Journal of Ecohumanism
2024
Volume: 3, No: 8, pp. 12426 – 12442
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i8.5849

Digital Transformation as a Catalyst for High-Quality Development: Examining Total Factor Productivity and ESG Performance in China's Manufacturing Sector

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Abstract

This study investigates the impact of digital transformation on total factor productivity (TFP) and environmental, social, and governance (ESG) performance in Chinese manufacturing firms, exploring the balance between economic output and sustainability for high-quality development. Results reveal two key mechanisms: innovation and efficiency. Digital transformation boosts productivity through open innovation and data-driven resource allocation while enhancing ESG performance via green technologies and efficient supply chains. The external institutional environment, including business climate and marketization, significantly influences its effectiveness. Over time, digital transformation's impact on TFP diminishes, but its role in promoting ESG performance strengthens as firms advance in sustainability. This research offers insights for enterprises and policymakers on leveraging digitalization to achieve sustainable growth, emphasizing the need to clarify specific pathways within China's manufacturing sector.

Keywords: *Digital Transformation, Total Factor Productivity (Tfp), Environmental, Social, and Governance (Esg) Performance, High-Quality Development, Manufacturing Sector.*

Introduction

Enterprise survival rests on economic performance and ESG practices serve as the road to sustainable development[1]. The premise of this study is if digital transformation can deliver both at once for enterprises. China has achieved an economic "growth miracle" around the world since reformand open, but scholars inside and abroad are increasingly questioning the qualityof this growth. Based on an extensive development model, the economy is still characterized by low contribution of total f actor productivity (TFP) to the growth with high resource and energy consumption resulting in considerable environmental debt. As a response, the Chinese government has introduced to counter ensemble of policies and measures to guide towards high-quality economic growth[2]. While the report of the 20th National Congress of the Communist Party of China highlighted "stressing to elevate total factor productivity" and pointed out that "Chinese modernization is a modernization for harmony between man and nature"[3], they reaffirmed whether ecological civilization has strategic status or sustainable development goal pressure scenario, Meanwhile, they put forward more detailed requirements.

The problem of how much energy regime corporate ESG practice becomes an important channel to achieve sustainable development goals has been based on the principle that Corporate ESG practices are practiced and proven[4]. The development of high-quality enterprises strengthens ESG With governance ability is also an urgent challenge. This is especially true for manufacturing enterprises, which run into countless challenges and bottlenecks to reach this goal. The Way to GoAppropriately balancing economic performance and better ESG outcomes is key to supporting the sustainable development of China's manufacturing sector[5]

In this context, the fusion of digital technology with industrial economies is a global trend towards China entering a new stage of technological revolution and great industrial transformation. China has demonstrated a profound commitment to digital transformation as a new engine for sustainable development and reconfiguration of the manufacturing production system [6]. Early in the "14th Five-Year Plan", the government has placed an important position for keeping new strengths in digital economy, promoting profound integration of digital and traditional industries and furthering systematic practices of

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intelligent manufacturing. Although digital transformation is an essential way to promote technological innovation and achieve efficient resource allocation, whether it can effectively promote high-quality development is an "urgent" but relatively unexplored "important issue"

Literature Review

Recent studies on digital transformation have primarily focused on its economic effects, such as production cost stickiness, total factor productivity, financial performance, input-output efficiency, bankruptcy risk, risk-taking, operational performance, innovation outcomes, and capital market performance[7]. Although some research has considered the implications of digital transformation for corporate sustainability, these studies often fail to fully capture the sustainable behavioral choices and green governance outcomes associated with digitalization. For instance, research based on case studies, such as that of Nike, demonstrates how digital technologies can transform business models, significantly impacting economic, environmental, and social outcomes[8]. Digital transformation not only reshapes markets but also provides enterprises with solutions for sustainable development by optimizing customer service, improving production efficiency, and enhancing corporate social responsibility within global supply chains[9].

Based on this context, this study adopts a dual perspective of economic performance and ESG performance in manufacturing enterprises to investigate whether digital transformation, while enhancing TFP, can encourage enterprises to achieve greater ESG performance and implement sustainable development principles, ultimately realizing high-quality development. This research seeks to address the conflict between economic and social performance in manufacturing enterprises and introduces a novel perspective on digital transformation.

This study makes several significant contributions to the literature and practice. First, it advances the evaluation dimensions of high-quality development by integrating TFP and ESG performance, moving beyond the economic-centric focus of prior research. By examining the interactions between these dimensions, this study enriches the discourse on the interplay between economic performance and sustainable development outcomes.

Second, it expands the research domain of digital transformation by emphasizing its sustainability aspects. While existing studies predominantly highlight the cost-reduction and efficiency-enhancing functions of digital transformation, this research assesses its dual impacts on economic performance and ESG outcomes, offering a broader and more integrated understanding of its effects.

Third, this study analyzes the mechanisms through which digital transformation enables high-quality development. It explores internal drivers, such as innovation quality, supply chain efficiency, and human resource allocation efficiency, and examines the asymmetric impacts of digital transformation across varying government and market conditions.

Finally, it provides practical insights for implementing and promoting digital transformation. By extending the practice of digital transformation beyond economic benefits to encompass social welfare and ecological domains, this study embeds digitalization into the broader framework of high-quality development. The findings offer theoretical support and actionable guidance for achieving the "win-win" goal of enhanced production efficiency and sustainable development through digital transformation.

This research thus contributes to both theory and practice by addressing the dual goals of economic and ESG performance in the manufacturing sector, offering a comprehensive framework for understanding the transformative potential of digital technologies in achieving high-quality development.

