

New-type Urbanization and Low-carbon Transformation of Tourism: A Moderated Framework of Fiscal Subsidies, Green Tax and Green Technology Innovation

Ying Fan^{1*}, Jianquan Guo²

¹Business School, University of Shanghai for Science and Technology, Shanghai 200093, P.R. China

²Sino German College, University of Shanghai for Science and Technology, Shanghai 200093, P. R. China

***Corresponding Author:** Ying Fan

Business School, University of Shanghai for Science and Technology, Shanghai 200093, P.R. China

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Abstract: The synergy between new-type urbanization (NTU) and low-carbon transition constitutes a vital pathway for reaching Chinese “dual carbon” targets. Present research predominantly focuses on socio-economic dimensions such as their interactive mechanisms and spatial governance strategies, while exhibiting insufficient attention to industrial perspectives. Thus, this study employs panel data of 30 Chinese provinces spanning 2008-2022 and exploits a panel two-way fixed effects model to investigate the association between NTU and the low-carbon development of tourism industry (LCDTI) through the analytical lenses of green technology innovation (GTI) and government intervention (GI), here GI is divided into green tax (GT) and financial subsidies (FS). The study shows: (1) NTU, GI, and GTI all significantly promote the LCDTI. (2) FS and GTI exhibit positive moderating effects on the association between NTU and LCDTI, whereas GT exhibits a negative moderating effect. (3) The moderating effects of FS and GTI display pronounced regional heterogeneity. Building upon these findings, this study proposes a tripartite synergistic framework integrating “targeted FS + GTI + optimized GT”. It emphasizes that high-economic-development regions should prioritize a “targeted FS + GTI” approach, while low-level regions should adopt a “GTI + optimized GT” paradigm to advance the LCDTI. Theoretically, this study enriches the industrial perspective research related to NTU; practically, it delivers implementable regional differentiation solutions for LCDTI.

Keywords: New-Type Urbanization; Low-Carbon Development of Tourism Industry; Government Intervention; Green Tax; Financial Subsidies; Green Technology Innovation.

1. INTRODUCTION

Under the dual backdrop of addressing global climate change and advancing sustainable development goals, low-carbon transition has become a central issue in nations’ economic and social development (Mbandi *et al.*, 2023). International agreements including the Kyoto Protocol, Paris Agreement, and resolutions from the United Nations Environment Assembly (UNEA-6) mandate that signatory states fulfill their carbon emission reduction obligations (Guo *et al.*, 2025a). COP16 explicitly emphasized the intrinsic linkages among ecosystem conservation, sustainable tourism, and low-carbon economic models (Peeters and Papp, 2024). This underscores the high importance that the international community attaches to low-carbon development in industries such as tourism that have both economic and emission attributes.

As a major carbon-emitting nations, China confronts dual pressures of accelerating urbanization and achieving carbon reduction targets (Cheng *et al.*, 2024; Gan *et al.*, 2025). While accelerated urbanization facilitates social progress and economic prosperity (Zhang *et al.*, 2025a), the massive influx of population into cities within a short time-frame substantially intensifies carbon emissions through heightened production and daily living activities (Wang and Zhang,

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2022). To resolve the “economic growth versus carbon reduction” dilemma, the Chinese government has integrated low-carbon principles into the National New-Type Urbanization (NTU) Plan (2021-2035) [1]. This plan revolves around technological innovation, industrial restructuring, and market institution coordination, forming a systematic solution to facilitate “dual carbon” goals. Furthermore, tourism integrating high-carbon sectors such as transportation, accommodation, and scenic operations into a unified system, represents a quintessential resource-intensive and high-carbon-emission industry (Peeters and Papp, 2024). Empirical research has indicated that tourism currently provides over 5% of universal carbon emissions, with this proportion persistently increasing (Isik *et al.*, 2018; Peeters and Papp, 2024). Consequently, investigating pathways for low-carbon development of the tourism industry (LCDTI) within the context of NTU has become imperative.

As a national strategy, NTU embodies high-quality dimensions, including optimized urban development patterns, upgraded industrial structures, and transformed production modes and lifestyles, which collectively facilitate LCDTI (Zhang *et al.*, 2025a). Its efficacy can be manifested through the following pathways: (1) Optimizing spatial layouts to establish low-carbon tourism development frameworks (Wei *et al.*, 2024); (2) Promoting low-carbon transportation systems to reduce travel-related carbon emissions (Gao *et al.*, 2025b); (3) Implementing smart technologies to enhance tourism operational efficiency (Bingöl and Yang, 2025); (4) Strengthening policy safeguards to construct institutional mechanisms for low-carbon development (Zhang *et al.*, 2025b).

Furthermore, in the process of LCDTI, government intervention (GI), which is subdivided into green tax (GT) and fiscal subsidies (FS) in this study, and green technology innovation (GTI), play pivotal roles (Liu *et al.*, 2025a; Wu *et al.*, 2025). On the one hand, governments can guide low-carbon behaviors of enterprises and tourists through GT (Zhao *et al.*, 2024; Křístková *et al.*, 2025), while leveraging FS or tax incentives to alleviate the financial burden on businesses during green transition and expedite technological adoption (Liu *et al.*, 2025b). On the other hand, GTI can effectively drive the industrial structures upgrade and composes a pivotal pathway for achieving green development (Liu *et al.*, 2024a).

Building upon the preceding analysis, this research implores the association between NTU and LCDTI by incorporating the moderating roles of GI (specifically GT and FS) and GTI. The research specifically examines the following questions:

- 1) Does NTU promote the LCDTI?
- 2) Do GI and GTI promote the LCDTI?
- 3) How do GI and GTI moderate the impact of NTU on LCDTI?
- 4) Are there heterogeneous effects in the above relationships across provinces with different levels of economic development?

This study contributes and innovates the following:

First, regarding research contents, existing research has extensively validated the effects of NTU on economic development and carbon emissions (Cheng *et al.*, 2024; Wang and Fang, 2025; Zhang *et al.*, 2025a); however, scant scholarly focus has been devoted to examining its impact on the low-carbon transformation of industries.

Second, this study operationalizes GI through two distinct policy instruments, GT and FS, and separately examines their moderating effects on the association between NTU and LCDTI. Contrasting with prevailing research that predominantly focuses on singular policy tools (Ma *et al.*, 2024; Yan *et al.*, 2024; Yang *et al.*, 2024), this dual-dimensional analysis enables more precise identification of differential policy efficacy, thereby providing empirical grounding for governments to formulate differentiated policy interventions.

Finally, diverging from prior research that concentrated on singular factors influencing LCDTI, this study incorporates GT, FS, and GTI as moderating variables within a unified analytical framework to investigate their mechanistic roles in the process of NTU driving LCDTI. This integrative perspective facilitates a more comprehensive elucidation of the complex interrelationships among these factors.

