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Article

# Technology exploring the impact of digital transformation on sustainable performance in the retail industry: the moderating role of market turbulence and innovative culture

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**ABSTRACT**

Digital transformation has emerged as a strategic imperative for organizations seeking to gain a competitive advantage in rapidly evolving markets. However, its impact on sustainable performance remains theoretically and empirically contested. This study examines the relationship between digital transformation and sustainable performance, investigating the moderating roles of market turbulence and innovative culture within China's retail sector. Grounded in Dynamic Capability Theory, we employed a quantitative approach using survey data from 353 Chinese retail managers. Structural equation modeling, using SmartPLS, was employed to test the proposed hypotheses and validate the measurement scales. Results demonstrate a significant positive relationship between digital transformation and sustainable performance ($\beta = 0.453$, $P < 0.001$). The model explained 24.4% of the variance in sustainable performance ($R^2 = 0.244$). Innovative culture significantly enhances this relationship through positive moderation ($\beta = 0.216$, $P = 0.004$), indicating that organizations with strong innovation-oriented cultures better leverage digital investments for sustainability outcomes. Market turbulence showed no significant moderating effect ($\beta = 0.099$, $P = 0.051$) but exhibited a direct negative impact on sustainable performance. Contrary to expectations, market turbulence does not moderate the digital transformation-sustainability relationship but exerts a direct negative effect on sustainable performance. These findings provide critical insights for retail managers pursuing digital-enabled sustainability strategies and offer practical guidance for enterprises entering emerging markets characterized by digital disruption.

## 1. Introduction

Industry 4.0 has accelerated digitalization, ushering economies into the digital age [1]. Digital transformation encompasses concepts fostering technological innovation across industries and society. Digital transformation profoundly impacts organizational change through various digital technologies [2]. Businesses have adopted digital transformation as a fundamental strategy to maintain competitive advantage and support economic development [3]. Digital transformation integration enhances sustainable value and competitive advantage. Companies increasingly leverage IoT, AI, and Big Data analytics to address market challenges, consumer demands, and regulatory requirements [4]. Sustainability has recently emerged as a key indicator of organizational performance. Digital transformation has become a critical tool for improving sustainable performance in enterprises [5]. China's retail sales growth has decelerated significantly since 2021, declining from 6.0% in 2021 to 3.0% in 2022 and 1.4% in Q1 2023, according to National Bureau of Statistics data. The industry experienced unprecedented losses in 2021, with ten major retailers averaging over 600 million yuan in losses. GCL Retail exemplifies this decline,

with net profits plummeting from 2.827 billion yuan in 2020 to merely 200 million yuan in 2021. Meanwhile, Yonghui Supermarket's net profit also fell from 1.794 billion yuan in 2020 to a loss of 3.944 billion yuan in 2021. Data from the China Chain Store Association showed that the average daily traffic of supermarket chains is also declining, from 2,414 in 2019 to 2,030 in 2020, indicating a decrease in the frequency of consumer patronage. Online sales among the top 100 supermarket enterprises continued to grow in 2021 [6], with nearly 40% reporting that online sales exceeded 60% of total sales. Digital transformation has become the primary strategy for enhancing performance in China's supermarkets. While digital transformation benefits are established, their impact on sustainable performance remains contested. Studies demonstrate digital transformation's positive sustainability effects [7-9]. However, it introduces challenges, including electronic waste and data security concerns. Some academics question direct sustainability benefits [10, 11], creating research focus on this relationship. Research demonstrates innovative culture in organizational capabilities [12], though its performance impact remains underexplored. Market turbulence's performance effects remain contested, with studies showing both positive and negative impacts, while research on its digital transformation influence remains. The present study proposes the subsequent research questions to address these gaps:

**RQ1:** Does digital transformation enhance sustainable performance?

**RQ2:** Does an innovative culture positively moderate the correlation between digital transformation and sustainable performance?

**RQ3:** Does market turbulence positively moderate the correlation between digital transformation and sustainable performance?

Therefore, this study aims to: (1) examine the direct relationship between digital transformation and sustainable performance in China's retail sector; (2) investigate the moderating role of innovative culture on the digital transformation-sustainable performance relationship; and (3) assess the moderating effect of market turbulence on this relationship within the framework of Dynamic Capability Theory. This research contributes to the literature by providing empirical evidence of the impact of digital transformation on sustainability in emerging markets, demonstrating the critical moderating role of innovative culture, and challenging conventional assumptions about the effects of market turbulence. The findings provide strategic guidance for retail managers seeking to implement digital-enabled sustainability strategies in challenging market conditions. The remainder of this paper is organized as follows. Section 2 reviews the relevant literature and develops the theoretical framework and hypotheses. Section 3 describes the research methodology, including the procedures for data collection and analysis. Section 4 presents the empirical results and hypothesis testing. Section 5 discusses the theoretical and practical implications of the findings. Section 6 acknowledges the study's limitations, and Section 7 concludes with recommendations for future research.

## 2. Literature review

### 2.1 Dynamic capability theory

Dynamic capability theory provides the theoretical foundation for this study, enabling a comprehensive understanding of interactions between digital transformation and sustainable performance, as well as the moderating effects of innovative culture and market turbulence. Digital transformation enables the reorganization of resources, thereby enhancing dynamic capabilities [13]. Furthermore, this study integrates innovative culture and market turbulence as moderating variables within the framework of Dynamic Capability Theory. Organizational culture encompasses shared assumptions, beliefs, and practices that guide operational behaviors and decision-making processes through both deliberate and emergent mechanisms. Innovative culture enables digital transformation integration into dynamic capabilities [14].

