not significant, which may be related to the level of economic development and urbanisation. This is because most prefecture-level cities in the eastern region have relatively high levels of economic development and urbanisation, and are in the post-urbanisation stage. In addition, the green technology innovation system is relatively well established, and other factors have a greater influence on green technology innovation than population urbanisation, so the effect is not significant. On the other hand, the situation in the western region is the opposite: both economic development and urbanisation levels are lower, and the region is in the early stage of urbanisation, so the effect of population urbanisation on green technology innovation is not significant. Columns (4) to (6) show that, in the central region, population urbanisation significantly positively impacts the quantity and quality of green technology innovation at the 1% level. This is because cities in the Central Region are currently undergoing a period of rapid economic transformation and urbanisation, and the impact of urbanisation on various aspects of socio-economic development is quite evident.

***Table 7.** Results of the heterogeneity test for geographical location*

Variable	*Greentech1* (1)	*Greentech2* (2)	*Greentech3* (3)	*Greentech1* (4)	*Greentech2* (5)	*Greentech3* (6)	*Greentech1* (7)	*Greentech2* (8)	*Greentech3* (9)
Urbanisation	-0.0817 (0.4195)	-0.2627 (0.4644)	0.0606 (0.4662)	2.4846*** (0.4566)	2.3478*** (0.6098)	2.5452*** (0.4497)	0.4120 (0.3440)	0.4878(0.4210)	0.1253(0.4002)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urban fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.9058	0.8549	0.8937	0.8687	0.7815	0.8482	0.8732	0.7816	0.8715
Sample size	1520	1520	1520	1584	1584	1584	1344	1344	1344

(1) *** indicates significant at the 1% level; robust standard errors are given in brackets. (2) 'Yes' and 'No' indicate whether the model controls for the variable of interest

Heterogeneity of resource endowments. The reliance on specific natural resources for development and production makes green technology innovation in resource-based cities more vulnerable to fluctuations in resource prices, adjustments in industrial structure and changes in market demand. Non-resource-based cities, which are not dependent on a single type of natural resource, tend to have a more diversified industrial structure and therefore a greater need for green technology innovation. Urbanisation can provide

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

enterprises with more resource elements and favourable conditions, thus accelerating the research and application of green technologies. In light of this, this paper analyses the heterogeneity of urban resource endowments based on the classification criteria outlined in the 'Notice on the National Sustainable Development Plan for Resource-Based Cities (2013-2020)'. Of these, 112 are resource-based cities, primarily located in north-east China and the central and western regions. The remaining 166 are non-resource-based cities, mainly located in the central and eastern regions respectively. The regression results are presented in *Table 8*. The regression coefficients for population urbanisation are significantly positive in both resource-based and non-resource-based cities, indicating that population urbanisation promotes both the quantity and quality of green technology innovation in different resource-based cities. However, there are significant differences between the two types of cities. The impact of population urbanisation on green invention patents is greater in non-resource-based cities than in resource-based cities. For green utility model patents, the effect is stronger in resource-based cities. The primary reason lies in the significant challenges associated with developing green invention patents, which require substantial human, financial and material resources. Cities that rely heavily on natural resources often have a narrow economic structure and development model. This restricts their ability to innovate technologically, creating additional hurdles for green invention projects. The urbanisation of the population of non-resource cities is more open and diversified, making it easier to accept and adapt to the innovative service model of digital finance, and the development of digital finance can provide more convenient and efficient financing channels for urban green technology innovation.

Table 8. *Resource endowment heterogeneity test results*

Variable	***Greentech1* (1)**	***Greentech2* (2)**	***Greentech3* (3)**	***Greentech1* (4)**	***Greentech2* (5)**	***Greentech3* (6)**
Urbanisation	0.7634** (0.3105)	0.8351** (0.3854)	0.5655* (0.3338)	1.2734*** (0.4234)	0.9835* (0.5118)	1.4855*** (0.4621)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Fixed time	Yes	Yes	Yes	Yes	Yes	Yes
Urban fixed	Yes	Yes	Yes	Yes	Yes	Yes
R^2	08994	0.8382	0.8844	0.8400	0.7339	0.8326
Sample size	2656	2656	2656	1792	1792	1792

(1) ***, **, * indicates significant at the 1%, 5%, 10% level; robust standard errors are given in brackets.
(2) 'Yes' and 'No' indicate whether the model controls for the variable of interest

Analysis of the mechanism of action

Analysis of the mediating effect

This paper theoretically analyses the transmission mechanism of population urbanisation on green technology innovation. It also conducts empirical tests based on the transmission channels of secondary industry and infrastructure, the results of which are presented in *Tables 9* and *10*. As shown in column (1) of *Table 9,* the estimated coefficient of population urbanisation on the mediator variable is significantly positive at the 1% level, indicating that population urbanisation facilitates the development of secondary industry. The estimated coefficients of the mediator variable on the three

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

indicators of green technology innovation are all significant at the 1% level. This suggests that population urbanisation promotes green technology innovation by developing the secondary industry. In addition, the direct effect of population urbanisation on green technology innovation is significant but weaker than the total effect, indicating that the development of secondary industry plays a partial mediating role in the quantitative and qualitative effects of population urbanisation on green technology innovation. The values of the mediation effect are 0.1052 (0.0869 × 1.2107), 0.1413 (0.0869 × 1.6265) and 0.0764 (0.0869 × 0.8795). Furthermore, Bootstrap and Sobel tests were performed to ensure the reliability of the mediation effect. These tests confirm the mediating effect of the development of the secondary industry, with the proportions through which urbanisation promotes the development of the secondary industry and thereby enhances the level of green technology innovation being 10.17%, 14.81% and 7.64% respectively.

