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An Empirical Study on the Transformation and Upgrading of Foreign Trade Exports in Zhanjiang Driven by Digital New-Quality Productivity

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ABSTRACT

Against the backdrop of the digital economy, digital new-quality productivity has evolved into a core new driver propelling the transformation and upgrading of Zhanjiang's foreign trade exports. Adopting a regional analytical lens, this paper compiles Zhanjiang's foreign trade data from 2010 to 2024, constructs a multi-dimensional comprehensive evaluation index system for digital new-quality productivity, and empirically investigates its impact on the transformation and upgrading of foreign trade exports using a multiple linear regression model. The results reveal that digital new-quality productivity exerts a significant positive effect on advancing the transformation and upgrading of Zhanjiang's foreign trade exports; however, its internal driving mechanism exhibits structural imbalance, marked by the characteristics of "infrastructure leading, innovation lagging, industrial integration pending, and green potential in reserve". Concurrently, latent risks such as misallocation of innovation resources and excessive administrative intervention are discerned. In light of these findings, Zhanjiang should consolidate its digital infrastructure advantages while enhancing inter-departmental synergy, address the bottlenecks in digital innovation, deepen integration between digital technology and industries, establish a green trade system, refine government functions, and facilitate the transition of the digital new-quality productivity-driven model toward "hardware-software synergy", thereby accelerating the high-quality transformation and upgrading of its foreign trade.

KEY WORDS: Digital new-quality productivity; Zhanjiang's foreign trade exports; Transformation and upgrading

Introduction

Driven by the dual forces of the global technological revolution and industrial transformation, digital new-quality productivity has emerged as a core engine for high-quality economic development and the reshaping of the global competitive landscape. Its deep integration with the foreign trade sector is injecting fresh momentum into the transformation and upgrading of export trade. As a key coastal opening-up hub in southwestern Guangdong, China, Zhanjiang has leveraged two national-level foreign trade transformation and upgrading bases—Lianjiang's small household appliances and characteristic aquatic products—to build an export industrial cluster with distinct regional advantages. However, amid the restructuring of the global value chain, Zhanjiang's foreign trade still faces multiple challenges: homogeneous competition in traditional models, low product added value, gaps in core and critical technologies, and increasingly stringent green trade barriers, all of which necessitate urgent transformation and upgrading. Against this backdrop, this paper draws on Zhanjiang's relevant data from 2010 to 2024, applying the entropy weight method and multiple linear regression model to empirically examine the impact of digital new-quality productivity and its four sub-dimensions on

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the transformation and upgrading of Zhanjiang's foreign trade exports.

Literature Review

Based on the extant literature, scholarly inquiry into digital new-quality productivity and its role in the transformation and upgrading of foreign trade exports has coalesced around three interrelated thematic dimensions.First, the enabling role of the digital economy in reshaping export trade. Early empirical work established that digital technologies enhance trade efficiency and broaden market access by mitigating transaction costs and alleviating information asymmetries (Brynjolfsson et al., 2019; Brambilla et al., 2016). More recent studies extend this foundation by demonstrating how digital industrialization, reallocation of production factors, and strengthened innovation capacity collectively advance *high-quality* export development—not merely quantitative expansion (Liang et al., 2025; Duan & Zhou, 2023). Second, the theoretical and empirical mechanisms through which new-quality productivity drives structural transformation in exports. As the concept gains conceptual traction, research has increasingly centered on its causal pathways: Tian (2026) identifies improvements in production efficiency, cost reduction, and industrial chain optimization as core transmission channels. Complementing this, Zhang et al. (2025) and Liu and Wu (2026) provide robust evidence that new-quality productivity elevates both the sophistication of export structures and aggregate trade performance. Further, Wang (2024), Li (2025), Gao (2024), Hao (2025), and Gao et al. (2024) systematically validate its multifaceted contributions—spanning export upgrading, competitiveness enhancement, product diversification, and innovation- and digitalization-led green transition toward high-quality development. Notably, Gao and Liu (2025) document a statistically significant yet gradual convergence in the coupling coordination between digital new-quality productivity and high-quality foreign trade development across provinces. Third, context-sensitive implementation pathways at regional and firm levels. A growing strand of literature adopts granular, empirically grounded approaches to uncover actionable transformation strategies. For instance, applying fuzzy-set qualitative comparative analysis (fsQCA), Wang (2025) identifies four distinct digital transformation configurations adopted by traditional export enterprises in Shaanxi—each contingent on specific combinations of digital capability, institutional support, and market orientation. Beyond case-based insights, cross-study synthesis reveals four critical enabling pillars: (i) digital infrastructure investment (Sun & Yu, 2025); (ii) enterprise-level technological innovation (Wang, 2024; Zhang & Li, 2024); (iii) sectoral upgrading within digital economy core industries (Xie & Gao, 2024); and (iv) integration of low-carbon imperatives into export strategy (Kang et al., 2025).

