The Influence of Digital Investment on Enterprise Resilience: A Case Study of Heavily Polluting Industries in A-Shares

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Abstract

In the face of increasing economic uncertainty caused by public health emergencies, geopolitical conflicts and supply chain disruptions, building enterprise resilience has become a key issue for enterprises around the world. Previous studies have mainly focused on the direct impact of digital investment on enterprise resilience. Still, the conclusions are inconsistent, and the characteristics of green development are not fully considered when exploring the relationship between the two. To address this research gap, this study explores how digital investment affects enterprise resilience via green technology innovation. Based on the natural resource-based view and knowledge-based view, we proposed four hypotheses. To test these research hypotheses, we developed four regression models and empirically tested them using a sample of 624 heavily polluting industries in China from 2016 to 2020. Our findings indicate that digital investment positively affects enterprise resilience, with green technology innovation as a partial mediator in this relationship. This study not only confirms the beneficial impact of digital investment on resilience but also contributes to the literature by demonstrating how enterprises can effectively utilize their digital assets for greater resilience. The findings provide two key recommendations for managers: first, companies should continuously adopt and implement digital technologies, as well as increase their digital investment, to better cope with economic downturns and other unexpected events, especially in the context of Industry 4.0 and with a long-term mission of green development; second, attention should be given to the channels through which digital investments influence enterprise resilience, particularly through green technology innovation.

Keywords: Digital investment, Enterprise resilience, Green technology innovation, Heavy pollution industry

Introduction

Public health emergencies, geopolitical conflicts, and shifts in industrial and supply chains have significantly heightened economic uncertainty and downward pressure on both national and global levels, making economic sustainability a critical concern for current development (Luo et al., 2024). As core economic entities, enterprises now face increasingly complex and dynamic external environments, resulting in heightened uncertainties surrounding their survival and growth trajectories. In response, enhancing enterprise resilience against external shocks and risks, while simultaneously striving for sustainable development has become an urgent priority.

Enterprise resilience is generally understood as an organization's ability to maintain stability, recover rapidly, and sustain growth amidst various disruptions (Markman and Venzin, 2014; Zhang et al., 2021; Luo et al., 2024). As resilience is crucial for companies aiming to navigate both immediate crises and long-term sustainability goals, it has drawn increasing attention from both researchers and practitioners alike.

Existing literature has examined how digital transformation-the broad adoption and integration of digital technologies within organizations-can enhance resilience (Luo et al., 2024). However, digital transformation encompasses a wide range of organizational

changes that extend beyond individual technology investments; it often involves shifts in corporate culture, structural reorganization, and changes in strategic management practices (Bellantuono et al., 2021). In contrast, digital investment specifically refers to the strategic allocation of resources toward targeted digital technologies, such as big data analytics, artificial intelligence, and cloud computing, to enhance operational efficiency and gain competitive advantages. Despite increasing scholarly attention, there remains a limited understanding of how digital investments, as distinct from comprehensive digital transformation efforts, contributes directly to resilience.

While some scholars argue that digital investment can strengthen resilience by increasing operational flexibility and adaptability (Dubey et al., 2021; Li et al., 2022), others highlight the so-called "digital paradox." This paradox posits that, despite substantial investment in digitalization, many companies struggle to achieve expected gains in short-term revenue growth, often due to high costs and low efficiencies (Kohtamäki et al., 2019). As Industry 4.0 progresses, enterprises are likely to increase their digital investment further (Ye et al., 2023). In this context, the following question warrants further discussion: can enterprises leverage their digital investment to develop the ability to adapt to a downturn market environment and achieve stable, sustainable development? In other words, can enterprises derive resilience from their digital investment?

The Natural Resource-Based View (NRBV) and the Knowledge-Based View (KBV) offer frameworks for understanding how digital investment impacts enterprise resilience and the underlying mechanisms. Both the KBV and NRBV suggest that firms must seek the knowledge, resources, and capabilities necessary to enhance their resilience (Ji et al., 2020).