Theoretical Analysis and Hypotheses

The Impact of Digital Transformation on Firms' Total Factor Productivity

With the advancement of digital transformation, next-generation information technology is penetrating

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deeper and deeper into the manufacturing sector, spatial barriers to resource utilization are constantly breaking through, and efficient sharing and utilization of data resources are taking place. The transfer of data as the key to production factor improves the allocation efficiency and opens up the end of traditional factors such as labor and capital for integration processing,[10]. Digital transformation can enhance firms' total factor productivity (TFP) through various channels, among which the two most crucial ones are the enhancement of technological innovation quality and the optimization of efficiency in resource allocation[11].

The diffusion of digital technologies has altered the model of innovations and firms have started to rearrange their production via various new channels in innovation. This has gone beyond the traditional closed innovation models of individual firms, into open innovation models with multiple departments as well as increased supply chain and industry chain participation[12]. This enables effective integration of information, technological, financial and logistic flows which helps those manufacturing firms to rapidly acquire sophisticated technology and managerial know-how. In addition, these integrations create inter-industry and intra-chain knowledge and technological spillovers that, with demonstration effects on firm's innovative capacities, increase TFP[13].

The integrated supply chain and the more efficient allocation of human resources facilitated by business process digitalization also boost TFP through efficiency channels. At one side, firms can easily process large amounts of data in production and logistics at scale via digital transformation on the back of enhanced supply chain and process efficiency. Digital platforms assist suppliers with accurate data on raw material demand forecasting. Using tools related to predictive analytics and big data management, such platforms center around the integration of upstream and downstream supply chain partners for efficient interaction management between them and any firm concerned with their operational processes. By this integration, firms are able to change production plans according to customer trends, hence providing transparency in manufacturing and operational efficiency. Moreover, the use of digital technologies allows upstream and downstream companies to create powerful connection points and common asset- and ecosystem pools that reduce transaction costs by up to 90 percent in some cases, as well as streamline production processes and realise efficiency gains[14].

While the resource allocation efficiency pertains to the use and maximization of internal resources, especially human resources[15]. Labor is one of the main elements for raising TFP (it is, after all, the mechanism through which material capital inputs are turned into output). With the benefit of digital transformation, it allows intelligent technology to take over process-oriented jobs, while you replace a tedious job with an algorithm which improves human capital allocation efficiency. Demand in enterprises for employees able to learn, understand, and apply new technologies grows as businesses scale up and their workforce sizes grow[16]. It rebalances the ratios of capital–labor input and refocuses this balance with more human capital on the labor side, optimizing such decisions for precision and scientific base makes digital transformation impact investment in labor crucially.

This study suggest the following hypotheses based on the above discussion:

Hypothesis 1: Digital transformation enhances firms' total factor productivity

Hypothesis 1a: Digital transformation improves firm TFP via an innovation channel.

Hypothesis 1b: Digital transformation increase firms TFP through efficiency channels

The Impact of Digital Transformation on Firms' Sustainable Development

High-quality development of manufacturing enterprises not only includes the economic performance, but also focuses on continuous social and environmental value creation as an evaluation dimension[17]. A lot of manufacturing enterprises have taken it to the next level by laying out digital workflows in their environmental process actions, upgraded technological equipment, and several factories directly go for a full-on "green factory." The initiatives harness intelligent technologies to boost product quality, create

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ongoing equipment viability and longevity, and minimize the consumption of fuels, raw materials and auxiliary materials during production as well as environmental technologies and conditions along with relieving the burden on employees. Digital transformation improves not only the technological innovation capacity but also the resource allocation efficiency by embedding intelligent production concepts into operational environments, which can stimulate or impede firms to perform sustainable development. Tech innovation as a tactical lever for sustainability. Clean production technologies are currently the main strategy for pollutants reduction in industry activities[18]. Digital transformation paves the way of green technology implementations for environmental enhancements via end-of-pipe and front-end solutions. This comprises creation of cleaner technologies and environmental efficiency mechanisms that rise above the typical "emit initial, recover once necessary" trajectory, boosting contaminant discount and stream functionality.

Even though green R&D investments are riskier in the contexts with extreme environmental uncertainty, digital transformation reduces these uncertainties through data collection, process monitoring, information sharing as well as prediction of market demands and technological trends[19]. This justifies the businesses belief in transforming green innovation results, which leads to better performance at source for environmental-impact. The theory of behavioral consistency suggests that with digital transformation, firms adopt more environmental governance through green technology innovation and also pay closer attention to social responsibility(e.g. employee well-being and product quality [20]. These measures collectively enhance ESG performance, providing a foundation for high-quality development.

Digital transformation facilitates the efficiency of supply chain and human resource allocation in firms, which results in improved ESG performance (efficiency channels). Second, digital transformation utilizes information advantages to more holistically assess supply chains to provide rich insights into the nature of upstream and downstream partner operations[21]. As a result, enabling firms to quickly modify their production and operational plans in order to maintain accurate inventory levels. A more efficient inventory also lowers costs without sacrificing customer services thanks to lower agency problems which tend to cause inefficiencies and waste resources. The use of digital technologies like automated identification and various cloud computing software solutions, the logistics or supply chain managed process gets stronger since there is better transparency and ability to optimize delivery routes. Such advancements improves the level of customer service and lowers the cost of production which also meets the aim of corporate social responsibility. And more so, digital transformation helps shorten product development cycles; reduce rework and waste; optimise resource use and energy conservation through real-time data from production systems and supply chain partners. Efficient supply chains put more resources at our disposal, use fewer materials, and are able to recycle and repair products into the original production processes with ease (increased resource utilization); thereby reducing material flow through ecosystems of pollution and non-productive waste.

