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Research article

Does Fintech lead to enhanced environmental sustainability? The mediating role of green innovation in China and India

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ABSTRACT

Fintech and green innovations are increasingly recognized as potential solutions for enhanced environmental sustainability. In this paper, we investigate the impact of Fintech on environmental sustainability through the lens of green innovation in manufacturing. Using questionnaire data from 477 manufacturing firms in China and India between February and June 2024, the study employs Partial Least Squares-Structural Equation Modelling to analyze the dynamic relationships. We find that both Fintech and green innovation significantly contribute to improving the environmental sustainability of manufacturing firms. Results further show that Fintech positively supports manufacturing firms' green innovation developments. Moreover, green innovations partially mediate Fintech's effect on environmental sustainability. Our results also highlight regional differences: the impact of Fintech and green innovation on environmental sustainability is stronger in China than in India. Additionally, Fintech's role in supporting green innovations is more pronounced in Chinese firms than in India. The paper highlights the importance of investments in Fintech and green innovation by manufacturing firms, particularly in emerging markets, to address environmental issues for sustainability.

1. Introduction

Recently, Fintech has emerged as a valuable strategy for businesses to tackle complex, unpredictable, and interconnected environmental issues (Vergara and Agudo, 2021; Awais et al., 2023). Defined as financial innovation powered by technologies such as big data, artificial intelligence (AI), blockchain, and the Internet of Things (IoT), Fintech promotes sustainable practices by creating new financial products, services, and business models that align with environmental goals (Liao et al., 2024; Bonsu et al., 2023; Bibri, 2018; Shan et al., 2024). For instance, big data and artificial intelligence enable companies to utilize predictive analytics for efficient resource allocation and emissions reduction through advanced decision-making capabilities (Rashid et al., 2025; Modgil et al., 2021). Blockchain technology improves transparency and traceability in supply chains and carbon trading systems, ensuring accountability and reducing fraud in sustainability initiatives (Boumaiza and Maher, 2024; Rani et al., 2024; Upadhyay et al., 2021). Meanwhile, IoT facilitates real-time environmental monitoring, offering actionable data to promote sustainable practices (Bibri, 2018; Rahimi et al., 2024). By harnessing such advancements, Fintech provides firms with new opportunities to optimize resource usage, reduce emissions, and promote green innovations, positioning them to meet both environmental goals and regulatory standards (Guo et al., 2023; Guo and Yin, 2024). Furthermore, Fintech enhances environmental monitoring and control by combining real-time data collection with advanced analytics, providing organizations with actionable insights and improving sustainability outcomes (Alshdaifat et al., 2024; Liu et al., 2024b; Arner et al., 2020; Atayah et al., 2023; Cruz Rambaud and López Pascual, 2023). In addition, evidence suggests that Fintech and digital finance reduce carbon emissions and promote environmental sustainability (Rao et al., 2022; Siddik et al., 2023; Chueca Vergara and Ferruz Agudo, 2021; Tao et al., 2022; Muganyi et al., 2021). Tao et al. (2022) show that Fintech reduces carbon emissions, improving environmental outcomes, while (Nenavath, 2022) underscores its positive impact on investment and sustainability.

To date, evidence shows that green innovation (GI) is an essential link between Fintech and sustainability in manufacturing. GI involves green products and processes utilizing sustainable materials and

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environmental design principles in manufacturing and operations to reduce costs, waste, and pollution (Yuan and Cao, 2022; Xie et al., 2024; Aftab et al., 2024). Fintech promotes green innovation by enhancing knowledge linkages, optimizing production management, and enabling resource-efficient practices, thus driving higher environmental sustainability (Guang-Wen and Siddik, 2022, Tian et al., 2023b). While the connection between Fintech and green innovation is still emerging (Tian et al., 2023a), previous research has shown that GI enhances environmental sustainability in manufacturing by reducing carbon emissions and utilizing sustainable resources (Oliva et al., 2018; Dubey et al., 2015; Chen et al., 2015; Awan et al., 2021; Rehman et al., 2021; Sun et al., 2022; Waqas et al., 2021).

Amid current environmental challenges, businesses are under increasing pressure to reduce emissions, improve resource efficiency, and adopt sustainable practices in line with the Sustainable Development Goals to balance economic growth with environmental responsibility (Aftab et al., 2022; Adomako et al., 2021; Longoni et al., 2018; Yu et al., 2017). Rapid global expansion has raised environmental sustainability concerns, particularly in Asian countries still facing challenges in environmental degradation (Moslehpour et al., 2023; Sadiq et al., 2023). The manufacturing sector, accounting for 16% of the global GDP, also significantly impacts environmental sustainability through resource depletion, pollution, environmental imbalances, and contributions to global warming (Kraus et al., 2020; Singh et al., 2020; Aftab et al., 2022). Since these activities have a significant negative impact on the environment, collective action is required to mitigate their environmental footprint (Tu, 2024). Consequently, companies are increasingly utilizing environmentally friendly digital technologies to promote sustainable manufacturing methods, reduce their energy resource consumption and carbon footprint, and decarbonize their operations (Jingliang et al., 2023; Chien et al., 2023a, Chen et al., 2024).

Although research has established a strong connection between Fintech and environmental sustainability, its impact on the sustainability practices of manufacturing firms remains underexplored (Tu, 2024). In manufacturing, Fintech fosters green innovation, resource optimization, and carbon emission reduction through digitalization and environmentally friendly production technologies, enabling firms to create sustainable solutions (Bonsu et al., 2024; Li et al., 2024; Shan et al., 2024). Recent research indicates that manufacturing firms contribute to countries' carbon emissions, and green innovation can help reduce these emissions (Guo et al., 2023). Despite these promising developments, the literature remains limited on Fintech's impact on the environmental sustainability of manufacturing firms, particularly in China and India (Mirza et al., 2023; Xu et al., 2023). Moreover, the mediating role of green innovation in the nexus between Fintech and environmental sustainability in manufacturing remains largely underexplored (Li et al., 2023b). While existing literature predominantly explores customer adoption and Fintech behavior, there is a critical gap in understanding how Fintech promotes sustainable practices within the manufacturing context (Siddik et al., 2023). This gap presents a compelling opportunity and the need to investigate how Fintech can advance environmental sustainability in manufacturing. In this paper, we aim to answer three key research questions.

RQ1: Does Fintech support green innovation and environmental sustainability?
RQ2: To what extent does green innovation enhance environmental sustainability?
RQ3: Does green innovation mediate Fintech effects on environmental sustainability?

We analyze manufacturing firms in China and India, two major global manufacturing contributors (Wang and Zhou, 2020) because both countries are grappling with increasing environmental challenges due to rapid urbanization and population growth (Razzaq et al., 2022; Wang et al., 2021; Tu, 2024). With a projected $150 billion Fintech market by 2025, Asia countries have attracted Fintech firms, especially China and India achieved 87% EY Global Fintech Adoption rate (Siddik et al., 2023). In this paper, we utilized a Partial Least Squares-SEM to analyze data from 477 manufacturing firms in China and India from February to June 2024 based on the dynamic capability view (DCV). Our findings indicate that Fintech positively influences green innovations and environmental sustainability, with green innovation serving as a partial mediator. Our findings also show that green innovation positively enhances environmental sustainability. Notably, the influence of Fintech on green innovation and environmental sustainability is stronger in China than in India. The findings offer valuable insights into green growth strategies in various emerging markets. Notably, our results remain robust when accounting for endogeneity issues.