The NRBV emphasizes that a company's sustainability relies on its ability to balance economic efficiency with its environmental impact. This can be achieved through improving clean technologies, designing green products with low life-cycle costs, and implementing sustainable practices to enhance productivity (Hart, 1995; Sehnem et al., 2022; Alkaraan et al., 2024). Digitalization theoretically allows companies to optimize resource allocation for implementing sustainable practices (Hwang and Kim, 2022) and to dismantle barriers to both internal and external knowledge exchange, thereby facilitating green technological innovation (Marion and Fixson, 2021). Green technology innovation significantly boosts firms' sustained growth and resilience by mitigating risks associated with environmental regulations and disasters, enhancing brand image and customer loyalty, and optimizing internal processes. Consequently, digital investment may enhance enterprise resilience through green technology innovation.

The KBV asserts that knowledge is a firm's primary strategic resource (Grant, 1996). Firms must integrate knowledge and information to generate innovative ideas for addressing surprises and uncertainties encountered during business operations (Ji et al., 2020). Additionally, integrating both internal and external knowledge is an effective means of achieving green technology innovation (Strambach, 2017). However, despite theoretical support, existing discussions about the impacts and mechanisms of digital investment on enterprise resilience are largely conceptual and lack empirical evidence. A theoretical framework is needed to clarify the channels through which digital investment impacts enterprise resilience.

Overall, the role of digital investment in enhancing enterprise resilience needs further exploration. Thus, this study aims to address the following research questions:

1. Does digital investment enhance firm resilience?

2. If so, does digital investment enhance enterprise resilience through its impact on green technology innovation?

To address these questions, this study examines publicly listed companies in China's heavily polluting industries. Building on NRBV and KBV, this research explores the relationships among digital investment, green technology innovation, and enterprise resilience within a "digital investment - green innovation behavior - enterprise resilience" framework. The originality and significance of this study are evident in several aspects: (1) it clarifies the direct impact of digital investment on resilience, distinguishing it from broader digital transformation; (2) it introduces green technology innovation as a mediator, underscoring its role in adapting to environmental changes; (3) it addresses the "digital paradox" by demonstrating that digital

investment, when aligned with green innovation, can yield long-term resilience benefits; and (4) it provides empirical insights specific to high-pollution industries, offering guidance for balancing economic and environmental objectives in high-pressure sectors.

The structure of this paper is as follows: We begin with a systematic review of the literature on digital investment and enterprise resilience, identifying gaps in current research and proposing relevant research hypotheses. This is followed by a detailed description of our research methodology. Subsequently, we empirically test the proposed theoretical relationships and provide an in-depth discussion of the research findings. Finally, we conclude with key insights and policy recommendations based on our study.

Literature Review

Digital Investment

In the context of Industry 4.0, companies are increasingly prioritizing the use of digital technologies to significantly transform their business models, production methods, and value creation strategies (Verhoef et al., 2021). Digital investment encompasses a company's investments in various areas, including information technology, software, hardware, cloud computing, big data analysis, and artificial intelligence. These investments aim to enhance operational efficiency, improve the customer experience, and drive business innovation.

Existing research has extensively discussed the impact of digital investments. On one hand, scholars primarily concentrate on the economic effects of digital investment. For instance, Yunis et al. (2018) analyzed the significant positive relationship between information and communication technologies and overall organizational performance based on questionnaire survey data. Jin et al. (2023) utilized China's A-share listed industrial enterprises as research samples and found a significant U-shaped relationship between digital investment and corporate environmental performance. Based on NRBV, Ye et al. (2023) analyzed 273 pollution-intensive enterprises in China from 2016 to 2020 and discovered a positive impact of digital investment on the environmental performance of these enterprises. On the other hand, some scholars have further investigated the additional benefits of digital investment. The empirical findings of Nwankpa and Merhout (2020) indicated a significant positive relationship between digital investment and IT innovation. Wang et al. (2024) argued that digital investment can foster radical innovation by effectively integrating external and internal resources. The empirical results of Bai et al. (2024) demonstrated that digital investment can enhance enterprise value through the utilization of intellectual capital.

