Research on the Impact and Mechanism of Technological Innovation on the High-Quality Development of China's Logistics Industry

--Empirical Test Based on Panel Data of 31 Provinces in China

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Abstract. This paper selects the balanced panel data of 31 provinces in China from 2015 to 2020, and utilizes benchmark regression, mediated effect regression, double fixed effect model, and least squares regression to study the impact of technological innovation on the high-quality development of China's logistics industry and the mechanism of influence. The results show that technological innovation obviously promotes the high-quality development of the logistics industry, and this conclusion still holds after a series of robustness tests, and the transportation level is an important mechanism for technological innovation to promote the high-quality development of the logistics industry. Finally, the samples are categorized according to the level of economic development, and group regression is carried out, and it is found that the influence of technological innovation on the high-quality development of China's logistics industry is the highest in the areas with medium level of economic development, followed by the areas with high level of economic development, but there is an inhibitory effect in the areas with low level of economic development. Finally, corresponding policy recommendations are put forward to provide new ideas for the high-quality development of China's logistics industry.

Keywords: technological innovation, technological improvement, high-quality development of the logistics industry

1 INTRODUCTION

With the swift advancement of the internet and online retail, the importance of the logistics industry as the foundation to support these industries has become increasingly prominent. In 2021, the aggregate value of China's logistics output reached 335.2 trillion yuan, up 9.2% from the previous year, surpassing the GDP expansion by 1.1 percentage points.Various logistics-related investments exceeded 3.5 trillion yuan, offering robust backing for the establishment of logistical facilities. The "14th Five-Year Plan" for the Construction of Modern Circulation System, the "14th Five-Year Plan" for the Development of Cold Chain Logistics, as well as a number of

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"14th Five-Year Plan" special plans for trade logistics, technological innovation, and other areas of strategic planning for modern logistics. Each field of modern logistics strategic deployment, the status of modern logistics industry to a new level. Yet, regarding the global context, China's modern logistics sector faces significant obstacles, necessitating the discovery of a novel trajectory for its high-standard development.How can we enhance the logistics sector's development to a higher standard? What are the underlying factors that drive the logistics industry towards superior development? This has become a hot topic of discussion in the academic community and is the main research question of this paper.

2 LITERATURE REVIEW

Ongoing advancements in technological innovations have emerged as the principal force propelling the rearrangement of global resources, the remodeling of economic frameworks, and the evolution of the competitive landscape. Advancing technological innovation is a strategic imperative to capitalize on the opportunities presented by the latest technological revolution and industrial shifts, and the sole path to enhance the logistics sector's high-standard development. In the 14th Five-Year Plan for Technological Innovation and Development, the development of intelligent logistics is clearly listed as a priority, which promotes the acceleration of the digitization of the logistics sector, involving new logistics infrastructure, the application of advanced technologies, the exploration of innovative models and the cultivation of new business forms. In this context, many scholars have deeply discussed the far-reaching impact of technological innovation pertaining to the superior advancement of the logistics sector from different dimensions. Zheng Caiyun et al.[1] found that technological innovation and the development level of the logistics industry as a whole show a fluctuating upward trend; Song Erxing et al.[2] found that the overall level of high-quality development of China's logistics industry is low and regional differences are obvious; Li Man et al.[3] found that the logistics industry can be promoted to realize high-quality development by lowering the threshold of financing and transaction costs and enhancing information transparency; Lian Jie et al.[4] Ltd. found that accelerating the promotion of advanced and green logistics organization mode is of great significance in promoting the high-quality development of the logistics industry; Cao Yunchun et al.[5] found that innovation, government intervention, and openness as the main core conditions of these three paths to accelerate the pace of China's construction of a modern logistics power; Luo Rui et al.[6] found that the impact of technological innovation on the high-quality development of the logistics industry has a spatial spillover effect; Richard Chen et al.[7] found that the level of economic development, infrastructure construction, government support policies and the level of financial development have a significant positive impact on the development of the logistics industry; Zhang Zhenju et al.[8] The study concludes that digital trade is highly coupled as the logistics industry evolves.