Our paper makes four significant contributions to the existing literature. First, we contribute to the literature considering the dearth of studies on Fintech's influence on environmental sustainability in the manufacturing setting (Siddik et al., 2023). To the best of our knowledge, we are the first to discover this nexus by considering Chinese and Indian manufacturing firms, providing insights into firms' capability to utilize Fintech to achieve environmental sustainability. Second, the literature lacks comprehensive research on how green innovation mediates Fintech's impact on environmental sustainability. Green innovation is recognized as a strong capability to reduce environmental impacts, combined with Fintech can promote higher sustainability through green products and processes (Li et al., 2024; Melander, 2017). Consequently, we highlight the vital role of green innovation in manufacturing firms in Fintech applications for achieving environmental sustainability. Thirdly, we contribute to the literature by using validated questionnaires at the firm level, as most studies utilized secondary data sources (Sarkodie and Ozturk, 2020; Khan et al., 2019; Nathaniel and Adeleye, 2021; Baz et al., 2020; Obuobi et al., 2024). Examining Fintech adoption in manufacturing firms provides key insights into its role in green innovation and environmental sustainability. Finally, we adopted the DCV as the theoretical foundation for our study to examine how manufacturing firms in China and India leverage Fintech to enhance environmental sustainability through green innovation. DCV highlights the significant role of Fintech in developing firms' adaptability to environmental challenges, providing practical implications for policymakers and industry leaders in emerging markets.

The rest of the paper is organized as follows. Section 2 highlights the theoretical background and hypothesis. Section 3 introduces the research data and methods. We used section 4 to discuss and test the hypothesis followed by robustness, and additional tests. Our final section presents conclusions and implications.

2. Theoretical background and hypothesis development

2.1. Theoretical background

This study utilizes the dynamic capability view (DCV) to develop a comprehensive theoretical framework for analyzing how manufacturing firms can utilize Fintech to enhance their environmental sustainability through green innovation. DCV posits that firms possess dynamic capabilities, enabling them to adapt to changing environments and technological opportunities by integrating and reorganizing internal and external resources (Teece, 2007; Yuan and Pan, 2023; Buzzao and Rizzi, 2021). Firms can maintain competitiveness by utilizing their dynamic capabilities to innovate and transform in rapidly changing industries (Dubey et al., 2019; Teece et al., 1997). The emerging market is facing increased pressure to adopt sustainable practices, necessitating firms to navigate the complexities of technological advancements and regulatory requirements (Adomako et al., 2021; Aftab et al., 2022). The DCV suggests that firms with dynamic capabilities are better equipped to adopt and integrate Fintech innovations, thereby improving decision-making, operational efficiency, and environmental sustainability (Warner and Wäger, 2019). In the context of this study, Fintech is a vital DC that enables companies to foster green innovation and advance environmental performance leading to achieving sustainability. Fintech solutions like blockchain, AI-powered data analytics, and digital financial tools enable businesses to optimize operations, reduce resource consumption, and integrate green technologies. The integration of these technologies promotes green innovation (Chen et al., 2024), stimulating eco-friendly manufacturing processes, sustainable product development, and efficient energy and resource use, which is crucial for global sustainability initiatives (Lisha et al., 2023).

Moreover, the DCV further suggests that firms with robust dynamic capabilities are better equipped to integrate green innovation and environmental sustainability practices (Dangelico et al., 2017). Firms can enhance their competitive advantage and environmental performance by fostering innovation and adapting to technological changes (Dubey et al., 2015). In the context of manufacturing firms, Fintech adoption fosters green innovation, enabling businesses to meet environmental standards, reduce their ecological footprint, and maintain market competitiveness. Despite DCV being widely adopted in technology adoption and innovation studies (Chaudhuri et al., 2024; Chatterjee et al., 2023), its application to the specific context of Fintech solutions and environmental sustainability in the manufacturing sectors especially in the emerging markets of China and India is underexplored, contributing to a new dimension to the theory. Consequently, we contribute to the DCV by extending its application in Fintech adoption and environmental sustainability through green innovation of manufacturing firms in emerging markets.

2.2. The relationship between fintech and green innovation

According to the dynamic capability view, a firm's capability to combine, build, and reconfigure both internal and external skills respond to changing environments (Dubey et al., 2019). A firm's innovativeness directly depends on its capability to process and analyze massive datasets beyond its core technological base to address rapid environmental changes. Fintech helps firms collect, examine, and analyze massive datasets for green projects, leveraging their expertise to develop green innovations while improving existing ones.

Fintech is recognized for its potential to tackle environmental issues and carbon emissions. In a scientific environment, Cheng et al. (2023) find that Fintech utilisations shape the industrial structure and achieve green innovations, supporting the argument that, manufacturing firms' green innovation can be dependent on the applications of Fintech. In this paper, we define Fintech as the firm's capability to tackle environmental issues and decrease carbon emissions, thereby boosting the drive for green innovation. Fintech significantly addresses environmental sustainability challenges by creating green products, recycling, reprocessing, and adapting sustainable production and customization. Fintech development such as big data analytics (BDA) and artificial intelligence (AI) enables companies to improve data collection, promoting green product development and environmental sustainability. BDA has proven to enhance firms' green innovation capabilities and offer predictive tools for future developments (Al-Khatib, 2022; Meiyou and Ye, 2022). Li et al. (2024) demonstrated that AI supports green products and processes, thereby enhancing environmental performance. The relationship between Fintech and green innovation is still in its early stages, with few studies indicating that Fintech supports green innovation (Li et al., 2023a; Tian et al., 2023a). The dynamic capability view suggests that firms can build their capabilities by processing and analyzing large datasets to innovate green products and processes. We argue that Fintech can facilitate firms' innovation and environmental sustainability by enhancing data analysis and processing through precise data analysis. Therefore, the first hypothesis is proposed that a firm's Fintech is positively related to the firm's green innovation.

H1. Fintech application is positively related to firms' green innovation.

2.3. Fintech and environmental sustainability

Fintech utilizes advanced technologies to minimize waste, allocate shareholders' funds towards eco-friendly products, and encourage green growth and environmental sustainability. According to Belhadi et al. (2018), environmental sustainability is defined based on two characteristics (1) the protection of environmental assets and entire ecosystems for future generations and (2) firms' performance in energy use, emissions, pollution, resource waste, and other negative impacts. Fintech solutions can enable manufacturing firms to streamline their operations and reduce consumption. Firms' application of Fintech can facilitate options for manufacturing firms that prioritize environmental sustainability, providing the necessary capital to implement environmentally friendly practices or invest in renewable energy sources.

Zhou et al. (2022) empirically examine Fintech and showed that utilizing Fintech can mitigate the natural resource curse, enhance environmental sustainability, and foster sustainable development. Despite the high levels of consumption and pollution, Liu et al. (2024) discovered that Fintech applications have the potential to drive green growth and environmental sustainability standards. Fintech solutions enable firms to optimize energy use and reduce consumption by utilizing grid technologies and energy management systems, identifying inefficiencies, and implementing energy-saving measures. Despite the lack of extensive studies on Fintech and environmental sustainability, some studies have provided strong support for their nexus (Tu, 2024). Green finance-based Fintech on environmental sustainability is capable of reducing carbon emissions in India, leading to environmental sustainability (Nenavath, 2022). Muganyi et al. (2021) suggest that Fintech lowers corporate emissions in China. According to DCV, Fintech enables firms to manage energy supply, identify product demand, and improve energy efficiency. Lobato et al. (2021) argued that Fintech investment can improve the environmental quality of enterprises, thus enhancing sustainability. Therefore, we argue that manufacturing firms' Fintech applications will positively contribute to reducing emissions, and energy consumption, which in turn lead to enhanced environmental sustainability.

H2. Fintech applications will positively lead to enhanced firms' environmental sustainability.

2.4. Green innovation and environmental sustainability

Studies indicate that factors determining environmental sustainability are crucial for decision-makers to implement effective countermeasures against environmental degradation. (Kuhl, 2021; Ulpiani et al., 2023). Green innovation is a practical approach to enhancing environmental sustainability (Khan et al., 2021; Cheng et al., 2021). The integration of green technology in production processes enhances factors' performance, automates processes, enhances industry competitiveness, reduces energy use, and facilitates the use of clean energy. (Huang et al., 2020). In line with this development, research suggests that green innovation mitigates the adverse effects of energy concerns and waste pollution associated with product manufacturing leading to enhanced sustainability (Yasmeen et al., 2022; Sun et al., 2022). Recent empirical studies indicate that green innovation has the potential to enhance environmental sustainability (Yang et al., 2021; Obuobi et al., 2024).