Normal and unpredictable changes in consumer preferences necessitate that companies swiftly recognize market needs and adjust their business plans to maintain value delivery, even during market turbulence [15], which directly impacts dynamic capabilities [16]. In conclusion, the Dynamic Capability Theory provides justification for the overall theoretical framework of the study. Despite the growing body of literature on digital transformation and sustainability, several critical gaps remain unaddressed. First, while studies acknowledge digital transformation's potential benefits for sustainability, empirical evidence regarding this relationship remains inconsistent and fragmented, particularly in emerging markets like China. Second, the theoretical mechanisms through which organizational culture influences the effectiveness of digital transformation initiatives for sustainability outcomes are poorly understood. Third, existing research provides conflicting evidence regarding market turbulence's role as a contextual factor in digital transformation strategies, with some studies suggesting positive effects while others indicate negative impacts. These gaps necessitate a comprehensive investigation of the complex interplay between digital transformation, organizational culture, market conditions, and sustainable performance outcomes.

### 2.2 Digital transformation and sustainable performance

Research demonstrates that digital transformation improves sustainable performance. Digital transformation refers to the modification of business processes and organizational structures made possible by digital technologies to meet market demand [17]. Digital transformation primarily impacts sustainable performance by increasing dynamic capabilities. However, building dynamic capabilities remains complex due to the continuous updates of organizational processes. During early phases of digital transformation, firms often struggle to maintain capability development and performance improvements while rapidly updating existing processes. As transformation progresses, organizations that effectively develop dynamic capabilities through process optimization can better adapt to evolving market demands, thereby achieving competitive advantage and superior financial performance. Building dynamic capabilities remains complex due to continuous process updates, though successful development enables competitive advantage. Studies show inconsistent findings regarding this relationship. Enterprises utilize digital transformation to reshape their business, connecting information and processes in real-time to enhance decision-making efficiency and employee productivity [18]. Digital transformation enhances economic sustainability through improved business models and market responsiveness [19], and environmental sustainability through energy efficiency [20]. Dynamic Capability Theory posits that digital transformation enhances adaptation capacity, thereby improving environmental, social, and economic outcomes.

However, it introduces challenges, including data security and electronic waste. Some research claims that sustainable performance is not directly derived from digital transformation. Some research questions direct benefits [21-23], requiring further investigation. The triple bottom line (TBL) framework emphasizes three sustainability dimensions: economic, environmental, and social performance, rather than solely focusing on financial outcomes. Integrating Dynamic Capability Theory with TBL provides a comprehensive framework for sustainability analysis, leading to:

**Hypothesis 1:** Digital transformation positively affects sustainable performance.

### 2.3 The moderating role of market turbulence

Market turbulence, characterized by rapidly changing consumer preferences, represents a key environmental factor [15, 24]. Market uncertainty requires enhanced managerial knowledge for informed decision-making. Digital transformation enables data access for a better understanding of consumer needs. Businesses must adapt rapidly to environmental changes and develop dynamic capabilities. Market turbulence, driven by competition and technological unpredictability, increases demand for digital competencies to achieve sustainable performance [25]. Digital transformation enables superior, sustainable performance under market turbulence. Research shows conflicting views on market turbulence effects, with some supporting positive impacts, while others show its negative results. Investigation of the influence of market turbulence on digital transformation remains limited. Hence, this study makes the following assumption:

**Hypothesis 2:** Market turbulence has a positive moderating effect on the influence of digital transformation on sustainable performance.

### 2.4 The moderating role of innovative culture

Innovative culture encompasses shared values and beliefs that guide employee behaviors, fostering environments that encourage risk-taking, creativity, and a results-oriented focus. Such environments promote transparency and experimentation, facilitating the sharing of knowledge and the development of innovative solutions. Organizations within innovative cultures demonstrate superior capabilities in assimilating digital technology [26]. Dynamic Capability Theory suggests that an innovative culture converts strategies into dynamic capabilities, enhancing competitiveness. Despite the recognition of the importance of innovative culture in resource practices [27], research on its mechanisms for enhancing performance remains limited. Accordingly, the present study proposes the following hypothesis:

**Hypothesis 3:** Innovative culture has a positive moderating effect on the influence of digital transformation on sustainable performance.

### 2.5 Conceptual framework

Based on the preceding discussions, this study formulated a conceptual model, illustrated in Figure 1. Figure 1 illustrates the hypothesized relationships between digital transformation and sustainable performance, with innovative culture and market turbulence as moderating variables within the Dynamic Capability Theory framework. The model illustrates the direct impact of digital transformation on sustainable performance, with market turbulence and innovative culture serving as moderating variables that influence this relationship.

## 3. Materials and methods

### 3.1 Research method

This study employed a quantitative research design characterized by analytical rigor and systematic data quantification. Following established theoretical frameworks, we tested formulated hypotheses using empirical quantitative methods to investigate the impact of digital transformation on sustainable performance within China's retail sector, while examining the moderating effects of innovative culture and market turbulence. A cross-sectional survey design was employed to capture data at a single time point, rather than through longitudinal tracking, where data were collected using questionnaires in a synchronous manner. Finally, SPSS and SmartPLS were applied for data analysis.

