

# *The Impact of Digital Transformation on Corporate Carbon Performance*

## *—Empirical Evidence from A-Share Listed Manufacturing Firms in China*

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**Abstract.** This study takes A - share listed manufacturing companies in China from 2013 to 2023 as the sample to deeply explore the impact mechanism of digital transformation on corporate performance. It first puts forward research hypotheses, then constructs the corresponding research models, and finally verifies them through empirical analysis, aiming to provide theoretical references for the digital transformation practice of manufacturing enterprises, the improvement of technological upgrading capabilities, and the optimization of carbon performance. The research finds that the implementation of digital transformation by A - share listed companies can not only significantly enhance corporate performance but also strongly promote technological upgrading. Moreover, digital transformation has a positive effect on corporate performance through its impact on technological upgrading.

**Keywords:** Digital Transformation, Corporate Carbon Performance, Technology Upgrading, Manufacturing Firms

### **1. Introduction**

With the intensification of global climate change and the awakening of environmental awareness, achieving sustainable development has become an international consensus. Against this backdrop, how to effectively reduce carbon emissions has emerged as a core challenge for enterprises. The Chinese government has explicitly proposed the "carbon peaking and carbon neutrality" goals, imposing higher requirements for corporate low-carbon transition. As a major source of carbon emissions, enterprises urgently need to explore effective pathways for carbon reduction. Digital transformation (DT), due to its potential in optimizing resource allocation, enhancing operational efficiency, and enabling innovation, is widely recognized as a crucial pathway for enterprises to improve their carbon performance.

The core of digital transformation lies in leveraging digital technologies such as the Internet of Things (IoT), big data, AI, and cloud computing to reshape corporate operational and management

models. In the realm of carbon emission management, DT enables precise monitoring of emission sources. By deploying smart sensors and IoT devices, it facilitates the real-time collection and analysis of emission data, significantly enhancing the "visibility" of carbon emissions. Concurrently, data-driven energy management systems can optimize energy usage and improve energy efficiency, thereby effectively reducing energy consumption and carbon emission intensity. Furthermore, digital platforms promote information sharing and collaboration between enterprises and their suppliers, partners, and consumers, contributing to the construction of a more transparent and efficient low-carbon industrial chain.

Academia has recently paid significant attention to the mechanisms through which DT affects corporate carbon performance, with a general consensus that its impact is primarily mediated through intermediary variables. However, the intermediary variables selected in existing research exhibit limitations. Some scholars focus on the mediating path of green technology innovation [1], demonstrating that DT improves carbon performance by stimulating corporate investment in green technology R&D and innovation vitality. Other research examines the mediating role of organizational learning, exploring how DT prompts enterprises to accumulate knowledge about green operations and enhances employees' low-carbon awareness and skills, thereby optimizing carbon emission performance.

Although these studies provide valuable insights, the exploration of other potential key mediating mechanisms through which DT influences carbon performance remains insufficient. Particularly, with the official launch and operation of China's national carbon emission trading market, carbon trading mechanisms, as an important market-based environmental regulation tool, and their interaction with DT, as well as their role in corporate carbon reduction pathways, have not yet received adequate attention. Existing literature rarely systematically incorporates carbon trading mechanisms into the theoretical framework examining the impact of DT on corporate carbon performance.

By integrating the practices of DT within Chinese manufacturing enterprises, this study aims to address the gap in existing literature regarding the exploration of key mediating mechanisms. It seeks to provide new theoretical perspectives for a deeper understanding of the intrinsic mechanisms by which DT drives corporate low-carbon transition. Furthermore, it aims to offer more targeted practical guidance for governments to improve carbon market policies and for enterprises to formulate "digitalization-low-carbonization" synergistic strategies.