Evident from the aforementioned literature, numerous studies have confirmed the impact of technological advancements on enhancing the high-standard development

of China's logistics sector, most of them have focused on the four aspects of development trend, regional differences, policy impact and coupling coordination, and seldom cut in from the impact mechanism behind. Utilizing panel data from 31 provinces in China between 2015 and 2020, this paper examines the influence of technological advancements on the superior development of the logistics sector and its influencing mechanism by using benchmark regression, mediation regression, double fixed-effects model, and least squares regression. The key contributions of this paper lie in exploring the influence of technological advancements on enhancing the high-standard development of China's logistics sector, which enriches the research results; second, it explores the mechanism of the impact of technological innovation on the high-quality development of the logistics industry, offering a novel perspective to bolster the superior development of China's logistics sector. Third, it explores the heterogeneity based on regions with different economic levels, highlights the key direction and key people of technological innovation pertaining to the advancement of the logistics sector, and it enhances the existing literature's findings on the effects of technological innovation on the superior development of the logistics sector.

3 THEORETICAL ANALYSIS AND RESEARCH HYPOTHESIS

3.1 Total Effect of Technological Innovation on the High-Quality Development of the Logistics Industry

With the continuous development of science and technology, a variety of advanced information technology tends to be more mature, such as big data, cloud computing, Internet of Things, etc.[9] etc. Through these information technologies, the visibility and transparency of logistics and transportation can be realized, the transportation path can be optimized, the transportation cost can be reduced, and the efficiency of logistics can be improved. Moreover, logistics enterprises can use digital platforms to realize real-time information sharing and collaborative operations with suppliers, producers, sellers, etc., and reduce delays and errors in information transmission. In addition, they can employ large-scale data analysis and mining to provide customers with personalized logistics solutions, intelligent distribution, supply chain finance and other value-added services, thus increasing their sources of income and enhancing market competitiveness.[10]In the future, the ongoing innovation and implementation of digital technology will continually present new opportunities for the logistics sector, driving its development to new heights. Therefore, this paper proposes the following research hypotheses:

H1: Innovations in technology can enhance the superior development of the logistics sector.

3.2 Mechanisms of Technological Innovation's Influence on the High-Quality Development of the Logistics Industry

Advancements in technology have propelled the utilization of IoT, AI, and other innovations in the transportation industry[11].These technologies can realize intelligent scheduling, automatic driving and other functions, and improve the automation and intelligence level of transportation. Intelligent scheduling can dynamically adapt transportation plans to real-time conditions, optimizing the utilization of transportation resources. Enhanced transportation standards establish a robust foundation for the superior development of the logistics sector. Streamlined and precise transportation services bolster customer satisfaction, thus strengthening the market competitiveness of logistics enterprises.[12]As the fundamental pillar supporting its superior development, the transportation standards of the logistics sector play a pivotal role in its steady progression. Elevating these standards not only mitigates losses and waste during logistics processes but also aids in minimizing environmental impact, thus attaining the objectives of green and sustainable development.Collectively, these components form a vital aspect of the superior development of the logistics sector. Therefore, this paper proposes the following research hypothesis, seeking to delve deeper into the specific role and impact of transportation standards in fostering the high-quality development of the logistics industry.H2 : Innovations in technology can foster the superior development of the logistics sector through the enhancement of transportation.

3.3 Heterogeneity of Technological Innovation on the High Quality Development of the Logistics Industry

Technological advancements significantly influence the superior development of the logistics sector, but the degree of impact may vary in regions with different economic levels[13] In high economic level regions, technological innovation is more developed. In regions with high economic statuses, technological innovation is more developed, which provides more technical support and innovation space for the logistics industry, such as intelligent logistics, big data analysis, etc., significantly enhancing the effectiveness and standards of logistics operations.In regions with moderate economic standings, the surge of technological advancements is more evident in the digital transformation and enhancement of the logistics sector,for instance, the widespread adoption of e-commerce has spurred the growth of the express delivery sector.In regions with low economic standings, the logistics sector's growth is primarily constrained by factors like inadequate infrastructure. Consequently, the driving force of technological advancements may not be immediately evident in the short term, and its impact may be comparatively minor.Based on this, this paper proposes the following research hypotheses:

H3: The influence of technological advancements on the superior development of the logistics sector may diverge in areas with varying economic standings.

4 STUDY DESIGN

4.1 Modeling

In response to the previous research hypotheses, the baseline regression model was first developed as follows:

$$HQLD_{it} = \alpha_0 + \alpha_1 DIGE_{it} + \alpha_c Z_{it} + \delta_t + \varepsilon_{it} \quad (1)$$

where $HQLD_{it}$ denotes the provincei in thet the level of high-quality development of the logistics industry in the period, the $DIGE_{it}$ indicates the level of high-quality development of the logistics industry of the province i in the t the level of technological innovation development in the period, and Z_{it} is the control variable; δ_t denotes time fixed effects, and ε_{it} is the random perturbation term.