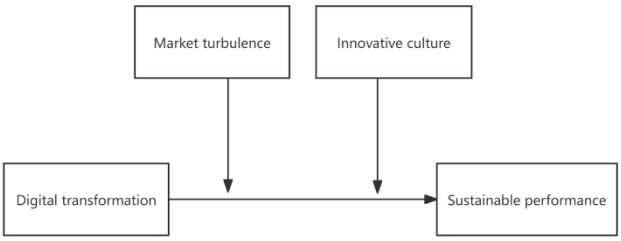


**Figure 1.** Conceptual framework

### 3.2 Questionnaire

Research conducted by Nasiri helped to derive the evaluation criteria for digital transformation, while sustainable performance was assessed using scales established by [28, 29]. The assessment of innovative culture was adapted from [30], while market turbulence was gauged using the scale established by [31]. Content validity was established through an expert review involving three specialists: a retail industry practitioner with over 15 years of experience, a digital transformation researcher, and a quantitative methodology expert. Experts evaluated item relevance, clarity, and theoretical alignment using a structured feedback form. Based on their recommendations, three items were reworded for clarity, and one redundant item was eliminated. Content Validity Index (CVI) calculations yielded acceptable values ranging from 0.83 to 0.96 across all constructs. Later, a pretest was conducted to assess the reliability and validity of the measurement items. From 1 (strongly disagree) to 5 (strongly agree), all objects were assessed using a five-point Likert scale. Anonymous questionnaires were used to collect data, guaranteeing the absence of personally private or commercially sensitive information. Each participant engaged voluntarily after understanding the study's objective. The research adhered to established ethical standards throughout the process. To address potential common method variance (CMV), several procedural and statistical remedies were implemented. Procedurally, questionnaire items were carefully ordered to separate predictor and criterion variables, anonymity was assured, and clear instructions were provided to reduce response biases. Statistically, Harman's single-factor test was conducted, revealing that no single factor accounted for the majority of variance (the largest factor explained 31.2% of the total variance), indicating CMV was not a significant concern. This study was conducted in accordance with established ethical research principles and institutional guidelines. Given the anonymous, non-invasive nature of the survey and the

absence of sensitive personal data collection, the research qualified as minimal risk under institutional review standards. Informed consent was obtained through digital consent forms presented at the survey beginning, where participants acknowledged understanding of study purposes, voluntary participation, data confidentiality, and withdrawal rights. No personally identifiable information was collected, ensuring complete participant anonymity. The research followed comprehensive ethical protocols, including voluntary participation, confidentiality protection, and secure data handling procedures. All measurement scales, originally developed and validated in English, were systematically adapted for the Chinese retail context through a rigorous translation and cultural adaptation process. The procedure involved forward translation from English to Simplified Chinese by two independent bilingual experts with advanced degrees in business management, followed by back-translation to English by a third bilingual expert without access to the original instruments. Discrepancies between the original and back-translated versions were identified and resolved through iterative discussion among the translation team, ensuring linguistic equivalence, cultural appropriateness, and semantic consistency. Additionally, cognitive interviews were conducted with five Chinese retail managers to assess the comprehensibility and cultural relevance of the items, resulting in minor wording adjustments to enhance clarity.

### 3.3 Sampling and data collection

This study targeted managers in the Chinese retail sector. Convenience sampling was employed due to practical constraints and the exploratory nature of digital transformation research in China's retail sector. While acknowledging limitations to generalizability, this approach was justified given the nascent stage of digital transformation implementation across Chinese retail enterprises and the difficulty in obtaining complete sampling frames for this specialized population [32]. To enhance representativeness, participants were recruited across multiple provinces and enterprise sizes, though future studies should employ stratified probabilistic sampling methods for improved external validity. Despite the limitations of convenience sampling, the achieved sample demonstrates reasonable representativeness across China's retail sector. Participants were recruited from 26 provinces with diverse enterprise scales (small 16.5%, medium 42.5%, large 41.0%) and organizational maturity levels (7.5% under 3 years to 31.0% over 16 years). While stratified convenience sampling could have improved sectoral representation, the geographical and organizational diversity provides adequate coverage of China's heterogeneous retail landscape. According to [33], the minimum sample size in the PLS path model must be ten times the number of arrows directed toward the dependent variable. Given our model's single predictor variable, the minimum requirement was 10 participants, with G-Power calculations indicating 77 samples as adequate. Data collection utilized online links and QR codes, restricting one response per enterprise to prevent duplication. Mandatory questions ensured completeness, with automatic screening exclusions. Following a two-week preliminary collection and reminder communications, 353 valid responses were obtained and processed through SPSS for descriptive analysis and SmartPLS for structural evaluation.

### 3.4 Data analysis and interpretation

Initially, the present study corrected data discrepancies and conducted frequency and descriptive analyses using SPSS. The validity and reliability of the measuring scales were assessed using SmartPLS. Using this statistical instrument, Partial Least Squares Structural Equation Modeling (PLS-SEM) helped clarify the inferential analyses, which fit the study's objectives [34]. SmartPLS was chosen for its compatibility with small sample sizes and its ability to manage non-normally distributed data effectively. Moreover, it has been extensively used recently to analyze complex interactions among variables. Before conducting structural equation modeling, comprehensive data screening and assumption testing were performed to ensure analytical appropriateness. Normality assessment revealed skewness values ranging from -1.23 to 1.87 and kurtosis values ranging from -0.89 to 2.34, remaining within acceptable thresholds for multivariate analysis (|skewness| < 2.0, |kurtosis| < 7.0). Multicollinearity evaluation using Variance Inflation Factor (VIF) analysis demonstrated that all constructs maintained VIF values below 3.5, well within the conservative threshold of 5.0, confirming the absence of multicollinearity concerns and supporting the appropriateness of PLS-SEM methodology for the current dataset. This study investigated moderating effects within the conceptual model and evaluated path correlations using SmartPLS.

## 4. Results

### 4.1 Descriptive analysis

Questionnaires were distributed to 500 Chinese retail managers across multiple provinces, with follow-up communications conducted to enhance response rates. A total of 353 valid and complete responses were collected within the designated timeframe, yielding a 71% response rate. All participants were assured of strict anonymity and confidentiality protocols. Table 1 presents comprehensive organizational characteristics revealing distinct patterns across multiple dimensions. As shown in Table 1, the organizational characteristics reveal significant diversity in the sample composition. The geographical distribution demonstrates concentration in economically developed regions, with Guangdong province representing the highest participation rate at 15.0%, followed by Henan and Shandong provinces at 10.0% each. Geographically, participants concentrated predominantly in economically developed regions, with Guangdong representing the highest concentration (15.0%), followed by Henan (10.0%), Shandong (10.0%), and Beijing (9.5%). Organizational maturity was evident, as most supermarkets operated for over 16 years (31.0%), with an additional 27.0% having 7-10 years of establishment, indicating well-established market presence. Employee distribution showed that 45.5% employ 100-500 personnel, while only 8.0% exceed 3,001 employees, suggesting medium-scale operations dominate the sector. Financial performance varied significantly, with 26.0% generating 10-50 million yuan annually. Medium-sized supermarkets (42.5%) slightly outnumbered large-sized (41.0%) and small-sized enterprises (16.5%). Notably, digital transformation implementation remained nascent across the sector: 50.0% were in progress, 27.5% achieved basic transformation, while only 1.5% completed full digital transition, highlighting substantial digitalization opportunities within China's retail industry.