Table 9. *Test results for the intermediation effect in secondary industry*

Variable	***Industries*** **(1)**	***Greentech1*** **(2)**	***Greentech2*** **(3)**	***Greentech3*** **(4)**
Urbanisation	0.0869*** (0.0305)	0.9289*** (0.2459)	0.8130*** (0.3040)	0.9245*** (0.2672)
Industries		1.2107*** (0.2892)	1.6265*** (0.3551)	0.8795*** (0.3022)
Control variable	Yes	Yes	Yes	Yes
Fixed time	Yes	Yes	Yes	Yes
Urban fixed	Yes	Yes	Yes	Yes
Sobel		0.1052 (z = 4.911, p = 0.000)	0.1413 (z = 4.996, p = 0.000)	0.0764 (z = 3.995, p = 0.000)
Efficiency ratio (%)		10.17	14.81	7.64
R^2	0.5524	0.8760	0.7984	0.8624
Sample size	4448	4448	4448	4448

(1) *** indicates significant at the 1% level; robust standard errors are given in brackets. (2) ‘Yes’ and ‘No’ indicate whether the model controls for the variable of interest

As shown in column (1) of *Table 10,* the estimated coefficient of population urbanisation on the mediator variable is significantly positive at the 5% level. This indicates that population urbanisation facilitates infrastructure development. The estimated coefficients of the mediator variable on the three indicators of green technology innovation are all significant at the 1% level, suggesting that population urbanisation facilitates green technology innovation through infrastructure development. In addition, the direct effect of population urbanisation on green technology innovation is significant but weaker than the total effect, indicating that the secondary sector plays a partial mediating role in the quantitative and qualitative effects of population urbanisation on green technology innovation. The values of the mediation effect are 0.0561 (4.3866 × 0.0128), 0.0561 (4.3866 × 0.0129) and 0.0520 (4.3866 × 0.0118). Additionally, Bootstrap and Sobel tests were performed to ensure the reliability of the mediation effect. The test results confirm the existence of the mediating effect of infrastructure development, with the proportion of the mediating effect of population urbanisation in improving the level of green technology innovation by promoting infrastructure development being 5.43%, 5.43% and 5.2%, respectively.

Table 10. *Test results of the infrastructure intermediation effect*

Variable	***Infrastructure*** **(1)**	***Greentech1*** **(2)**	***Greentech2*** **(3)**	***Greentech3*** **(4)**
Urbanisation	4.3866** (2.0981)	0.9780*** (0.2476)	0.8980*** (0.3056)	0.9490*** (0.2693)
Infrastructure		0.0128*** (0.0037)	0.0129** (0.0050)	0.0118*** (0.0036)
Control variable	Yes	Yes	Yes	Yes
Fixed time	Yes	Yes	Yes	Yes
Urban fixed	Yes	Yes	Yes	Yes
Sobel		0.0561 (z = 3.389, p = 0.000)	0.0561 (z = 3.389, p = 0.002)	0.0520 (z = 3.226, p = 0.000)
Efficiency ratio (%)		5.43	5.43	5.20
R^2	0.4899	0.8755	0.7965	0.7826
Sample size	4448	4448	4448	4448

(1) ***, ** indicates significant at the 1%, 5% level; robust standard errors are given in brackets. (2) 'Yes' and 'No' indicate whether the model controls for the variable of interest

Threshold effect analysis

To test whether the impact of population urbanisation on green technology innovation is influenced by economic development. This paper uses the level of economic development as a threshold variable and population urbanisation as a threshold dependent variable to examine the possible non-linear threshold relationship between population urbanisation and green technology innovation. To accurately test the specific form of the panel threshold model, the effects of three thresholds (alternative hypotheses), two thresholds (alternative hypotheses) and one threshold (alternative hypothesis) are tested sequentially. This ensures the validity of the threshold effect tests and avoids bias in the empirical results due to omitted threshold effects. The test results show that, of he three green technology innovation indicators, the level of economic development passes the dual-threshold effect test but fails the triple-threshold effect test, as shown in *Table 11*. Consequently, this paper adopts a dual-threshold regression model.