2. Literature Review and Hypothesis Development

2.1 NTU and LCDTI

As China’s pivotal strategy toward an ecological civilization, NTU exerts profound impacts on LCDTI (Li *et al.*, 2023). Xu *et al.*, (2020) stated that China’s urbanization rate will reach 70% by 2030 and urbanization will continue to drive economic development, but there are controversies about its environmental effects in the academic community: while some believe that urbanization may aggravate energy consumption and pollution (Hao *et al.*, 2020), others emphasize that it can reduce emissions by strengthening environmental regulations and the application of clean energy (Zhao and Wang, 2022).

¹ https://www.gov.cn/zhengce/content/202407/content_6965542.htm

Following the National NTU Plan (2014-2020) [2], the academic community has gradually formed a consensus that NTU, centered on “people-oriented, industrial coordination and systemic balance”, promotes carbon emission reduction through a variety of ways: (1) NTU can promote the compact layouts of functional areas to improve the utilization efficiency of infrastructure (Liu and Liu, 2019); (2) Reducing transportation energy consumption through shortened urban commuting distances enabled by spatial intensification (Zhang *et al.*, 2025b); (3) Enforcing ecological constraints to phase out high energy consumption industries (Zhang *et al.*, 2023); (4) The sustainable urban development paradigm is constructed through the synergy of environmental governance, spatial optimization, industrial upgrading and public service integration (Li *et al.*, 2023).

Beyond pursuing scale economies, NTU prioritizes enhancing public services, improving eco environmental quality, and advancing people-centered development (Tahmasbi *et al.*, 2019; Schnell *et al.*, 2020). It necessitates coordinated integration of equity-efficiency trade-offs and economy-resource balance to achieve synergistic scale effects and energy structure upgrading (Zhang and Xing, 2023). Conversely, rapid tourism expansion intensifies land-use pressure, degrades carbon sequestration capacity, and generates multi-source pollution through high-energy-consumption activities across transportation, accommodation, and sightseeing sectors (Zhang, 2022; Liu *et al.*, 2024b). Consequently, NTU intrinsically generates positive spillover effects for LCDTI. Empirical evidence further confirms NTU’s capacity to reduce carbon emissions (Yao *et al.*, 2025) while stimulating rural tourism revitalization (Jiang and Wang, 2022).

To sum up, this paper tenders the following hypothesis:

H1: NTU can promote LCDTI.

2.2 GI, NTU and LCDTI

Recently, carbon emission governance has become a global imperative, with GI policies targeting emission reduction becoming a focal point of academic inquiry (Zheng and Yu, 2022; Huang, 2023; Fei *et al.*, 2024; Xu *et al.*, 2025). Extant research identifies two distinct policy instruments: The first involves governments leveraging GT to elevate environmental costs, thereby compelling enterprises toward low-carbon transition (Arogundade and Hassan, 2024). The second approach is for the government to provide FS to alleviate research and development expenditures for green technologies, thus incentivizing corporate innovation (Shi and Zhou, 2024). Given that NTU constitutes a national strategic priority whose implementation inherently necessitates GI, and recognizing the inherent limitations of singular policy approaches, this study integrates both aforementioned policy instruments to systematically examine their moderating roles within the process whereby NTU drives LCDTI.

2.2.1 GT, NTU and LCDTI

GT, as a kind of environmental taxes, aims to internalize environmental costs by levying charges on environmentally damaging activities such as carbon emissions and pollution (Chen *et al.*, 2021). While some research suggests that GT may increase corporate costs, dampen investment, and weaken competitiveness (Fida and Saeed, 2023), a substantial body of research supports its effectiveness in decreasing emissions. When exploring the dynamic impacts of environmental taxes on Chinese emissions spanning the period 1970 to 2022, Liu (2025) showed that the association between environmental taxes and emissions exhibits multiple patterns. Initially, due to increased short-term compliance costs, environmental taxes may cause a rise in emissions; however, over the longer term, they can significantly reduce carbon emissions. Furthermore, the “Double Dividend” theory posits that GT can not only mitigate carbon emissions (Sharif *et al.*, 2023), but also generate revenue that can be used to fund environmental protection projects (Usman and Alola, 2022).

Many empirical studies further corroborate the positive impact of GT on low-carbon development. Yadav *et al.*, (2024) contended that GT can be strategically employed to support R&D in GTI and simultaneously foster sustainable development within the transportation sector. Utilizing time-series data from 15 nations undergoing energy transitions spanning the period 1990-2020, Ahmad *et al.*, (2024) identified that a statistically significant negative relationship between the implementation of GT and carbon emissions generated by the tourism industry. Through empirical analysis of data covering 273 Chinese prefecture-level cities from 2010-2021, Kong *et al.*, (2025) demonstrated that environmental taxes enhance eco-efficiency through multiple pathways, such as stimulating GTI, driving industrial structure upgrading, and promoting public participation. With a Difference-in-Differences (DID) model to examine the association between carbon taxes and tourism consumption in 117 countries, Doan and Nguyen (2025) reached substantively congruent conclusions.

² https://www.gov.cn/zhengce/2014-03/16/content_2640075.htm

To sum up, this paper tenders the following hypothesis:

H2: GT can promote LCDTI.

In recent years, China has progressively refined its institutional framework by establishing a GT system centered on environmental protection taxes and resource taxes, effectively guiding the advancement of NTU. Specifically, GT provides a stable funding source for urban green infrastructure development (Behera *et al.*, 2025). Environmental taxes not only contribute to emission reduction by optimizing local energy structures, production technologies and regulatory standards, but also exert spillover effects on environmental governance in neighboring regions (Espinosa *et al.*, 2025). NTU, through optimizing the spatial distribution of low-carbon industrial parks, furnishes essential implementation platforms for deploying green technologies (Yu *et al.*, 2024), while the environmental regulation embedded in GT incentivizes enterprises to adopt more environmentally friendly technologies, thus decreasing emissions (Yeboah *et al.*, 2024). Furthermore, Espinosa *et al.*, (2025) discussed the role of carbon taxes as automatic stabilizers in small open economies and their contribution to low-carbon energy transitions. Xie *et al.*, (2025) found that GT can accelerate the green transformation of high-pollution enterprises by promoting the adoption of green technologies.

To sum up, this paper tenders the following hypothesis:

H3: GT can positively moderate the impact of NTU on LCDTI.

2.2.2 FS, NTU and LCDTI

Given the public acceptance challenges associated with GT policies, Van (2025) proposed setting the optimal carbon tax below the Pigouvian tax threshold while concurrently implementing FS policies to incentivize the production of green products, thereby establishing a “constraint-incentive” dual mechanism. As a crucial instrument for policy regulation and control, FS plays an indispensable role in advancing low-carbon development (Gao *et al.*, 2025a). First, FS can guide enterprises towards adopting cleaner production processes and pollution control technologies, thereby enhancing carbon abatement efficiency (Liu *et al.*, 2025a). Second, FS may contribute to increasing product recovery rates, consequently reducing associated carbon emissions (Li *et al.*, 2025b). Finally, FS can exert a positive influence on corporate environmental investment and may further stimulate such investment through channels such as heightened media attention (Deng *et al.*, 2025).