Research in green innovation and environmental sustainability literature has investigated the correlation between green and environmental innovation and environmental pollution. (Xin et al., 2021; Ding et al., 2021; Lingyan et al., 2022). Considering the research of (Ji et al., 2021; Ahmed et al., 2023), green innovation aims to decrease the use of renewable energy sources and carbon emissions in polluting nations. In addition (Zhong et al., 2021), Argued that China's pollution is projected to decrease due to the advancements in technology. Green technologies are a significant contributor to the increase in renewable energy consumption in OECD nations (Khan et al., 2021; Lingyan et al., 2022) showed that green innovation is a strategy that significantly reduces carbon dioxide, thereby promoting environmental sustainability in highly decentralized countries. In addition, green innovation plays a critical role in achieving environmental sustainability through energy savings and emission reductions (Albort-Morant et al., 2017; Castellacci and Lie, 2017). We argued that prioritizing green innovation can lead to more sustainable and environmentally friendly production and consumption. Hence, we propose hypothesis 3.

H3. Green innovation has a positive impact on environmental sustainability.

2.5. The mediating effect of green innovation

Sustainability has influenced corporate decision-making to integrate greening concepts in product and process innovation, and networking as a sign of social responsibility (Lin et al., 2021; Wang et al., 2020). Manufacturing firms are utilizing Fintech applications to promote green products, sustainable practices, and personalized green labels using big data analytics and artificial intelligence (Pan and Nishant, 2023). Manufacturing firms can exploit Fintech to track carbon emissions and pollution in green products to enhance transparency and consumer trust (Dahlquist, 2021; Dwivedi et al., 2023). However, Fintech firms can improve green design and production through algorithmic optimization, demonstrating self-learning and adaptability to environmental changes, reshaping green manufacturing processes, and supporting business and digital technology components (Di Vaio et al., 2020; Tian et al., 2023). Indeed, firms are promoting Fintech investments for green innovations and intelligence control systems, enabling early emission identification at production sources through dynamic sensing and analytical decisions (Xie et al., 2022a; Huang and Li, 2017).

Evidence indicates that green product innovation significantly enhances environmental performance by reducing impacts through ecodesign and solid waste processing (Singh et al., 2020; Zameer et al., 2023; Li et al., 2024; Melander, 2017). In addition, research suggests Fintech can improve business production, pollution control, and green process innovation efficiency, necessitating green process standards prioritizing, governance methods, and sustainability values (Liu and Chen, 2022; Bhatia, 2021, Li et al., 2024; Rehman et al., 2021). Green process innovation fosters ecological information sharing, pollution prevention experiences, and pollution mitigation technologies, ultimately reshaping established enterprises' production patterns (Ye et al., 2023). The green business segment is enhancing sustainability by creating green products, and processes, and integrating digital technology to optimize production, reduce waste, and reduce pollution (Xie et al., 2019). Overall, Fintech allows firms to quickly adapt to green product preferences, minimizing resource waste and carbon emissions throughout the product's lifecycle through green process innovation. However, the literature is underexplored on the impact of Fintech on firms' environmental sustainability through green innovation. Thus, we propose that.

H4. Green innovation mediates the nexus between Fintech and environmental sustainability.

Fig. 1 illustrates our research conceptual framework. To summarize, our paper expects a positive association between Fintech and green innovation (H1). Further, Fintech is expected to positively impact environmental sustainability, supporting H2. In addition, we expect a positive effect of green innovation impacting environmental sustainability (H3). Finally, we expect a positive mediating impact of green innovation between Fintech and environmental sustainability (H4).

3. Research method

3.1. Questionnaire development

A survey instrument was designed to measure the Fintech of manufacturing firms' managers along with firms' green innovation and environmental sustainability. The questionnaire was written in English and included information about the respondent's demographic and firm profile. The research team utilized a 5-point Likert-type scale for all constructs, with a panel of academics reviewing the English version and translating it into Chinese. The Chinese version was translated back into English and compared to the original English version to ensure its reliability. The Chinese version was applied in China for data collection, while the English version was employed in India.

To ensure the questionnaire's validity, a pretest was conducted with Fintech and Sustainability Finance experts to review the questionnaire to ensure its relevance, clarity, and alignment with the study's objectives and target population's understanding. Moreover, three innovation and environmental management experts were consulted to ensure the questionnaire's content validity and accurate capture of key constructs and dimensions. The instrument was revised to enhance its representativeness, accuracy, and comprehensive coverage of research variables, and maintain contextual relevance, following their suggestions. Additionally, the instrument was enhanced by incorporating scales from previous studies to bolster its content validity.

A pilot test was conducted with ten Chinese manufacturing companies, and the feedback helped revise the instrument by addressing ambiguities and improving clarity, ensuring the questions were relevant and comprehensible to the target population. The survey form consisted of three sections. The research objectives were explained in the first segment, followed by a detailed analysis of demographic information, firm characteristics, and questions on industry competition and research and development intensity. The final segment of the investigation

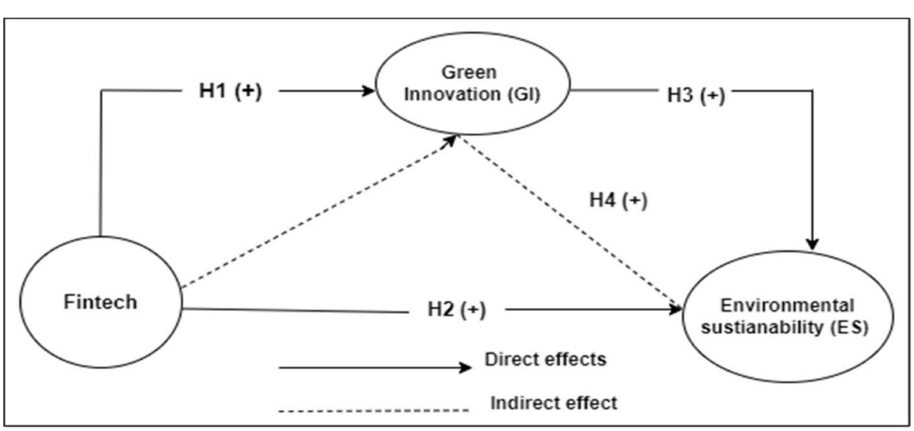

Fig. 1. Research conceptual framework.

required respondents to evaluate 27 items of study constructs adapted from literature and tailored to the study context, as detailed in Table 1.

Fintech was modified and adapted from (Bag et al., 2021; Lin et al., 2024b). Green product and process innovation are the two main categories of a firm's green innovation, focusing on their environmental impacts (Wang and Ahmad, 2024; Wang et al., 2019). Green product innovation is the peak level of green innovation aimed at eliminating pollution emissions at their source (Wang et al., 2019). Consequently, five items were adapted from (Chen and Liu, 2020; Wang et al., 2021). Meanwhile, green process innovation is a proactive approach to environmental management mainly occurring in a firm's manufacturing processes. (Wang et al., 2019; Xie et al., 2019). Therefore, we adapted five items from (Xie et al., 2019; Wang et al., 2021). Finally, we adapted seven items from (Huang and Li, 2017; Lin et al., 2024b) To measure environmental sustainability.

We controlled industry competitiveness (INDCOM), R&D intensity, and firm characteristics such as firm size (FS) and firm age (FA), as these variables influence organizational behavior and outcomes. Previous studies have utilized FS and FA to analyze green innovation performance and sustainability practices of firms (Ren et al., 2022; Liu et al., 2023; Nazuri et al., 2025). Larger firms have more resources for investing in technological innovations, and sustainable practices, while smaller organizations may face resource limitations but are more adaptable. Meanwhile, FA can influence sustainable product development speed and readiness, as older firms may resist new technologies due to legacy constraints, while younger firms may be more open to innovation. To control for FS and FA, the natural logarithm of the total number of firm employees and the number of years since the firm's establishment.