Table 11. *Threshold test results*

Explained variable	**Hypothesis test**	**F- value**	**P-value**	**Bootstrap**	**Critical value**		
					10%	**5%**	**1%**
Greentech1	H0: linear model H1: Single threshold	42.13	0.0300	300	26.8621	34.9169	56.3909
	H0: Single threshold H1: Double threshold	47.40	0.0033	300	24.5316	32.4683	40.0014
Greentech2	H0: linear model H1: Single threshold	36.33	0.0133	300	25.7041	29.4376	38.2475
	H0: Single threshold H1: Double threshold	30.32	0.0133	300	22.5230	24.7042	33.9890
Greentech3	H0: linear model H1: Single threshold	42.48	0.0233	300	25.7136	35.4922	44.5594
	H0: Single threshold H1: Double	56.88	0.0023	300	23.5579	26.5628	35.7394

H0 and H1 represent the null hypothesis and alternative hypothesis, respectively

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

Following the threshold effect test, a dual threshold effect was observed in the impact of population urbanisation on green technology innovation at different levels of economic development. Next, we estimate the thresholds and confidence intervals for economic development to verify the authenticity of the estimation results. *Figures 1, 2* and *3* show the likelihood ratio function graphs of the levels of economic development under the three indicators of green technology innovation. From these three figures, the estimated values and confidence intervals of the threshold variables can be clearly observed. From the three figures, it can be concluded that the LR values of the thresholds are all lower than their rejection regions, indicating that the estimated threshold effects are indeed valid. The emergence of this dual threshold phenomenon is linked to the stage of economic development. At the lower stages, urbanisation manifests as 'extensive agglomeration', with insufficient impetus for green technological innovation. At intermediate stages, however, urban economies undergo transformation, knowledge spillover effects intensify and green technological innovation begins to accelerate. At the highest stage, strengthened environmental regulations and market-based policy instruments cause green technological innovation to become a core corporate strategy.

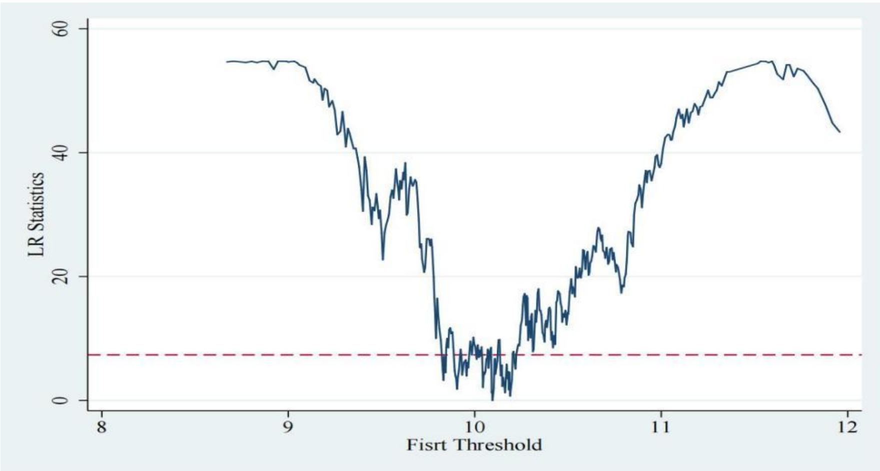

Figure 1. *Estimated PGDP threshold and confidence interval for the total number of green patents*

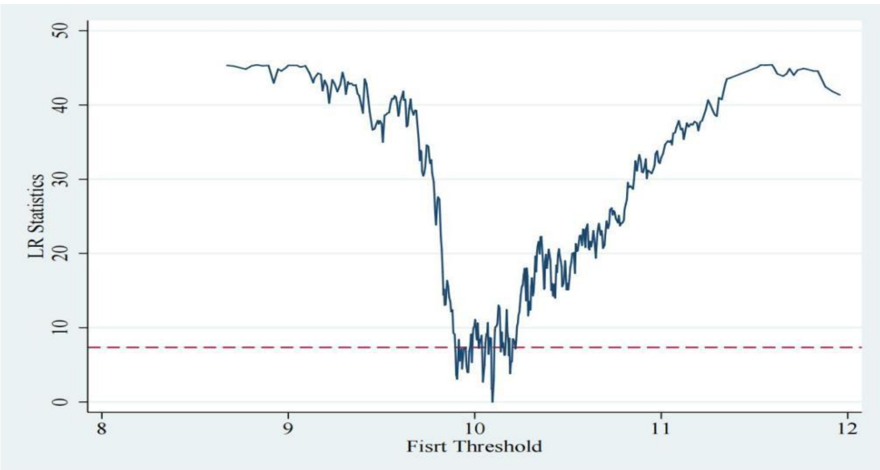

Figure 2. *Estimated PGDP threshold and confidence interval for green invention patents*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