A considerable body of empirical research further substantiates the positive impact of FS on low-carbon development across various industries. Chen and Gao (2025), employing a tripartite asymmetric dynamic evolutionary game model, confirmed that FS play a pivotal role in fostering green development within the agricultural sector. Huang *et al.*, (2024) found that FS effectively catalyze the development of ecotourism during its introductory phase. Lyu *et al.*, (2024), utilizing a sample of Chinese listed industrial companies spanning the period 2007 to 2021, empirically demonstrated that government innovation subsidies significantly enhance energy utilization efficiency and drive a reduction in production carbon intensity. Rishan *et al.*, (2024), focusing on tourism development challenges in the northern and southern regions of the Maldives, empirically validated FS as a potential solution through their analysis.

To sum up, this paper tenders the following hypothesis:

H4: FS can promote LCDTI.

Within the advancement of NTU, the government plays a central guiding role through FS, a role specifically manifested in areas such as public good provision and resource allocation (Feng *et al.*, 2021). From a policy perspective, the National NTU Plan (2014–2020) explicitly delineated the strategic direction for establishing the urbanization development framework and corresponding financial subsidy policies, thereby providing critical financial support for green development.

Furthermore, leveraging provincial-level panel data from China spanning 2010-2019, Ma *et al.*, (2024) discovered that the promotional effect of FS on green development efficiency is significantly stronger during the progression of NTU. Concurrently, the FS mechanism underwent continuous optimization, gradually forming a positive intermediary effect. Through precise fiscal support, resources were effectively guided towards the allocation of green sectors, which promotes the deep integration and synergistic efficiency of NTU and green development.

To sum up, this paper tenders the following hypothesis:

H5: FS can positively moderate the impact of NTU on LCDTI.

2.3 GTI, NTU and LCDTI

GTI aims to decrease environmental effects and increase energy utilization efficiency through the development of environmentally friendly technologies, products, or services. Its core value resides in driving the optimization of energy

structures and the application of clean energy, thereby reducing carbon emissions (Li *et al.*, 2025a). As a key driving force for industrial green transformation, GTI plays a decisive role in achieving low-carbon development (Liu *et al.*, 2024a).

The tourism industry generates substantial carbon emissions across multiple domains including commerce, transportation, accommodation, catering, and scenic attractions, while GTI effectively mitigates these emissions (Erdoğan *et al.*, 2022). Kwilinski *et al.*, (2024) identified that some specific GTI such as sustainable aviation fuel technology, hybrid propulsion technology, and hydrogen energy technology can enhance vehicular energy efficiency and provide decarbonization solutions for the transportation sector.

A substantial body of empirical research further corroborates the positive impact of GTI on low-carbon development. Based on data from the 30 Chinese provinces from 2013-2023 and utilizing the entropy weight method, Dai *et al.*, (2025) confirmed a positive correlation between GTI and low-carbon development. Erdoğan *et al.*, (2022), in their study focusing on the transportation sector, found that GTI promotes the adoption of new energy vehicles and the greening of tourism facilities, thereby effectively curbing carbon emissions from tourism activities. Research by Liu *et al.*, (2024c) demonstrated that GTI can facilitate industrial restructuring while enhancing energy efficiency by adjusting energy mixes and refining low-carbon industrial systems, thereby driving urban low-carbon development and improving tourism eco-efficiency. Asadi *et al.*, (2020) argued that GTI can enhance tourism enterprises' labor productivity, organizational performance, and competitive advantage, consequently reducing the carbon emissions of the tourism industry. Sun *et al.*, (2022) pointed out that GTI in the tourism industry can help achieve environmentally friendly utilization of tourism resources and its sustainable development, making it an effective way to solve the problems of low efficiency and high pollution that affect the tourism industry.

To sum up, this paper tenders the following hypothesis:

H6: GTI can promote LCDTI.

Based on the preceding analysis, NTU can facilitate LCDTI through pathways such as spatial optimization, industrial upgrading, and public service integration. However, some scholars contend that the NTU process incurs environmental costs by increasing energy consumption and pollutant emissions (Hao *et al.*, 2020). GTI can effectively alleviate the pollution emissions problems generated during NTU, which has also received support from many scholars. Zhang *et al.*, (2025a) demonstrated that GTI can upgrade industrial structures, thereby reducing energy consumption and generating environmental benefits. Shang *et al.*, (2018) established that NTU exhibits a statistically significant positive correlation with technological innovation, demonstrating long-term stability. Following the integration of GTI into NTU initiatives, smart cities and eco-cities have experienced accelerated development (Cai *et al.*, 2023), ameliorating the adverse environmental impacts historically associated with urbanization (Cheng *et al.*, 2022). Li *et al.*, (2023) further emphasized that incorporating GTI into the NTU process constitutes a critical pathway for achieving low-carbon urban development and reconciling the contradiction between rapid urbanization and sustainable development. Within this context, NTU contributes to low-carbon objectives by reshaping residents' lifestyles, while GTI provides technological underpinning for high-quality urbanization through its dual role in driving industrial upgrading and improving environmental quality. Thus, this research proposes the following hypothesis:

H7: GTI can positively moderate the impact of NTU on LCDTI.

Figure 1 illustrate the study framework, where the dotted arrow indicates the potential moderating effect.

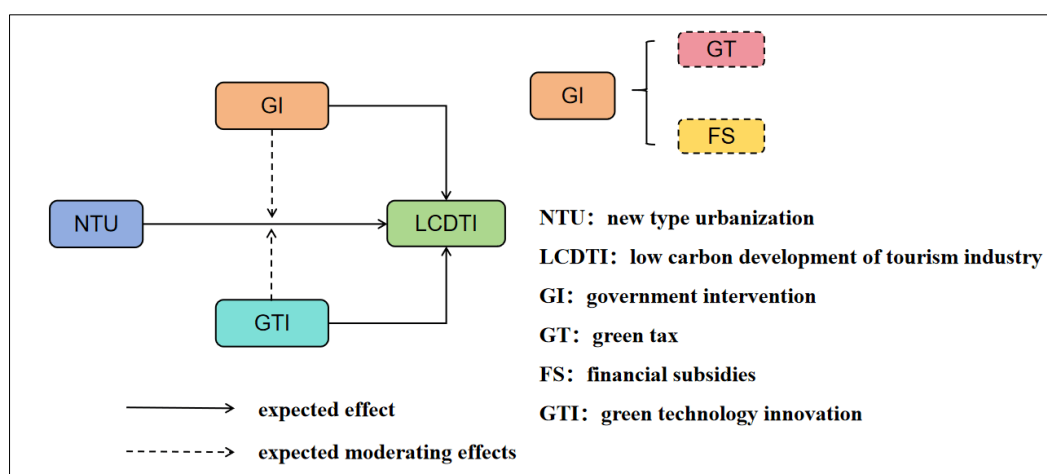


Figure 1: Impact mechanism framework

3. Models, Variables and Data

3.1 Econometric Model

This study employs a panel two-way fixed effects model to investigate the effect of NTU, GI, and GTI on the LCDTI, while further examining the moderating effects of GI and GTI within these relationships. Given regional disparities in economic development levels, sub-sample regressions are conducted to further reveal the regional heterogeneity of the above relationship.