Workers — the fundamental unit of firms — are critical to technological advancement. Human resource allocation enables more efficient digital transformation along a productive capacity, talent pool with fewer labor price distortions, optimized workflows, better working conditions and protections for employees. The introduction of digital technologies demands technical skills, especially in the area of the new technology implementation associated with energy conservation and emission reduction. Shifting clean production devices, data management systems, software, and green product development are part of these technologies assuring that they have to be accompanied with quality human resources. This alignment is instantiated through digital transformation, which can direct the move from lower to higher-skilled positions, facilitating employees' innovation and technical learning capabilities [22]. As a result, this facilitates the spillover of technical knowledge papers, promotes green and clean technology advancements, spurs energy-saving and emission reduction innovations, into better ESG performance.

From this analysis, we derive the following hypotheses:

Hypothesis 2: Digital transformation positively affects firms' ESG performance.

Hypothesis 2a: Digital transformation improve firms ESG performance via the innovation channels.

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Hypothesis 2b: Digital transformation improves ESG performance via efficiency channels.

Research Design

Sample Selection

Since 2010, China has entered a phase of rapid development in information technology. However, the outbreak of the COVID-19 pandemic in 2020 had a significant impact on the manufacturing sector. To mitigate the interference of such an extraordinary period, this study selects data from China's Shanghai and Shenzhen-listed manufacturing firms for the period 2010–2020. The dataset is obtained from the China Stock Market and Accounting Research (CSMAR) database. Firms issuing B-shares and H-shares, as well as those marked as ST/*ST or with missing financial data, are excluded. The final sample comprises an unbalanced panel of 13,912 firm-year observations. To control for outliers, continuous variables are winsorized at the 1% and 99% levels. Additionally, year and firm fixed effects are included, and standard errors are clustered to account for heteroskedasticity and within-group correlation.

Model Specification

Based on the theoretical analysis outlined earlier, the following baseline regression model is constructed. The primary focus is on the signs and statistical significance of the estimated coefficients:

$$\mathrm{TFP}_{it} / ESG_{it} = \alpha_0 + \alpha_1 Digital_{it-1} + \alpha_2 Controls_{it} + \mu_1 Year_t + \mu_2 Firm_i + \varepsilon_{it} \quad (1)$$

Specifically, TFPit represents the total factor productivity of firm i in year t; ESG denotes ESG performance; Digital is the degree of corporate digital transformation; Controls includes other control variables; Year represents year fixed effects; Firm denotes firm fixed effects; and ε is the random error term.

Variable Definitions

Dependent Variables: Based on the theoretical analysis above, this study uses a multidimensional indicator approach to measure high-quality corporate development from two dimensions: total factor productivity (TFP) and ESG performance.

Total Factor Productivity (TFP)

The GMM, Ackerberg-Caves-Frazer (ACF) method semi-parametric estimation methods (referred to as Levinsohn-Petrin (LP) and Olley-Pakes (OP)) are applied to estimate TFP. For instance, the OP method overcomes simultaneity bias, but discards all samples where their investment value is non-positive which can in turn lead to bias. LP method — optimization improved from OP which more adequately captures gaps in data.

The LP model used to estimate TFP is specified as follows:

$$y_t = \beta_0 + \beta_l l_t + \beta_k k_t + \beta_m m_t + \omega_t + \varphi_t \quad (2)$$

In the model, $y_t$represents total output, while the right-hand side includes various production inputs. Labor input l_t is measured by the number of employees, and capital input k_t is represented by the net value of fixed assets. Intermediate input m_t is calculated as the sum of operating costs and expenses, minus the current period's depreciation and amortization, as well as cash payments to employees. Total factor productivity ω_t captures the efficiency of production, where a higher ω_t indicates greater productivity and improved economic performance.

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ESG Performance

This study targets sustainable development goals selection rooted in the traditional sustainability dimensions; social, environmental and economic pillars of sustainability (Khasawneh & Harbili, 2021). ESG Generally Behaves with the Elements of Macro Objectives of High Quality Economic Development in China Accordingly, ESG performance is used as an indicator of sustainable development providing different levels of composite scores including environmental responsibility, social responsibility and corporate governance.

Following the methodology emphasized in prior research, this study points to ESG ratings from Huazheng ESG system as a reference. The ratings are translated into scores from 1 to 9 according to a nine-level scale from lowest to highest. The higher the score, the better a company is doing in terms of ESG performance.

*Explanatory Variable***:** This study measures the degree of enterprise digital transformation using the following methodology:

First, policies and research reports related to digitalization were reviewed. Combined with existing research and discussions with experts in related fields, keywords were extracted to form a "bag of words" based on two dimensions: foundational technology applications and integrated technology applications (as shown in Figure 1).

Second, the annual financial reports of listed companies (hereinafter referred to as "annual reports") were downloaded from the Shanghai and Shenzhen Stock Exchange websites using Python and converted into text format. The jieba library was then employed to perform text segmentation, and irrelevant content in the annual reports was removed using text extraction functions.

Third, expressions containing negation prefixes preceding keywords were excluded. Subsequently, a full-text search for the keywords in the "bag of words" was conducted within the annual reports, and the total word frequency of the keywords was calculated. Finally, the natural logarithm of the total keyword frequency was taken as the measure of digital transformation.