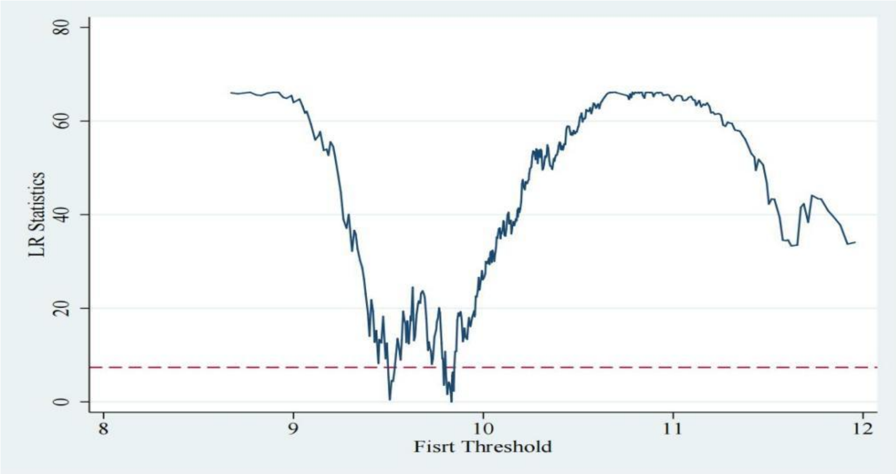

Figure 3. *Estimated threshold values and confidence intervals for PGDP with new green patents*

Columns (1) to (3) of *Table 12* show that the direction and significance of the regression coefficients for population urbanisation are well consistent, indicating the robustness of the model estimation results. The three columns show that when the level of economic development has not crossed the first threshold, the coefficient of population urbanisation on green technology innovation is significantly positive. When the level of economic development is between the first and second thresholds, the regression coefficient remains significantly positive at the 1% level, with the coefficient value increasing. Once the level of economic development exceeds the second threshold, the coefficient of population urbanisation is also significantly positive at the 1% level and the coefficient value further increases, indicating that the promoting effect of population urbanisation on green technology innovation is further strengthened. In summary, the level of economic development affects the 'quantity and quality' of the promoting effect of population urbanisation on green technology innovation, with significant observed across different threshold ranges. As the level of economic development gradually increases, the promoting effect of population urbanisation on the 'quantity and quality' of green technology innovation gradually strengthens, thus verifying the validity of Hypothesis 3.

Discussion

Discussion of results

The empirical findings of this study reveal a picture characterised by 'conditionality, multiple pathways, and nonlinearity'. Population urbanisation can be a significant driver of quantitative and qualitative improvements in urban green technology innovation in China. However, the realisation of these effects depends on specific economic development stages, regional location and industrial structure, and is achieved through concrete pathways such as promoting industrial upgrading and improving infrastructure. These findings enrich the theoretical link between the environmental impacts of urbanisation and technological innovation, and provide empirical evidence for designing differentiated, targeted policy approaches.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

Table 12. *Threshold effect regression results*

Variable	***Greentech1*** (1)	***Greentech2*** (2)	***Greentech3*** (3)
PGDP ≤ 10.0955	2.5911*** (0.2896)		
10.0955 < PGDP ≤ 11.5941	2.9602*** (0.3088)		
11.5941 < PGDP	3.3867*** (0.3449)		
PGDP ≤ 10.0955		2.2099*** (0.3241)	
10.0955 < PGDP ≤ 11.5941		2.6173*** (0.3484)	
11.5941 < PGDP		3.0316*** (0.3882)	
PGDP ≤ 9.8323			2.3881*** (0.2971)
9.8323 < PGDP ≤ 10.7861			2.9344*** (0.3049)
10.7861 < PGDP			3.3094*** (0.3760)
Control variable	Yes	Yes	Yes
Fixed time	Yes	Yes	Yes
Urban fixed	Yes	Yes	Yes
R^2	0.8358	0.7667	0.8227
Sample size	4448	4448	4448

(1) *** indicates significant at the 1% level; robust standard errors are given in brackets. (2) 'Yes' and 'No' indicate whether the model controls for the variable of interest

The findings of this study engage in valuable dialogue with, and complement, existing literature. Firstly, the study confirms the direct promotional effect of a specific urbanisation indicator - the urbanisation rate - on green technological innovation. This addresses a gap in prior research, which has often focused on urbanisation policies (such as pilot programmes for new-type urbanisation) while neglecting the underlying demographic impact (Wang and Qiu, 2023). Secondly, the study reveals a crucial mediating mechanism through which urbanisation influences green innovation: the secondary industry and infrastructure. It naturally links the macro-level urbanisation process with the meso-level development of industry and infrastructure, and the micro-level output of innovation, thereby expanding the theoretical implications of the 'urbanisation-innovation' chain. This addresses the issue raised by Glaeser (2012) and others regarding the lack of empirical verification for the intermediate mechanisms through which urban agglomeration promotes innovation. Finally, the threshold effect identified at different levels of economic development provides new empirical evidence with which to understand the complex non-linear relationship between urbanisation and green innovation. This finding aligns with the theoretical emphasis on developmental stages by Chen et al. (2020) and provides specific estimates for the threshold intervals.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

Study limitations

The limitations of this study are mainly reflected in two aspects. Firstly, the sample size is limited. Due to data availability, the sample used in this paper consists of 278 prefecture-level cities in China. However, China has more than 2800 county-level administrative regions. Using county-level administrative regions as a research sample would provide more objective and representative results. However, data on county-level administrative regions are severely lacking, and future efforts will focus on improving these data to strengthen research using county-level administrative regions as samples. Second, the limitation in the choice of indicators. Although the level of urbanisation development is a comprehensive indicator, this paper only examines it from the perspective of population urbanisation, which has certain limitations. Future research will expand and optimise the range of indicators used to measure the level of urbanisation development, improving the comprehensiveness and accuracy of the conclusions drawn.