To test H1, H2, H4 and H6, this study models the following:

$$LCDTI_{it} = \alpha_0 + \alpha_1 NTU_{it} + \alpha_2 Control_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (1)$$

$$LCDTI_{it} = \beta_0 + \beta_1 GTI_{it} + \beta_2 Control_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (2)$$

$$LCDTI_{it} = \sigma_0 + \sigma_1 FS_{it} + \sigma_2 Control_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (3)$$

$$LCDTI_{it} = \delta_0 + \delta_1 GTI_{it} + \delta_2 Control_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (4)$$

Here $LCDTI_{it}$ and NTU_{it} respectively stands for the degree of LCDTI and NTU of a province i in period t , GTI_{it} refers to the level of GT, FS_{it} represents the level of FS, GTI_{it} stands for the level of GTI, $Control_{it}$ stands for the following control variables: economic development (GDP), human capital (HC), openness degree (OP), and social consumption (SC), δ_i captures entity fixed effects, σ_t accounts for time fixed effects and ε_{it} it is a random error term.

To verify H3, H5 and H7, this study constructs models as follows:

$$LCDTI_{it} = \mu_0 + \mu_1 NTU_{it} + \mu_2 GTI_{it} + \mu_3 NTU_{it} * GTI_{it} + \mu_4 Control_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (5)$$

$$LCDTI_{it} = \eta_0 + \eta_1 NTU_{it} + \eta_2 FS_{it} + \eta_3 NTU_{it} * FS_{it} + \eta_4 Control_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (6)$$

$$LCDTI_{it} = \theta_0 + \theta_1 NTU_{it} + \theta_2 GTI_{it} + \theta_3 NTU_{it} * GTI_{it} + \theta_4 Control_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (7)$$

Here, the sign of interaction term coefficient μ_3 , η_3 , θ_3 indicates the direction of moderating effects exerted by GT, FS, and GTI on the association between NTU and LCDTI.

3.2 Variable Interpretation

3.2.1 Explained Variable

This study constructs the tourism carbon intensity index (Guo and Fu, 2023; Li and Guo, 2025) to measure the low-carbon development of tourism industry (LCDTI).

3.2.2 Core Explanatory Variables

Referring to Wu and Guo (2024), this study constructs a comprehensive measurement index system to measure New-type urbanization (NTU). The system incorporates 15 specific indicators as detailed in Table 1.

Table 1: New-type urbanization measurement index system

Primary indicator	Secondary index	Attribute
demographic urbanization	Urbanization rate of permanent residents (%)	Positive
	Employees in secondary and tertiary industries/total employees (%)	Positive
	Urban registered unemployment rate (%)	Negative
economic urbanization	Per capita GDP (Yuan)	Positive
	Added value of tertiary industry/gdp (%)	Positive
	Local general budget revenue per capita (10000 yuan)	Positive
	Total retail sales of consumer goods per capita (10000 yuan)	Positive
social urbanization	Education expenditure/fiscal expenditure (%)	Positive
	Per capita bed capacity in hospitals and township health centers (bed)	Positive
	Per capita total holdings in public libraries (volume)	Positive
	Public transit vehicles per 10,000 population (unit)	Positive
ecological urbanization	Per capita park green space area (m ²)	Positive
	Greening coverage rate of built-up area (%)	Positive
	Centralized treatment rate of domestic sewage (%)	Positive
	Harmless treatment rate of domestic waste (%)	Positive

Source: Authors' own work.

3.2.3 Adjusting Variables

Government intervention (GI) is divided into GT and FS. Following Peng *et al.*, (2025), this study employs environmental protection tax, urban maintenance and construction tax, and pollution discharge tax to measure GT. Drawing on Fan *et al.*, (2025), the ratio of local government expenditure to GDP is adopted to measure FS.

Following Sun and Li (2024) and Tang *et al.*, (2025), this study employs the natural logarithm of the number of green invention patent applications per province to measure Green technology innovation (GTI).

3.2.4 Control Variables

Following Liu *et al.*, (2024c), this study employs the natural logarithm of regional GDP per capita to measure Economic Growth (GDP).

Following Guo *et al.*, (2025a) and Zhang *et al.*, (2025b), this study determines the level of Human Capital (HC) across provinces based on educational attainment.

Following Zhang *et al.*, (2025b), this study employs the ratio of Foreign Direct Investment (FDI) to Gross Domestic Product (GDP) to measure Openness (OP).

Following Qi and Li (2025), this study employs the ratio of total retail sales of consumer goods to GDP to measure Social Consumption Level (SC).

Following Ntafloukas *et al.*, (2025), this study employs the natural logarithm of the total length of highways and railways to measure Transportation Network Density (TP).

Following Sukor *et al.*, (2025), this study employs the ratio of the resident population to the land area to measure Population Density (PD).

For detailed explanations of the related variables, please refer to Table A2 in online appendix.

3.3 Data Sources

We collect panel data of 30 provinces in mainland China from 2008 to 2022. Table 2 summarizes the variables, their measurements, and data sources.

In the panel data analysis, the unit root tests revealed that some variables are non-stationary but became stationary after the first-order difference. Consequently, co-integration tests are conducted to ascertain the existence of a long-run equilibrium relationship among the variables, thereby avoiding spurious regression and capturing their genuine long-term association. As shown in Table 3, the co-integration test results are statistically significant ($P < 0.1$), confirming a stable equilibrium mechanism between the variables. Subsequently, multi-collinearity is assessed using the Variance Inflation Factor (VIF). Table 4 demonstrates the absence of significant multi-collinearity issues. Descriptive statistics are stated in Table 5.