Enterprise Resilience

Amid heightened global economic volatility, compounded by the effects of COVID-19 and other emergencies, enterprise resilience has emerged as a significant focus of research. When confronted with external shocks, enterprise resilience refers to an organization's ability to maintain stability, achieve rapid recovery, and ensure sustainable development. The core of enterprise resilience is risk resistance and sustainable development (Ortiz-de-Mandojana and Bansal, 2016). Risk resistance refers to the ability of enterprises to effectively identify, assess and respond to various risks in the face of uncertainties and emergencies. Sustainable development hinges on an organization's ability to balance economic benefits with environmental impacts (Ye et al., 2023). To effectively respond to changing market conditions, organizations must continually enhance their adaptability and flexibility, ensuring they can not only survive risks during crises but also achieve sustainable development. Rapid technological advancements, proactive policy support, and heightened awareness of social responsibility are broadening the concept and scope of corporate resilience. Consequently, understanding and enhancing enterprise resilience will be a critical issue that cannot be overlooked in future management practices.

Current research primarily examines the antecedents of enterprise resilience at the individual, organizational, and network levels. At the individual level, employees' positive behavior and mental health can enhance organizational innovation and coping abilities, thereby improving the enterprise's flexibility and adaptability in responding to changes and challenges (Coutu, 2002). Competent leaders can guide employees and the organization to recover quickly and return to normalcy (Hillmann & Guenther, 2002).

At the organizational level, effective corporate governance (Carmeli and Markman, 2011), technological innovation (Zhao et al., 2023), and digital technology deployment (Li et al., 2022) contribute to improved responsiveness and recovery during challenges and crises. At the network level, enterprises can leverage established social network relationships to expedite their recovery to the original state when facing difficulties (Xie et al., 2022).

Digital Investment and Enterprise Resilience

As the global digital wave rises and economic volatility intensifies, scholars increasingly focus on the relationship between digital investment and enterprise resilience. Some studies indicate that digital investment serves as an effective strategy for enhancing enterprise resilience. For instance, Dubey et al. (2021) state that investing in data analytics capabilities enables managers to identify potential threats or outages, facilitating the development of business continuity plans that expedite recovery following an outage. Li et al. (2022) argue that high-intensity deployment of digital technologies can significantly enhance Supply chain resilience.

Conversely, some scholars have introduced the concept of the digital paradox, suggesting that enterprises frequently fail to attain the anticipated revenue growth from digital investment (Kohtamäki et al., 2019). Research by Kohtamäki et al. (2019) indicated that when the cumulative level of digital investment is relatively low, enterprises can typically meet their revenue growth expectations. However, as investment continues to increase, an increasing number of companies are encountering the digital paradox and failing to achieve their anticipated revenue growth. As digital investment rises, the likelihood of encountering this paradox also increases, with only a few companies ultimately achieving significant revenue growth that matches their high investment. This implies that digital investment does not consistently result in sustained growth or enhanced resilience. Li et al. (2022) argued that while digital investment allows enterprises to acquire diverse data, excessive data volume may disrupt decision-making, particularly in emergencies, resulting in negative consequences for risk management.

Overall, there is a lack of consensus regarding the impact of digital investment on enterprise resilience. As a result, some enterprises have become skeptical of digital investments, hindering their ability to effectively deploy and utilize digital assets in the digital age and maximize both direct and indirect benefits. Furthermore, the existing research does not consider the characteristics of The Times of green development. In the context of green development, green technology innovation is crucial for promoting the sustainable growth of enterprises and addressing environmental challenges (Shu et al., 2022; Zhang et al., 2023). Additionally, digital investment can foster enterprises' green technology innovation (Marion and Fixson, 2021). Consequently, green technology innovation may serve as a mediating factor in the relationship between digital investment and corporate resilience. To address this research gap, this study aims to explore how digital investment influences firm resilience through green technology innovation and the underlying mechanisms involved.