The study assessed the impact of INDCOM on firms' readiness and speed in adopting technological innovations for sustainability practices, using respondents' sector-specific scales (1 = highly competitive to 7 = strongly competitive), following the works of (Zhou et al., 2016; Bonsu et al., 2024). Competitive pressures prompt firms to innovate and adopt technologies for efficiency, cost reduction, and sustainability, with highly competitive industries embracing sustainable practices as strategic advantages. Finally, R&D intensity was determined by the ratio of R&D employees to full-time employees (Kang and Park, 2012).

3.2. Sample and data collection

This study designed a survey questionnaire to gather data for the empirical investigation of the conceptualized model. The data was gathered from manufacturing firm managers in China and India, two of the most significant emerging global markets. Notably, we communicated the study purpose to the managers, who were assured that the data would only be used for academic purposes and confidentiality would be maintained.

In China, manufacturing firms were selected from major special economic zones, including Guangdong, Shanghai, Jiangsu, Zhejiang, Hebei, Liaoning, Shandong, and Guangzhou. These regions were chosen for their significant contributions to China's manufacturing output. A random sampling technique was employed to identify 1000 firms, and potential participants were contacted by phone to explain the research purpose and encourage their involvement. In India, manufacturing firms were identified from industrial hubs including Delhi, Mumbai, Bangalore, Chennai, and Kolkata using IndiaMart's comprehensive business directory. 500 firms were contacted through email and phone to select eligible participants based on their roles and motivation to participate. In both countries, participants provided informed consent before being invited to complete the online questionnaire. Comprehensive guidelines were provided to ensure participants understood the process while maintaining anonymity and confidentiality.

The data collection was conducted from February to June 2024. Managers from senior, middle, and lower levels of manufacturing firms in both China and India participated, leveraging their comprehensive understanding of the Fintech solution's impact on environmental

Table 1
Variable information.

Variables	Items	Sources
Fintech	"Please specify the extent to agree or disagree with the below"	(Bag et al., 2021; Lin et al., 2024b).
FT1	Fintech is used within the firm to improve decision-making power.	
FT2	Fintech helps to integrate data from diverse sources.	
FT3	Fintech is frequently utilized to assist users or managers in interpreting complex information.	
FT4	Fintech supports green products and processes.	
FT5	My firm utilizes Fintech to analyze production problems by decomposing data and focusing on continuous improvement.	
FT6	Fintech can enhance the machine life cycle, reduce industrial waste, and facilitate faster process adaptation for increased efficiency.	
FT7	We utilize Fintech to optimize resource utilization and efficiently utilize assets.	
FT8	Fintech offers our firm various recycling options.	
FT9	Fintech enables efficient adaptation to consumer demands, optimizes resource utilization, and swiftly responds to changes in energy supply.	
FT10	We continuously evaluate our Fintech to adapt to the dynamic business environment.	
Green Innovations	"Please specify the extent to agree or disagree with the below"	
Green product innovation		(Chen and Liu, 2020; Wang et al., 2021).
GPI-1	The focus is on creating environmentally friendly alternatives to traditional products.	
GPI-2	My firm utilizes products with minimal energy and resource consumption in product development.	
GPI-3	My firm uses the fewest number of materials possible in product development.	
GPI-4	We recycle waste products produced by ourselves.	
GPI-5	My firm improves environment-friendly packaging.	
Green process innovation	"Please specify the extent to agree or disagree with the below"	(Xie et al., 2019; Wang et al., 2021).
GPRI	Our production technique efficiently lowers hazardous chemical and waste emissions.	
GPRI	Waste and emissions from our production process are recycled, allowing them to be treated and reused.	
GPRI	My firm increased R&D investment in environmental protection technology.	
GPRI	My company is modifying its operations to reduce energy waste and environmental emissions.	
GPRI	My firm has implemented a green process planning supportive system.	
Environmental sustainability	"Please specify the extent to agree or disagree with the below"	(Huang and Li, 2017; Lin et al., 2024b).
ES-1	We reduce environmental business wastage.	
ES-2	My firm reduces emissions or units of production.	
ES-3	My firm reduces material usage.	

(*continued on next page*)

Table 1 (*continued*)

Variables	Items	Sources
ES-4	My firm reduces energy or fuel usage.	
ES-5	My firm reduces the consumption of hazardous and toxic materials.	
ES-6	Reduction of frequent environmental accidents.	
ES-7	We have improved our environmental situation.	

sustainability through green innovation. This multi-level approach was adopted to capture diverse perspectives on Fintech investments, from strategic decision-making to practical implementation and monitoring. By involving managers at different levels, the study ensured alignment with corporate sustainability targets while scrutinizing both strategic and operational aspects. This approach provided a holistic assessment of Fintech's impact on environmental sustainability and green innovation.

We received 267 and 210 completed responses from China and India, showing 26.7% and 42% response rates for the countries after several reminders through email and phones. The response rates align with previous studies using a similar questionnaire methodology (Delic and Eyers, 2020; Li et al., 2020). For instance (Wamba et al., 2024), examined artificial intelligence-enabled dynamic capability on environmental performance and found a 7% and 12% response rate for France and the USA. Table 2 presents the respondents and their firms' profiles. With 477 participants, 50.6% were obtained from China and 41% from India. Regarding respondents' status, we obtained 50.9% of middle managers from China and 47.1% respondents of middle managers from India. Male participants were greater than females (54.29% vs. 45.71%). For education, 48.6% acknowledged holding a postgraduate degree, 26.5% a bachelor's degree, and 25.2% declared to have other certificates. For years of working experience, the majority of the respondents have worked from 1 to 5 years representing 31.4%, followed by those with 6–10 years (114, 23.9%).

3.3. Common method bias (CMB)

Our paper based on self-reported data, has been validated due to potential common method bias issues with all data originating from one instrument. (Podsakoff et al., 2012). First, we included a lengthy introduction of the questionnaire to explain Fintech, which benefited respondents in providing correct responses. Second, our questionnaire's measurement items were randomized to prevent participants from recognizing causal relationships concerning constructs. Additionally, we ensured the privacy and confidentiality of respondents on the information gathered. Third, with a view to statistical measurement control, we initially analyzed common method bias using a single-factor Harman statistical test. The result is validated as a single factor accounts for 43%, below the 50% threshold of the total variance. In addition, we utilized a marker variable strategy to assess the impact of CMB on the validity and reliability of data analysis (Lindell and Whitney, 2001). Gender was used as a marker variable with a correlation between Fintech and the manager's gender, as it is theoretically unrelated to key variables. We discovered a non-significant connection amid the marker variable 0.100. Finally, we utilized variance inflation factors to assess multi-collinearity, resulting in a suitable value of less than 3.3 (Kock, 2015). Therefore, there is no significance of CMB on the dataset ensuring the validity of the research findings.

Table 2
Respondents' statistics.