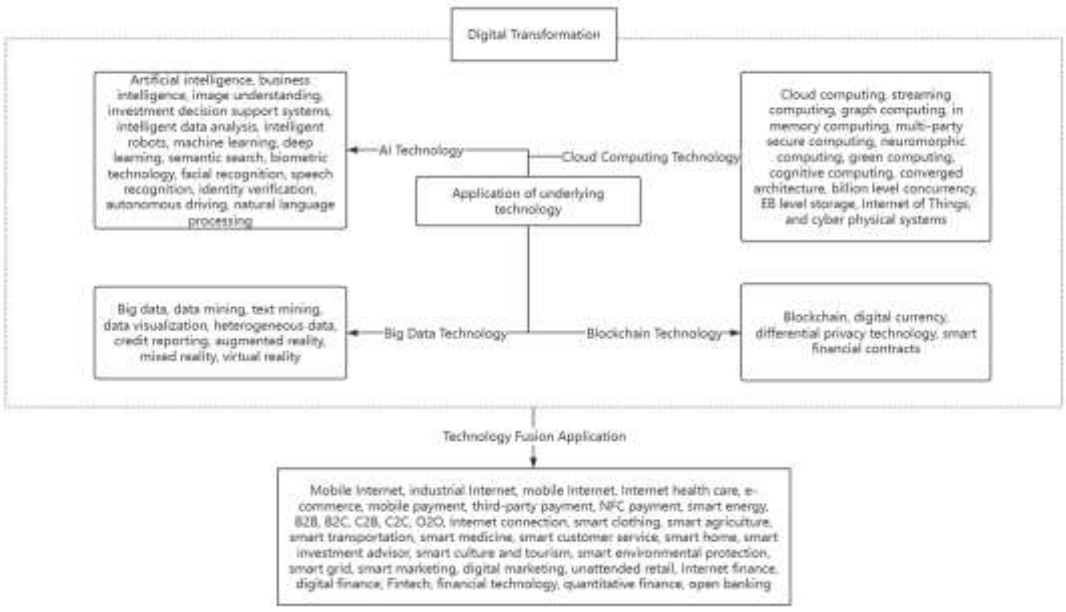

Figure 1. Keywords for Text Analysis of Enterprise Digital Transformation: 'Word Bag'

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Denote other control variables in accordance with literature and include listed companies basic characteristics. Firm size is the natural logarithm of total assets. We define financial leverage as the asset-liability ratio. Profitability can be expressed as the ratio of net profit to average balance of total assets. Listing years are defined as ln(current year – listing year). The ratio of cash and net cash flow from operating activities to current assets Independent directors ratio is calculated as Number of independent directors / Total number of directors Market value — including the natural logarithm of the sum of the market value of circulating shares and book value of non-circulating shares Ownership type — Ownership type is a binary variable, being set equal to 1 for state-owned enterprises and 0 otherwise. Tobin-Q = (![equity market value + book value of liabilities] / total assets) Board size: natural logarithm of the number of directors on board; Institutional ownership is measured by the ratio of shares held by institutions divided by circulating shares. For growth — Revenue growth rate

Table 1 shows descriptive statistics for the principal variables. Panel A summarizes the key characteristics of manufacturing enterprises.The average value of TFP is 9.03 (standard deviation: 1.01). There is considerable variation in the average ESG performance (M = 4.05, SD = 1.06). The mean of digital transformation is 1.13 (SD = 1.25, Min = 0.00), which shows that some manufacturing enterprises have never carried out the digital transformation and that there exists significant heterogeneity among firms. Stating this, other principal variables are in concordance with the statistical outcomes specified in previous research.

Table 1. Descriptive Statistical Results of Main Variables

Variable	Observations	Avg.	Min	Max	Median	SD
Total factor productivity	13912	9.03	6.81	12.07	8.93	1.01
ESG performance	13912	4.05	1.00	6.00	4.00	1.06
Digital Transformation	13912	1.13	0.00	5.00	0.69	1.25

Empirical Results and Analysis

Baseline Regression Results

Table 2 presents the regression results of digital transformation on high-quality corporate development. Columns (1) and (2) report the regression outcomes for total factor productivity (TFP) and ESG performance, respectively, after incorporating control variables as well as individual and year fixed effects. The coefficients of digital transformation are both significantly positive, indicating that corporate digital transformation contributes to enhancing TFP and promoting sustainable development. These findings provide empirical support for Hypotheses 1 and 2.

Table 2. Benchmark Regression Results

	Total factor productivity	ESG performance
Digital Transformation	0.01***(2.42)	0.03***(2.51)
Company Size	0.54***(30.00)	0.31***(8.87)
Financial Leverage	0.36***(6.10)	-0.75***(-6.51)
Profitability	1.09***(10.84)	0.79***(3.72)
Number of years IPO	0.23***(3.06)	-0.73***(-3.63)
Cash Holding Ratio	0.59***(9.46)	-0.27*(-1.85)
Proportion of Independent Directors	0.20(1.51)	1.10***(3.38)
Total Market Value	-0.03***(-2.43)	-0.03(-1.23)
Property Rights Nature	0.02(0.50)	0.08(1.10)
Tobin Q	0.02***(4.46)	-0.01(-1.23)
Board Size	0.11***(2.12)	0.03(0.27)
Institutional Shareholding Ratio	0.01(0.21)	0.08(1.18)

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Growth	0.16***(12.61)	-0.09***(-3.81)
Constant	-4.23***(-10.00)	-1.03(-1.19)
Annual/Company Fixed Effects	Control	Control
Adjusted R^2	0.64	0.05
Sample Size	13912	13912

Note:The value of t is in parentheses; ***,** And * represent significance levels of 1%, 5%, and 10%, respectively.

Endogeneity Tests

Instrumental Variable Approach

To reduce the influence of bidirectional causality between digital transformation and high-quality corporate development, this study uses an instrumental variable (IV) method to remedy the estimation bias caused by endogeneity. Consistent with studies aforementioned, this study employs industry-level average digital transformation (except for focal firm) as an instrumental variable to conduct 2SLS estimation. Although the digitalization level of cities and industries may have an impact on firm-level digital transformation, it does not directly affect the quality development of a single firm. The coefficient of the industry-average digital transformation is positive at the 1% level in terms of statistical significance, suggesting that the instrumental variable and endogenous variable are strongly correlated according to regression results. Further, the value of F-statistic is also greater than ten points which mean that instrumental variable is passes weak instrument test. In addition, the coefficients of digital transformation are still highly significant ($p < 0.05$, $p < 0.01$). The regression results for the instrumental variable approach are not reported in this paper due to space limitations, but are available from authors per request. These results are in line with the baseline evidence.