To summarize, existing research primarily centers on three core themes: the enabling effect of the digital economy on export trade, the mechanisms and pathways through which new-quality productivity empowers the transformation of foreign trade exports, and local practices alongside multi-dimensional enabling pathways. However, research on the specific subfield of digital new-quality productivity remains relatively limited—most studies focus on the national or provincial levels, with a dearth of granular research on foreign trade exports in prefecture-level cities and lower-tier regions. Additionally, the majority of studies only examine the overall enabling effect of digital new-quality productivity, without clarifying the heterogeneous impacts of its sub-dimensions (e.g., digital infrastructure construction, digital innovation development) on the transformation of foreign trade exports.This paper focuses on foreign trade exports in Zhanjiang City, investigating the enabling effects of digital new-quality productivity and its four sub-dimensions. It aims to refine the research system linking digital new-quality productivity and regional foreign trade export transformation, while enriching region-specific research content.

Theoretical Mechanisms and Research Hypotheses

Mechanism of the Overall Effect

Digital new-quality productivity—centered on digital technology, oriented toward innovation, and underpinned by green development—serves as the core driver of the transformation and upgrading of foreign trade exports. Its positive impact on the transformation and upgrading of Zhanjiang's foreign trade exports is primarily realized through the synergistic effect of multiple pathways.From the perspective of Zhanjiang's current foreign trade export development, most traditional foreign trade exports still face pain points in transformation and upgrading, including low production efficiency, low product added value, single international market channels, and prominent financing constraints (Mo et al., 2024). Digital new-quality productivity can effectively address these development dilemmas. On one hand, by promoting the deep integration of digital technology with the entire processes of production, trade, and management, it optimizes the efficiency of export resource allocation, drives the intelligent transformation of production processes, and enhances product quality and production efficiency (Li et al., 2026)—thereby helping Zhanjiang's foreign trade exports break away from the traditional labor-intensive development model and transition toward a technology-intensive, brand-oriented model. On the other hand, digital new-quality productivity can spawn new formats and models such as cross-border e-commerce and digital trade, expand the international market layout of Zhanjiang's foreign trade exports, enable precise alignment of exports with global demand, and enhance international market competitiveness. Additionally, the concept of green and low-carbon development driven by digital new-quality productivity can facilitate Zhanjiang's foreign trade exports in adapting to international green trade rules, breaking through green trade barriers, and further expanding export scale while improving export quality.

H1: Digital new-quality productivity has a significant positive impact on the transformation and upgrading of Zhanjiang's foreign trade exports.

Mechanism of the Disaggregated Dimensions

As constitutive and functionally distinct dimensions of digital new-quality productivity, its four sub-dimensions deliver differentiated yet complementary contributions to the transformation and upgrading of Zhanjiang's foreign trade exports. (1) Digital infrastructure—encompassing 5G networks, industrial internet platforms, and big data centers—serves as the foundational enabler of digital empowerment. By substantially lowering information asymmetries, transaction frictions, and logistics coordination costs (Hu & Li, 2025), it mitigates geographical constraints and lowers entry barriers for SMEs, thereby facilitating their integration into global digital trade ecosystems. (2) Digital innovation development—including R&D investment, high-skilled talent cultivation, and application-oriented technological innovation—directly addresses structural weaknesses such as product homogenization and core technology dependency. In Zhanjiang's export-intensive sectors (e.g., small household appliances), it drives both process optimization and product differentiation, catalyzing a strategic shift from cost-based to innovation-led competitiveness (Shi & Xiong, 2025). (3) Digital industry development—spanning digital hardware manufacturing, digital services, and digital trade