Next, in order to test whether transportation level (TRL) is a mechanism variable of technological innovation on the high-quality development of the logistics industry, on the basis of the significant results of the benchmark regression, this paper establishes the mediation effect regression model as follows:

$$Entrep_{it} = \beta_0 + \beta_1 DIGE_{it} + \beta_c Z_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

$$HQLD_{it} = \gamma_0 + \gamma_1 DIGE_{it} + \gamma_2 Entrep_{it} + \gamma_c Z_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

where $Entrep_{it}$ is the mediating variable, if the regression coefficient of TNI in Eq. (2) isβ_1 is significant, the regression coefficient of TNI in equation (3)γ_1 is smaller than the coefficient in the benchmark regressionα_1 , then it indicates that there is a mediating effect.

4.2 Variable Selection and Description

Explained Variables. The explanatory variable, HQLD (High-Quality Logistics Development), is evaluated in this paper using five key aspects: logistics growth rate, infrastructural foundation, industrial composition, employment enhancement, and innovation funding. Drawing from Wang Qinmei et al. (2023)[14], the specific metrics include logistics industry value-added, grade highway mileage, logistics GDP to regional GDP ratio, logistics sector urban employment count, and R&D spending. To assess its comprehensive development, the entropy value approach is employed.As shown in Table 1.

Table 1. Evaluation system of high-quality development indicators for the logistics industry

form	norm	unit (of measure)	causality
Pace of development of logistics	Value added of the logistics industry	billions	+
Logistics infrastructure	Miles of classified roads	kilometer	+

Logistics Industry Structure	Logistics GDP/Gross Regional Product	%	+
employment promotion	Employees in urban units of the logistics industry	all the people	+

Core explanatory Variables. The core explanatory variable is the level of technological innovation (TNI). Drawing on the reference Liu Jun et al. (2020)[15] , this paper selects five aspects of Internet penetration, Internet infrastructure, Internet-related output, cell phone penetration and digital financial inclusion development to evaluate technological innovation. The metrics for the aforementioned five dimensions consist of: the count of Internet broadband subscribers, fiber-optic cable length, total telecommunication service value, mobile phone users per 100 individuals, and the China Digital Financial Inclusion Index. To assess their overall development, the entropy value method is once again utilized.As shown in Table 2.

Table 2. Evaluation System of Technological Innovation Indicators

form	norm	unit (of measure)	causality
Internet penetration	Number of Internet broadband access subscribers	ducal title meaning lord of 10,000 households	+
Internet infrastructure	Fiber optic line length	kilometers	+
Internet-related outputs	Total telecommunication services	billions	+
Cell phone penetration rate	Cell phone subscribers per 100 population	troops	+
Innovative inputs	R&D funding	ten thousand dollars	+

Mechanism Variables. The mechanism variable in this paper is the Transportation Level TRL, and based on the established literature, cargo turnover is used as its measure.

Control Variables. Based on the existing literature, industrial structure rationalization level (IRTL), population density (PD), education level (EL), and transportation input (TI) are selected as the control variables in this paper. Here, the rationalization of industrial structure is reflected by the urban-to-total population ratio, while population density is gauged by individuals per unit land area. Education level is quantified by the enrollment count in general higher education institutions, and transportation input is evaluated through local finance's expenditure on transportation.

Data Sources and Descriptive Statistics. Utilizing available sample data, this paper conducted a study encompassing 31 provinces (excluding Hong Kong, Macau, and Taiwan) from 2015 to 2020, compiling balanced panel data for six years across these provinces. Data sources include the China Statistical Yearbook and the China Logistics Yearbook, with missing values filled in using interpolation. Table 3 presents descriptive statistics for key variables, revealing an average technological innovation

level of 0.34, ranging from a maximum of 0.83 to a minimum of 0.01, with a standard deviation of 0.19. This indicates significant regional disparities in technological innovation. Similarly, the high-quality development of the logistics industry exhibits a consistent trend. Regarding control variables, notable differences are observed in industrial structure rationalization, population density, education level, and transportation investment across provinces. Overall, the sample data satisfy the requirements for subsequent analysis.