Table 2 illustrates the demographic profile of participating managers, revealing substantial industry expertise within the sample. The professional experience distribution shows that 85.5% of respondents possess moderate to extensive sector knowledge, with the largest group (34.0%) having 5-10 years of experience.

**Table 1.** Organizational characteristics of supermarkets (n = 353)

| Category | Subcategory | Frequency | Percentage (%) |
|---|---|---|---|
| Location | Anhui | 9 | 2.5 |
| | Beijing | 34 | 9.5 |
| | Fujian | 5 | 1.5 |
| | Gansu | 2 | 0.5 |
| | Guangdong | 53 | 15.0 |
| | Guangxi | 7 | 2.0 |
| | Guizhou | 11 | 3.0 |
| | Hebei | 12 | 3.5 |
| | Henan | 35 | 10.0 |
| | Heilongjiang | 2 | 0.5 |
| | Hubei | 16 | 4.5 |
| | Hunan | 12 | 3.5 |
| | Jiangsu | 14 | 4.0 |
| | Jiangxi | 12 | 3.5 |
| | Liaoning | 5 | 1.5 |
| | Inner Mongolia | 5 | 1.5 |
| | Qinghai | 2 | 0.5 |
| | Shandong | 35 | 10.0 |
| | Shanxi | 4 | 1.0 |
| | Shannxi | 4 | 1.0 |
| | Shanghai | 27 | 7.5 |
| | Sichuan | 16 | 4.5 |
| | Tianjin | 2 | 0.5 |
| | Yunnan | 5 | 1.5 |
| | Zhejiang | 18 | 5.0 |
| | Chongqing | 7 | 2.0 |
| Length of Establishment | Less than 1 year | 2 | 0.5 |
| | 1–3 years | 25 | 7.0 |
| | 4–6 years | 55 | 15.5 |
| | 7–10 years | 95 | 27.0 |
| | 11–15 years | 67 | 19.0 |
| | More than 16 years | 109 | 31.0 |
| Total Number of Employees | 100 people and less | 90 | 25.5 |
| | 100–500 persons | 160 | 45.5 |
| | 501–1000 people | 51 | 14.5 |
| | 1001–1500 people | 16 | 4.5 |
| | 1501–2000 people | 7 | 2.0 |
| | 2001–2500 people | 0 | 0 |
| | 2501–3000 people | 0 | 0 |
| | More than 3001 people | 28 | 8.0 |
| Total Sales in 2024 | Less than 5 million yuan | 34 | 9.5 |

**Table 2.** Demographic characteristics of participants (n = 353)

| Category | Subcategory | Frequency | Percentage (%) |
|---|---|---|---|
| Working Hours | Less than 6 months | 4 | 1.0 |
| | Six months to 1 year | 21 | 6.0 |
| | 1 year to 3 years | 79 | 22.5 |
| | 3 years to 5 years | 104 | 29.5 |
| | 5 years to 10 years | 120 | 34.0 |
| | More than 10 years | 25 | 7.0 |
| Job Classification | Top Managers | 11 | 3.0 |
| | Middle Managers | 78 | 22.0 |
| | First-Line Managers | 264 | 75.0 |
| Age | 25 years old and below | 0 | 0 |
| | 26–35 years old | 242 | 68.5 |
| | 36–45 years old | 106 | 30.0 |
| | 46 and above | 5 | 1.5 |

Professional experience analysis reveals substantial industry knowledge, with the majority possessing moderate to extensive sector exposure: 34.0% had 5-10 years of experience, 29.5% had 3-5 years, and 22.5% had 1-3 years, collectively representing 85.5% of respondents. Only 7.0% reported over 10 years of experience, while a minimal representation (1.0%) had less than six months. Hierarchically, the sample predominantly comprised operational-level personnel, with 75.0% serving as first-line managers, 22.0% as middle managers, and merely 3.0% in top management positions, ensuring insights derived from frontline operations. Age demographics demonstrated concentration among early- to mid-career professionals, with 68.5% aged 26-35 years and 30.0% aged 36-45 years, while participants over 46 constituted only 1.5% and none under 25. This demographic composition ensures representation from experienced yet actively engaged retail management professionals directly involved in organizational operations.

## 4.2 Measurement model

### 4.2.1 Factor loadings

Factor loadings above 0.60 are acceptable, with values exceeding 0.70 indicating strong associations. Table 3 demonstrates robust construct validity across all latent variables, with every loading surpassing the 0.60 threshold. Digital Transformation exhibited strong representation through DT3 (0.860), DT4 (0.837), and DT2 (0.804), while DT1 (0.643) remained acceptable. Innovative Culture achieved excellent measurement quality, with IC2 reaching the highest loading (0.920), followed by IC1 (0.854), IC3 (0.851), and IC5 (0.763), though IC4 (0.611) was marginally weaker yet retained. Market Turbulence displayed stable factor structure via MT2 (0.854), MT4 (0.836), and MT3 (0.826), while MT1 (0.637) and MT5 (0.620) approached thresholds. Sustainable Performance demonstrated superior convergent validity, with all six indicators exceeding 0.70, ranging from SP6 (0.703) to SP3 (0.844). These results confirm reliable measurement relationships and internal consistency.