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formats—creates novel value channels, most notably cross-border e-commerce. Leveraging Zhanjiang's coastal location and port connectivity, it enables agile alignment with globally fragmented, demand-driven supply chains (Qin et al., 2026), enhancing market responsiveness and export resilience. (4) Green and low-carbon development—covering clean production practices, green technology adoption, and eco-design in R&D—equips enterprises to proactively navigate tightening international environmental regulations (e.g., EU CBAM), reduce compliance expenditures, and capture premium pricing through certified green product attributes (Ma & Meng, 2023).

H2: Each of the four theoretically grounded sub-dimensions of digital new-quality productivity—digital infrastructure endowment, digital innovation capacity, digital industrial integration, and green-digital transition performance—exerts a statistically significant and economically meaningful positive effect on the transformation and upgrading of Zhanjiang's foreign trade exports.

Comprehensive Evaluation System and Measurement Methodology

Selection and Construction of the Index System

Drawing on the indicator selection and framework design by Liu et al. (2025), Pei et al. (2025), and Yue et al. (2025), this study constructs a comprehensive index system for measuring the development level of Zhanjiang's digital new-quality productivity across four dimensions encompassing 15 indicators in total (see Table 1). This system is constructed to strike a balance among three core criteria: the research time span (2010–2024), the comprehensiveness of indicator coverage to ensure systematicity, and data availability to ensure empirical feasibility. It thus supports a scientific and comprehensive assessment of the development of digital new-quality productivity in Zhanjiang during the research period.

Table 1 Comprehensive index measurement system

First-level indicators	Secondary indicators	Unit of measurement	Source of data	Indicator attributes
Digital infrastructure construction	Internet broadband access users (A1)	Ten thousand households	Statistical Yearbook of Zhanjiang City 2011-2025, Statistical Bulletin of Zhanjiang National Economic and Social Development 2010-2024	+
	Total Telecom business growth rate (A2)	%		+
Development of digital innovation	Working as a technology developer (B1)	people		+
	Project (topic) (B2)	item		+
	Fiscal Expenditure on Science and Education (B3)	%		+
Development of digital industries	Employees in information transmission, software and information technology services (C1)	people		+
Green and low-carbon development	Regulated Comprehensive Industrial energy consumption (D1)	Tons of standard coal When measured		-
	Total industrial exhaust emissions (D2)	100 million standard cubic meters		-
	Industrial wastewater discharge (D3)	Ten thousand tons		-
	Industrial solid waste Comprehensive utilization rate of materials (D4)	%		+

Processing of Indicator Data

This paper employs the entropy weight method to measure the development level of digital new-quality productivity in Zhanjiang City from 2010 to 2024. The specific procedures are outlined as follows:

Step 1: Data Standardization

The specific calculation formula is presented below:

$$P_{ij}=\frac{X_{ij}-\min X_{ij}}{\max X_{ij}-\min X_{ij}} \qquad \text{Formula (4-1)}$$

Step 2: Calculation of Indicator Weights

First, the entropy value of the j-th indicator is computed using the following formula:

$$e_j=-\frac{1}{\ln n}\sum_{i=1}^{n} P_{ij}\ln(P_{ij}),0\ll e_j\leq 1 \qquad \text{Formula (4-2)}$$

Subsequently, the redundancy of indicator j for city i is calculated, with the formula given as follows:

$$g_j=1-e_j \qquad \text{Formula (4-3)}$$

Finally, the weights of each evaluation indicator are determined, and the entropy weight of indicator j for city i is calculated using the following formula:

$$W_{ij}=\frac{g_j}{\sum_i^m g_j},j=1,2,3\ldots m \qquad \text{Formula (4-4)}$$

Step 3: Calculation of Comprehensive Scores

Based on the weights of each indicator, the comprehensive score is

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calculated using the following formula:

$$Y=\sum_{i=1}^{n} P_i X_i \ (i=1,2,3\ldots n) \qquad \text{Formula (4-5)}$$

Step 4: Construction of the Weighted Decision Matrix and Calculation of Digital New-Quality Productivity Development Level The weighted decision matrix is constructed, and the digital new-quality productivity development level of city \(i \) is calculated using the following formula:

$$Score=w_i * x_{ij}' \qquad \text{Formula (4-6)}$$

Measurement Model and Variable Specification

Variable Selection and Model Construction

Based on the above theoretical analysis and research hypotheses, this paper adopts a multiple linear regression model to examine the impact of digital new-quality productivity on the transformation and upgrading of Zhanjiang's foreign trade exports. The logarithmic form of the constructed multiple linear regression model is presented as follows:

$$lnUpgrade_t = \beta_0 + \beta_1 DNPL_t + \beta_2 lnPort_t + \beta_3 lnStruc_t + \beta_4 lnResearch_t + \beta_5 lnOpen_t + \beta_6 lnGov_t + \varepsilon_t \quad \text{Formula (5-1)}$$

In the above equation, t denotes the year; $lnUpgrade_t$ represents the level of transformation and upgrading of foreign trade exports in Zhanjiang City in year t ; β_0 is the constant term; $DNPL_t$ denotes the development level of digital new-quality productivity in Zhanjiang City in year t ; $lnPort_t$ represents the comprehensive port competitiveness of Zhanjiang City in year t; $lnStruc_t$ denotes the level of industrial structure upgrading in Zhanjiang City in year t ; $lnResearch_t$ represents the scientific and technological innovation capability of Zhanjiang City in year t; $lnOpen_t$ denotes the degree of foreign trade openness of Zhanjiang City in year t ; ε_t is the random disturbance term; and β represent the regression coefficients of the respective variables.

Variable and Data Specifications

The dependent variable lnUpgrade denotes the level of foreign trade export transformation and upgrading in Zhanjiang, measured by the export volume of small household appliances, a traditional competitive export industry, reflecting both export scale expansion and improvements in product structure, technology content and brand value. The core independent variable DNQP represents the development level of digital new-quality productivity, a comprehensive index constructed using the entropy weight method that reflects the integration of digital technology into the real economy, the upgrading of production modes, and the emergence of new industries, business forms and models, with higher values indicating stronger digital-driven development and economic enabling effects. Control variables include: lnPort (comprehensive port competitiveness), measured by Zhanjiang Port's cargo throughput, which reflects logistics support for the export-oriented economy and is expected to positively affect export upgrading; lnStruc (industrial structure upgrading level), measured by the share of tertiary industry in GDP, which optimizes the industrial ecosystem and promotes value-chain upgrading of exports; lnResearch (regional technological innovation capability), measured by the number of approved science and technology projects at or above the provincial level, which supports core technology breakthroughs and high-value-added product development; lnOpen (trade openness), measured by actual utilized FDI, which introduces capital, advanced technology and international market channels to drive export upgrading; and lnGov (local government fiscal capacity), measured by the ratio of local general public budget revenue to GDP, which provides fiscal support for infrastructure and innovation to foster a favorable institutional environment. All control variables are expected to exert a positive impact on Zhanjiang's foreign trade export transformation and upgrading.

Table 2 Definitions of main variables

Variables	Expected sign	Variable description
lnUpgrade	--	The export volume of small household appliances in Zhanjiang City (unit: ten thousand yuan)
DNQP	+	A comprehensive evaluation index of digital new quality productivity based on entropy weight method
lnPort	+	The cargo throughput of Zhanjiang Port (unit: ten thousand tons)
lnStruc	+	The proportion of the output value of the tertiary industry in the gross domestic product (GDP)
lnResearch	+	The number of provincial and above approved science and technology projects (projects) in Zhanjiang city
lnOpen	+	The actual amount of foreign direct investment used by Zhanjiang City (unit: USD10,000)
lnGov	+	The proportion of the local general public budget revenue in the regional GDP of Zhanjiang City

Sample Selection and Data Sources

The sample period of this study is 2010–2024. Data on Zhanjiang's small household appliance exports, digital new-quality productivity, industrial structure upgrading, technological innovation, and trade openness are obtained from the Zhanjiang Statistical Yearbook (2011–2025) and the Statistical Bulletin of National Economic and Social Development of Zhanjiang (2010–2024). Foreign direct investment data are sourced from the Zhanjiang Municipal Bureau of Commerce. The mean imputation method is used to deal with a small number of missing values. Descriptive statistics of all variables are shown in the following table.