Research conclusions and policy implications

Research conclusions

This paper uses a sample of 278 prefecture-level cities in China to study the impact of urban population growth on the quantity and quality of urban green technology innovation between 2006 and 2021. The study uses panel data and applies bidirectional fixed effects models, mediation effect models and threshold effect models to draw several innovative conclusions. Firstly, population urbanisation can significantly promote the 'quantitative and qualitative improvement' of urban green technology innovation, with strong robustness in the results. However, this result shows significant heterogeneity under different conditions. For example, in regions with high levels of economic development, population urbanisation does not effectively promote the 'quantitative and qualitative improvement' of green technology innovation. In contrast, in regions with medium to low levels of economic development, this effect is very significant. For example, in east and western regions, population urbanisation does not effectively promote the 'quantitative and qualitative improvement' of green technology innovation. In central regions, however, the effect is very significant.

Furthermore, in resource-based and non-resource-based cities, the effect of population urbanisation on green invention patents is stronger in non-resource-based cities. In resource-based cities, the impact of population urbanisation on green utility patents is stronger. Secondly, during the process of population urbanisation, which promotes the 'quantitative and qualitative improvement' of urban green technology innovation, the secondary industry and infrastructure construction play partial mediating roles, both passing Bootstrap and Sobel tests. Specifically, the mediating effects of secondary industry account for 10.17%, 14.81% and 7.64% of the total effect, respectively. The mediating effects of infrastructure construction account for 5.43%, 5.43% and 5.2% of the total effect, respectively. Thirdly, the impact of population urbanisation on the quantity and quality of urban green technology innovation exhibits significant non-linear characteristics. Empirical tests show that the level of economic development has a dual threshold effect on this influence. Furthermore, as the level of economic development gradually increases, the positive impact of population urbanisation on green technology innovation strengthens.

Policy implications

Based on the empirical conclusions of this study, three policy suggestions are made to promote the coordinated development of population urbanisation and green technology innovation.

Firstly, implement differentiated urbanisation strategies. For underdeveloped regions in central and western China, further promote household registration reform to lower the population settlement threshold, optimise the allocation of public service resources, and fully exploit the role of population concentration in promoting green technology innovation. In the economically developed eastern regions, focus on improving the quality of urbanisation by addressing the marginal effects of population size through industrial upgrading and the integration of innovative elements. Prioritise the development of knowledge-intensive services and high-end green manufacturing to avoid insufficient innovation momentum during the transition from 'scale expansion' to 'quality improvement'.

Secondly, strengthen the green transformation of secondary industries and infrastructure support. Make full use of the leading role of industrialisation in technological innovation by establishing a tripartite policy system of 'industrial upgrading - environmental regulation - innovation incentives'. Guide secondary industries into low-carbon technology areas through fiscal subsidies and tax incentives, and encourage traditional industrial cities to establish green technology research centres. Build a new type of infrastructure support system, increase investment in 5G, intelligent transportation, smart grids and other technologies, and develop 'smart city' management systems to create data sharing platforms and provide application scenarios for green technology innovation. Thirdly, implement categorised urban development guidelines and establish a dynamic adjustment mechanism. Resource-based cities should prioritise support for practical new technologies such as clean coal and tailings management. Non-resource-based cities should focus on breakthrough technology research and development, and offer rewards to enterprises that obtain international green invention patents. A two-dimensional evaluation system centred on 'economic development level' and 'green innovation performance' is recommended, with policy incentives adjusted dynamically. For example, we will implement a threshold incentive mechanism for urban per capita GDP and set an automatic trigger for additional deductions for RD expenses.

REFERENCES

[1] Awan, A., Alnour, M., Jahanger, A., Onwe, J. C. (2022): Do technological innovation and urbanization mitigate carbon dioxide emissions from the transport sector? – Technology in Society 71: 102128. DOI: https://doi.org/10.1016/j.techsoc.2022.102128.

[2] Baron, R. M., Kenny, D. A. (1986): The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. – Journal of Personality and Social Psychology 51(6): 1173. DOI: https://doi.org/10.1037//0022-3514.51.6.1173.

[3] Boamah, K. B., Du, J., Boamah, A. J., Appiah, K. (2018): A study on the causal effect of urban population growth and international trade on environmental pollution: evidence from China. – Environmental Science and Pollution Research 25: 5862-5874. DOI: https://doi.org/10.1007/s11356-017-0882-5.

[4] Braun, E., Wield, D. (1994): Regulation as a means for the social control of technology. – Technology Analysis & Strategic Management 6(3): 259-272. DOI: https://doi.org/10.1080/09537329408524171.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2401_17371762

[5] Cai, J., Yuan, J., Yu, C., Yu, C. (2024): Can the establishment of intellectual property demonstration cities stimulate green technology innovation of enterprises in China? – Journal of the Knowledge Economy. DOI: https://doi.org/10.1007/s13132-024-02548-x.