Table 3. Descriptive statistics

Variable	*N*	*Mean*	*SD*	*p*50	*Min*	*Max.*
HQLD	186	0.30	0.18	0.27	0.07	0.80
TNI	186	0.34	0.19	0.32	0.01	0.83
IRTL	186	0.60	0.12	0.59	0.27	0.94
PD	186	5.33	1.49	5.62	1.01	8.27
EL	186	4.23	0.94	4.37	1.23	5.52
TI	186	5.69	0.51	5.72	4.29	7.59

5 EMPIRICAL RESULTS AND ANALYSIS

5.1 Benchmark Regression

Table 4 presents the regression outcomes of how technological innovation impacts the high-quality development of the logistics sector. As per column (1) in Table 4, the TNI coefficient for technological innovation stands at 0.788 and is statistically significant at the 1% level. When incorporating all control variables in column (2), the TNI regression coefficient remains significantly positive, signifying that technological innovation fosters the high-quality development of the logistics industry, thus validating hypothesis H1.

Table 4. Benchmark regression

	(1)	*(2)*
	HQLD	*HQLD*
TNI	0.788***	0.732***
	*(*20.587*)*	*(*11.838*)*
IRTL		0.194***
		*(*2.986*)*
PD		0.031**
		*(*4.678*)*
EL		0.058**
		*(*5.181*)*
TI		-0.019*
		(-1.044*)*
_cons	0.071***	0.010**
	*(*3.691*)*	*(*0.101*)*
Year fe	*Yes*	*Yes*
N	186	186
r2_a	0.697	0.729
F	368.54	74.25

5.2 Mechanism Testing

To ascertain if transportation level serves as a conduit for technological innovation to enhance the high-quality development of the logistics industry, an empirical analysis was conducted using a mediating effect regression model. The regression outcomes are summarized in Table 5.

Based on the confirmed positive influence of technological innovation on logistics industry's high-quality development from the benchmark regression, it is evident from column (1) of Table 5 that TNI's regression coefficient is 1.647, significant at the 1% level, signifying that technological innovation enhances transportation levels. Furthermore, in column (2) of Table 5, TNI's regression coefficient is 0.667, also significant at the 1% level, and it is lower than the coefficient in the benchmark regression. This suggests that the transportation level (TRL) functions as the mechanism through which technological innovation drives the high-quality development of the logistics industry, thereby validating hypothesis H2.

Table 5. Level of intermediation - transportation

	(1)	*(2)*
	TRL	*HQLD*
TNI	1.647***	0.667***
	*(*3.306*)*	*(*10.713*)*
TRL		0.040***
		*(*5.182*)*
control variable	*YES*	*YES*
cons	4.121***	0.154***
	*(*3.305*)*	*(*2.032*)*
Year fe	*Yes*	*Yes*
Province fe	*Yes*	*Yes*
N	186	186
r2_a	0.679	0.749
F	142.491	51.381

5.3 Heterogeneity Test

Given the unequal economic development across China's regions, the sample was categorized based on per capita GDP into high, medium, and low-level economic groups for regression analysis. Table 6 presents the results, revealing that technological innovation positively impacts the high-quality development of the logistics industry in regions with high and medium economic levels, with coefficients of 0.262 and 0.271, respectively, significant at the 1% level. However, in regions with lower economic development, the coefficient is negative and only significant at the 10% level. This phenomenon can be attributed to several factors. Firstly, in regions with higher economic levels, technological innovations enhance the efficiency and accuracy of the logistics industry through advanced technological support and data analysis tools. Secondly, the relatively weak economic base and infrastructure in lower-level regions may hinder their ability to fully embrace and adapt to the rapid pace of technological innovation. Consequently, the introduction of technological advancements may dis-

rupt the traditional logistics industry, impeding its capacity to respond effectively to evolving market challenges. Therefore, hypothesis H3 is supported.

Table 6. Heterogeneity test

	high	*moderate*	*relatively low*
	HQLD	*HQLD*	*HQLD*
TNI	0.262***	0.271***	-0.397*
	*(*4.466*)*	*(*1.232*)*	*(*-1.785*)*
control variable	*YES*	*YES*	*YES*
_cons	1.448***	0.170***	-0.310*
	*(*7.939*)*	*(*0.692*)*	*(*-1.125*)*
Year fe	*Yes*	*Yes*	*Yes*
Province fe	*Yes*	*Yes*	*Yes*
N	60	60	66
r2_a	0.949	0.587	0.474
F	145.608	27.656	6.132

6 ROBUSTNESS TESTS

6.1 Two-Way Fixed Effects

To address potential endogeneity issues arising from neglecting province-level variables, province fixed effects were introduced alongside year fixed effects. The estimation results incorporating these two-way fixed effects are detailed in Table 7. The findings reveal that the regression coefficients for the core explanatory variable TNI remain consistently positive and significant at the 1% level, closely aligning with the coefficients reported in Table 4. This consistency underscores the robustness of the baseline regression results. However, a noteworthy difference is observed in column (2) of Table 7, where the TNI coefficient is slightly reduced compared to Table 4. This suggests that overlooking endogeneity could lead to an overestimation of the role of technological innovation in fostering high-quality development within the logistics industry.

