

The Impact of the Digital Economy on the Export Competitiveness of Green Products in China

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Abstract: This paper utilizes Chinese firms' import and export data and applies a difference-in-differences (DID) method to study the impact of the digital economy on the export competitiveness of green products, while exploring its mechanisms and heterogeneity. The findings indicate that firms' digital transformation significantly enhances the export competitiveness of green products, and this result remains robust under various control variables. The mechanism of influence is primarily reflected in improving production efficiency, reducing production costs, and enhancing firms' Environmental, Social, and Governance (ESG) performance, ultimately helping firms improve their competitiveness in the international market. Heterogeneity analysis reveals that the enhancement effect on export competitiveness is more pronounced for local and innovative firms compared to central enterprises. Additionally, firms exporting to RCEP member countries benefit more from digital transformation due to the characteristics of market demand. Importing firms also see significant competitiveness improvements by increasing supply chain efficiency and adopting advanced technologies. This study has important practical implications for deepening the understanding of the economic effects of the digital economy, promoting green transformation among Chinese firms, and addressing international green trade barriers.

Keywords: Green products, Export competitiveness, Digital economy.

1. Introduction

In the progression of global trade liberalization, countries worldwide are increasingly emphasizing environmental protection. International markets now place greater importance on sustainability and social responsibility. As traditional trade barriers gradually weaken and trade protectionism rises, a new trade protection measure—"green barriers"—is rapidly becoming a significant non-tariff barrier in developed countries and is accelerating in its development. Amid this broader context of green production, China's 20th Party Congress report explicitly highlighted the need to accelerate the green transformation of development models and to actively yet prudently advance carbon peaking and carbon neutrality goals. While green barriers negatively impact China's export trade in the short term, justifiable green barriers contribute to the sustainable development of international trade. Protecting and improving the environment aligns with China's long-term interests. Therefore, for China, green barriers represent both pressure and motivation, challenges, and opportunities. According to the Porter Hypothesis, reasonable and stringent environmental regulations can drive innovation and enhance productivity. Although environmental investments may impose additional costs on firms in

the short term, these costs are offset by productivity gains in the long run, ultimately enhancing firms' competitiveness [1]. Consequently, firms must adopt green production and consumption practices, improve their capacity for pollution reduction and carbon mitigation, and further increase the efficiency of resource utilization. This comprehensive green transformation of economic and social development will ultimately enhance the international competitiveness of China's green product exports. Given the current prevalence of green trade barriers, this study innovatively focuses on the export competitiveness of green products, investigating how firms' digital transformation affects this competitiveness. The study also incorporates research on RCEP countries as a focal point, analyzing the mechanisms at play. This approach aims to provide empirical evidence on how digital transformation can help enhance China's green product export competitiveness.

The paper is structured as follows: The first section reviews the literature, the second section establishes the model, the third section presents the empirical analysis, and the final section summarizes the conclusions and offers policy recommendations.

2. Theoretical Hypotheses

A body of literature closely related to this study examines the impact of firms' digital transformation on the export competitiveness of Chinese products. Digital transformation has a significant positive effect on improving export quality [2]. However, when firms have low digital capability, the risks and increased investment in digital transformation may hinder innovation activities and reduce export quality. As firms enhance their digital capability, their ability to innovate and improve export quality increases significantly [3]. Many studies suggest that firms' digital transformation enhances the export competitiveness of green products by improving production efficiency, export product quality, and Environmental, Social, and Governance (ESG) performance. First, digital transformation enhances decision-making efficiency and monitoring effectiveness, promoting total factor productivity [4-7]. On the one hand, digital transformation enables firms to analyze consumer preferences through big data, build a more efficient supply chain integration system, and optimize resource allocation efficiency, thereby enhancing firm performance. This can result in a U-shaped effect on export product quality [3]. On the other hand, firms can leverage the vast information collected through digital transformation to integrate advanced technologies, accelerate product updates, and enhance production efficiency. Digital transformation also optimizes production processes, reducing costs and improving production efficiency, ultimately boosting competitiveness in export markets. Second, the impact of digital transformation on total factor productivity primarily manifests in technological and corporate governance dimensions. At the technological level, it drives efficiency changes and technological innovation. At the governance level, it enhances decision-making efficiency and monitoring effectiveness [4]. It also determines firms' dynamic capabilities to perceive opportunities, acquire and reconfigure internal and external resources in a dynamic environment [8], significantly promoting high-quality development [9]. Moreover, digital transformation positively influences regional innovation in Chinese cities [10]. Finally, digital transformation significantly enhances firms' ESG performance, boosts international reputation, and strengthens competitiveness in international markets [11-14]. Based on this analysis, the following hypothesis is proposed:

Hypothesis 1: Firms' digital transformation affects green product exports by improving production efficiency, export product quality, and ESG performance.