### 4.2.2 Construct reliability and convergent validity

Table 4 demonstrates satisfactory construct reliability and convergent validity through three key metrics. All constructs exceeded established thresholds, with Cronbach's alpha coefficients ranging from 0.803 to 0.926.

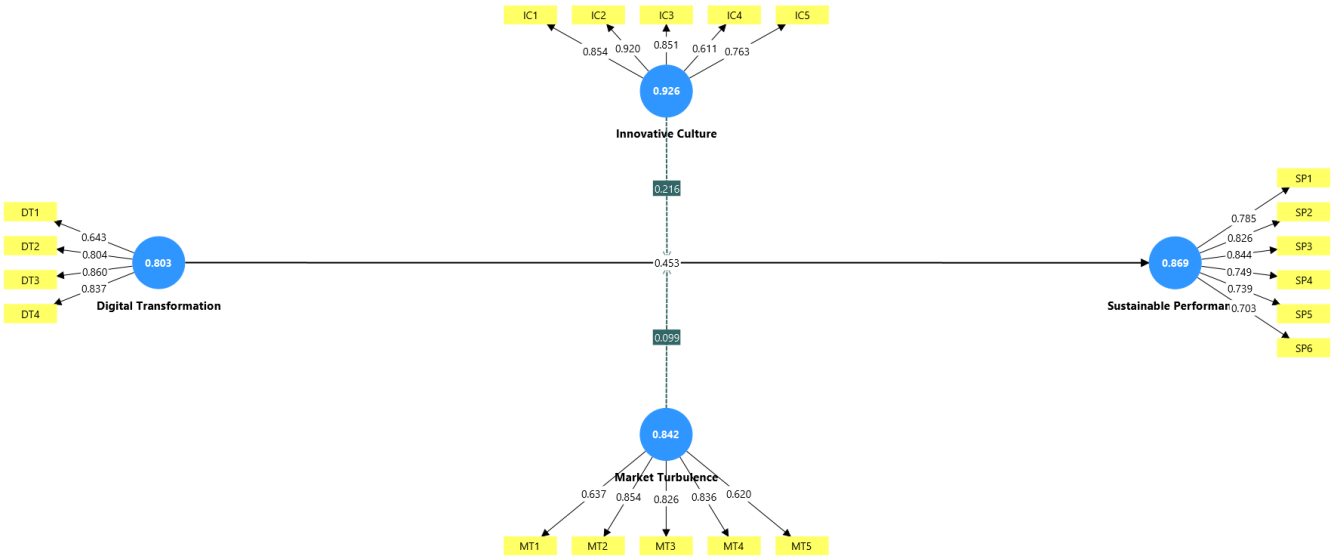


**Figure 2.** Measurement model

Innovative Culture achieved the highest internal consistency (α = 0.926), followed by Sustainable Performance (α = 0.869), Market Turbulence (α = 0.842), and Digital Transformation (α = 0.803). Composite reliability scores consistently surpassed the 0.70 benchmark, spanning 0.868 to 0.902. Figure 2 presents the comprehensive measurement model demonstrating the structural relationships among all latent constructs in the study. The model illustrates strong factor loadings across all constructs, with Digital Transformation showing robust loadings ranging from 0.643 to 0.860, Innovative Culture achieving excellent loadings from 0.611 to 0.920, Market Turbulence displaying stable loadings from 0.620 to 0.854, and Sustainable Performance demonstrating superior convergent validity with all loadings exceeding 0.703. The path diagram clearly illustrates the hypothesized direct relationship between Digital Transformation and Sustainable Performance, with Innovative Culture and Market Turbulence serving as moderating variables within the theoretical framework. Notable loadings include IC2 (0.920), DT3 (0.860), MT2 (0.854), and SP3 (0.844), demonstrating strong item-construct associations.

**Table 3.** Factor loadings

| Digital Transformation | Innovative Culture | Market Turbulence | Sustainable Performance |
|---|---|---|---|
| DT1: 0.643 | IC1: 0.854 | MT1: 0.637 | SP1: 0.785 |
| DT2: 0.804 | IC2: 0.920 | MT2: 0.854 | SP2: 0.826 |
| DT3: 0.860 | IC3: 0.851 | MT3: 0.826 | SP3: 0.844 |
| DT4: 0.837 | IC4: 0.611 | MT4: 0.836 | SP4: 0.749 |
| | IC5: 0.763 | MT5: 0.620 | SP5: 0.739 |
| | | | SP6: 0.703 |

**Table 4.** Cronbach's alpha, Composite reliability, and AVE

| Construct(s) | Cronbach's alpha | Composite reliability | Average variance extracted (AVE) |
|---|---|---|---|
| Digital Transformation | 0.803 | 0.868 | 0.625 |
| Innovative Culture | 0.926 | 0.902 | 0.651 |
| Market Turbulence | 0.842 | 0.872 | 0.580 |
| Sustainable Performance | 0.869 | 0.900 | 0.602 |

The model shows direct paths from Digital Transformation to Sustainable Performance, with Innovative Culture and Market Turbulence positioned as moderating variables. Although Market Turbulence exhibited the lowest AVE (0.580), all constructs remained acceptable for convergent validity, confirming satisfactory measurement properties for structural analysis.

### 4.2.3 Heterotrait-monotrait ratio (HTMT)

The Heterotrait-Monotrait (HTMT) ratio assesses discriminant validity through construct-based similarity quantification, with values below 0.85 indicating adequate discriminant validity. Table 5 presents HTMT ratios demonstrating strong discriminant validity across all constructs. All HTMT values remained substantially below the conservative 0.85 threshold, confirming empirical distinctiveness among constructs. The highest ratio (0.470) occurred between Digital Transformation and Sustainable Performance, indicating modest correlation while preserving discriminant validity. Other relationships demonstrated considerably weaker associations: Digital Transformation-Innovative Culture (0.105), Innovative Culture-Sustainable Performance (0.087), Market Turbulence-Innovative Culture

(0.252), Digital Transformation-Market Turbulence (0.177), and Market Turbulence-Sustainable Performance (0.097). These low HTMT values confirm that each construct captures unique theoretical dimensions without redundancy, aligning with established validity standards.