Profiles	China	India	Full sample
Gender Male	135 (50.6%)	124 (59%)	259 (54.29%)
Female	132 (49.4%)	86 (41%)	218 (45.71%)
Position			
Top Manger	35 (13.1%)	37 (17.6%)	72 (15.1%)
Senior Manager	96 (36.6%)	74 (35.2%)	170 (35.6%)
Middle-Level Manager	136 (50.9%)	99 (47.1%)	235 (49.3%)
Work Experience			
1–5 Yrs	67 (25.1%)	83 (39.5%)	150 (31.4%)
6–10 Yrs	64 (24%)	50 (23.8%)	114 (23.9%)
11–15 Yrs	88 (33%)	46 (21.9%)	134 (28.1%)
>16 Yrs	48 (18%)	31 (14.8%)	79 (16.6%)
Firm age			
<10 Yrs	151 (25.8%)	120 (42.9%)	300 (33.3%)
>10 Yrs	116 (43.4%)	90 (29%)	177 (37.1%)
Firm employees			
1-15	34 (12.7%)	75 (35.7%)	146 (30.6%)
16 - 25	81 (30.3%)	80 (38.1%)	167 (35%)
26 - 35	84 (31.5%)	32 (15.2%)	96 (20.1%)
36 and above	68 (25.5%)	23(11%)	68 (14.3%)

3.4. Data analysis and model assessment

The paper uses Partial Least Square-Structural Equation Modelling instead of Composite-based SEM to test and estimate reflective-formative constructs in a model. In recent years, the Partial Least Square-Path Modelling method has become a prominent estimating tool in information systems and management research (Benitez et al., 2020). The PLS-SEM adoption is based on the small sample size ($N = 477$) and the relationship complexity among the 27 items of the model constructs (Wright et al., 2012). We test the proposed model's fit and hypothesis interrelationship using a two-step procedure. The model's reliability and validity were assessed through confirmatory factor analysis (CFA) and composite analysis, followed by structural path examination to test the hypothesis.

We evaluate the model fit adopting fit indices before testing the hypotheses. Consequently, the study estimated the measurement scale of indicators for each variable using Confirmation Factor Analysis (CFA) for construct reliability, convergent validity, and discriminant validity. We utilize properties including Cronbach's alpha (CA), Factor Loadings (FL), Composite Reliability (CR), and Average Variance Extracted (AVE) to achieve this goal. The measurement model's outputs meet reliability standards, with factor loadings for each item exceeding 0.5, such as Fintech items ranging from 0.592 to 0.911. Green product and process innovations measured through ten items ranged from 0.895 to 0.924. Finally, environmental sustainability had factor loadings from 0.579 to 0.907. Further, the composite reliability has been confirmed to be convergent, exceeding the average variance estimate, and meeting both requirements of greater than 0.7 (Hair, 2009). Notably, CA (α) exceeds 0.7. Table 3 reports the summary of the findings.

Similarly, the research assessed model validity using the square root of average variance estimates (Fornell-Larcker standard) and the Heterotrait-Monotrait ratio (HTMT) standards for discriminant validity (Henseler et al., 2015). Tables 4 and 5 display the inter-construct correlation values and the diagonal square root of AVEs. Results show the square root of AVE values in China and India is higher than the corresponding correlation values. For the full sample, the study reveals that the AVE square root values outperform all construct correlations that meet the Fornell-Larcker criterion standards (Fornell and Larcker, 1981).

The HTMT is a suitable indicator for discriminant validity testing, with a significant value of 0.82 meeting the criteria of 0.85 (See Table 6). Subsequently, the results of the Fornell-Larcker and HTMT criteria indicate that there are no discriminant validity issues. Finally, confirmatory composite analysis was used to evaluate the fit of a saturated model, assessing three key discrepancies including SRMR, d_{ULS}, and dG, showing empirical evidence of construct validation. (Lin et al., 2020). We reveal that the differences within the 99% quantile of bootstrap discrepancies indicate the accuracy of the measurement structure of composite constructs. The SRMR, calculated to be 0.074, falls below the suggested 0.080, demonstrating strong compatibility between the measurement model and the data. (Lin et al., 2024b). Therefore, our findings evidence model's goodness of fit with the measurement

Table 3
Reliability and validity tests.

		China	India	Full sample	VIF
Study Variables	Items	Extraction			
Fintech		CA = 0.949, CR = 0.950, AVE = 0.686	CA = 0.943 CR = 0.944 AVE = 0.623	CA = 0.974 CR = 0.974 AVE = 0.809	
	FT-1	0.771	0.823	0.857	1.24
	FT-2	0.879	0.790	0.911	2.73
	FT-3	0.795	0.818	0.886	2.56
	FT-4	0.811	0.766	0.887	3.25
	FT-5	0.864	0.730	0.911	3.02
	FT-6	0.848	0.741	0.911	2.69
	FT-7	0.879	0.767	0.916	2.58
	FT-8	0.815	0.817	0.900	2.42
	FT-9	0.801	0.809	0.905	2.51
	FT-10	0.803	0.825	0.592	1.24
Green Innovation		CA = 0.883 CR = 0.733 AVE = 0.696	CA = 0.913 CR = 0.724 AVE = 0.681	CA = 0.852 CR = 0.831 AVE = 0.844	
Green Product Innovation		CA = 0.899 CR = 0.901 AVE = 0.712	CA = 0.918 CR = 0.918 AVE = 0.712	CA = 0.948 CR = 0.948 AVE = 0.828	
	GPI-1	0.887	0.816	0.908	2.87
	GPI-2	0.820	0.847	0.911	2.21
	GPI-3	0.865	0.824	0.922	2.61
	GPI-4	0.814	0.808	0.911	2.06
	GPI-5	0.831	0.819	0.914	2.23
Green Process Innovation		CA = 0.883 CR = 0.883 AVE = 0.681	CA = 0.913 CR = 0.913 AVE = 0.677	CA = 0.950 CR = 0.950 AVE = 0.834	
	GPP-1	0.831	0.820	0.924	2.31
	GPP-2	0.836	0.844	0.918	2.35
	GPP-3	0.846	0.822	0.912	2.44
	GPP-4	0.818	0.833	0.895	2.14
	GPP-5	0.792	0.839	0.902	2.02
Environmental sustainability		CA = 0.927) CR = 0.928) AVE = 0.695	CA = 0.942 CR = 0.942 AVE = 0.700	CA = 0.892 CA = 0.943 AVE = 0.606	
	ES-1	0.806	0.838	0.886	2.27
	EP-2	0.853	0.822	0.895	2.80
	EP-3	0.819	0.847	0.889	2.43
	EP-4	0.860	0.822	0.911	2.95
	EP-5	0.842	0.843	0.598	2.59
	EP-6	0.821	0.846	0.579	2.68
	EP-7	0.833	0.840	0.592	2.52

structure is suitable for evaluation.

4. Empirical results and discussions

We present the empirical results leading to our research hypothesis testing. Notably, the constructs' predictive relevance is assessed using R^2 and Q^2 with Cohen's (1988) requirement of R^2 being over 0.26 for substantial predictive power (Cohen, 1998). Fig. 2 reveals that Fintech accounts for 79% of the total variance in green innovation and Fintech and green innovation account for 84% of the environmental sustainability variance. The results indicate that both constructs have excellent predictive capacity. In addition, the Q^2 value indicates the predictive significance of endogenous components, with a value greater than 0 indicating their predictive significance. The findings further showed that research variables obtained predictive relevance (ES $Q^2 = 0.524$ and green innovation $Q^2 = 0.412$).

Table 4
Correlations and Discriminant validity.

China	1	2	3	4
1. Fintech	**0.828**			
2. Green product innovation	0.262 ***	**0.844**		
3. Green process innovation	0.146 ***	0.462 ***	**0.825**	
4. Environmental sustainability	0.363 **	0.549 ***	0.434 ***	**0.834**
Observation	267	267	267	267
India	**1**	**2**	**3**	**4**
1. Fintech	**0.789**			
2. Green product innovation	0.386***	**0.843**		
3. Green process innovation	0.489***	0.112 ***	**0.822**	
4. Environmental sustainability	0.398 ***	0.291 ***	0.298 ***	**0.836**
Observation	210	210	210	210

Table 5
Correlations and discriminant validity.

Constructs	1	2	3	4
1. Fintech	**0.899**			
2. Green product innovation	0.510	**0.909**		
3. Green process innovation	0.499	0.440	**0.913**	
4. Environmental sustainability	0.363	0.249	0.344	**0.778**
Observation	477	477	477	477

Table 6
Heterotrait-Monotrait ratio (HTMT) – Matrix.

	1	2	3	4
1. Fintech				
2. Green product innovation	0.717			
3. Green process innovation	0.811	0.712		
4. Environmental sustainability	0.725	0.821	0.717	
Observation	477	477	477	477

4.1. Direct effects

We tested the direct hypothesis using PLS-SEM and bootstrapping methods after confirming the reliability, validity, and model fitness. The PLS path results show that direct relationships are positive and significant in their corresponding outcome constructs. Fig. 2 provides a summary of the results.