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Table3 Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnUpgrade	15	12.07	0.244	11.59	12.376
DNQP	15	0.464	0.107	0.277	0.648
lnPort	15	10.01	0.24	9.521	10.315
lnStruc	15	44.955	2.813	39.9	48.7
lnResearch	15	9.949	0.377	9.313	10.529
lnOpen	15	9.719	0.961	8.208	11.091
lnGov	15	0.045	0.005	0.036	0.052

Empirical Tests and Results Analysis

Full-sample Regression Analysis: To mitigate multicollinearity among variables—which may introduce bias into regression results—this study employs the variance inflation factor (VIF) to test for multicollinearity across all explanatory and control variables. A commonly accepted criterion is that a VIF value below 10 indicates no severe multicollinearity, while a value above 10 signals severe multicollinearity. The test results are presented in the table below: As shown in Table 3, all variables have VIF values below 15, with an average VIF of 8.23 (see Table 3), which is less than 10. This confirms the absence of severe multicollinearity among variables in the model, justifying the implementation of subsequent regression analyses.

Table 3 Results of Multicollinearity Test

Variable	VIF	1/VIF
lnPort	13.72	0.072894
DNQP	13.08	0.076466
lnStruc	8.15	0.122730
lnResearch	7.85	0.127458
lnOpen	4.06	0.246373
lnGov	2.54	0.392949
Mean VIF	8.23	

This study uses a multiple linear regression model for benchmark regression (results in Table 4). The model's R-squared is 0.9643, indicating good overall goodness-of-fit, and the F-statistic (56.19) is highly significant at the 1% level, confirming the model's global significance and rejecting the null hypothesis of all independent variable coefficients being zero.

The regression results reveal that the coefficient of the core explanatory variable—digital new-quality productivity (DNQP)—is significantly positive. Specifically, a one-unit increase in the development level of digital new-quality productivity leads to a significant 1.6890-unit improvement in the transformation and upgrading level of Zhanjiang's export trade, which aligns with the expected sign and validates the proposed hypothesis. The underlying mechanism lies in its effective mitigation of financing constraints for export trade, providing critical support for technological innovation and model transformation.Among control variables:The coefficient of openness (lnOpen) is significantly positive, indicating that digital new-quality productivity drives technological innovation and management upgrading in Zhanjiang's export trade by enhancing openness. A one-unit increase in openness is associated with a 0.1-unit improvement in transformation and upgrading.Industrial structure (lnStruc) is significant at the 10% level with a positive coefficient, suggesting that digital new-quality productivity-driven industrial structure optimization provides a favorable industrial ecosystem for the transformation of Zhanjiang's export trade.Government intervention (lnGov) shows no statistical significance. While R&D investment (lnResearch) is significant at the 10% level, its marginal effect is weak and negative. These findings suggest that Zhanjiang should further optimize policy guidance and innovation conversion mechanisms for digital new-quality productivity, avoid excessive administrative intervention, and improve R&D investment efficiency to better enable the transformation and upgrading of export trade.

Table 4 Regression Results

	Coef.	Std. Err.	t	P>|t|
lnUpgrade	——			
DNQP	1.6890**	0.5370	3.1500	0.0140
lnPort	0.0101	0.2366	0.0400	0.9670
lnStruc	0.0312*	0.0168	1.8600	0.0950
lnOpen	0.1001**	0.0399	2.5100	0.0360

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lnGov	-15.3206*	7.9163	-1.9400	0.0890
lnResearch	-0.3774**	0.1169	-3.2300	0.0120
_cons	13.2562***	2.2754	5.8300	0.0000
Observations	15			
R-squared	0.9643			
F-test	56.19			

Note: Values in parentheses are t-statistics. *, **, and *** denote significance at the 10%, 5%, and 1% levels (i.e., rejection of the null hypothesis), respectively; the same notation applies to subsequent tables/results.