Policy Shock

In 2015, the State Council released the Made in China 2025 plan, which called for deep integration of next generation information technologies into manufacturing processes to spur industrial transformation and upgrading and innovation with a goal of making China one of the manufacturing powers[9]. This policy creates a natural experiment to study the effect of digital transition on high-quality corporate evolution for manufacturing firms. The sample was divided into two groups based on the year when policy implementation started (before 2015 and after 2015), and regression models were run. The coefficients of digital transformation are insignificant prior to the policy implementation, while after the policy shock, the coefficient increases in size and is significantly positive at 5% and 1% levels, respectively. The results indicate that the baseline conclusions are robust to endogeneity, which is addressed by means of quasi-experimental external shocks.

Robustness Tests

This study performs two robustness tests to confirm the validity of research results. The dependent variable measure is first modified. TOTAL FACTOR PRODUCTIVITY (TFP)-Using the TFP calculated based on Olley-Pakes method in place of TFP measured using Levinsohn-Petrin (Total Factor Productivity 21 %) model for re-estimating; However, a modification of the ESG performance indicator is proposed based on some existing studies that give relevance for sustainable development. Based on the selection and aggregation of environmental, social and governance advantages of firms from the CNRDS database, we construct a sustainable development performance indicator index that can reflect ESG with larger absolute values corresponding to better sustainable development performance.

Second, the independent variable digital transformation is measured differently. The first metric is simply the number of relevant keywords in corporate reports. However, since the report length differs from one firm to another, we divide it by the total word count of the reports leading us to another measure we call digitalization proportion.

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The results of these robustness tests are shown in Table 3 (Columns 1–4). All coefficients remain strongly positive and statistically significant, in line with baseline conclusions, providing support for the robustness of our main results.

Table 3. Test Results of Replace Dependent and Independent Variables

	OP TFP	Advantage ESG Perf	TFP	ESG Perf
Digital Transformation	0.01***(3.79)	0.08*(1.66)	\	
% of Digitalization			30.32***(3.80)	51.81**(2.08)
Constant	2.96***(15.83)	-25.60***(-9.48)	-4.27***(-22.58)	-1.20**(-2.04)
Control variable	Control	Control	Control	Control
Annual/Company Fixed Effects	Control	Control	Control	Control
Adjusted R^2	0.59	0.15	0.64	0.04
Sample Size	13912	13912	13810	13810

Note:The value of t is in parentheses; ***,** And * represent significance levels of 1%, 5%, and 10%, respectively.

The Special Action Plan for Deep Integration of Informatization and Industrialization (2013–2018) issued by the Ministry of Industry and Information Technology in 2013 marks the beginning of a series of initiatives to promote integration, with requirements identified for different user types within specific timeframes. Following this, the sample period was re-analysed between 2013–2020. Again, columns (1) and (2) of Table 4 display the regression coefficients of digital transformation on high-quality corporate development, which are still persistently positive significant.

Second, a regression analysis was examined without high-tech manufacturing firms. Such competition can rely on the technological features of firms, which may influence the disclosure of digital information and performance inclusion (inaccurate results). Based on the Classification of High-Technology Industries (Manufacturing) (2017) published by National Bureau of Statistics, firms identified as high-tech industries were excluded. In Columns (3) and (4), we regress non-high-tech manufacturing firms only, and the coefficients are still significantly positive.

Third, those who received a zero level of digital transformation were excludeddue to the potential strategic corporate behavior bias. Excluding firms that did not disclose on any digital-related keywords, the regression was re-run. Columns (5) and (6) show the results of incorporating control variables, which suggest that the coefficients of digital transformation remain significantly positive.

These analyses show that the results of this study are strong and not sensitive to alternative time periods, firm specific differences or possible strategic disclosure behaviors.

Table 4. Results of Change the Time and Sample Inspection

	TFP	ESG Perf	TFP	ESG Perf	TFP	ESG Perf
Digital Transformation	0.01 **(2.38)	0.05 ***(3.80)	0.01 **(2.25)	0.04 ***(3.26)	0.01 **(2.10)	0.03 **(2.11)
Constant	-4.17 ***(-16.81)	0.28 (0.36)	-3.69 ***(-16.79)	-1.28 *(-1.78)	-5.06 ***(-18.88)	-1.58 *(-1.80)
Control Variable	Control	Control	Control	Control	Control	Control
Annual/Company Fixed Effects	Control	Control	Control	Control	Control	Control
Adjusted R^2	0.61	0.04	0.62	0.05	0.66	0.05
Sample Size	11624	11624	10034	10034	8129	8129

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Note:The value of t is in parentheses; ***,** And * represent significance levels of 1%, 5%, and 10%, respectively.

Mechanism Analysis of the Impact of Digital Transformation on High-Quality Development in Manufacturing Firms

The analysis above confirms the impact of digital transformation on the high-quality development of manufacturing firms. This section focuses on two specific pathways, **innovation** and **efficiency,** to explore how digital transformation enables high-quality corporate development. Based on Equation (1), this study designs a recursive equation model and constructs Equations (3) and (4) to analyze the corresponding coefficients. In these equations, M represents the mediating variable, while other variables remain as previously defined.

$$M_{it} = \beta_0 + \beta_1 Digital_{it-1} + Controls_{it} + \mu_1 Year_t + \mu_2 Firm_i + \varepsilon_{it} \quad (3)$$

$$TFG_{it} / ESG_{it} = \gamma_0 + \gamma_1 Digital_{it-1} + \gamma_2 M_{it} + Controls_{it} + \mu_1 Year_t + \mu_2 Firm_i + \varepsilon_{it} \quad (4)$$

Innovation Channel

Theoretical Analysis 1: Technology Innovation as a Mediator of Digital Transformation TFP and ESG Performance Link Thus, we consider the quality of innovation (measured by the number invention patent application) and that of green innovation (number of green invention patent applications).