Additionally, numerous studies indicate that the effect of digital transformation on firms' competitiveness varies across different firm types and export destinations. Local and innovative firms, due to their higher autonomy, are more flexible in applying digital technologies to enhance production efficiency and cost management, thereby improving export competitiveness. In contrast, central enterprises experience relatively limited effects from digital transformation. Importing firms benefit significantly from digital transformation by leveraging digital technology to select cost-effective

intermediate goods and improve supply chain connectivity. Imported intermediate and capital goods often represent high-quality and advanced technological products, enabling digitally transformed firms to learn advanced technologies through imports. Finally, as the most promising free trade area, RCEP member states generally aim to import high-quality products. Given that production systems in these regions are not fully mature, digital transformation has a stronger effect on enhancing export competitiveness. For exports to more developed non-RCEP countries, which demand higher product quality and possess well-developed product systems, the effect of digital transformation on export competitiveness is less pronounced.

Hypothesis 2: Firms' digital transformation has heterogeneous impacts on the export competitiveness of green products based on firm types, export regions, and internal and external conditions.

3. Data Sources

3.1. Data Sources

This study focuses on the export competitiveness of green products by Chinese firms. The required data are primarily drawn from the China Customs Import and Export Database and the Chinese Industrial Enterprise Database. By matching and merging shared firm-level identifiers such as firm names, this study constructs a firm-product panel dataset. This dataset encompasses information on export scale, destination, and various firm economic indicators. To identify green products, the study references and compares environmental product lists from the OECD and compiles a comprehensive list of 255 products based on HS6 codes. For analysis, a final selection of 194 products with HS6 codes is included in the green product directory.

3.2. Baseline Econometric Model

To analyze the relationship between firms' digital transformation and their export competitiveness in green products, this study employs a semi-continuous difference-in-differences (DID) method. This approach accounts for varying start times and degrees of digital transformation among firms, which standard DID methods cannot accurately capture [6] [15]. Specifically, firms with zero digital transformation are set as the control group, and firms with non-zero digital transformation are treated as the experimental group. Most firms in the observation period transition from zero to non-zero levels of digital transformation, providing a quasi-natural experimental environment. The model is specified as follows:

$$\ln \text{ESI}_{it} = \beta_0 + \beta_1 \text{Digital}_{it} + \gamma \text{Controls}_{it} + \gamma_i + \lambda_t + \varepsilon_{it}$$

Where i and t represent firms and years, respectively. The dependent variable $\ln \text{ESI}_{it}$ represents the logarithm of firm i 's export competitiveness at year t . The core explanatory variable Digital_{it} captures the degree of digital transformation for firm i at year t . The term Controls_{it} includes a set of control variables to account for other influencing factors. Fixed effects γ_i and λ_t represent firm-specific and year-specific fixed effects, respectively, while ε_{it} denotes the random error term. The expected outcome is $\beta_1 > 0$, indicating that firms' digital transformation positively contributes to enhancing their export competitiveness in international markets.

3.3. Variable Definitions

3.3.1. Dependent Variable: Export Competitiveness of Green Products

To comprehensively measure the export competitiveness of China's green products, this study adopts multiple dimensions of measurement, including export market share, revealed comparative advantage,

export centrality, and export hub degree. These methods follow the approaches of Cai Qicheng [16] and Meng Xia & Dong Wenting [6]. The selected green product catalog contains 194 products classified using HS 6-digit codes, and analyses are conducted based on this dataset.

3.3.2. Independent Variable: Degree of Firms' Digital Transformation

Based on analyses by Yuan Chun et al. [17] and Meng Xia & Dong Wenting [6], this paper uses text analysis to construct an index of firms' digital transformation. The semi-continuous difference-in-differences method is applied for quantification. The operational steps are as follows: 1. Keyword Identification: Keywords representing digital transformation are extracted from national digital economy policy documents and relevant literature. 2. Keyword Expansion: Frequently appearing digital transformation-related terms in annual reports of publicly listed companies are identified and added to the keyword library. 3. Categorization: Keywords are grouped into four dimensions—digital management, digital operations, digital marketing, and digital products—based on the "2021 Central Enterprises Digital Transformation Research Report." 4. Quantification: Using the constructed keyword library, keyword frequency in annual reports of listed companies is calculated. The total keyword frequency is then log-transformed to construct the digital transformation index, denoted as Digital. A higher index value indicates a greater degree of digital transformation in the firm.