Impact of Digital Investment and Enterprise Resilience

The core of enterprise resilience is risk resistance and sustainable development (Ortiz-de-Mandojana and Bansal, 2016). Enterprise resilience should not be viewed as a capability that can be independently acquired; it relies on digital technologies for support and advancement (Li et al., 2022). This study posits that digital investment positively influences both the sustainability and risk resilience aspects of firm resilience. First, the NRBV theory highlights the unique capabilities of firms in utilizing and managing natural resources, which are integral to sustainable growth. Digital investments, utilizing big data analytics and Internet of Things technologies, allow firms to monitor and optimize natural resource management in real time. This capability reduces production costs, minimizes environmental impacts, and enhances corporate sustainability.

Second, firms need knowledge and information to generate creative and innovative ideas to cope with external shocks and crisis scenarios (Ji et al., 2020). Based on KBV, firms' capabilities often depend on their knowledge acquisition and sharing (Grant, 1996; Ji et al., 2020). The application of digital technology enables firms to access market and industry information more efficiently and accurately,

and to formulate response strategies quickly, so that they can quickly adjust their business strategies and maintain the standardization and agility of their risk management activities in the face of unforeseen events or market volatility (Zhang et al., 2021).

Accordingly, this paper proposes the following hypotheses.

H1: Digital investment enhances firm resilience.

Impact of Digital Investment on Green Technological Innovation

While the importance of green technological innovation is widely acknowledged, it is characterized by long cycles, high risks, and negative externalities. Enterprises, as the primary contributors to green technological innovation activities, often lack the motivation to engage in these efforts (Ye et al., 2023). From a knowledge management perspective, introducing and applying digital technology enables enterprises to dismantle communication barriers internally and externally, providing avenues for creating and disseminating green technology innovation knowledge (Marion and Fixson, 2021). Adopting digital tools can help enterprises acquire real-time information on market dynamics, technological advancements, and environmental policies. This enhances information flow and transparency, allowing for better identification of green technology innovation opportunities and increasing enterprises' willingness to innovate.

According to NRBV, technology is a key resource for enterprises to carry out green technological innovation and build sustainable competitive advantages (Yang and Chai, 2015). Green technological innovation usually involves the intersection and application of multidisciplinary knowledge, and it is difficult to achieve success in carrying out green technological innovation only by relying on the enterprise's previous technological experience and knowledge in a single technological field. The introduction and application of digital technology help to absorb and utilize technological knowledge in a wider field and on a larger scale, which is conducive to solving the complexity of breakthrough innovation problems, reducing the risk of enterprise innovation, optimizing the allocation of resources, and enhancing the

efficiency of innovation (Shu et al.,.2022). Based on this, hypothesis 2 is proposed.

H2: Digital investment has a positive impact on green technology innovation.

Impact of Green Technological Innovation on Enterprise Resilience

Green technological innovation involves the adoption of new technologies, materials, and processes in production and operations to reduce resource consumption and environmental pollution, achieving a harmonious balance between economic and environmental benefits. Green technological innovation focuses on the long-term sustainable development of enterprises. Through green technological innovation, enterprises can create more environmentally friendly products that meet market demand while minimizing resource consumption and preventing further environmental damage. This long-term perspective is crucial for the sustainable development of enterprises committed to green development.

By implementing green technological innovation, enterprises can effectively mitigate dysfunction within their original production systems during green development scenarios. Additionally, they can enhance their ability to anticipate and respond to environmental crises, thereby strengthening their risk defense capabilities and resilience (Zhang et al., 2023). Enterprises that adopt green technological innovations often enjoy a better reputation among the public and consumers. This positive social image fosters consumer support and trust during crises, enhancing firms' market resilience.

Based on these observations, this paper proposes the following hypothesis.

H3: Green technological innovation positively impacts enterprise resilience.

The Mediating Role of Green Technological Innovation

As discussed above, digital investment is beneficial for enhancing green technological innovation. Firms with a high level of green technological innovation can not only respond to environmental crises but also improve their sustainability in green development scenarios, thereby enhancing organizational resilience. In other words, green technological innovation may mediate the relationship between digital

investment and enterprise resilience. Therefore, we propose the following hypothesis:

H4: Digital investment can enhance enterprise resilience by improving the level of green technological innovation.