Table 2: Variable definition and data source

Variables	Symbol	Measure	Data sources
New-type urbanization	NTU	Entropy method	Statistical yearbook of China and provinces
low-carbon transformation of tourism industry	LCTT	Ratio of total tourism revenue to carbon emissions from tourism	China-Statistical-Yearbook
Green tax	GT	Take logarithm of tax revenue related to environmental protection	National Bureau of Statistics; CNRDS
Green technology innovation	GTI	Natural logarithm of green invention patent applications	CNRDS
Social consumption level	SC	Ratio of total retail sales of consumer goods to regional GDP	China-Statistical-Yearbook
Financial subsidies	FS	Ratio of local fiscal expenditure to GDP	China-Statistical-Yearbook; EPS database
Economic growth	GDP	Logarithm of per capita GDP	China-Statistical-Yearbook
Human capital	HC	Education level of permanent residents	China-Statistical-Yearbook
Openness	OP	Ratio of foreign direct investment to GDP	China-Statistical-Yearbook
Transportation network density	TP	Logarithm of total length of Expressway and railway	China-Statistical-Yearbook
Population density	PD	Ratio of permanent population to land area	Statistical yearbook of China and provinces

Source: Authors' own work

Table 3: Co-integration Test

	Statistic	p-value
Unadjusted t	-7.7686	
Adjusted t*	-3.3220	0.0004

Source: Authors' calculation

Table 4: Variance inflation factor

Variable	VIF	1/VIF
NTU	7.33	0.136
GTI	5.84	0.171
GT	5.57	0.179
GDP	2.60	0.385
RE	2.60	0.384
HC	1.53	0.655
OP	1.59	0.502
FS	1.77	0.565
SC	1.86	0.536
Mean VIF	3.65	.

Source: Authors' calculation

Table 5: Descriptive statistics of major variables

Variable	N	Mean	SD	Min	Max
LCTT	450	1.47	1.00	0.14	4.79
NTU	450	0.29	0.10	0.11	0.59
GT	450	2.04	1.93	0.07	11.73
FS	450	10.05	0.39	9.21	11.24
GTI	450	8.8	0.26	7.64	9.22
GDP	450	1.26	0.80	0.41	5.05
HC	450	0.02	0.01	0.01	0.04
OP	450	0.24	0.27	0.01	1.59
SC	450	0.37	0.07	0.22	0.54
RE	450	8.89	0.11	8.48	9.08

Source: Authors' calculation

4. Empirical Analysis

4.1 Fixed Effect Regression

This study employs a panel two-way fixed effects model, estimated using Driscoll-Kraay (D-K) standard errors (Guo *et al.*, 2025a), to examine the impact of NTU on LCDTI, and to assess the moderating role of GI and GTI in this association. The results are presented in Table 6.

Results from Model 1 in Table 1 show that at the 1% significance level, the coefficient for NTU is 7.6109. This suggests that, holding other conditions constant, 1-unit increase in the level of NTU is associated with 7.6109-unit increase in the level of LCDTI, which is in line with Zhang and Xing (2023) and Wu *et al.*, (2023). Therefore, hypothesis 1 has been validated.

Results from Models 2-4 indicate that at the 1% significance level, the coefficients are 0.2299 for GT, 1.0521 for FS, and 1.4066 for GTI, demonstrating that GT, FS, and GTI significantly promote LCDTI. These empirical findings align with the results of Rasoulinezhad (2025), Gao and Lu (2025), and Cheng *et al.*, (2025). Consequently, Hypotheses 2, 4, and 6 are empirically substantiated.

Results from Model 5 reveal a significantly negative coefficient for the interaction term between NTU and GT. This indicates that GT exerts a significant negative moderating effect on the relationship. A similar negative moderating effect was reported by Fida and Saeed (2023). However, this finding contradicts Hypothesis 3. This paper posits the following possible explanations for this inconsistency:

First, as an asset-light and highly mobile service industry, tourism exhibits heightened sensitivity to cost fluctuations. GT directly increases operational costs for tourism enterprises (Hassan *et al.*, 2025), while NTU already increases costs through mandatory environmental and infrastructure investments. When tax pressure becomes

excessive, firms may scale back environmental expenditures, thereby undermining the low-carbon effects generated by NTU.

Secondly, there are significant differences in tax collection and management capacity among regions in China. In some regions, there is a phenomenon of “tax on behalf of management”, which simplifies the implementation of GT collection into “penalty style”, fails to effectively encourage enterprises to reduce emissions (Lu and Yang, 2024), and may also attack enterprises’ enthusiasm for low-carbon transformation. Especially when NTU investment focuses on hardware facilities (such as transportation and construction) and ignores soft management (such as carbon trading), the negative moderating effect of tax is more obvious.

Finally, the moderating effect of GT hinges on firms’ technological response capacity. However, the tourism industry faces significant time lags between research and development and deployment of low-carbon technologies (Such as motorization of vehicles). During accelerated NTU phases, GT imposed cost pressures compel firms toward cost-driven compliance strategies-such as purchasing carbon allowances rather than pursuing innovation (Yang *et al.*, 2024). This further amplifies GT’s negative moderating effect.

Results from Model 6 reveal a statistically significant positive coefficient (2.4392, $p < 0.05$) for the interaction term between NTU and FS. This indicates FS exerts a significant positive moderating effect, aligning with findings by Ma *et al.*, (2024). Hypothesis 5 is therefore empirically supported.

Results from Model 7 demonstrate a statistically significant positive coefficient (7.0217, $p < 0.01$) for the NTU with GTI interaction term. This confirms GTI exerts a significant positive moderating effect, consistent with findings by Li *et al.*, (2025a) and Zhao *et al.*, (2025). Hypothesis 7 is therefore empirically substantiated.

Table 6: Fixed effects regression results

Explained variable: LCDTI							
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
NTU	7.6109*** (0.9171)				8.4794*** (1.3267)	-16.5993 (11.6399)	-58.7854 (20.5918)
GT		0.2299*** (0.0419)			0.6704*** (0.1332)		
FS			1.0521*** (0.2440)			0.0338 (0.3825)	
GTI				1.4066*** (0.2554)			0.0891 (0.3457)
NTUGT					-1.2267*** (0.2057)		
NTUFS						2.4392** (1.1980)	
NTUGTI							7.0217*** (2.2090)
GDP	-0.4312** (0.2041)	-0.0476 (0.2026)	0.4081** (0.1876)	0.2048 (0.1886)	-0.4954** (0.2013)	-0.3653* (0.2032)	-0.4905** (0.2003)
HC	68.9732*** (14.4516)	146.485*** (9.1359)	167.628*** (8.1463)	129.9842*** (10.8823)	71.5370*** (16.4250)	64.6185*** (15.3233)	83.0131*** (16.4447)
OP	0.7365* (0.3758)	1.1096** (0.4591)	0.1448 (0.3915)	0.0408 (0.3732)	1.0109*** (0.3914)	1.0311*** (0.3837)	1.3592*** (0.4013)
SC	1.3086* (0.6689)	2.5904*** (0.6688)	2.6595*** (0.6779)	1.7928** (0.6773)	1.0424 (0.6927)	0.9101 (0.6809)	1.1523*** (0.6785)
_cons	-2.2175*** (0.3459)	-3.1174*** (0.3308)	- 14.0150*** (2.4676)	-14.4549*** (2.0208)	-4.0609*** (1.0190)	-2.5208 (3.9210)	-2.1328 (2.9648)
Year-fixed effect	√	√	√	√	√	√	√
Country-fixed effect	√	√	√	√	√	√	√
N	450	450	450	450	450	450	450
R-square	0.6575	0.6277	0.6178	0.6279	0.6851	0.6671	0.6741

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. The standard error in parentheses

4.2 Heterogeneity Analysis

To further examine heterogeneous effects across economic development levels, this study employs the approach of Li and Guo (2025). Using 2008 as the base year, we calculate per capita GDP for all provinces during 2008-2022, ranked the outcomes, and divide the sample into high-economic-development regions (top 15 provinces) and low-level regions (bottom 15 provinces). Group-specific regression analyses are subsequently conducted, with results presented in Table 7.