**Table 5.** HTMT- matrix

| Construct (s) | Digital Transformation | Innovative Culture | Market Turbulence | Sustainable Performance |
|---|---|---|---|---|
| Digital Transformation | | | | |
| Innovative Culture | 0.105 | | | |
| Market Turbulence | 0.177 | 0.252 | | |
| Sustainable Performance | 0.470 | 0.087 | 0.097 | |

#### 4.2.4 Fornell-larcker criterion

The Fornell-Larcker criterion compares the square root of the average variance extracted (AVE) with the correlations among constructs to evaluate discriminant validity. To validate discriminant validity, the diagonal values show the square root of the average variance extracted (AVE), which has to surpass the correlations in the related rows and columns. Digital Transformation possessed a square root AVE of 0.791, which was greater than its correlations with Innovative Culture (0.112), Market Turbulence (0.147), and Sustainable Performance (0.431). Similarly, Innovative Culture showed a diagonal value of 0.807, which exceeded all its inter-construct correlations. These results confirmed strong discriminant validity. The constructs were empirically distinct and did not overlap in measurement, satisfying the Fornell-Larcker criterion [35]. The findings also reinforced results from the HTMT matrix. The present study's Fornell-Larcker criterion values are presented in Table 6.

#### 4.2.5 Cross loadings

Table 7 presents a cross-loading analysis confirming discriminant validity at the item level. All indicators loaded highest on their intended constructs compared to alternative constructs. Notably, IC2 achieved the strongest loading (0.920) on Innovative Culture with minimal cross-loadings (≤0.162), while DT3 loaded 0.860 on Digital Transformation with the highest observed cross-loading of 0.418 on Sustainable Performance, still substantially lower than its primary loading. Similarly, SP3 (0.844) and MT2 (0.854) demonstrated strong construct associations with negligible cross-loadings. These patterns confirm item uniqueness and construct distinctiveness, satisfying established discriminant validity criteria.

### 4.3 Predictive relevance

Table 8 demonstrates acceptable model predictive capability. The R-square value (0.244) explained 24.4% variance in sustainable performance, representing reasonable explanatory power for complex models. The $Q^2$ predicted value (0.206) exceeded the zero threshold, confirming predictive relevance. These results validate the structural model's predictive utility and practical applicability.

**Table 6.** Fornell-larcker criterion

| Construct (s) | Digital Transformation | Innovative Culture | Market Turbulence | Sustainable Performance |
|---|---|---|---|---|
| Digital Transformation | 0.791 | | | |
| Innovative Culture | 0.112 | 0.807 | | |
| Market Turbulence | 0.147 | 0.175 | 0.762 | |
| Sustainable Performance | 0.431 | 0.126 | 0.087 | 0.776 |

**Table 7.** Cross loadings

| | Digital Transformation | Innovative Culture | Market Turbulence | Sustainable Performance |
|---|---|---|---|---|
| DT1 | 0.643 | 0.104 | 0.209 | 0.189 |
| DT2 | 0.804 | 0.045 | 0.138 | 0.340 |
| DT3 | 0.860 | 0.104 | 0.056 | 0.418 |
| DT4 | 0.837 | 0.111 | 0.126 | 0.358 |
| IC1 | 0.093 | 0.854 | 0.151 | 0.066 |
| IC2 | 0.125 | 0.920 | 0.162 | 0.096 |
| IC3 | 0.053 | 0.851 | 0.153 | 0.051 |
| IC4 | 0.053 | 0.611 | 0.148 | -0.064 |
| IC5 | 0.052 | 0.763 | 0.236 | 0.020 |
| MT1 | 0.054 | 0.121 | 0.637 | 0.025 |
| MT2 | 0.154 | 0.115 | 0.854 | 0.082 |
| MT3 | 0.145 | 0.152 | 0.826 | 0.079 |
| MT4 | 0.075 | 0.175 | 0.836 | 0.066 |
| MT5 | 0.058 | 0.233 | 0.620 | 0.000 |
| SP1 | 0.305 | 0.050 | 0.083 | 0.785 |
| SP2 | 0.400 | 0.093 | 0.038 | 0.826 |
| SP3 | 0.374 | 0.093 | 0.024 | 0.844 |
| SP4 | 0.278 | 0.170 | 0.042 | 0.749 |
| SP5 | 0.387 | 0.088 | 0.129 | 0.739 |
| SP6 | 0.174 | 0.104 | 0.109 | 0.703 |

**Table** 8. Predictive relevance

| Outcome Variable | R-square | $Q^2$predict |
|---|---|---|
| Sustainable Performance | 0.244 | 0.206 |

### 4.4 Structural model

#### 4.4.1 Path analysis

Table 9 presents path coefficients and significance levels for hypothesis testing. The analysis revealed a statistically significant positive relationship between digital transformation and sustainable performance (β = 0.453, t = 9.380, P < 0.001), confirming hypothesis acceptance. This substantial coefficient demonstrates that organizations implementing digital transformation initiatives achieve significantly higher sustainable performance levels. The highly significant p-value validates digital transformation as a strategic enabler for organizational sustainability outcomes.

**Table 9.** Path analysis

| Relationship | Coefficient | T statistics (\|O/STDEV\|) | P values | Status |
|---|---|---|---|---|
| Digital Transformation -> Sustainable Performance | 0.453 | 9.380 | 0.000 | Accepted |

#### 4.4.2 Moderation analysis

Table 10 presents moderation analysis results examining innovative culture's role in the digital transformation-sustainability relationship. Digital transformation maintained a significant positive effect on sustainable performance (β = 0.453, t = 9.380, P < 0.001), while innovative culture showed no direct significant impact (β = 0.072, t = 0.590, P = 0.278). Critically, the interaction term (Innovative Culture × Digital Transformation) demonstrated significant positive moderation (β = 0.216, t = 2.632, P = 0.004), confirming that innovative culture amplifies digital transformation's beneficial effects on sustainable performance. These findings indicate that organizations with strong innovation-oriented cultures can better leverage digital initiatives to achieve superior sustainability outcomes.