Based on the above theoretical analysis, this study constructs a conceptual model, as shown in Figure 1.
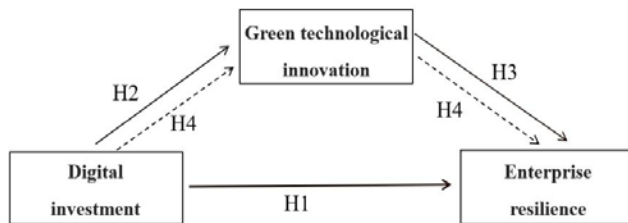
Figure 1 Conceptual model.

Methodology

Sample Selection and Population

This study focuses on publicly listed companies within China's heavily polluting industries, specifically those listed on the Shanghai and Shenzhen Stock Exchanges, covering the period from 2016 to 2020. Pollution-intensive industries, such as chemicals, steel, and mining, were chosen because of their high environmental impact, energy consumption, and emissions, which make them ideal candidates for studying the intersection of digital investment, green technological innovation, and enterprise resilience in the sustainability context (Chirumalla, 2021). With the rise of Industry 4.0, pollution-intensive enterprises are facing an increasing demand for green development and are actively seeking to enhance their environmental performance through digital investment and digital technologies, thereby achieving sustainable development goals (Chirumalla, 2021). Studying the strategies these enterprises employ to address environmental challenges is crucial not only for their own survival and growth but also for the broader sustainable development of society.

The population of this study consists of all pollution-intensive enterprises listed on both exchanges during the specified period. To ensure data integrity and reliability, we implemented specific inclusion and exclusion criteria: (1) companies with outliers in key indicators and those with a listing period of fewer than three years were excluded to avoid

volatility; (2) companies with "Special Treatment" (ST, SST, and PT) status due to financial distress were removed, as their resilience metrics could skew results. The application of these filtering criteria resulted in a final sample of 624 companies suitable for further examination.

Measurement of Variables

Dependent variable: enterprise resilience. Based on the methodology described by Markman and Venzin (2014), ROE data for the enterprises were collected, and enterprise resilience was calculated using their outlined steps.

Independent variable: digital investment. Based on the work of Zhao et al. (2021), the enterprise digital transformation index was developed through text analysis techniques applied to the annual reports published by the enterprises. This index was used to evaluate the extent of digital investment in this study. Measuring digital investment is a multidimensional process that involves not only investment in technology and capital but also investment in cultural change within the enterprise, as well as the limited attention of management (Bellantuono et al., 2021; Sun and Sun, 2021). We believe the digital transformation index more comprehensively captures the depth and breadth of an enterprise's digital investment.

Mediating variables: green technological innovation. Referring to Xu et al. (2023), the quantity of green patent applications was quantified by taking the natural logarithm of the number of applications plus one to measure green technological innovation.

Control variables. In addition to being influenced by the levels of digital investment and green technological innovation, enterprise resilience is also affected by other variables. The control variables selected for this study include: firm size (SIZE), ownership type (SOE), listing age (AGE), and growth capability (GROW).

Data Collection and Processing

The digital transformation index reflecting digital investment was obtained through the collection and organization of annual report data from 2016 to 2020, utilizing text analysis methods. The ROE data used to calculate organizational resilience was sourced from the CSMAR database, while data on green technological innovation was obtained from the National Intellectual Property Patent

Database. To ensure the integrity of the data and mitigate the impact of outliers, a 1% winsorization was applied to all continuous variables. The processing and analysis of the data were conducted utilizing tools such as Excel, Python, and Stata, thereby facilitating robust statistical evaluation of the relationships under study.

Statistical Techniques and Model Specification

The study employed a series of regression models to evaluate the hypothesized relationships, following Baron and Kenny's (1986) method for testing the direct and mediated effects:

$$ER_{it} = \alpha_0 + \alpha_1 DI_{it} + \alpha_2 Controls_{it} + \varepsilon_{it} \quad (1)$$

$$GTI_{it} = \beta_0 + \beta_1 DI_{it} + \beta_2 Controls_{it} + \varepsilon_{it} \quad (2)$$

$$ER_{it} = \gamma_0 + \gamma_1 GTI_{it} + \gamma_2 Controls_{it} + \varepsilon_{it} \quad (3)$$

$$ER_{it} = \theta_0 + \theta_1 DI_{it} + \theta_2 GTI_{it} + \theta_3 Controls_{it} + \varepsilon_{it} \quad (4)$$

Here, ER_{it} denotes the resilience level of enterprise i at time t, DI_{it} represents the digital investment level of enterprise i at time t, GTI_{it} indicates the level of green technological innovation of enterprise i at time t, and $Controls_{it}$ refers to a set of control variables, while ε_{it} representing the residual term.