The findings in Table 7 are similar to those in Table 6, but there is significant heterogeneity. Specifically:

(1) Results from Models 1, 3, and 4 reveal statistically higher coefficient estimates in high-economic-development regions: 8.0899 for NTU, 1.8605 for FS, and 2.2089 for GTI. These substantially exceed corresponding estimates in low-level regions (6.8911, 0.1733, and 0.9845 respectively). This result is consistent with Dai *et al.*, (2025). We posit this divergence is partly attributable to economic development levels and partly linked to systemic constraints in low-level regions, including technological innovation capacity deficits, limited energy transition awareness, governance inefficiencies, and funding shortages (Li and Guo, 2025).

(2) Results from Model 2 indicate a significantly lower GT coefficient estimate in high-economic-development regions (0.2007) compared to low-level regions (0.4644). We attribute this disparity to the following causes:

First, consistent with the Environmental Kuznets Curve theory, tourism enterprises in high-economic-development regions have transitioned to a quality-driven phase (Rahman *et al.*, 2025). With limited emission reduction potential and heightened susceptibility to tax fatigue, GT exhibits diminishing marginal effects in these regions. Conversely, firms in low-level regions remain in an extensive growth phase, where GT imposed cost pressures are more acutely felt. Consequently, GT demonstrates stronger policy efficacy in low-level contexts.

Second, Jaeger (2025) demonstrated that GT's "double dividend" effect manifests more prominently in low-level regions. Here, tax revenues are typically directed toward ecological restoration, creating a closed-loop "tax-to-low-carbon" system. Conversely, high-economic-development regions' greater fiscal autonomy often diverts GT revenues to non-tourism sectors (such as infrastructure), thereby weakening GT's catalytic effect on LCDTI. This fiscal redistribution differential results in more direct policy efficacy in low-level regions.

Third, tourists in high-economic-development regions demonstrate willingness to pay low-carbon premiums (He *et al.*, 2022), creating market-driven rather than policy-driven decarbonization pathways. This market substitution effect dilutes GT's price signaling function. Conversely, weak tourist environmental awareness in low-level regions positions GT as the primary enforcement lever compelling supply-side reforms. Policy efficacy in these regions consequently depends more critically on tax incentives.

(3) Results from Model 6 demonstrate significantly stronger moderating effects of FS in high-economic-development regions compared to their low-level counterparts. We believe that it may be related to the following advantages of high-economic-development regions: for example, the financial market in these regions is mature, and FS can quickly leverage social capital, making its multiplier effect surge; The flow of factors in these regions is efficient, and subsidies can quickly match the demand, so as to play a role efficiently; The tourism industry in these regions is deeply coupled with low-carbon industry, and the industrial chain synergy effect is obvious; Enterprises in these regions have strong technological innovation and talent reserves, and have the ability to quickly transform subsidies. In addition, low-level regions also have relatively high corruption losses, insufficient support for low-carbon infrastructure, and low activity of the green consumption market, which also weaken the moderating role of FS.

(4) Results from Model 7 show that the moderating effect of GTI in low-level regions is more significant than that in high-economic-development regions. The possible reasons are as follows:

First, these findings refine the concept of "diminishing marginal effects in technological innovation" (Si *et al.*, 2024). GTI enhancements in low-level regions generate amplified technological spillovers, promote LCDTI, and catalyze development in related industries.

Second, tourism infrastructure in low-level regions exhibits systematically higher carbon intensity (Hsu *et al.*, 2021), resulting in greater marginal abatement benefits from GTI.

Third, compared to high-economic-development regions, the process of NTU in low-level regions is often relatively slow; furthermore, these regions often possess high-quality natural resources (such as sunshine, water, and geothermal). Given this context, the introduction of GTI can maximize its value if combined with the experience of NTU construction in high-economic-development regions.

Table 7: Regional heterogeneity based on economic development level

Explained variable: LCDT														
Variables	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
NTU	8.089*** (1.0889)	6.8911*** (1.7209)												
GT			0.2007*** (0.0450)	0.4644*** (0.1337)										
FS					1.8655*** (0.3187)	0.1733 (0.3749)								
GTI							2.2089*** (0.0670)	0.9845*** (0.3349)						
NTUGT									-1.5192*** (0.2008)	-1.3697* (0.8331)				
NTUFS											0.3490* (1.4442)	1.1535 (2.6386)		
NTUGTI													3.6478 (2.9160)	8.7282** (3.8913)
NTURE														
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Country-fixed effect	>	>	>	>	>	>	>	>	>	>	>	>	>	>
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*p < 0.1; **p < 0.05; ***p < 0.01. The standard error in parentheses

4.3 Robustness Test

4.3.1 Endogenous Test (2SLS)

Endogenous problems can lead to estimation errors. To address this, referring to Guo *et al.*, (2025b), this study uses the explanatory variable with a lag of one period as the instrumental variable. Because its historical value has “pre certainty”, it has nothing to do with the current error term and meets the exogenous requirements. Therefore, using the two-stage least square method (2SLS), the regression results are shown in table 8-9. It can be observed that the core conclusions have not changed significantly, showing that the instrumental variables effectively control the endogeneity and have no distortion effect on the original estimation results.

Table 8: Test of endogeneity

Variable	NTU	GT	FS	GTI	GDP	HC	OP	SC
Instrumental variable	L.NTU	L.GT	L.FS	L.GTI	L.GDP	L.HC	L.OP	L.SC
F	0.1431	0.0558	2.3227	1.4036	0.1254	0.7742	4.4522	1.7915
Chi-sq	0.1399	0.0568	2.3557	1.4267	0.1272	0.7863	4.4692	1.8148

Note: The data corresponding to F-statistic and chi-square statistic are p-values of Wu Hausmann F-test and Durbin Wu Hausmann chi-square test respectively.

Table 9: Calculating results of Models (1) - (7) using 2SLS method

Explained variable: LCDTI							
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
L.NTU	7.6347*** (1.0152)						
L.GT		0.2341*** (0.0462)					
L.FS			1.4069** (0.2587)				
L.GTI				1.6930*** (0.2745)			
L.NTUGT					-1.5465*** (0.2417)		
L.NTUFS						3.5895** (1.5421)	
L.NTUGTI							4.6595** (2.2889)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	√	√	√	√	√	√	√
Country-fixed effect	√	√	√	√	√	√	√

*p < 0.1; **p < 0.05; ***p < 0.01. The standard error in parentheses

4.3.2 Eliminate Extreme Values

To mitigate extreme value influence and verify robustness, we implement quantile winsorization at the 1%, 5%, and 10% levels for key variables (such as NTU) following Guo *et al.*, (2025a). Fixed effects regressions are subsequently performed on the remaining 28, 26, and 24 provinces respectively. Results in Tables 10-11 demonstrate highly consistent coefficient magnitudes and significance levels with baseline estimates, confirming the robustness of our study.