[6] Cao, Q., Kang, W., Xu, S., Sajid, M. J., Cao, M. (2019): Estimation and decomposition analysis of carbon emissions from the entire production cycle for Chinese household consumption. – Journal of Environmental Management 247: 525-537. DOI: https://doi.org/10.1016/j.jenvman.2019.06.044.

[7] Chen, J., Wei, S., Mei, C. (2023): Do structural transformation and urbanization assist in enhancing sustainable energy technologies innovations? Evidence from ASEAN countries. – Renewable Energy 211: 895-902. DOI: https://doi.org/10.1016/j.renene. 2023.03.063.

[8] Chen, Q., Huang, W. V., Mo, J. J. (2020): Country size and technology innovation: a comparative study of countries based on different levels of economic development. – International Journal of Technology, Policy and Management 20(3): 177-192. DOI: https://doi.org/10.1504/IJTPM.2020.109780.

[9] Cheng, J., Chen, J. R. (2024): Can new urbanization pilot policies promote green technology innovation in cities: empirical evidence from China. – PLoS ONE 19(5): e0303404. DOI: https://doi.org/10.1371/journal.pone.0303404.

[10] Ciołek, D., Golejewska, A., Zabłocka-Abi Yaghi, A. (2022): Innovation drivers in regions. Does urbanization matter? – Growth and Change 53(4): 1933-1960. DOI: https://doi.org/10.1111/grow.12632.

[11] Deng, F., Chen, X. (2024): Executive compensation contract effectiveness and firms’ green technology innovation structure. – Finance Research Letters 67: 105766. DOI: https://doi.org/10.1016/j.frl.2024.105766.

[12] Deng, J., Li, Y., Ding, Y., Liu, F. (2024): Effect of media attention on corporate green technology innovation: mechanism and evidence from China. – Empirical Economics 1-31. DOI: https://doi.org/10.1007/s00181-024-02660-6.

[13] Dong, Y., Li, Y., Zhang, L., Yan, M., Shao, W., Zhang, Q., et al. (2024): Improved urbanization-vegetation cover coordination associated with economic level in port cities along the Maritime Silk Road. – Ecological Indicators 163: 112116. DOI: https://doi.org/10.1016/j.ecolind. 2024.112116.

[14] Du, Y. -S., Chen, H., Chen, X. W. (2023): Consumption upgrading, innovation effect and urban economic resilience. – Consumer Economics 39(6): 52-64 (in Chinese).

[15] Enkel, E., Gassmann, O., Chesbrough, H. (2009): Open RD and open innovation: exploring the phenomenon. – Rd Management 39(4): 311-316. DOI: https://doi.org/10. 1111/j.1467-9310.2009.00570.x.

[16] Fogarty, M. S., Garofalo, G. A. (1988): Urban spatial structure and productivity growth in the manufacturing sector of cities. – Journal of Urban Economics 23(1): 60-70. DOI: https://doi.org/10.3390/su12010214.

[17] Fujita, M., Krugman, P., Mori, T. (1999): On the evolution of hierarchical urban systems. – European Economic Review 43(2): 209-251. DOI: https://doi.org/10.1016/ S0014-2921(98)00066-X.

[18] Glaeser, E. (2012): Triumph of the City. – Shanghai Academy of Sciences Press, Shanghai.

[19] Guo, B., Hu, J., Guo, X. (2025b): Can the industrial transformation and upgrading demonstration zones policy improve urban green technology innovation? An empirical test based on old industrial cities and resource-based cities in China. – Frontiers in Environmental Science 12: 1505177. DOI: https://doi.org/10.3389/fenvs.2024.1505177.

[20] Guo, X., Xu, J. (2025a): The impact of China’s 2014 Hukou reform on economic growth. – Economic Analysis and Policy 85: 641-655. DOI: https://doi.org/10.1016/ j.eap.2024.12.031.

[21] Hansen, B. E. (1999): Threshold effects in non-dynamic panels: estimation, testing, and inference. – Journal of Econometrics 93(2): 345-368. DOI: https://doi.org/10.1016/ S0304-4076(99)00025-1.