Initially, Models (1) to (3) will be run to establish the direct relationships. If α_1 in Model (1) is significantly greater than 0, then H1 is accepted; if β_1 in Model (2) is significantly greater than 0, then H2 is accepted; and if γ_1 in Model (3) is significantly greater than 0, then H3 is accepted.

Following this, the study constructs Model (4) based on Models (1) and (3) to examine the mediating effect of green technology innovation. Once H1 to H3 are confirmed, it can be inferred that digital investment influences both enterprise resilience and green technology innovation, with the latter significantly correlated to enterprise resilience. In this context, digital investment can indirectly strengthen enterprise resilience by fostering green technology innovation, thus providing support for H4. Moreover, the significance of the parameter θ_1 in Model (4) determines the type of mediating effect. If θ_1 is not significant, it indicates that green technology innovation plays a full mediating role. If θ_1 is significant, it implies that green technology innovation serves as a partial mediator.

However, before proceeding with the regression analysis, we performed correlation and multicollinearity analyses. This preliminary step is essential as it identifies potential relationships between variables and checks for multicollinearity, ensuring the reliability of the regression models. By establishing these foundational insights, we enhance the robustness of our subsequent analysis, thereby providing greater confidence in the validity of our findings.

Results and Discussion

Results

Table 1 presents the correlation analysis and variance inflation factor analysis among variables. Digital investment positively correlates with green technological innovation and enterprise resilience, providing initial support for our hypothesis. Importantly, the correlation coefficients are below 0.5, and VIF values remain under 10, suggesting no significant multicollinearity and permitting valid regression analysis.

Table 1 Correlation analysis and Variance inflation factor analysis.

Variables	1	2	3	4	5	6	7
1.ER	1						
2.GTI	0.0131**	1					
3.DI	0.0020**	0.0312*	1				
4.SIZE	0.1341***	0.3332***	0.1301***	1			
5.SOE	-0.0130	0.0671***	0.0291	0.1272***	1		
6.AGE	0.0191	0.0150	0.0362**	0.3512***	0.1321***	1	
7.GROW	0.0880***	0.0080	0.0240	0.0781***	0.0240	0.0632***	1
VIF Value	——	3.1071	2.3532	1.8017	1.7549	2.0518	1.9543

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2 Regression Analysis Results for Testing Direct and Mediating Effects.

Variables	Model (1)	Model (2)	Model (3)	Model (4)
Control variable				
SIZE	0.0380***	0.1928***	0.0413***	0.0432***
SOE	-0.0969	0.2319**	-0.0941	-0.0922
AGE	-0.0011	-0.0115***	-0.0013	-0.0014
GROW	0.0709***	-0.0524*	0.0698***	0.0707***
Independent variable				
DI	0.0070*	0.0098*		0.0066**
Mediating variable				
GTI			0.0187*	0.0192*
$\overline{R}^2$	0.0244	0.1232	0.0240	0.0251

Note: * p<0.05, ** p<0.01, *** p<0.001

In the regression analysis (Table 2), Model (1) confirms that digital investment is significantly related to enterprise resilience ($\alpha_1 = 0.0070$, p<0.05), supporting H1. Model (2) reveals a positive relationship between digital investment and green technology innovation ($\beta_1 = 0.0098$, $p < 0.05$), supporting H2.