The mediation effect of innovation quality between digital transformation and high-quality corporate development is shown in Table 5. In columns (1) and (2), the coefficients of both invention patents and green invention patents are significantly positive, indicating that digital transformation can effectively promote technological innovation. Table 3: Regression results for TFP and ESG performance Column (3) and (4) report the results of regressions on TFP and ESG performance, respectively, confirming that the coefficients of digital transformation as well as two types of patents remain significantly positive.

It indicates that the innovation channel is one of the main channels by which digital transformation affects high-quality corporate development. As such, we find support for Hypotheses 1a and 2a.

Table 5. Estimation Results of Innovative Channels for Empowering High-Quality Development of Enterprises Through Digital Transformation

	Invention Patent	Green Invention Patent	TFP	ESG Perf
Digital Transformation	0.03***(3.19)	0.02***(3.28)	0.01***(3.83)	0.03***(2.89)
Invention Patent			0.01*(1.95)	
Green Invention Patent				0.06***(3.52)
Constant	-6.81***(-13.80)	-1.44***(-4.59)	-4.20***(-22.19)	-0.99*(-1.70)
Control Variable	Control	Control	Control	Control
Annual/Company Fixed Effects	Control	Control	Control	Control
Adjusted R^2	0.14	0.03	0.64	0.05
Sample Size	13912	13912	13912	13912

Note:The value of t is in parentheses; ***,** And * represent significance levels of 1%, 5%, and 10%, respectively.

Journal of Ecohumanism
2024
Volume: 3, No: 8, pp. 12426 – 12442
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i8.5849

Efficiency Channel

Supply Chain Efficiency

Following the theorization in this section, supply chain efficiency is chosen as a mediating variable and can refer to management efficient of inventories due to their dynamic nature—measured using inventory turnover days. It is, in particular, measured as 365×365× (average inventory / cost of goods sold), with lower turnover periods reflecting greater efficiency of the supply chain.

Columns 1 to 3 of Table 6 show the functional mediation test result of supply chain efficiency in the digital transformation–high-quality development relationship. The coefficient of supply chain efficiency is significantly negative in Column (1), suggesting that digital transformation has a significant positive impact on supply chain efficiency. Specification (2) regress TFP and Specification (3) ESG performance with both coefficients of Digital Transformation and Supply Chain Efficiency are significant as it is shown in Columns (2) to (3), respectively. These results indicate that supply chain efficiency is a crucial channel in the relationship between digital transformation and high-quality corporate development.

Human Resource Allocation Efficiency

Labor investment efficiency is used as a proxy for the mediating variable representing human resource allocation efficiency. It is calculated as the absolute value of the residual from regressing the rate of change in employment on other related economic variables. This residual represents the absolute difference between the actual and expected rate of change in employment, with smaller values indicating higher human resource allocation efficiency.

Table 6 (Columns 4 to 6) presents the results of the mediation test for human resource allocation efficiency. Column (4) shows that human resource allocation efficiency is significantly negative, indicating that digital transformation significantly reduces inefficiency in resource allocation. Columns (5) and (6) report the regression results for TFP and ESG performance, respectively. The results show that while the coefficients of digital transformation and human resource allocation efficiency are both significant for TFP, the effects on ESG performance are only partially significant.

These findings suggest that human resource allocation efficiency is another critical pathway through which digital transformation impacts TFP but is not the primary mechanism for influencing ESG performance. Thus, Hypotheses 1b and 2b are supported.

Table 6. Efficiency Channel Estimation Results of Digital Transformation Empowering High-Quality Development of Enterprises

	Supply chain efficiency	TFP	ESG perf	HR efficiency	TFP	ESG perf
Digital Transformation	-4.01***(-4.40)	0.01**(2.40)	0.03***(2.92)	-0.001*(-1.73)	0.001***（3.57）	0.03***(2.84)
Supply chain efficiency		-0.01***(-40.70)	-0.00***(-2.95)			
Efficiency of H allocation					-0.03***(-2.76)	-0.04(-1.27)
Constant	162.06***(3.29)	-4.02***(-22.86)	-1.03*(-1.77)	-0.77***(-4.27)	-4.26***(-22.60)	-1.04*(-1.77)
Control Variable	Control	Control	Control	Control	Control	Control

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Annual/Company Fixed Effects	Control	Control	Control	Control	Control	Control
Adjusted R^2	0.07	0.69	0.05	0.08	0.64	0.04
Sample Size	13912	13912	13908	13818	13818	13818

Note:The value of t is in parentheses; ***,** And * represent significance levels of 1%, 5%, and 10%, respectively.

Resource Reallocation Effect of Digital Transformation on Production Efficiency and ESG

The results above demonstrate that both the innovation and efficiency channels contribute to high-quality corporate development, highlighting the role of digital transformation in optimizing resource allocation from the perspectives of technology, supply chain, and human resources. The relationship between economic and sustainable benefits during the implementation of digital transformation is reflected in its ability to influence factor mobility, guiding resources toward effective allocation among firms. Digital production systems enhance economic efficiency by reallocating resources to higher-efficiency firms, enabling these firms to achieve better sustainable outcomes and optimizing overall resource reallocation.

This effect manifests in several ways: improved working conditions reduce employee workload, while energy consumption and pollution per unit of product decrease, driving the green development of high-efficiency firms and laying the foundation for achieving greater social and environmental benefits.