3.3.3. Control Variables

Drawing from Meng Xia & Dong Wenting [6], the following control variables are incorporated: 1. Log of Sales Expenses (Market): Higher sales expenses indicate increased costs, potentially leading to higher product prices and reduced export competitiveness. 2. Return on Assets (ROA): A higher ROA reflects better asset utilization and stronger product export competitiveness. 3. Log of Employee Count (Size): A greater number of employees often indicates a larger firm size, which tends to correlate with stronger international competitiveness and resilience against market elimination. 4. Herfindahl Index (Herfindahl): A higher Herfindahl index suggests greater market concentration and monopoly power, potentially enhancing export competitiveness. 5. Cash Ratio (Solvency): A higher cash ratio indicates stronger debt-paying ability, which builds trust among supply chain partners and enhances efficiency in upstream and downstream activities, potentially improving export competitiveness.

4. Empirical Results Analysis

4.1. Baseline Regression and Robustness Tests

The baseline regression results are summarized in Column (1) of Table 1. The dependent variable is the export competitiveness of green products, and the independent variable is the degree of firms' digital transformation. Fixed effects for firms, years, and export countries are progressively controlled from Columns (1) to (4). The regression results show that the coefficient for digital transformation is significantly positive, indicating that digital transformation significantly enhances the export competitiveness of green products in China. This evidence supports Hypothesis 1.

Table 1: Baseline Regression Results

VARIABLES	Ln ESI			
	(1)	(2)	(3)	(4)
digital	3.382*** (-0.170)	0.684 (-0.011)	3.371*** (-0.120)	3.370*** (-0.162)

Table 1: (continued).

Constant	14.588 *** (-0.854)	14.837 *** (-0.772)	14.836 *** (-0.737)	14.593 *** (-0.981)
Controls	Yes	Yes	Yes	Yes
Industry	No	Yes	Yes	Yes
Year	No	No	Yes	Yes
Exporter	No	No	No	Yes
Observations	1048572	1048572	1048572	1048572
R-squared	0.383	0.416	0.395	0.383

4.2. Heterogeneity Analysis

4.2.1. Classification by Firm Type

The results of firm heterogeneity analysis are shown in Columns (1) to (3) of Table 2. The coefficients in Columns (1) and (2) are significantly positive, while the coefficient in Column (3) is not significant. This indicates that digital transformation significantly improves the export competitiveness of local firms and innovative firms, while it has no significant impact on the export competitiveness of central enterprises. Compared to central enterprises, local and innovative firms possess greater autonomy, as their decisions are primarily driven by profitability and local revenue generation. These firms are better positioned to leverage digital transformation technologies to optimize costs and improve export competitiveness.

4.2.2. Classification by Export Destination

The Regional Comprehensive Economic Partnership (RCEP), signed by 15 countries including ASEAN member states, China, Japan, South Korea, New Zealand, and Australia, came into effect on January 1, 2022. This agreement is expected to drive regional economic recovery, boost international trade and investment, and contribute to global economic development and trade stability. According to the United Nations Conference on Trade and Development (UNCTAD), the implementation of RCEP is projected to increase intra-regional exports by USD 41.8 billion and enhance trade connectivity among member nations, strengthening their roles as significant trade partners for one another. Based on export destination, this study classifies countries into RCEP and non-RCEP members. The regression coefficients for digital transformation in Columns (4) and (5) of Table 2 are both positive, but the coefficient for firms exporting to RCEP countries is higher. This suggests that most RCEP countries aim to import high-quality products, with production lines that are not yet fully developed, making the impact of digital transformation on export competitiveness more pronounced. Conversely, exports to relatively developed non-RCEP countries face stricter quality requirements and compete with well-established domestic systems, thereby reducing the incremental competitiveness gained through digital transformation. In the future, RCEP countries are expected to achieve even greater trade outcomes.

4.2.3. Classification by Importing and Non-Importing Enterprises

The status of importing activities significantly affects firms' export performance. Brandt and Morrow [18] highlighted that importing intermediate goods enhances firms' export depth and breadth. To examine this issue, this study classifies firms into importing and non-importing categories for analysis. The results are presented in Columns (6) and (7) of Table 2. Digital transformation significantly improves the export competitiveness of importing firms but has no noticeable impact on non-importing firms. Post-digital transformation, importing firms can effectively leverage digital technology to select cost-effective intermediate goods and enhance supply chain efficiency. Additionally, imported intermediate and capital goods are often high-tech and high-quality foreign products. Digitally transformed firms are better positioned to learn advanced technologies through these imports.