In Model (3), green technology innovation significantly impacts enterprise resilience ($\gamma_1 = 0.0187$, $p < 0.05$)), confirming Hypothesis H3. Model (4) introduces green technological innovation based on Model (1). The results show that the regression coefficient of digital investment on enterprise resilience is $\theta_1 = 0.0066$ ($p < 0.01$), which is lower than the regression coefficient of $\alpha_1 = 0.0070$ ($p < 0.05$) in Model (1). This indicates that green technological innovation plays a partial mediating role in the relationship between digital investment and enterprise resilience, supporting H4.

Discussion

Digital investment has a significant impact on enterprise resilience, consistent with the findings of Li et al. (2022). Li et al. (2022) examined how digital technology deployment affects supply chain resilience, arguing that it enhances transparency, visibility, and speed within the supply chain, thereby positively influencing supply chain disruptions and improving overall resilience. In the current context of uncertainty and increasing downward pressure on both the Chinese and global economies, enterprises are confused about how to increase their resilience to external shocks and achieve sustainable development goals. The findings offer a feasible solution: increasing digital investment and actively implementing digital technologies within enterprises. Specifically, digital investment enhances resilience by introducing and implementing digital technologies that allow companies to monitor and optimize natural resource management in real-time, reduce costs, and minimize environmental impact, while also improving the efficiency of market information acquisition and strategy development, thus bolstering both resilience and sustainable development. This interpretation is further supported by Soni et al. (2014), who identified information sharing and collaboration as key resilience drivers.

Digital investment also significantly impacts green technology innovation, aligning with Sia et al. (2021), who argued that digital transformation improves resource integration, information acquisition, and data analysis capabilities, thereby becoming a key driver of technological innovation in enterprises. This finding is further supported by the empirical study conducted by Ye et al. (2023), which found that digital investment significantly promotes green innovation in enterprises.

The positive relationship between green technological innovation and resilience mirrors Ardito et al. (2021), who identified innovation as a key factor for resilience during downturns. Expanding this understanding, our study finds that green technology innovation enhances resilience by improving companies' public image and satisfying environmentally conscious consumers, thus supporting sustainable development goals.

The findings indicate that digital investment enhances enterprise resilience by fostering green technology innovation, which drives efficient resource allocation, improvements

in clean production technologies, and the development of green products, thereby bolstering the company's environmental image. This process aligns with the Natural Resource-Based View (NRBV), suggesting that while pursuing economic gains, companies can also achieve environmental benefits through digital-enabled green innovation. Acting as a mediating mechanism, green technology innovation enhances customer satisfaction and loyalty, further reinforcing the resilience of enterprises, and equipping them to adapt robustly to evolving environmental policies, changing consumer demands, and market fluctuations.

The broader implications of green technology innovation as a mediating mechanism lies in its redefinition of the relationship between enterprises and the natural environment, integrating sustainability as a core strategic component of resilience. Through digital investment, firms can establish long-term competitive advantages within a broader ecological system, characterized by operational efficiency and optimized resource management, brand reputation, and corporate social responsibility. The synergy of digitalization and green technology innovation enables companies to secure a sustainable market position amid increasingly stringent global environmental standards and societal expectations, driving them toward sustainable business models. Thus, the mediating role of green technology innovation further underscores the strategic importance of digital investment, establishing it as a crucial pathway to achieving resilience and sustainable development.

Conclusions and Recommendations

Conclusions

Amid global economic volatility, pandemics, and other emergencies, corporate resilience has emerged as a central focus in management research. While previous studies have examined the direct impact of digital investment on resilience, findings have been inconsistent, and few studies have explored this relationship within the context of green development. This study addresses this gap by analyzing how digital investment influences firm resilience and investigating the mediating role of green technology innovation in this relationship. We constructed four regression models to test our hypotheses based on data from companies in heavily polluting industries listed on the Shanghai and Shenzhen stock exchanges from 2016 to 2020.

Our findings reveal that digital investment not only enhances enterprise resilience directly but also promotes resilience indirectly by fostering green technology innovation. This dual pathway suggests that digital investments, when aligned with sustainability goals, can offer enterprises a strategic advantage in navigating disruptions while contributing to long-term sustainable development. These insights underscore the importance of incorporating green innovation into digital investment strategies, particularly for firms in high-pollution industries facing increasing regulatory and environmental pressures.