Table 11 examines market turbulence's moderating role in the digital transformation-sustainability relationship. Digital transformation maintained significant positive effects (β = 0.453, t = 9.380, P < 0.001), while market turbulence showed no direct significant impact (β = 0.029, t = 0.390, P = 0.348). The interaction term (Market Turbulence × Digital Transformation) approached significance (β = 0.099, t = 1.633, P = 0.051), suggesting marginal moderating effects.

**Table 10.** Moderation analysis (innovative culture)

| Relationships | Coefficients | T statistics (\|O/STDEV\|) | P values |
|---|---|---|---|
| Digital Transformation -> Sustainable Performance | 0.453 | 9.380 | 0.000 |
| Innovative Culture -> Sustainable Performance | 0.072 | 0.590 | 0.278 |
| Innovative Culture x Digital Transformation -> Sustainable Performance | 0.216 | 2.632 | 0.004 |

**Table 11.** Moderation analysis (market turbulence)

| Relationships | Coefficients | T statistics (\|O/STDEV\|) | P values |
|---|---|---|---|
| Digital Transformation -> Sustainable Performance | 0.453 | 9.380 | 0.000 |
| Market Turbulence -> Sustainable Performance | 0.029 | 0.390 | 0.348 |
| Market Turbulence x Digital Transformation -> Sustainable Performance | 0.099 | 1.633 | 0.051 |

To further illustrate the moderation effects, simple slope analyses were conducted for the significant innovative culture interaction. Results reveal that the positive relationship between digital transformation and sustainable performance is stronger for organizations with high innovative culture (β = 0.669, P < 0.001) compared to those with low innovative culture (β = 0.237, P < 0.01). This demonstrates that innovative culture amplifies the benefits of digital transformation initiatives for sustainability outcomes. To provide comprehensive visual representation of the significant moderation effect, interaction plots were generated using one standard deviation above and below the mean for innovative culture. The interaction plot clearly reveals that organizations with high innovative culture (one standard deviation above the mean) demonstrate a substantially steeper positive relationship between digital transformation and sustainable performance (simple slope β = 0.669, P < 0.001) compared to organizations with low innovative culture (one standard deviation below the mean, simple slope β = 0.237, P < 0.01). The divergent pattern in the plot illustrates that innovative culture particularly amplifies the beneficial effects of digital transformation initiatives, with the performance gap between high and low innovative culture organizations widening progressively as digital transformation implementation intensifies. This visual evidence strongly supports the theoretical proposition that organizational culture serves as a critical contingency factor in determining digital transformation effectiveness for sustainability outcomes.

Figure 3 presents the interaction plot demonstrating the moderating effect of innovative culture on the digital transformation-sustainable performance relationship. The plot clearly shows the divergent slopes between high and low innovative culture conditions, confirming the significant moderation effect.

Figure 4 illustrates these statistical relationships with corresponding p-values and includes the interaction plot showing the moderating effect of innovative culture. This near-significant result for market turbulence indicates potential enhancement of digital transformation benefits under turbulent conditions, though cautious interpretation is warranted given the threshold exceedance.

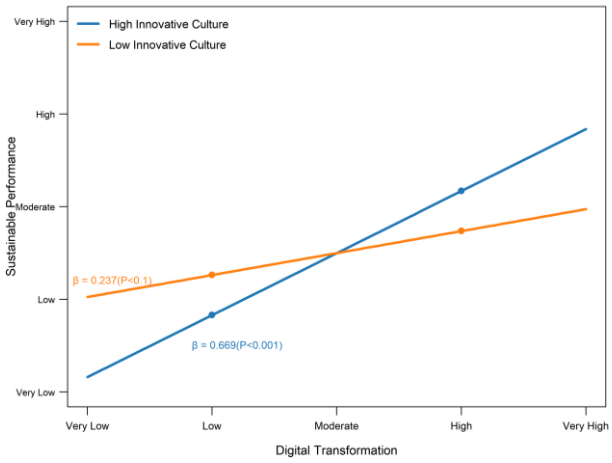


**Figure 3.** Interactive effect of innovative culture and digital transformation on sustainable performance

## 5. Discussion

This study elucidates the transformative impact of digital transformation on sustainable performance within China's retail sector, revealing significant theoretical and practical implications. Results demonstrate that digital transformation exerts a substantial positive influence on sustainable performance (β = 0.453, P < 0.001), while innovative culture significantly amplifies this relationship through positive moderation (β = 0.216, P = 0.004). Conversely, market turbulence exhibits no significant moderating effect (P = 0.051), challenging conventional assumptions about environmental volatility's role in digital-sustainability relationships.

### 5.1 Theoretical contributions

This study fills important gaps in the literature regarding digital transformation by studying digitalisation-related changes at the intersection of sustainability, incorporating its environmental, economic, and social aspects. These gaps are significant considering the literature's fragmented discourse on the impacts of digital transformation, which shifts a firm's viewpoint towards growth opportunities versus risks and challenges to be managed [36].

The study also clarifies the confounding evidence around the constructive impacts alongside risks, highlighting the paradox of benefit and harm. Furthermore, the study provides an understanding of market turbulence's contextual influence, which is novel in theory, as such environmental volatility is assumed to always act as a moderator on organisational performance causal relationships, forming a significant gap that this study addresses. In contrast, research showcases the contradictory effects of turbulence alongside the absence of a comprehensive systematic exploration of digital transformation frameworks, representing a significant theoretical gap. Moreover, confirming the role of an innovative organisational culture as a moderator adds to the theory on organisational culture in enhancing the effectiveness of digital transformation, addressing the culture-technology-sustainability nexus that has been minimally researched. These findings demonstrate how stronger innovation cultures assist firms in leveraging technology for sustainability. By embedding these moderation factors into Dynamic Capability Theory, the study develops a comprehensive framework to explain how diverse digital undertakings, culture, and ecosystem elements interact toward achieving sustainable performance at the organisational level.