## 2. Research hypotheses

### 2.1. Digital transformation and corporate carbon performance

As global climate governance deepens and China advances its "dual-carbon" goals, the question of how manufacturing firms can leverage digital transformation to improve carbon performance has become a shared concern for both academia and industry. Grounded in the Resource-Based View (RBV) [2], this study argues that the embedding of digital technologies enables firms to build carbon-monitoring systems that span the entire production cycle. For instance, smart sensors and Internet-of-Things (IoT) devices collect real-time energy-consumption data on the shop floor, while big-data analytics precisely identify high-emission processes and generate dynamic optimization plans [3]. In this way, firms can curb energy waste and avoid ineffective emissions. A leading Chinese automaker, for example, deployed a digital-twin system to simulate its painting workshop, cutting natural-gas consumption by 12 % and reducing annual carbon emissions by roughly 15,000 t. Such cases illustrate that digital tools not only enhance the "visibility" of carbon emissions but

also translate low-carbon objectives into actionable technical solutions through algorithm-driven decision-support systems.

From an RBV perspective, this paper systematically explains the positive mechanisms through which digital transformation improves carbon performance in manufacturing firms and presents evidence from the Chinese context. First, digital transformation enhances carbon performance via two complementary pathways: Digital technologies—exemplified by IoT and digital twins—break the multi-level “equipment–workshop–enterprise” energy-information silos, enabling systemic integration of energy data and cross-departmental coordinated scheduling. This significantly reduces energy-transmission losses and optimizes real-time energy decisions, laying a data and decision foundation for carbon abatement. Machine-learning algorithms uncover the “carbon lock-in” effects inherent in traditional manufacturing processes, while digital simulations test the feasibility of low-carbon alternatives through multi-scenario modeling. Together, these capabilities foster technology-driven resource reconfiguration and markedly lower carbon intensity per unit of output.

Second, China’s “digitalization–decarbonization” co-evolution provides contextual validation for these mechanisms. At the policy level, the national “Smart+” strategy and the formal launch of the “dual-carbon” targets in 2021 constitute an institutional coupling that creates an incentive framework driven by both digitalization and decarbonization. At the market level, panel data from 2018–2022 for A-share listed companies show that firms in the top 20 % of digital-investment intensity experienced an annual decline in carbon intensity that was 23 percentage points faster than the industry average ( $p < 0.01$ ).

Accordingly, we propose Hypothesis H1: Digital transformation has a significant positive effect on manufacturing firms’ carbon performance, operating through the dual pathways of improved resource-utilization efficiency and enhanced innovation-driven resource-reconfiguration capability.

## 2.2. The mediating effect of technological innovation

Traditional manufacturing upgrades have long been constrained by information asymmetry and resource misallocation; digital technologies now disrupt this impasse. Industrial-internet platforms, for example, aggregate real-time equipment data, process parameters, and energy-consumption information to forge a closed “data–knowledge–technology” loop [4]. This process reveals that digital transformation acts as an accelerator of technological capability: data-driven problem diagnosis and agile iteration convert fragmented incremental demands into systematic low-carbon innovations.

Accordingly, we hypothesize:

H2 Digital transformation indirectly improves corporate carbon performance through the mediating effect of technology upgrading.

## 2.3. Sample selection and data sources

This study begins with all A-share manufacturing firms listed on the Shanghai and Shenzhen stock exchanges from 2013 to 2023. After data cleaning, we drop firms marked as ST, \*ST; exclude observations with missing or erroneous data; and winsorize all continuous variables at the 1st and 99th percentiles to mitigate the influence of outliers. The final sample comprises 6,434 firm-year observations.

## 2.4. Variable definitions

### 2.4.1. Dependent variable

Carbon performance. Consistent with the prevailing literature [5], we use carbon performance as a proxy for environmental governance effectiveness and operationalize it as carbon emissions per unit of revenue. The underlying data are retrieved from the CSMAR database, where we extract firms' environmental disclosure and energy-consumption information and scale these figures by annual revenue to obtain the final measure.