Table 7. Two-way fixed effects regression

	(1)	*(2)*
	HQLD	*HQLD*
TNI	0.777***	0.699***
	*(*20.020*)*	*(*10.897*)*
control variable	*YES*	*YES*
_cons	0.039***	-0.008*
	*(*3.420*)*	*(*-0.077*)*
Year fe	*Yes*	*Yes*
Province fe	*Yes*	*Yes*
N	186	186
r2_a	0.686	0.707
F	400.809	82.214

6.2 Instrumental Variables Approach

Over the long haul, the advancement of the logistics industry's high-quality development will inevitably influence technological innovation. For instance, the escalating demand for logistics services has spurred the emergence of numerous novel digital technologies tailored to meet these needs. To address the issue of potential mutual causality between the two, this study employs the instrumental variable approach for a robustness check. Drawing from the characteristics of the data and the criteria for selecting instrumental variables, we choose technological advancements (Ti) and the lagged technological innovation from the previous period (L.TNI) as the instrumental variables for the core explanatory variables. Regression analysis is then conducted using the least squares method. The regression outcomes, presented in Table 8, reveal that the TNI regression coefficients in columns (2) and (4) are 0.782 and 0.752, respectively, both significant at the 1% level. This indicates that the primary findings of this study remain robust even after introducing instrumental variables to mitigate endogeneity issues, such as reverse causation. Furthermore, our tests confirm that the selected instrumental variables are not weak and satisfy the exclusivity criterion, thus validating their use.

Table 8. Instrumental variables regression

	(1)	*(2)*	*(3)*	*(4)*
	TNI	*HQLD*	*TNI*	*HQLD*
Ti	0.265***			
	*(*8.862*)*			
L.TNI			0.964***	
			*(*86.865*)*	
TNI		0.782***		0.752***
		*(*7.016*)*		*(*11.318*)*
control variable	*YES*	*YES*	*YES*	*YES*
_cons	3.080***	0.061	-0.011	0.064
	*(*11.693*)*	*(*0.442*)*	*(*0.513*)*	*(*0.583*)*
Year fe	*Yes*	*Yes*	*Yes*	*Yes*
Province fe	*Yes*	*Yes*	*Yes*	*Yes*
N	186	186	155	155
r2_a	0.792	0.728	0.992	0.730
F	45.943	56.583	294.920	189.12

7 CONCLUSIONS AND POLICY RECOMMENDATIONS

7.1 Conclusions of the Study

The study examines the impact of technological innovation on the high-quality development of China's logistics industry, utilizing data from 31 provinces spanning from 2015 to 2020. Employing methods such as benchmark regression, mediation regression, a double fixed-effects model, and least squares regression, the research reaches several key findings.

Firstly, technological innovation plays a significant role in advancing the high-quality development of the logistics industry.

Secondly, this innovation contributes to the industry's growth by enhancing transportation efficiency and boosting local financial allocations.

Lastly, when dividing the provinces based on their economic development levels, the research reveals that regions with moderate economic development benefit the most from technological innovation, followed by those with high economic development. However, in regions with low economic development, technological innovation appears to have an inhibitory effect.

7.2 Policy Recommendations

Firstly, the government must establish and endorse policies that bolster digital infrastructure, enhance logistics information technology, cut integration costs, and steer financial institutions towards greater credit support. Additionally, talent cultivation is paramount; thus, fostering high-quality professionals skilled in digital technologies and logistics expertise is imperative.

Secondly, authorities should actively urge transportation enterprises to harness big data, artificial intelligence, and other digital technologies to refine transportation route planning and scheduling, minimize idle rates, and optimize transportation efficiency, thereby fostering a conducive transportation environment for logistics. Local administrations can allocate special funds to sponsor innovative projects merging technological advancements with the logistics sector, motivate enterprises to adopt cutting-edge technologies to enhance logistics and transportation efficiency, and propel the industry's high-quality development.

Thirdly, regions with high and moderate economic growth should persevere in fostering the integration and development of technological advancements and the logistics sector, expedite the construction and utilization of intelligent logistics, and elevate the logistics industry to new heights. For regions with lower economic growth, infrastructure development should be reinforced. While fostering technological advancements, support for the traditional logistics industry and its transformation and upgrading must be bolstered. Policy guidance and financial backing should be utilized to foster the integration and development of technological advancements and the logistics sector.

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