[22] He, Z., Chen, Z. (2025): High-speed rail, market segmentation, and the rise of green technology innovation cities: evidence from China. – Research in Transportation Business & Management 62: 101429. DOI: https://doi.org/10.1016/j.rtbm.2025.101429.
[23] Henderson, J. V., Wang, H. G. (2007): Urbanization and city growth: the role of institutions. – Regional Science and Urban Economics 37(3): 283-313. DOI: https://doi.org/10.1016/j.regsciurbeco.2006.11.008.
[24] Ji, L., E, E. D. T. L. (2019): Urbanization and environmental regulation will promote regional technological progress? – Scientific Decision Making 10: 54-72. DOI: 10.3773/j.issn.1006-4885.2019.10.054.
[25] Kolko, J. (2010): Urbanization, Agglomeration, and Coagglomeration of Service Industries. – In: Glaeser, E. L. (ed.) Agglomeration Economics. – University of Chicago Press, Chicago, pp. 151-180.
[26] Kong, H., Sun, L., Zhang, W. (2024): Digitization and Green Technology Innovation of Chinese Firms Under Government Subsidy Policies. – Systems 12(11): 447. DOI: https://doi.org/10.3390/systems12110447.
[27] Kou, Z. L., Liu, X. Y. (2020): On patenting behavior of Chinese firms: stylized facts and effects of innovation policy. – Economic Research Journal 55(3): 83-99 (in Chinese).
[28] Krugman, P. (1991): Increasing returns and economic geography. – Journal of political economy 99(3): 483-499. DOI: https://doi.org/10.1086/261763.
[29] Li, H., Su, Y., Ding, C. J., Tian, G. G., Wu, Z. (2024): Unveiling the green innovation paradox: exploring the impact of carbon emission reduction on corporate green technology innovation. – Technological Forecasting and Social Change 207: 123562. DOI: https://doi.org/10.1016/j.techfore.2024.123562.
[30] Li, W., Zhang, G. H., Xu, S. K. (2023): The development of digital economy and the integration of producer services and manufacturing. – Commercial Research 6: 11-19. DOI: 10.13902/j.cnki.syyj.2023.06.012.
[31] Liu, L., Fu, P., He, K., Meng, Q., Liu, X. (2024): Impact assessment and mechanism analysis of the construction of pilot free trade zones on the efficiency of urban green technology innovation. – Ecological Indicators 163: 112137. DOI: https://doi.org/10.1016/j.ecolind.2024.112137.
[32] Liu, Y., Zhou, X. (2025): Does the new-type urbanization policy promote green technological innovation? Evidence from a quasi-natural experiment in China. – Applied Economics 1-16. DOI: https://doi.org/10.1080/00036846.2025.2453760.
[33] Lu, Y. P., Wang, P. C., Zhu, X. P. (2017): Urbanization, spatial spillover and technological innovation—based on 264 cities in China. – Finance & Economics 11: 78-89 (in Chinese).
[34] Luo, Q., Wang, J. (2024): Digital finance and green technology innovation: a dual path test based on market and government. – Finance Research Letters 70: 106283. DOI: https://doi.org/10.1016/j.frl.2024.106283.
[35] Ma, R., Lin, B. (2024): Internet development, information availability, and Chinese enterprises' cooperative green technology innovation. – Journal of Environmental Management 367: 121972. DOI: https://doi.org/10.1016/j.jenvman.2024.121972.
[36] Meng, S., Song, J., Li, C., Xu, W., Tan, D., Sha, Y. (2025): How does the scale of new agricultural business entities stimulate enthusiasm for green technology innovation? A perspective based on market incentives. – Environment, Development and Sustainability 1-28. DOI: https://doi.org/10.1007/s10668-025-06357-3.
[37] Qiangmin, X. I., Peng, J. I. (2023): Does the development zone promote population urbanization? Evidence from China. – Land Use Policy 131: 106736. DOI: https://doi.org/10.1016/j.landusepol.2023.106736.
[38] Qiu, Y. (2013): Technological innovation effects of urbanization: an empirical study based on1990-2010 panel data of China's regions. – Chinese Journal of Population Science 1: 26-35 + 126 (in Chinese).
[39] Qiu, Y., Zeng, D., Wu, J. J. (2023): Have China's low-carbon pilot policies improved green technology innovation in cities? – Jiangxi Social Sciences 43(10): 50-60 (in Chinese).