### 2.4.2. Independent variable

Drawing on prior research on digital transformation [6], we adopt an established lexicon of transformation-related keywords as our benchmark. Using Python-based text-mining techniques, we match the annual-report texts of our sample firms against this lexicon. After tallying the total number of keyword occurrences, we take the natural logarithm of the resulting frequency to construct our key explanatory variable—an innovative, text-derived indicator of the extent of each firm's digital transformation.

### 2.4.3. Mediating variable

Technology upgrading [7] refers to the process by which manufacturing firms enhance production efficiency and product quality by improving production processes, introducing advanced equipment, and strengthening R&D capabilities. It is a pivotal step in the transition from traditional to intelligent manufacturing. This process not only reflects a firm's capacity for technological innovation but also directly determines its sustainable development potential in a low-carbon economy. At its core, technology upgrading relies on innovation-driven reductions in energy use and carbon intensity during production, thereby improving environmental performance.

We operationalize technology upgrading as the mediating variable linking digital transformation to corporate carbon performance, and we quantify it along two dimensions: (1) innovation input and (2) technology application. This approach allows us to examine how digital transformation propels firms toward low-carbon operations through the critical pathway of technology upgrading.

### 2.4.4. Control variables

To enhance the robustness and completeness of our empirical model, we include a comprehensive set of control variables drawn from the extant literature. Specifically, we control for total assets [8], operating profit margin [9], cash ratio [10], leverage (asset–liability ratio) [11], firm age [12], ownership concentration [13], number of independent directors [14], R&D expenditure [15], and revenue growth rate [16]. Detailed definitions of all control variables are provided in Table 1.

Table 1. Variable definitions

Type of Variable	Variable Names	Variable Symbols	Variable Descriptions
Dependent Variable	Corporate Carbon Performance	CP	Standardized index constructed based on carbon emission intensity and carbon management capability
Independent Variable	Digital Transformation	DCG	Logarithm of the total word frequency of digital transformation plus one
Mediating Variable	Technology Upgrading	TeUp	Standardized sum of R&D investment rate and logarithm of patent applications
	Total Assets (logged)	size	Natural logarithm of total corporate assets
	Operating Profit Margin	roa	Operating profit / Revenue × 100%
	Cash Ratio	Cash	Cash and cash equivalents / Current liabilities × 100%
	Asset-Liability Ratio	lev	Total assets / Total liabilities × 100%
Control Variables	Firm Age	Age	Number of years since the firm's establishment
	Ownership Concentration	soe	Top ten shareholders' equity stake (%)
	Number of Independent Directors	Indep	First largest shareholder's equity stake (%)
	R&D Expenditure (logged)	RD	Natural logarithm of annual R&D expenditure
	Revenue Growth Rate	Growth	Current year's revenue / Last year's revenue × 100%

### 2.4.5. Model construction

Equation (1) represents the model for the impact of digital transformation on corporate carbon performance; Equation (2) indicates the effect of digital transformation on technology upgrading; Equation (3) is the model for the mediating effect of technology upgrading.

$$C_{Pit} = \alpha_0 + \alpha_1 DCG_{it} + \alpha_2 Cashw_{it} + \alpha_3 levw_{it} + \alpha_4 Growthw_{it} + \alpha_5 sizew_{it} + \alpha_6 soe_{it} + \alpha_7 Indep_{it} + \alpha_8 RDw_{it} + \epsilon_{it} + year + id \quad (1)$$

$$TeUp_{it} = \beta_0 + \beta_1 DCG_{it} + \beta_2 Cashw_{it} + \beta_3 levw_{it} + \beta_4 Growthw_{it} + \beta_5 sizew_{it} + \beta_6 soe_{it} + \beta_7 Indep_{it} + \beta_8 RDw_{it} + \epsilon_{it} + year + id \quad (2)$$

$$C_{Pit} = \gamma_0 + \gamma_1 DCG_{it} + \gamma_2 TeUp_{it} + \gamma_3 Cashw_{it} + \gamma_4 levw_{it} + \gamma_5 Growthw_{it} + \gamma_6 sizew_{it} + \gamma_7 soe_{it} + \gamma_8 Indep_{it} + \gamma_9 RDw_{it} + \epsilon_{it} + year + id \quad (3)$$