### 5.2 Practical contributions

The research has various applied implications in the Chinese context and beyond. To start, it strategically advises Chinese supermarket owners on achieving sustainability through digital transformation, allocating greater focus to the culture of innovation and its impact on resource utilisation and supply chain productivity. It also informs retail practitioners wishing to enter the Chinese and other emerging markets about the driving forces of digital transformation under different market conditions, and thus offers valuable market understanding. Furthermore, it aids in developing additional policies and guidelines that support the digitalisation and sustainable development efforts of the retail industry. Lastly, it provides insight on how retailers can achieve long-term sustainability while demonstrating the potential of digital technologies to enhance environmental stewardship, economic outcomes, and stakeholder engagement, and thus transform society through sustainable business liberated by technology.

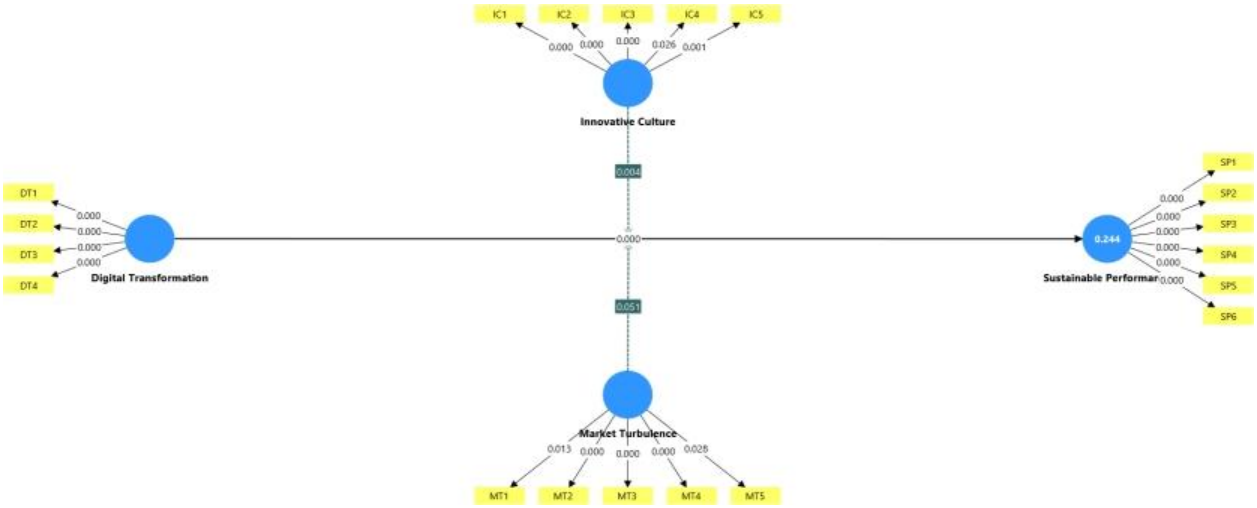


**Figure 4.** Structural Model

## 6. Limitations

This study, unlike others, is not free of practical and theoretical boundaries. Its most salient recurring limitation is the geographic constraint, as the data was collected solely from Chinese supermarket managers. This singular focus undermines global comparability and external validity. Future studies need to focus on a broader range of countries to enhance cross-cultural generalisability. Another limitation is that the digital transformation is still in the exploratory stages; primary implementation was cited as being over 70% done, with only the implementation phase just starting. This means most responses provided are based on outcome expectation rather than actual results achieved. This time frame invalidates the preliminary findings due to a lack of longitudinal authentication; without careful consideration, interpretation has to be restricted, and the verification for application persists until trustworthy longitudinal validation materialises. The last two notable limits revolve around the sample used. At a superficial glance, the inclusion of 75% first-line managers stemming from medium to large supermarkets gives the sample a more representative feel, but it is deceivingly non-representative. Better representational validity would result from incorporating more small business enterprises along with their subordinate managerial levels.

The combination of pedagogical and professional requirements was met through the sample size of n=353. However, this number fails to encapsulate the organisational ecosystem and its plethora of hindering complexities. Optimal comprehension of the processes shaping organisational digital transformation necessitates higher sample numbers across sectors and multi-level environments. Despite these limitations, this research contributes important ideas and practical knowledge about the connections between digital transformation and sustainability. The results articulate the necessity for firms to adopt digital strategies within turbulent contexts while simultaneously drawing attention to the case for greater investigation of the role of digitalisation in enduring corporate sustainability.

## 7. Conclusion

This study focuses on the effects of analysing the impacts of digital transformation on sustainable performance in China's retail industry, whilst looking at the moderation effect of market turbulence and an innovative culture. By employing Dynamic Capability Theory with survey data obtained from 353 managers at different retail chains in China using SmartPLS, the results reveal that the sustainable performance of businesses is certainly improved by the advancement of technology, while also being influenced further by an innovative culture. Market turbulence showed no moderating effect but directly undermines sustainability. These results resolve theoretical ambiguities regarding digital-sustainability linkages and emphasize the importance of cultural factors in digital strategy effectiveness. The study provides strategic guidance for retail enterprises entering Chinese markets and similar developing economies. Organizations should prioritize innovative culture development to maximize digital transformation benefits while recognizing the negative effects of market volatility. Future research should expand the geographical scope for enhanced cross-cultural validation.

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**Ethical issue**

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

**Data availability statement**

The manuscript contains all the data. However, more data will be available upon request from the authors.

**Conflict of interest**

The authors declare no potential conflict of interest.

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