Table 2: Heterogeneity Analysis

VARIABLES	The Type of the Enterprise			Export Destination Country		Import Enterprises	
	Local Enterprises	Innovative Enterprises	State Enterprises	REPC	No REPC	Yes	No
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Digital	0.077** (4.166)	0.0084*** (2.953)	0.143 (1.326)	0.077*** (2.470)	0.022 (2.804)	0.067*** (2.101)	0.032 (0.357)
Constant	11.972*** (10.885)	10.220*** (89.643)	12.643 (3.129)	9.423*** (13.967)	10.790 (15.574)	11.986*** (9.724)	9.773*** (10.843)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7489818	2231964	731734	304085	744487	524261	524255
R-squared	0.173	0.190	0.223	0.386	0.347	0.133	0.170

4.3. Robustness Checks

To ensure the stability of the results and address potential issues such as measurement errors, omitted variables, and sample selection bias, the study conducted the following robustness checks:

4.3.1. Alternative Variable Measurements

To mitigate the potential effects of measurement errors, alternative measures of firms' export competitiveness were used for re-estimation. Following the methods of Wen Dongwei et al. [19], the study constructed an enterprise-level competitiveness index (ECI). The results, shown in Column (1) of Table 3, confirm the robustness of the findings. Additionally, alternative measures for digital transformation were tested, with results presented in Column (2). The outcomes consistently indicate that digital transformation significantly enhances export competitiveness.

4.3.2. Decomposing Digital Transformation Indicators

The digital transformation index was decomposed into four dimensions: digital technologies and applications (Digital 1), networking technologies and applications (Digital 2), intelligent technologies and applications (Digital 3), and information technologies and applications (Digital 4). Each

dimension's impact on export competitiveness was examined individually, as shown in Columns (3) to (6) of Table 3. All four dimensions significantly improve the export competitiveness of green products.

4.3.3. Controlling for Multi-Dimensional Fixed Effects

In practice, firms face shocks from various dimensions. Employing multi-dimensional fixed effects helps minimize bias caused by omitted variables [20]. The sample was expanded to include "firm-export destination-industry-year" as four-dimensional fixed effects, resulting in a total of 1,048,572 observations. The results in Column (7) of Table 3 demonstrate that digital transformation continues to significantly enhance export competitiveness even after expanding the fixed effects dimensions.

Table 3: Robustness Checks

VARIABLES	ECI	LnESI	LnESI				LnESI
	Change Variables	Change Variables	Decompose Variables				Multidimensional Fixed
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
digital	0.0249*** (-0.002)						2.423 -0.299
Digital		3.355*** (-0.173)					
Digital 1			3.346*** (-0.190)				
Digital 2				0.628 (-6.058)			
Digital 3					3.371*** (-0.160)		
Digital 4						6.949 (61.890)	
Constant	0.223*** (0.016)	14.524*** (1.065)	14.475*** (1.169)	- 5.863*** (0.188)	14.612*** (0.984)	- 5.863*** (0.88)	8.824*** (-1.859)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exporter	No	No	No	No	No	No	Yes
Industry×Time	No	No	No	No	No	No	Yes
Observations	1048533	1048572	1048572	1048572	1048572	1048572	1048517
R-squared	0.106	0.38	0.377	0.001	0.383	0.001	0.389

4.4. Mechanism Analysis

To further examine the potential pathways through which firms' digital transformation impacts green product export competitiveness, this study conducted the following tests:

4.4.1. Firms' ESG Performance

Building on previous literature and referencing the methodology of Zhang Jiajia and Yang Rong [21], this paper selects the following control variables to mitigate potential influencing factors: Shareholding Concentration (Share): Measured by the proportion of shares held by the top 10

shareholders. This variable reflects the degree of ownership concentration and its potential impact on corporate governance and decision-making. Leverage Ratio (Lev): Measured as the ratio of total liabilities to total assets at the end of the fiscal year. This variable indicates the financial stability and debt management capacity of the firm. Firm Age (Age): Calculated as the natural logarithm of the difference between the accounting year and the firm's establishment year. This metric accounts for the firm's maturity and accumulated operational experience. A fixed-effects regression model is constructed as follows:

$$\ln \text{ESI}_{it} = \beta_0 + \beta_1 \text{Digital}_{it} \times \text{ESG}_{it} + \beta_2 \text{Share}_{it} + \beta_3 \text{Lev}_{it} + \beta_4 \text{Age}_{it} + \mu_i + \gamma_t + \varepsilon_{it}$$

In Table 4, ESG_{it} represents the Environmental, Social, and Governance (ESG) rating of firm i in year t . The coefficient of the interaction term $\text{Digital} \times \text{ESG}$ is 0.023, which is greater than zero. This indicates that digital transformation positively moderates the relationship between ESG performance and firm value. Specifically, when the degree of digital transformation is higher, the positive impact of ESG performance on firm value becomes more pronounced. This finding suggests that the enhancement of ESG performance is a critical channel through which digital transformation contributes to the competitiveness of green product exports.