4.1.1. Direct effects of Fintech on green innovation and environmental sustainability

We present the results of the analysis of the effect of Fintech on green innovation. In Fig. 2, H1 anticipated that Fintech would positively support firms' green innovations. As expected, the direct impact is positive and significant ($\beta = 0.829$, PV < 0.001). Thus, H1 is validated supporting the notion that Fintech significantly contributes to green innovation. The study indicates that Fintech is a dynamic capability that

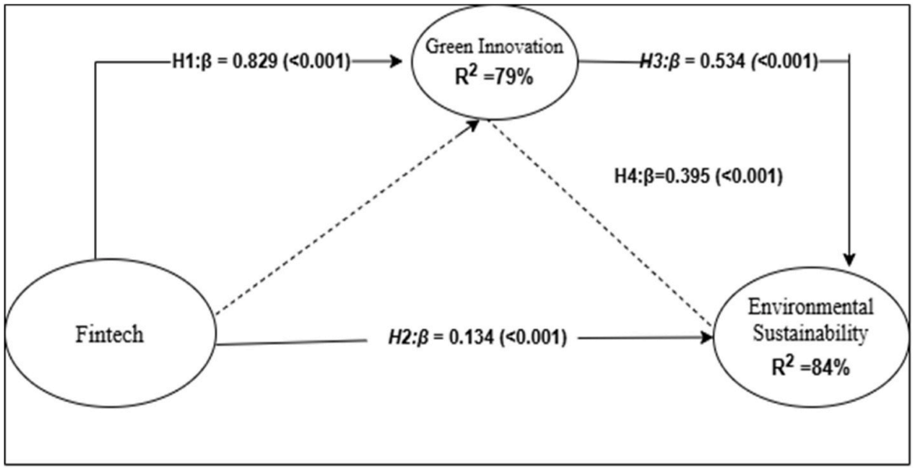

Fig. 2. PLS-SEM Results, Note: significant at *** (0.000) and 1%.

aids manufacturing organizations in enhancing their environmental investments and performance (Guang-Wen and Siddik, 2022). The study supports previous research highlighting the transformative potential of Fintech in promoting green practices within industries (Liu et al., 2022, 2024a; Tian et al., 2023). Furthermore, the findings support the literature indicating that Fintech usage significantly influences industrial structure and environmental sustainability through green products, recycling, and reprocessing (Cheng et al., 2023). The study suggests that while the link between Fintech and green innovation is still developing, it could potentially support manufacturing firms green products and process innovation developments, thereby promoting environmental sustainability. More specifically, Fintech supports green product and process innovation by enhancing funding accessibility, enabling data-driven decision-making, and streamlining resource allocation. These advancements are fostering sustainable operations, minimizing environmental influence, and aligning closely with global sustainability objectives. The study further supports that Fintech significantly promotes eco-friendly practices, including cleaner production methods and efficient energy utilization, contributing to environmental sustainability. (Zhou et al., 2022). The integration of Fintech into sustainability strategies is crucial for achieving sustainable environmental and economic benefits.

In H2, we expected that Fintech would positively enhance firms' environmental sustainability. Indeed, our result shows a positive and significant impact on firms' environmental sustainability ($\beta = 0.134$ PV < 0.001). Hence, H2 is validated. The result matches with (Liu et al., 2024a) and further complements and advances previous studies (Cheng et al., 2023; Zhou et al., 2022). This result substantiates claims in the literature that, firms' Fintech solutions can optimize resource uses within production processes, innovate green products and processes, enhance supply chain sustainability, and manage environmental risks (Muganyi et al., 2021; Yan et al., 2022). However, it contracts with (Li et al., 2023a) who argued that Fintech is negatively related to environmental pollution of Chinese industrial firms. The disparity underscores the intricate interplay between Fintech and environmental sustainability, varying across different industries and geographical regions. This also restated the importance of Fintech in China's goal of carbon neutrality by 2060 (Liu et al., 2024a; Nenavath, 2022) highlights that green finance-based Fintech significantly lessens carbon emissions to achieve environmental sustainability. The study indicates that manufacturing companies are utilizing Fintech to enhance operational efficiency, reduce waste, and adopt cleaner production methods, ultimately promoting sustainability. Notably, we discover Fintech and environmental sustainability nexus in manufacturing organizations, focusing on China and India. Therefore, we highlight Fintech's capability to promote sustainable industrial practices and advance global environmental goals.

4.1.2. Direct effects of green innovation and environmental sustainability

We expected that green innovation would positively enhance firms' environmental sustainability. In Fig. 2 and Table 7, green innovation positively impacts environmental sustainability ($\beta = 0.534$, $PV < 0.001$), supporting H3. This indicates that green innovation in manufacturing reduces carbon pollution emissions to enhance environmental sustainability. This result validates previous studies from the literature (Hao and Chen, 2023; Chien et al., 2022, 2023), underscoring the crucial role of green technological innovation in reducing greenhouse carbon emissions. Furthermore, recent studies suggest that green technological innovation is a significant global strategy for reducing carbon emissions (Omri, 2020; Ullah et al., 2021; Li et al., 2023b). Green innovation is essential for manufacturing firms to become environmentally sustainable, reducing their CO2 emissions and promoting eco-friendly technologies and innovative practices. Green innovation enables firms to develop advanced energy production and conservation methods, transitioning from conventional sources to sustainable alternatives. Particularly, green innovation enables manufacturing companies to utilize renewable energy solutions and energy-efficient technologies, thereby reducing CO2 emissions, operational costs, and environmental impact. Yet, the result contrasts with Weina et al. (2016) who argued that green innovation increases environmental productivity rather than reduces carbon emissions. However, our analysis suggests that manufacturing firms are increasingly adopting green processes and product innovations to mitigate their environmental impact throughout their entire life cycle. The integration of clean technologies and environmentally friendly materials is being implemented to decrease energy consumption, greenhouse gas emissions, and pollution, thus promoting sustainability. The significance of green innovation extends to its alignment with the United Nations Sustainable Development Goals. Considering the global challenge of climate change, international environmental policies now emphasize the importance of collaboration in advancing green innovation. Manufacturing firms are actively promoting sustainable practices and technologies to combat global warming and pollution. Notably, this finding supports the DCV perspective that firms possess the DCs to lessen the environmental consequences through

Table 7
Confirmatory composite Tests.

Tests	Values	HI_{99}	Decision
SRMR	0.074	0.079	Supported
d_{ULS}	2.098	2.333	Supported
d_G	0.736	0.801	Supported

green innovation. Hence, we argue that GI enables manufacturing firms capabilities to reduce environmental impacts, leading to contributing to both organizational and global sustainability goals.

For the control variables, results indicate that FA positively and significantly influences green innovation and environmental sustainability (ES), suggesting that older firms may possess the necessary resources and knowledge to effectively implement sustainable practices. Older firms, with their considerable financial and human capital, established processes, and strong reputations, are adept at managing environmental issues, adhering to regulations, and adapting to sustainability trends. However, the FA effect is greater on ES suggesting that older manufacturing firms in China and India are better positioned to adopt and implement sustainable practices. This can be attributed to their established operations, extensive resources, and expertise in navigating intricate regulatory and market environments. The significance of environmental compliance and sustainability in manufacturing is growing, with mature firms in these countries leveraging their stability and expertise to meet global sustainability standards. Similarly, results evidence positive and significant effect of FS on both green innovation, and environmental sustainability, indicating that larger firms are more likely to develop green products and process innovations for environmental sustainability practices considering their substantial financial resources, advanced infrastructure, and skilled workforce. The study highlights the benefits of scale in driving technological and sustainable advancements in manufacturing firms in China and India, highlighting their capability to absorb costs, comply with regulations, and align with global sustainability trends. The study supports DCV suggesting that older and larger manufacturing firms demonstrate their dynamic capabilities by utilizing their expertise, financial resources, and workforce to develop green processes and sustainability policies.