Recommendations

This study provides valuable insights with practical recommendations for managers and policymakers.

The findings indicate that companies should prioritize increasing digital investment and integrating digital technologies to confront environmental challenges and navigate economic pressures. In the context of Industry 4.0 and with a focus on long-term green development, digital investment can facilitate cleaner production practices and optimize resource allocation, strengthening resilience to external shocks and the capacity for sustainable development. Managers are encouraged to view digital technologies as operational tools and strategic levers that support green innovation and resilience simultaneously.

A critical aspect of leveraging digital investment lies in understanding how this investment impacts resilience, particularly through green technology innovation. Many companies struggle to fully realize the benefits of digital transformation because managers often allocate resources and establish strategies without a comprehensive grasp of these underlying pathways. The findings indicate that, particularly within Industry 4.0, focusing on digital investment that drive green technology innovation is essential for building resilience. Recognizing the synergy between digital and green transformations is paramount in markets where environmental standards are increasingly prioritized. For instance, companies can implement

production management systems that monitor resource consumption and emissions, using real-time feedback to optimize production and resource use continuously. Additionally, engaging with stakeholders through digital platforms can help develop environmentally sustainable products and practices, fostering a culture of shared innovation and sustainability.

The study also highlights the importance of supportive policy frameworks that encourage digital investment aimed at advancing green technology innovation. Such policies incentivize businesses to adopt digital solutions and align this investment with broader resilience and sustainability goals. Policymakers can support this alignment by providing incentives for companies investing in green technologies, thereby fostering a stronger connection between economic objectives and environmental responsibilities. For industry leaders, digital investment should be recognized as strategic assets that reinforce resilience and green development, making sustainability a key component of digital transformation agendas.

Sector-specific strategies are crucial to maximize the effectiveness of digital investment. Different industries can leverage digital investment based on unique operational requirements and environmental impacts. For example, heavy manufacturing sectors can benefit from real-time monitoring systems to track environmental metrics like emissions and waste, improving efficiency and regulatory compliance. Conversely, sectors such as pharmaceuticals and high-tech industries might focus on innovations in clean production and efficient resource utilization. By tailoring digital strategies to each sector's specific challenges and goals, companies can more effectively harness digital investment, enhancing resilience in ways that resonate with the distinct demands of their industry.

Finally, for companies operating across various international contexts, adapting these recommendations to fit local regulatory and environmental landscapes is essential. International applications of digital investment strategies should account for regional variations in regulatory standards and market expectations. Comparative studies across countries with differing environmental regulations can validate these strategies on a global scale, offering insights into how digital investment in green

innovation enhance resilience in diverse settings. Such adaptations can ensure that digital transformation and green innovation strategies remain effective and sustainable across different geopolitical and regulatory environments, ultimately fostering resilience on a global scale.

Limitations and future research

While this study provides valuable insights, several limitations highlight opportunities for further research. For instance, although the research centers on heavily polluting industries, it does not differentiate between sub-sectors within this broad category. Different types of heavy polluting industries-such as the capital- and technology-intensive pharmaceutical manufacturing industry versus the labor-intensive textile industry-are likely to exhibit distinctive operational and environmental characteristics. Therefore, future studies that explore these distinctions in greater detail may reveal industry-specific insights. Segmenting these industries to analyze how distinct sub-sectors interact with digital investment and green technology innovation might provide tailored strategies for resilience-building.

Additionally, given that this study's data primarily reflects Chinese enterprises, the findings may have limited generalizability across global contexts. To extend the applicability of these results, cross-national studies that test and refine the model across diverse geopolitical and regulatory settings would be beneficial. Comparative studies across countries and regions would affirm the model's relevance and provide insights into how differences in environmental regulations and market conditions affect the dynamics between digital investments, green innovation, and resilience. Such research could offer valuable perspectives for adapting resilience-building strategies in line with international environmental standards and policies.

Finally, this paper examines enterprise resilience as a holistic construct. Considering that enterprise resilience can be divided into situation awareness, management of keystone vulnerabilities and adaptive capacity (He et al.,

2023), investigating these sub-dimensions may provide new insights.

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