Table 4: Mechanism Analysis

VARIABLES	LnESI			
	(1)	(2)	(3)	(4)
Digital	-0.011*** (-1.056)	-0.012*** (-1.064)	-0.013*** (-1.073)	-0.014 (-0.083)
ESG	0.003 (0.129)	0.000 (0.139)	0.000 (0.104)	0.002 (0.070)
Digital× ESG	0.023*** (-3.763)	0.033*** (-3.642)	0.025*** (-3.764)	0.024*** (-3.697)
Constant	10.905*** (28.695)	10.902*** (28.778)	10.895*** (29.107)	10.908*** (29.246)
Controls	Yes	Yes	Yes	Yes
Industry	Yes	No	Yes	No
Year	Yes	Yes	No	No
Observations	3351	3351	3351	3351
R-squared	0.265	0.264	0.257	0.310

5. Conclusion

Enhancing the export competitiveness of green products plays a pivotal role in helping China expand its overseas markets, adapt to the current green trade barriers, and gain leverage in establishing and negotiating these barriers. It also strengthens international cooperation on green standards, indirectly improves China's manufacturing and service levels, and elevates the quality of life for its citizens. This paper establishes a theoretical framework to measure the digital economy, selecting HS6-digit codes for green products to theoretically analyze the impact and mechanisms of digital transformation on firms' green product export competitiveness. Key Findings: 1. Digital Transformation Enhances Green Export Competitiveness: The study finds that digital transformation significantly improves firms' production efficiency, reduces costs, and enhances the export competitiveness of green products. This effect remains robust across different control variables, consistently showing positive coefficients. 2. Heterogeneity Analysis Results: RCEP Countries: Digital transformation has a

stronger effect on export competitiveness for firms exporting to RCEP countries, as their production lines are not yet fully mature. 3. Local and Innovative Firms: Local and innovative firms, characterized by stronger autonomy and profit-driven decision-making, utilize digital transformation technologies more effectively to reduce costs and increase efficiency, resulting in more significant improvements. 4. Importing Firms: Digital transformation enables importing firms to enhance supply chain efficiency and adopt advanced technologies from imported goods, significantly boosting their competitiveness.

Based on the above research, this paper provides the following policy recommendations: 1. Encourage Green Product Consumption and Digital Transformation: The government should use policy guidance and incentive mechanisms to encourage the consumption of green products. This includes strengthening the construction of supporting infrastructure and after-sales service guarantees to encourage users to expand their consumption of green energy, thereby indirectly enhancing enterprises' motivation to produce green products. Additionally, it is crucial to seize the current global opportunities in the digital economy by encouraging and assisting enterprises in achieving digital transformation. Efforts should focus on supporting breakthroughs in major technological equipment and industrial infrastructure construction. Specific assistance measures should be implemented for underperforming enterprises, market regulation should be improved, and a fair competitive environment should be created to promote internal and external improvements. Considering the green trade and import barriers of destination countries, industry organizations and professional service institutions should be encouraged to provide businesses with services for trade risk avoidance and response strategies, increasing enterprises' capacity to address trade protection policies in target markets. 2. Strengthen Environmental Supervision and Promote Green Industry Development: The government must seize opportunities in green development and the digital economy to strengthen the supervision and governance of corporate pollution behaviors. Environmental regulations should be improved, forming effective legal constraints on polluting enterprises. Leveraging global green development consensus and free trade area collaborations, China should refine its green industry directory, strengthen green product labeling, and enhance product quality and technological content to help Chinese green products enter high-end markets. New policies should be introduced to help enterprises reduce costs, improve efficiency, and explore new markets. By empowering foreign trade with digital and green initiatives, efforts should accelerate the cultivation of new business models and innovative trade patterns. 3. Lead and Guide Enterprise Digital Transformation: The government should take the lead in guiding enterprises to develop digital transformation strategies and integrate into digital ecosystems. Enterprises should actively connect with core entities in industrial and supply chains, seeking digital innovation at the product level to continuously enhance product value. The production process should emphasize integration throughout the entire production and operation chain, improving communication efficiency, strengthening regulation, and achieving complementary advantages in upstream and downstream resources.

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