Heterogeneous Analysis: Table 5 examines the impacts of four dimensions of digital new-quality productivity—digital infrastructure construction, digital innovation development, digital industry development, and green low-carbon development—on export transformation and upgrading.(1) Digital Infrastructure Construction (lnInfra): Its regression coefficient is 2.7704 (1% significance), exerting a strong positive driving effect by reducing cross-border trade costs and improving supply chain collaboration, and lnPort and lnOpen are also significantly positive (1% level), forming a synergistic effect with digital infrastructure to promote export scale and quality; (2) Digital Innovation Development (lnInno): Its coefficient is negative but insignificant, reflecting low innovation outcome conversion in Zhanjiang—digital innovation remains in basic R&D and is not embedded in enterprise operations, and notably, lnPort is significantly negative, as over-reliance on port hardware without sufficient innovation may cause resource misallocation and crowding-out effects; (3) Digital Industry Development (lnInd): Its coefficient is 0.9035 but insignificant, and though it spawns new trade formats, its enabling effect is underutilized due to small industry scale and low integration with traditional foreign trade industries, with lnGov being significantly negative as excessive government intervention may constrain its role; (4) Green Low-Carbon Development (lnGreen): Its coefficient is 1.1875 but insignificant, while green transformation is inevitable amid global green trade barriers, Zhanjiang is in the initial stage of green technology and product R&D, and lnPort is significantly positive, as integrating green concepts with port logistics improves export green compliance.

Table 5: Regression Results of Heterogeneous Impacts

	（1）lnInfra	（2）lnInfra	（3）lnInd	（4）lnGreen
lnUpgrade	——			
DNQP	2.7704** （2.90）	-0.2804 （-0.32）	0.9035 （0.7）	1.1875 （0.93）
lnPort	0.3578** （2.98）	-0.2804** （3.29）	0.4318 （1.36）	0.6681** （3.30）
lnStruc	-0.0029 （-0.11）	.0387 （1.13）	0.0412 （1.66）	0.0384 （1.66）
lnOpen	0.1439** （2.97）	0.0510 （0.95）	0.0589 （1.27）	0.0610 （1.34）
lnGov	-2.0816 （-0.29）	-12.8421* （-2.22）	-15.4646* （-2.15）	-16.8605* （-1.82）
lnResearch	-0.2388* （-1.88）	-0.2123 （-0.66）	-0.1892 （-0.78）	-0.1935 （-1.02）
_cons	9.422*** （7.71）	5.9383* （1.83）	7.8480*** （4.56）	5.5573** （3.07）
Observations	15	15	15	15
R-squared	0.9645	0.9234	0.9291	0.9298
F-test	79.17	13.75	14.81	17.65
Mean VIF	8.08	8.33	6.65	6.32

Conclusions and Suggestions

Based on Zhanjiang's foreign trade data from 2010 to 2024, this study establishes an evaluation index system for digital new-quality productivity (DNQP) and uses a multiple linear regression model to analyze its impact on the transformation and upgrading of Zhanjiang's export trade. The results show that DNQP overall has a significant positive effect on export transformation and upgrading, serving as a core driver of trade upgrading. Among its sub-dimensions, digital infrastructure acts as the main driving force with

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strong synergies with port logistics and opening-up, while digital innovation, digital industrial development, and green low-carbon transformation show insignificant positive effects due to low innovation transformation, insufficient industrial integration, and weak competitive advantages, presenting an imbalanced structure of "strong infrastructure, weak innovation, pending industrial integration, and accumulating green transformation". Additionally, the significantly negative coefficient of R&D investment and the inhibitory effect of government intervention in some regressions reflect potential risks including innovation resource misallocation and excessive administrative intervention in Zhanjiang.

To fully release the enabling role of digital new-quality productivity (DNQP) in Zhanjiang's export transformation and upgrading, policies should focus on strengthening digital infrastructure and its synergy with port logistics and opening-up, improving industry-university-research-application innovation to boost technology commercialization, promoting digital integration with traditional export industries to avoid low-end competition, cultivating green advantages against global green trade barriers, and optimizing government functions to improve resource allocation efficiency. By shifting to a high-quality development model supported by infrastructure, innovation, industrial integration, green development and efficient governance, Zhanjiang can comprehensively enhance the resilience, vitality and international competitiveness of its export trade.

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