To examine whether digital transformation facilitates the flow of capital from low-return to high-return activities within firms, this study uses the investment-investment opportunity sensitivity model to test the resource allocation capability of digital transformation, as shown in Equation (5). Based on the resource reallocation theory, the study further tests whether digital transformation enhances the sustainable benefits of high-efficiency firms by constructing Equation (6).

$$\begin{aligned}\text{Invest}_{it} = {} & \beta_0 + \beta_1 TFP_{it} Digital_{it} TobinQ_{it-1} + \beta_2 TFP_{it} Digital_{it} + \beta_3 Digital_{it} TobinQ_{it-1} + \\ & \beta_4 TFP_{it} TobinQ_{it-1} + \beta_5 TobinQ_{it-1} + \beta_6 TFP_{it} + \beta_7 Digital_{it} \\ & + \beta_8 Controls_{it} + \mu_1 Year_t + \mu_2 Firm_i + \varepsilon_{it}\end{aligned} \tag{5}$$

$$\begin{aligned}\text{ESG}_{it} = {} & \theta_0 + \theta_1 Digital_{it} + \theta_2 TFP_{it} + \theta_3 Digital_{it} TFP_{it} + \\ & \theta_4 Controls_{it} + \mu_1 Year_t + \mu_2 Firm_i + \varepsilon_{it}\end{aligned} \tag{6}$$

In Equation (5), investment (Invest) is measured as the standardized value of the sum of changes in fixed assets, construction-in-progress, and R&D expenditures divided by total assets. To ensure robustness, investment opportunities (TobinQ) are measured using the lagged Tobin's Q value. The independent variables include investment opportunities, digital transformation, total factor productivity (TFP), and their interaction terms, to test the impact of digital transformation on firms' resource allocation efficiency. Other control variables are consistent with those used earlier. The results are presented in Table 7.

In Column (1), the coefficient of the interaction term *digital transformation* × *investment opportunities* is significantly positive, indicating that digital transformation effectively facilitates resource allocation. In Column (2), the coefficient of *digital transformation* × *investment opportunities* × *TFP* is also significantly positive, suggesting that digital transformation leads to better resource allocation efficiency in high-productivity firms, with resources being more inclined toward these firms.

Equation (6) focuses on the regression coefficient of the interaction term *digital transformation* × *TFP* on ESG performance. As shown in Column (3), the coefficient of the interaction term is significantly positive, indicating that digital transformation enables high-productivity firms to achieve superior sustainable benefits, thereby realizing the resource reallocation effect.

Journal of Ecohumanism
2024
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https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i8.5849

Table 7. Estimation Results of The Resource Reallocation Effect of Digital Transformation on Production Efficiency And ESG

	Investment	Investment	ESG Performance
Digital Transformation * Investment Opportunities * TFP		0.02**(2.09)	
Digital Transformation * Investment Opportunities	0.10**(2.17)	-0.01(-0.10)	
Digital Transformation * TFP		0.03(0.42)	0.03***(2.85)
Investment Opportunities * TFP		-0.05(-0.96)	
Digital Transformation	-0.16(-1.20)	-0.55(-0.79)	-0.25**(-2.49)
Investment Opportunity	-0.23***(-2.64)	0.25(0.54)	
TFP		-4.28***(-11.35)	0.07(1.63)
Constant	-29.57***(-5.35)	-47.81***(-7.91)	-0.31(-0.33)
Control Variable	Control	Control	Control
Annual/Company Fixed Effects	Control	Control	Control
Adjusted R^2	0.16	0.19	0.05
Sample Size	13270	13270	13912

Note:The value of t is in parentheses; ***,** And * represent significance levels of 1%, 5%, and 10%, respectively.

Extended Analysis

The Impact of External Institutional Environment on Digital Transformation-Enabled High-Quality Corporate Development

Business is another vital institutional factor that affects the behavior of corporates in all stages of its operation. A well-enabled market and administrative regime enhances an optimized business environment to allow firms to better allocate scarce resources toward production activities and hence increase operational efficiency and productivity [7]. A conducive policy environment can help to break down data silos among governments, banks, and firms; reallocate resources to the most efficient use; broaden financing channels available; and assist digitally-enabled enterprises in building a sustainable asset allocation framework for managing the challenges from digital transformation practices. Hence, policies to improve the business environment may better facilitate digital transformation processes, increase productivity and accountability in relation to ESG goals and lead towards high quality corporate development.

The principal component analysis (PCA) method is used in the study to build a "Regional Business Environment – Policy Environment Index" using indicators like government governance, which includes government intervention and the burden of corporate taxes. Index is clustered based on its mean to perform regression The results in Panel A of Table 8 (Columns 1 to 4) show that digital transformation has a positive impact on TFP and ESG performance when regions have better business environments. It suggests that a better business environment is more conducive to digital transformation in promoting the high quality development of enterprises.

The economic and legal systems are relatively more developed, and foundational industrial capabilities (especially talent, technological innovation and public services) are stronger in markets with greater degrees of marketization. The infrastructure and intellectual property protection in these areas are also better, so that the low-cost allocation of production factors has a higher efficiency, and its digital transformation can play a more significant role in promoting corporate high-quality development. Marketization is not a direct construct; with higher levels of marketization, firms compete more seriously in the marketplace with increased sensitivity to their competitors due to highly visible streamlining by rival firms. Firms are more

Journal of Ecohumanism
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DOI: https://doi.org/10.62754/joe.v3i8.5849

likely to adopt digital transformation in a bid to stand out and drive up productivity by leaps and bounds. The contingency theory argues that the corporate behavior should react to the environment by adjusting its ESG performance targets in order to adopt social and environmental responsibility (SER) and realize sustainable development of enterprise under competitive pressure, especially social pressure. Therefore, the external institutional factor of marketization will reinforce the effect of digital transformation on quality high-quality corporate development.

The China Provincial Marketization Index Report is employed to measure marketization at the provincial level in this study. Interpolation is used to estimate missing values. For Regression analysis the index is grouped by its mean As presented in table 8 (columns 5 to 8), the results show that digital transformation significantly promotes TFP and ESG performance, especially in regions with a higher degree of marketization. It shows that a more rapid marketization process can only further strengthen the part played by digital transformation in facilitating high-quality corporate development.