Table 10: Elimination of extreme value test results

Explained variable: LCDTI						
	(1)			(2)		
Variables	28	26	24	28	26	24
NTU	7.4738*** (0.9941)	7.7677*** (0.9895)	6.3070*** (1.2538)	8.2717*** (0.9585)	8.5620*** (1.0096)	9.0452*** (1.0596)
GT	0.2135*** (0.0447)	0.2440*** (0.0453)	0.2145*** (0.0615)	0.3384*** (0.0467)	0.3970*** (0.0532)	0.4519*** (0.0568)
FS	0.9946*** (0.2557)	0.9954*** (0.2792)	0.7802** (0.3038)	1.1564*** (0.2704)	1.2895*** (0.2869)	1.2275*** (0.3129)
GTI	1.3260*** (0.2647)	1.7551*** (0.2975)	2.1305*** (0.3394)	1.8667*** (0.2970)	2.4193*** (0.3227)	2.3855*** (0.3443)
NTUGT	-1.2192*** (0.2132)	-1.0372*** (0.2142)	-1.3240*** (0.3148)	-1.0227*** (0.2466)	-0.9471*** (0.2880)	-0.5661*** (0.3321)
NTUFS	2.5970* (1.3381)	3.2126** (1.4820)	5.7692*** (1.7466)	3.2261** (1.5489)	3.7218** (1.8052)	4.0109** (1.9304)
NTUGTI	7.7890*** (2.4108)	7.2533*** (2.4920)	7.2454** (2.9785)	7.6140*** (2.3606)	7.7423*** (2.5166)	8.2192*** (2.6799)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	√	√	√	√	√	√
Country-fixed effect	√	√	√	√	√	√

*p < 0.1; **p < 0.05; ***p < 0.01. The standard error in parentheses

Table 11: Elimination of extreme value test results

Explained variable: LCDTI						
	(3)			(4)		
Variables	28	26	24	28	26	24
NTU	7.6109*** (0.9171)	7.9451*** (1.0074)	6.5772*** (1.1349)	7.5714*** (1.0163)	7.7432*** (1.0702)	8.4859*** (1.0993)
GT	0.2299*** (0.0419)	0.2489*** (0.0474)	0.1657*** (0.0529)	0.2169*** (0.0455)	0.2203*** (0.0503)	0.3857*** (0.0579)
FS	1.0521*** (0.2440)	1.2364*** (0.2774)	1.0867*** (0.2891)	1.1057*** (0.2753)	1.2437*** (0.2927)	1.2485*** (0.3076)
GTI	1.4066*** (0.2554)	1.9561*** (0.3040)	2.3308*** (0.3219)	1.8599*** (0.3008)	2.4102*** (0.3282)	2.7197*** (0.3593)
NTUGT	-1.2267*** (0.2057)	-1.2198*** (0.2405)	-1.3272*** (0.2509)	-1.2182*** (0.2181)	-1.1977*** (0.2503)	-0.9498*** (0.3089)
NTUFS	2.4392** (1.1980)	5.0820*** (1.6909)	6.8941*** (1.7915)	5.1339*** (1.6553)	6.5504*** (1.8807)	4.9883** (2.1318)
NTUGTI	7.0127*** (2.2090)	7.3961*** (2.4839)	6.5048** (2.6350)	6.8382*** (2.4974)	6.8264** (2.6829)	7.2426*** (2.9085)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	√	√	√	√	√	√
Country-fixed effect	√	√	√	√	√	√

*p < 0.1 ; **p < 0.05 ; ***p < 0.01. The standard error in parentheses

4.3.3 Adding Control Variables

In order to control the interference of spatial infrastructure and population agglomeration effect, this study introduces the traffic network density reflecting accessibility, which has a two-way impact on carbon emissions, and the population density reflecting population agglomeration, which has the duality of scale effect and resource consumption, as control variables (Gao *et al.*, 2025c), to verify the robustness of the above results. The results in Table 12 show that the regression coefficient and significance level of each model are similar to the previous results, confirming the robustness of our study.

Table 12: Add control variable result

Explained variable: LCDTI							
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
NTU	6.8839*** (0.9637)				8.3673*** (1.4308)	-11.2793 (12.2871)	- 64.3726*** (21.4676)
GT		0.2279*** (0.0431)			0.6239*** (0.1372)		
FS			0.8182*** (0.2485)			0.0764 (0.3851)	
GTI				1.0881*** (0.3355)			-0.3679 (0.4258)
NTUGT					-1.1736*** (0.2221)		
NTUFS						1.8411* (1.2680)	
NTUGTI							7.6218*** (2.3067)
GDP	-0.5389** (0.2102)	-0.2397 (0.2072)	0.1274 (0.2021)	0.0571 (0.2020)	-0.2897 (0.2095)	-0.4802** (0.2108)	-0.5361** (0.2077)
HC	50.2773*** (16.4843)	101.3242*** (13.8849)	136.2899*** (13.2011)	125.6213*** (13.1215)	49.5684*** (16.6420)	55.4522*** (17.0018)	72.8196*** (17.4184)
OP	0.8914** (0.3866)	1.3441*** (0.4529)	0.4349 (0.4055)	0.2387 (0.3921)	0.4148 (0.4457)	1.1421*** (0.3972)	1.3908*** (0.4058)
SC	0.6500 (0.6934)	1.5281** (0.6991)	1.6487** (0.7125)	1.4300** (0.7174)	-0.3286 (0.7057)	0.4927 (0.7012)	0.9714 (0.6955)
TP	1.0466*** (0.3932)	1.7269*** (0.4029)	1.1426*** (0.4206)	0.4447 (0.5176)	0.1390 (0.4371)	0.6509 (0.4256)	0.9017* (0.6956)
PD	0.7520 (0.8389)	0.1046 (0.9002)	1.5758* (0.8725)	1.4552* (0.8737)	1.2694 (0.8643)	0.9697 (0.8434)	-0.0042 (0.8569)
_cons	- 17.6322*** (5.0280)	-22.3887*** (5.0789)	-32.3341*** (5.2557)	-24.4328*** (5.1815)	-10.4872** (5.0601)	-15.2083** (6.6004)	-8.2345 (5.5972)
Year-fixed effect	√	√	√	√	√	√	√
Country-fixed effect	√	√	√	√	√	√	√
N	450	450	450	450	450	450	450
R-square	0.6662	0.6465	0.6322	0.6320	0.6875	0.6716	0.6770

*p < 0.1 ; **p < 0.05 ; ***p < 0.01. The standard error in parentheses

5. CONCLUSION AND DISCUSSION

5.1 Conclusion

This study examines the impacts of NTU, GI, and GTI on the LCDTI, along with their regional heterogeneity characteristics, using panel data from 30 Chinese provinces from 2008 to 2022. The study yields the following conclusions:

First, NTU, GI (FS and GT), and GTI all exert positive effects on the LCDTI. Second, regarding the moderating effects, FS and GTI can significantly enhance the promoting effect of NTU on LCDTI, whereas GT conversely undermines this effect. Finally, heterogeneity analysis shows that the positive effects of NTU, FS, and GTI on LCDTI are stronger in high-economic-development regions compared to low-level regions, while GT exhibits the opposite pattern (stronger effects in low-level regions). Furthermore, the moderating effect of FS is more pronounced in high-economic-development regions, whereas the moderating effect of GTI is more significant in low-level regions.