## 3. Empirical analysis

### 3.1. Descriptive statistics

Table 2 reveals substantial heterogeneity across firms. Carbon performance (CP) averages 0.35 with a standard deviation of 0.22; its range spans 0 to 4.99 and the median is 0.31, indicating pronounced

cross-sectional variation. Digital transformation, measured on a log scale, has a mean of 0.370 and a standard deviation of 0.520; the minimum is 0 and the maximum 1.800, with a median of 0. These figures imply that roughly half of the sample firms have either not yet embarked on digital transformation or remain at a very early stage, although a non-negligible subset has progressed considerably. Technology upgrading averages 0.250 with a standard deviation of 2.150; the extremes stretch from -6.580 to 18.11, and the median is 0.070. This distribution suggests that while most firms exhibit modest upgrading, a small number have achieved dramatic improvements, and a few have even experienced deterioration.

Table 2. Descriptive statistics

Variable	N	Mean	SD	Min	p50	Max
CP	6223	0.350	0.220	0	0.310	4.990
DCG	6223	0.370	0.520	0	0	1.800
roaw	6223	0.250	2.150	-6.580	0.0700	18.11
Cashw	6223	0.660	1.150	0	0.290	7.960
levw	6223	0.380	0.200	0.0100	0.370	0.960
Growthw	6005	0.240	0.590	-0.780	0.110	3.730
sizew	6223	9.720	0.510	8.550	9.670	11.17
RDw	3926	7.760	0.590	6.290	7.720	9.400
soe	3025	58.81	15.51	13.09	59.18	101.0
Indep	6219	3.410	0.970	0	3	10

### 3.2. Regression analysis

According to the regression analysis results in Table 3, digital transformation has a significant positive impact on corporate carbon performance. Specifically, the regression coefficient of digital transformation is 0.0297 and is significant at the 5% level. This indicates that for every one-unit increase in the level of digital transformation, corporate carbon performance will improve by 0.0297 units. This finding confirms that digital transformation has a significant positive effect on the carbon performance of manufacturing firms, thus validating the reliability of Hypothesis H1.

Table 3. Regression analysis

Variable	CP
DCG	0.0297** (0.0116)
roaw	0.00126 (0.00190)
Cashw	-0.000226 (0.00513)
levw	0.0695** (0.0293)
Growthw	-0.0163** (0.00790)
sizew	-0.00279 (0.0249)
RDw	0.00974 (0.00845)
soe	0.000174 (0.000340)
Indep	YES
year	YES

\*\* denotes significance at the 5% level;

standard errors are in parentheses.

p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01

### 3.3. Robustness test

To verify the robustness of the research results, this study conducted a robustness test. The results are shown in Table 4. The regression coefficient of digital transformation (DCG) is 0.394 and is significant at the 5% level (t-value = 5.41), indicating that the positive impact of digital transformation on corporate carbon performance is robust.

Table 4. Robustness test

Variable	roaw
Cashw	0.394*** (0.0728)
levw	-1.492*** (0.437)
Growthw	0.0430 (0.114)
sizew	0.869** (0.427)
RDw	-0.0499 (0.119)
soe	0.00635 (0.00471)
Indep	YES
year	YES

\*\* denotes significance at the 5% level;

standard errors are in parentheses.

p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01

### 3.4. Mediation effect

The mediation effect analysis in Table 2.4 shows that technology upgrading has a significant mediating effect between digital transformation and corporate carbon performance. Specifically, the regression coefficient of digital transformation on technology upgrading is 0.163, which is significant at the 5% level. Meanwhile, the regression coefficient of technology upgrading on corporate carbon performance is 0.0280, also significant at the 5% level. This confirms that digital transformation indirectly improves corporate carbon performance through technology upgrading, thus verifying Hypothesis H2. The direct effect analysis indicates that the direct impact coefficient of digital transformation on carbon performance is 0.0297, while the indirect impact coefficient through technology upgrading is 0.0280, demonstrating that technology upgrading plays a crucial mediating role in the process of digital transformation enhancing corporate carbon performance.