Moreover, INDCOM shows a positive and significant effect on GI and ES implying that competitive pressure drives firms to innovate and adopt advanced practices to maintain their market position. China and India's manufacturing firms are adopting Fintech, green innovation, and sustainability practices to meet regulatory standards and consumer expectations, driven by competition. Literature discovered that competitive pressure drives sustainable practices creating a dynamic market where firms aim to improve performance and gain a competitive advantage (Sin and Sin, 2020; Ocloo et al., 2018). Notably, the effect of INDCOM is larger on environmental sustainability compared to green innovation suggesting that competitive pressures compel firms to prioritize sustainable practices more strongly. Organizations in China and India are prioritizing environmental sustainability to comply with regulations, meet consumer expectations, and gain a reputation advantage (Lin et al., 2024a). While green innovation may be driven by competition, sustainability efforts may provide a more visible way to differentiate and comply in competitive markets. This supports the DCV suggesting that dynamic capabilities empower manufacturing companies to navigate complex and competitive environments, especially in emerging economies like China and India, under increasing regulatory scrutiny and international sustainability standards. Finally, the results suggest that R&D intensity plays a pivotal role in fostering GI and environmental sustainability, highlighting the necessity of investing in eco-friendly technologies and practices. The study indicates that manufacturing firms prioritizing R&D innovate more environmentally, improve resource efficiency, and uphold sustainability standards, thereby gaining a sustainable competitive advantage. Therefore, policymakers and business leaders may consider increasing incentives for R&D to foster a greener and more sustainable industrial sector.

4.2. Mediation effects

To test the mediating effect, we utilized SPSS Macro-Processes (Model 4) to perform 5000 repeated samplings using the bootstrap method, overcoming constraints like low statistical efficiency and normal distribution of Sobel test mediation effect value. We constructed a 95% unbiased confidence interval to examine the mediating impact of green innovation between Fintech and environmental sustainability in the conceptual model. Table 8 reveals that the research's proposed pathway was statistically significant, with confidence intervals excluding zero.

Results evidence positive indirect effect of green innovation on Fintech and environmental sustainability ($\beta = 0.395$, *p-value*< 0.001, 95% CI = [0.286, 0.506]), supporting H4. The direct and total impacts were significant ($PV < 0.001$) confirming the partially mediating effect of green innovation between Fintech and firms' environmental sustainability. In particular, the findings suggest that green product innovation promotes environmental sustainability in Fintech enterprises by predicting consumer demand, monitoring environmental impact, and establishing green marketing feedback systems (Wang et al., 2021; Singh et al., 2020). On the other hand, the findings explain that green process innovation helps manufacturing firms in environmental governance, production lines, manufacturing developments, learning digital transformation strategies, and promoting green development. Therefore, we argued that Fintech-based manufacturing companies are promoting green process innovation to enhance operational efficiency and environmental governance in various industries, focusing on coordinating capabilities towards sustainability (Xie et al., 2022; Bhatia, 2021). Previous studies have utilized institutional, stakeholder, and resource-based view (RBV) theories to evidence how green innovation develops and improves firm performance influenced by internal and external factors (Xie et al., 2019; Qiu et al., 2020; Chang, 2011). However, the research fails to completely investigate the links between digital technology use and firms' environmental sustainability. Therefore, we utilize the DCV to investigate how firms exploit Fintech for green innovations in a dynamic business environment. We complement the existing literature, providing a comprehensive knowledge of how green innovation (product and process innovation) influences Fintech on the environmental sustainability of manufacturing firms. Finally, we conducted numerous alternative estimations to check the robustness of the findings together with some additional analysis. These results underline the validity of our results.

4.3. Robustness analysis

We adopted the PLS-SEM to analyze and compare China and India to understand individual country effects. As shown in Table 10, we have evidence significant impact of Fintech on green innovation in both countries, with China showing a greater impact than India. The findings can be attributed to countries' market size and development. China's larger manufacturing sector and developed Fintech offer more opportunities for green innovation adoption by manufacturing firms due to its larger market size. Notwithstanding, the Indian manufacturing sector is experiencing rapid growth, with the increasing Fintech adoption potentially positively impacting green innovations. Likewise, Fintech and GI reveal positive and significant impacts on environmental sustainability with their effect larger in China than India. The findings can be linked to the below factors. First, China's manufacturing sector,

Table 8
Direct results.

Variables	Green Innovation		Environmental Sustainability	
	Coff (T-Stats)	P-value	Coff (T-Stats)	P-value
Fintech	0.829 (39.448)	<0.001	0.134 (4.167)	<0.001
Green innovation			0.534 (15.360)	<0.001
Control Variables				
Firm Age	0.038 (1.084)	<0.001	0.281 (0.739)	<0.001
Firm Size	0.301 (0.205)	<0.001	0.059 (1.690)	<0.001
INDCOM	0.093 (4.013)	<0.001	0.122 (2.052)	<0.001
R&D Intensity	0.032 (1.567)	<0.001	0.018 (0.602)	<0.001
Obs.	477		477	

Note: ***, **, *, indicate significance level at 1%, 2%, and 5% levels.

Table 9
Mediation results.

Hypothesis	Indirect Effect	Direct Effect	Total Effects
H4: Fintech →GI→ ES	0.395 ***(14.866) CI = [0.286, 0.506]	0.138***(4.323) CI = [0.075,0.201]	0.534***(19.189) CI = [0.478,0.588]

Table 10
Hypothesis validation.

Hypothesis	Path	β-value	P-value	Supported
H1	Fintech → GI	0.671	<0.001	Yes
H2	Fintech → ES	0.138	<0.001	Yes
H3	GI → ES	0.547	<0.001	Yes
H4	Fintech → GI→ES	0.395	<0.001	Yes

larger than India's, has a larger environmental footprint, prompting firms to adopt Fintech, green innovation for environmental sustainability. Second, China's "Made in China (2025)″ initiative aims to promote environmental sustainability by implementing green technologies and fostering innovation in manufacturing (Wang et al., 2024). Notably, the Chinese government is inspiring manufacturing firms with Fintech and green innovation investments, creating a favorable environment for Fintech integration into manufacturing processes to enhance environmental sustainability. Finally, China's advanced technological infrastructure promotes Fintech solutions in manufacturing, promoting green product innovations, energy efficiency, smart manufacturing, and supply chain optimization. Notwithstanding, India is making significant progress in environmental sustainability through the promotion of renewable energy, sustainable manufacturing, and smart technologies. Indeed, India's growing manufacturing sector and sustainability focus support the country's contribution to environmental sustainability through Fintech and green innovation. On the mediation effect, as determined by bootstrap method using a 95% confidence level and employing 5000 samples. Table 9 shows the positive indirect effect of green innovation on Fintech and environmental sustainability for both China and India. Mainly, green innovation mediates Fintech's effect on environmental sustainability in both Chinese and Indian samples. Therefore, we confirm that green product innovation partially mediates the relationship between Fintech and manufacturing firms' environmental sustainability in China and India, ensuring robustness.

Finally, we adopted split sample analysis using firm age as a theoretical variable. Our sample consisted of two groups FA (<10yrs, *N=300*) and FA (>10 yrs, *N=171*). Considering the works of (Dietrich and Wanzenried, 2011; Corbet et al., 2023), such characteristics can drive the nexus amid Fintech adoption, innovation, and sustainability initiatives. By leveraging on PLS-SEM, the results are shown in Table 11.