5.2 Discussion

Although most empirical results in this study validate the proposed hypotheses, certain findings deviate. To delve deeper into the underlying causes and implications of these divergent outcomes, further discussion is warranted.

5.2.1 From the Perspective of Main Effect

This research confirms that NTU, GI (FS and GT), and GTI all promote the LCDTI, the finding consistent with the conclusions of most existing literature (Xiao *et al.*, 2023; Cheng *et al.*, 2024; Wu *et al.*, 2025). This suggests that the population agglomeration, economic restructuring, and spatial optimization accompanying the NTU process underpin the LCDTI. It also empirically underscores the necessity of China's ongoing NTU strategy. Furthermore, the study affirms the

positive role of GT in driving emission reduction by internalizing environmental costs (Sharif *et al.*, 2023), FS in lowering the barriers to technology adoption through financial incentives (Liu *et al.*, 2025a), and GTI in enhancing energy efficiency and emission reduction capabilities.

5.2.2 From the Perspective of Moderating Effect

The results indicate that GT exerts a negative moderating effect on the association between NTU and LCDTI, whereas FS and GTI demonstrate positive moderating effects. This suggests that enterprises may exhibit resistance toward GT due to increased environmental compliance costs; however, FS and GTI can effectively compensate for these cost constraints, thereby strengthening the promoting effect of NTU on the sector's low-carbon transition.

5.2.3 From the Perspective of Heterogeneity

The findings reveal significant heterogeneity in the moderating effects of FS and GTI on the association between NTU and LCDTI. Specifically, FS demonstrates a statistically significant positive moderating effect in high-economic-development regions, whereas their moderating effect is not statistically significant in low-level regions. This indicates that in high-economic-development regions, NTU leverages sufficient fiscal capacity, mature markets, and industrial infrastructure to effectively channel capital investment and accelerate technological adoption. This establishes a self-reinforcing cycle of “policy driven - market responsive - industry transforming” dynamics, thereby effectively facilitating LCDTI through FS. Conversely, GTI exhibits a more pronounced moderating effect in low-level regions than in high-economic-development regions. This implies that compared to high-economic-development regions, GTI in low-level regions generates stronger technology spillovers and delivers greater marginal abatement benefits per unit of investment. Through such technological empowerment, NTU in these regions (low-level regions) can more effectively impart new momentum to LCDTI.

6. Theoretical and Policy Implications

6.1 Theoretical Implications

First of all, breaking through the shortcomings of present research that predominantly focus on the macro-economic level, this research for the first time unravels the role of NTU in promoting the LCDTI from the perspective of industry, and also reveals the complex driving mechanism of LCDTI.

Secondly, this research uncovers the double-edged sword effect of GI (positive moderation of FS and negative moderation of GT) in the process of LCDTI, deepening the understanding of the differentiated roles of policy tools. It also provides thoughts on how to properly use GI tools in the process of low-carbon transition of other industries.

Finally, this research reveals the bidirectional heterogeneous characteristics of the moderating roles played by FS and GTI in the process of NTU driving LCDTI. It substantiates the intrinsic connection between regional development gradients and the adaptability of policy instruments (for instance, GTI should be used to compensate for the insufficient efficiency of FS conversion in low-level regions, while FS should be used to amplify technological efficiency in high-economic-development regions), which introduces a new analytical dimension of “development stage-policy instrument matching” to regional economics and tourism policy research, thereby enriching theoretical studies on the microscopic mechanisms of heterogeneous policy effects.

6.2 Policy Implications

6.2.1 From the Main Effect Results

The government should actively deepen the implementation of the NTU strategy by coordinating development between urban areas and surrounding scenic spots to create distinctive low-carbon tourism town clusters; Simultaneously, it should integrate major carbon emission sources in the tourism sector (such as scenic area transportation) into the taxation system to guide low-carbon behaviors among enterprises and tourists; Additionally, FS and incentives should be provided to enterprises adopting green products to stimulate GTI. Through spatial optimization and policy synergy, these measures will collectively promote LCDTI.

6.2.2 From the Moderating Effect Results

Considering the positive moderating role of FS and GTI, coupled with the negative moderating effect of GT. In order to better leverage the role of NTU in LCDTI, the government should focus on high emission links in the tourism industry and provide targeted FS for GTI or green investment projects in these links. At the same time, the government should make fine-tuned adjustments to GT (one of the optimization methods for GT), such as implementing phased tax reductions and exemptions to alleviate compliance cost pressures for enterprises; and also, the government should consider setting up a “GT – FS for GTI” conversion channel to convert part of the enterprise's environmental protection tax payment into a special subsidy for GTI to offset the cost pressure. Based on the above analysis, a three-dimensional synergistic framework combining “targeted FS +GTI + optimized GT” can be ultimately formed for facilitating deep integration between NTU and LCDTI.

6.2.3 From the Perspective of Heterogeneity Results

In view of the efficiency advantage of FS in regions with high-economic-development, the government should jump out of the traditional poverty alleviation thinking and encourage tourism enterprises' low-carbon technology innovation and research through targeted FS to promote LCDTI; For the moderating potential of GTI in low-level areas, the government needs to build a regional technology sharing platform, encourage technology transfer, talent exchange and other ways to provide technical support for LCDTI in low-level regions, and guide enterprises' low-carbon behavior by taxing high pollution projects (the other optimization method for GT), because from the main effect result, the promotion effect of GT in low-level regions is more obvious. Finally, the regional differentiation development strategy of promoting LCDTI will be realized, which is led by "targeted FS+GTI" in high-economic-development regions and "GTI+ optimized GT" in low-level regions.

7. Limitations and Future Recommendation

Firstly, this research only uses the panel two-way fixed effect model to analyze the relationship between variables. In the future, other methods such as coupling coordination model or game theory can be introduced to explore the optimal ratio of different policy tools.

Secondly, although the panel data of 15 years is used, it does not fully reveal the dynamic differences in the effects of policy tools at different stages of NTU. In the future, segmented regression or event research methods can be used to further reveal the policy effect.

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