Table 5. Mediation effect analysis

Variable	Patent1	CP
DCG	0.163** (0.0640)	0.0280** (0.0116)
roaw	-0.0119 (0.0104)	0.00138 (0.00189)
Cashw	0.0102 (0.0282)	-0.000331 (0.00513)
levw	0.125 (0.161)	0.0683** (0.0293)
Growthw	-0.00200 (0.0435)	-0.0163** (0.00789)
sizew	-0.0513 (0.137)	-0.00227 (0.0249)
RDw	0.00501 (0.0465)	0.00969 (0.00844)
soe	0.00137 (0.00187)	0.000160 (0.000340)
Indep	YES	YES
year	YES	YES

\*\* denotes significance at the 5% level;

standard errors are in parentheses.

p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01

#### 4. Conclusions and recommendations

We analyzed data from China's A-share listed manufacturing companies from 2013 to 2023. Through solid empirical research, we proved the impact of digital transformation on corporate carbon performance and the role played by technology upgrading in this process.

The findings are as follows: Digital transformation can significantly help companies improve their carbon performance. As shown in Table 2.2, the regression coefficient of digital transformation is 0.0297 ( $p < 0.05$ ), meaning that for every one-unit increase in the level of digitalization, carbon performance rises by an average of 2.97%. This result confirms Hypothesis H1, demonstrating that digital transformation helps firms build a full-cycle carbon monitoring system, enables more rational resource allocation, and strengthens the role of green data assets, thereby effectively reducing carbon emission intensity per unit of output.

Technology upgrading plays a key mediating role between digital transformation and corporate carbon performance. As seen in Table 2.4, the path coefficient from digital transformation to technology upgrading is 0.163 ( $p < 0.05$ ), and the coefficient from technology upgrading to carbon performance is 0.0280 ( $p < 0.05$ ). Moreover, the mediating effect of technology upgrading accounts for 48.5% of the total effect ( $0.163 \times 0.0280 / 0.0297$ ), strongly supporting Hypothesis H2. This

indicates that digital transformation can leverage industrial internet platforms to effectively integrate equipment data and process parameters, converting fragmented improvement needs into systematic low-carbon innovations, ultimately driving improvements in carbon performance.

Analysis of control variables shows that the asset-liability ratio has a significant positive impact, suggesting that highly leveraged firms may use energy-saving and emission-reduction initiatives to reduce operating costs and alleviate financial pressure. However, the potential risk of “greenwashing” should be guarded against, as firms may selectively disclose carbon data. The negative effect of revenue growth rate confirms the existence of a “carbon lock-in effect” during corporate expansion, where the marginal increase in carbon emissions outpaces the firm’s technological abatement capacity. Additionally, the significant impact of independent directors indicates that professional oversight mechanisms play a crucial institutional role in balancing short-term growth with long-term low-carbon transition.

Robustness tests in Table 2.3 further confirm the reliability of our conclusions, with the coefficient of digital transformation remaining significant. This study provides important insights for both companies and policymakers: firms should build an integrated strategic framework of “digitalization–technology upgrading–carbon performance,” prioritizing data-driven carbon reduction tools such as blockchain-based carbon traceability systems; at the policy level, differentiated incentive policies should be implemented—for example, providing low-carbon technology subsidies to high-growth firms—to help them overcome the carbon lock-in dilemma during expansion.

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