Table 8. Estimation Results of Heterogeneity at the Government and Market Levels

	Business Environment				Marketization Process			
	TFP		ESG Perf		TFP		ESG Perf	
	Good	Poor	Good	Poor	Good	Poor	Good	Poor
Digital Transformation	0.02**(2.15)	0.01(1.63)	0.06***(3.68)	-0.01(-0.43)	0.02**(2.06)	0.01(1.57)	0.03*(1.91)	0.03(1.46)
Constant	-3.70***(-6.07)	-4.20***(-6.50)	-1.97(-1.51)	-2.68*(-1.68)	-3.81***(-6.62)	-4.56***(-7.07)	-2.04*(-1.64)	-1.01(-0.73)
Control Variable	Control	Control	Control	Control	Control	Control	Control	Control
Annual/Company Fixed Effects	Control	Control	Control	Control	Control	Control	Control	Control
Adjusted R^2	0.61	0.62	0.05	0.05	0.64	0.64	0.05	0.05
Sample Size	7126	6786	7126	6786	7935	5977	7935	5977

Note:The value of t is in parentheses; ***,** And * represent significance levels of 1%, 5%, and 10%, respectively.

Marginal Effect Test of Digital Transformation on High-Quality Corporate Development

To explore whether the relationship between digital transformation and high-quality corporate development is influenced by the levels of total factor productivity (TFP) and ESG performance, this study examines whether the marginal effect of digital transformation varies significantly across different levels of corporate development. A panel quantile regression model is employed for this analysis, with results presented in Table 9.

Columns (1) to (3) show that the coefficients of digital transformation are significantly positive across all TFP quantiles, indicating that digital transformation positively contributes to TFP regardless of whether a firm's TFP level is high or low. However, the coefficients decrease as TFP increases, suggesting a diminishing marginal return of digital transformation on TFP.

Similarly, the effects of digital transformation on ESG performance exhibit heterogeneity across different ESG performance levels. Columns (4) to (6) indicate that as ESG performance increases, the coefficients of digital transformation also increase, implying that digital transformation generates higher marginal effects in enhancing sustainable development for firms with higher ESG performance. For firms with lower ESG performance, the effect of digital transformation is not significant. This finding suggests that digital transformation requires firms with lower ESG performance to increase R&D investments and optimize resource allocation to promote high-quality development.

Journal of Ecohumanism
2024
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https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i8.5849

Table 9. The Marginal Effect Test Results of Digital Transformation Empowering High-Quality Development of Enterprises

	TFP			ESG Performance		
	25th percentile	50th percentile	75th percentile	25th percentile	50th percentile	75th percentile
Digital Transformation	0.04***(8.99)	0.03***(8.73)	0.01***(27.82)	-0.00***(-6.77)	0.01***(3.77)	0.06***(31.74)
Control Variable	Control	Control	Control	Control	Control	Control
Annual/Company Fixed Effects	Control	Control	Control	Control	Control	Control
Sample Size	13912	13912	13912	13912	13912	13912

Note:The value of t is in parentheses; ***,** And * represent significance levels of 1%, 5%, and 10%, respectively.

Conclusion

This paper investigates the two-way effect of digital transformation on total factor productivity (TFP) and ESG performance in manufacturing enterprises of China, helping to answer whether enterprise can realize high-quality development at the cost of ignoring economic performance or sustainability technologies. These findings point to a few important contributions.

First, the high-quality development of manufacturing enterprises is promoted by digital transformation through two main paths: innovation path and efficiency path. Digital transformation boosts both economic productivity and ESG performance as it fosters open innovation models and makes possible data-driven supply chain and resource allocation improvements. This binary path implies that the digital transformation allows enterprises to yield the "win-win" objective of increased economic and sustainable performance.

Thirdly, the paper identifies that the effect of digital transformation on high-quality development is contingent upon external institutional surroundings in terms of government support and market settings. The effect of digital transformation on the development of enterprises will be further amplified in regions with high-quality business environments and fast marketization process. However, the third study is largely novel and makes an important contribution to helping understanding of external conditions that are necessary to realize the full benefits of digital transformation.

Third, the analysis reveals different marginal effects of digital transformation on total factor productivity (TFP) and ESG performance. Note that the weakening return on TFP is indicative of decreasing marginal returns while the positive impact on ESG performance is linear with enterprise sustainability. It reveals that digital transformation is an important catalyst for facilitating sustainable development (even more so amongst enterprises with low initial ESG performance).

While gaining these manuscripts is insightful, the sample of firms is limited to Chinese manufacturing ones and the insights gained may defer in other industries or in different place. Future studies need to examine the interplay between digital transformation and sustainability across various industries or global contexts. Further, long-term impacts of digital transformation on corporate governance and stakeholder engagement could be examined in future studies.

The digital transformation is an important mobilizer to high-quality development, helping enterprises find ways to make these two forces — economic growth and environmental and social sustainability — work together. Theoretical as well practical implications are listed to guide enterprises and policymakers in their efforts to use digitalization as a means of achieving sustainable and inclusive growth.

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DOI: https://doi.org/10.62754/joe.v3i8.5849

Funding Information

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contributions

The manuscript has a single author who was solely responsible for the research design, data collection and analysis, and the drafting and revision of the manuscript.

Conflict of Interest Statement

The author declares no conflicts of interest.

Ethical Statement

This study adhered to all relevant ethical standards for academic research. Where applicable, any research involving humans or animals was conducted in accordance with ethical guidelines.

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Journal of Ecohumanism
2024
Volume: 3, No: 8, pp. 12426 – 12442
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i8.5849

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