[40] Ruan, X., Lin, S., Huang, J., Li, C. (2025): The impact of economic complexity on green technology innovation in China. – Scientific Reports 15(1): 39979. DOI: https://doi.org/10.1038/ s41598-025-23738-w.
[41] Segal, D. (1976): Are there returns to scale in city size? – The Review of Economics and Statistics 339-350. DOI: https://doi.org/10.2307/1924956.
[42] Tao, T. (2023): Urbanization, low carbon technology innovation and carbon emission efficiency. – Journal of Technical Economics Management 1: 38-44 (in Chinese).
[43] Tappeiner, G., Hauser, C., Walde, J. (2008): Regional knowledge spillovers: fact or artifact? – Research Policy 37(5): 861-874. DOI: https://doi.org/10.1016/j.respol. 2007.07.013.
[44] Tian, Y. P., Liu, M. Y., Zhang, W. G. (2018): Influences on regional technological innovation level by urbanizaiton progress. – Urban Problems 4: 4-11. DOI: 10.13239/j.bjsshkxy.cswt.180401.
[45] Wang, B., Khan, I., Ge, C., Naz, H. (2024b): Digital transformation of enterprises promotes green technology innovation-The regulated mediation model. – Technological Forecasting and Social Change 209: 123812. DOI: https://doi.org/10.1016/j. techfore.2024.123812.
[46] Wang, D., Sun, M., Meng, B., An, Y., Cheng, W., Ye, B. (2024c): Can carbon market efficiency promote green technology innovation for Chinese companies? – Energy 309: 133157. DOI: https://doi.org/10.1016/j.energy.2024.133157.
[47] Wang, H., Qiu, Y. (2023): Effect of new urbanization on cities' innovation in China: evidence from a quasi-natural experiment of a comprehensive pilot. – PloS ONE 18(4): e0284772. DOI: https://doi.org/10.1371/journal.pone.0284772.
[48] Wang, L., Yu, X., Zhang, Y. (2025b): The effects of outward foreign direct investment on green technological innovation: a quasi-natural experiment based on Chinese enterprises. – Environmental Impact Assessment Review 110: 107666. DOI: https://doi.org/10.1016/j.eiar.2024.107666.
[49] Wang, N., Yang, G., Wu, J., Wenya, L. (2025a): Impact of environmental information disclosure on green technology innovation: evidence from China's listed companies. – Finance Research Letters 71: 106375. DOI: https://doi.org/10.1016/j.frl.2024.106375.
[50] Wang, X., Wang, S., Wu, K., Zhai, C., Li, Y. (2024a): Environmental protection tax and enterprises' green technology innovation: evidence from China. – International Review of Economics Finance 96: 103617. DOI: https://doi.org/10.1016/j.iref.2024.103617.
[51] Wu, J., Xue, Y., Zhang, Q., Liu, Y. (2024): Digital economy, financial development, and corporate green technology innovation. – Finance Research Letters 66: 105552. DOI: https://doi.org/10.1016/j.frl.2024.105552.
[52] Wu, M., Huang, W. (2022): A preliminary study on the relationship between environmental constraints, technological innovation and economic development in China-based on the development level and degree of coordination of the combined system. – International Journal of Environmental Technology and Management 25(5): 427-444. DOI: https://doi.org/10.1504/ IJETM.2022.125533.
[53] Wu, Y. (2025): The impact of climate risks on green technology innovation: an empirical study based on panel data of 269 cities in China. – Frontiers in Environmental Science 12: 1510883. DOI: https://doi.org/10.3389/fenvs.2024.1510883.
[54] Xu, B. (2024): Fostering green technology innovation with green credit: evidence from spatial quantile approach. – Journal of Environmental Management 369: 122272. DOI: https://doi.org/10.1016/j.jenvman.2024.122272.
[55] Xu, J., Cui, J. B. (2020): Low-carbon cities and firms' green technological innovation. – China Industrial Economics 12: 178-196. DOI: 10.19581/j.cnki.ciejournal.2020.12.008.
[56] Yan, Y., Li, Z., Zhang, Y., Wu, J., Zhang, Y. (2025): The effects of foreign direct investment on green technology innovation: new evidence from China's 278 cities. – Emerging Markets Finance and Trade 61(4): 940-963. DOI: https://doi.org/10.1080/1540496X.2024.2401476.

[57] Yu, L. (2025): Synergy or contradiction: environmental concerns, digital empowerment and green technology innovation. – Journal of Cleaner Production 528: 146761. DOI: https://doi.org/ 10.1016/j.jclepro.2025.146761.

[58] Zhang, D., Jiao, F., Zheng, X., Pang, J. (2023b): Analysis of the influence mechanism of new urbanization on high-quality economic development in northeast China. – Sustainability 15(10): 7992. DOI: https://doi.org/10.3390/su15107992.

[59] Zhang, G., Zhang, N. (2024): Environmental regulation and worker earnings: evidence from city-level air quality standards in China. – Energy Economics 138: 107834. DOI: https://doi.org/10.1016/j.eneco.2024.107834.

[60] Zhang, J., Zhang, D., Huang, L., Wen, H., Zhao, G., Zhan, D. (2019): Spatial distribution and influential factors of industrial land productivity in China's rapid urbanization. – Journal of Cleaner Production 234: 1287-1295. DOI: https://doi.org/10.1016/j.jclepro. 2019.06.287.

[61] Zhang, Q., Wang, Y., Chen, Q. (2024a): Green bond issuance and the spillover effect of green technology innovation from the perspective of market attention: evidence from China. – Systems 12(10): 399. DOI: https://doi.org/10.3390/systems12100399.

[62] Zhang, R., Kong, G., Sun, H. (2023a): Can new-type urbanization promote enterprise green technology innovation? A study based on difference-in-differences model. – Sustainability 15(7): 6147. DOI: https://doi.org/10.3390/su15076147.

[63] Zhang, Z., Luo, C., Zhang, G., Shu, Y., Shao, S. (2024b): New energy policy and green technology innovation of new energy enterprises: evidence from China. – Energy Economics 136: 107743. DOI: https://doi.org/10.1016/j.eneco.2024.107743.

[64] Zhao, M., Fu, X., Fang, G., Cui, L., Nassani, A. A. (2024): Exploring the impact of ESG ratings on enterprises' green technology innovation. – Environment, Development and Sustainability 1-30. DOI: https://doi.org/10.1007/s10668-024-04725-z.

[65] Zhou, Y. B., Duan, Y. H., Huang, X. Z. (2025): Corporate green technology innovation under environmental regulation: substantive or strategic? – Research on Economics and Management 46(1): 124-144. DOI: 10.13502/j.cnki.issn1000-7636.2025.01.008.