From the results, we find a positive and significant effect of all direct hypotheses for firm groups (see Table 12). Specifically, Fintech has a positive and 1% significance on green innovation for the groups. Interestingly, the effects of Fintech on green innovation for firms (<10 years) is larger, suggesting that, early manufacturing firms often have more financial resources to invest in research and development activities focused on green innovation, allowing firms to allocate a larger portion of their budget towards environmentally friendly processes and products. Similarly, results evidence the positive effect of Fintech and green innovation on environmental sustainability for both firm types. However, firms that existed for 10 years had the largest effects indicating that early manufacturing firms tend to have a culture that values innovation and sustainability. Such firms that embrace Fintech can leverage its dynamic capabilities to support green processes and product innovation. For example, Fintech enhances the efficiency of data collection and analysis in early manufacturing firms, providing valuable insights into operations and environmental performance (Dhiaf et al., 2024). By leveraging data analytics, firms can identify areas where energy consumption can be reduced, waste can be minimized and sustainable practices can be implemented, leading to enhanced environmental sustainability. For mediation, results remained unchanged for both firm types. Overall, the findings remain consistent and robust.

4.4. Endogeneity test

We adopted Two Stage Least Squares and instrumental variable approaches to account for likely endogeneity. Numerous scholarships indicate that organizations frequently incorporate Fintech into their daily business operations (Hu and Pan, 2023; Ghouri et al., 2022). We utilized a prior research approach to identify instrumental variables, focusing on the routine use of Fintech as the instrumental variable (Chen et al., 2021). Lin et al. (2024b) emphasize that instrumental variables must adhere to exogenous conditions and selection rules, considering many factors. First, regular use of Fintech in business influences decision-making by manufacturing companies and employees for problem-solving and innovation. Second, Fintech is primarily utilized for managing structured business tasks, but it can also be utilized to enhance environmental sustainability within companies. This suggests that regular use of Fintech does not directly influence the environmental sustainability of firms. Results show a significant relationship between instrumental variables and Fintech ($\beta = 0.223$, *p-value*< 0.001), but not with enterprises' environmental sustainability ($\beta = 0.021$, *p-value*> 0.1). The results of the first-stage F statistic exceed the threshold of 10, and the Cragg-Donald Wald F statistic exceeds 16.38 critical value at the significance level of 10% showing the lack of weak instrumental variable problems. The second stage evidences a positive nexus between Fintech and environmental sustainability, indicating no significant concern for endogeneity.

5. Conclusions and implications

The study examines the relationship between Fintech, green innovation, and environmental sustainability. We utilize a dynamic capability view to illustrate the impact of Fintech on firms' environmental sustainability, through green innovation. The proposed links were

Table 11
Country comparison results.

Relationships	China *(N=267)*			India *(N=210)*		
	βeta	T Stats	P-Values	βeta	T Stats	P-Values
Fintech → GI	0.447	27.968	0.000	0.344	6.292	0.000
Fintech→ ES	0.558	19.09	0.000	0.198	4.318	0.000
GI→ES	0.428	7.405	0.000	0.370	6.312	0.000
Mediation Effects	**Indirect Impact**	**Direct Impact**	**Total Impact**	**Indirect Impact**	**Direct Impact**	**Total Impact**
Fintech→ GI → ES	0.316 *** [0.180,0.439]	0.306 *** [0.087,0.348]	0.622 *** [0.267,0.787]	0.324 *** [0.231,0.404]	0.209 *** [0.146,0.273]	0.533 *** [0.478,0.578]

Note: GI and **ES** denote green innovation and environmental sustainability.

Table 12
Firm types of results.

Hypothesis	Full sample (N = 477)		China (N = 267)		India (N=(210)	
	<10 Yrs	>10 Yrs	<10 Yrs	>10 years	<10 years	>10 years
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Direct effects	Estimates	Estimates	Estimates	Estimates	Estimates	Estimates
Fintech→ GI	0.548 ***	0.322 ***	0.507 ***	0.308 ***	0.407 ***	0.318 ***
Fintech→ ES	0.336 ***	0.198 **	0.318 ***	0.231 ***	0.112 ***	0.086 ***
GI → ES	0.593 ***	0.337 *	0.533 ***	0.412 ***	0.423 ***	0.326 ***
Mediation						
Fintech → GI →ES	0.418 ***	0.246 ***	0.392 ***	0.293 ***	0.376 ***	0.289 ***

Note: GI and **ES** denote green innovation and environmental sustainability.

empirically verified using data from 477 Chinese and Indian manufacturing enterprises. The empirical findings show that (1) Fintech positively supports green innovations (2) Fintech positively influences environmental sustainability (3) Green innovation positively enhances firms' environmental sustainability (4) Green innovation partially mediates Fintech effect on firms' environmental sustainability. The research findings strongly support that, Fintech has a positive effect on environmental sustainability and green innovation is the mechanism that shapes these links in the field of information systems and environmental management. Overall, we highlight the significant role of Fintech in supporting green innovation in manufacturing enterprises, leading to improved environmental sustainability at the firm level.

5.1. Theoretical implications

Our research significantly contributes to the existing literature. First, Fintech and sustainability literature cover various disciplines, tackling environmental challenges. Liu et al. (2024a) studied Fintech on natural resources and environmental sustainability from 2000 to 2020, focusing on green growth and technological solutions. Additionally (Cheng et al., 2023), studied Fintech development on carbon emissions in prefecture-level cities in China from 2011 to 2019, highlighting its growth potential. However, limited research uses information systems to discover Fintech's impact on manufacturing firms' environmental sustainability, suggesting an undiscovered mediating variable. Fintech recognized as a promising modern technology, has the potential to significantly lead to enhanced environmental sustainability, which requires an appropriate lens to explain its rationale (Goralski and Tan, 2020). Notably, the mechanism behind the issue remains uncertain. Therefore, we address the need for further scholarship on the potential mediating impact of green innovation in technological advancement (Tariq et al., 2017). The study reveals that Fintech and environmental sustainability are influenced by green innovation explaining the implication of Fintech for green innovation developments to achieve environmental sustainability. Hence, we shed insight on the underlying mechanism by which Fintech enhances the environmental sustainability of manufacturing firms and further provides insights into their relationships through green product and process innovations.

Second, numerous studies explore customers' adoption and Fintech behavior, yet limited studies on its influence on environmental sustainability in manufacturing settings (Siddik et al., 2023). Few studies have explored Fintech's role in enhancing environmental sustainability in manufacturing firms, with studies being conceptual (Siddik et al., 2023). Further, most studies focused on digital finance in promoting sustainability, instead of Fintech in general (Rao et al., 2022). Notably, research calls for empirical scholarship on Fintech's impact on firm-level sustainability performance (Pizzi et al., 2021). Therefore, we highlight the significant positive impact of Fintech on the environmental sustainability of manufacturing firms, filling observed gaps in existing literature. Particularly, we shed light on manufacturing firms in China and India's capability to utilize Fintech to better address ecological issues to achieve environmental sustainability. Third, most literature studies utilized firm secondary data sources to estimate and measure environmental sustainability, green innovation, and Fintech measurements (Sarkodie and Ozturk, 2020; Nathaniel and Adeleye, 2021; Obuobi et al., 2024). In this paper, we utilized validated questionnaires adapted from literature to measure variables at the manufacturing level. The study aims to understand green innovation and environmental sustainability by analyzing the Fintech application levels of manufacturing firms, gathered from managers. Therefore, we offer valuable insights for China-India, and other emerging markets on reducing manufacturing industry emissions through green innovation research, digitization, and Fintech integration.

Finally, we examine Fintech's contribution to enhancing environmental sustainability through green innovation, thereby validating and extending the DCV within IS and environmental management literature. The DCV suggests that firms can reduce their environmental impact by utilizing dynamic capabilities that enable swift adaptation to changing challenges and market conditions (Dubey et al., 2019; Li et al., 2024). Building on this insight, we argue that Fintech is a transformative mechanism that promotes green innovation, enabling firms to strategically respond to environmental uncertainties and sustainability demands in emerging markets. By linking Fintech's dynamic capabilities to green innovation strategies (Steininger et al., 2022), we advance the theoretical foundation of the DCV and offer a novel, actionable framework for sustainability in the digital age. Furthermore, we offer valuable insights for policymakers and industry leaders, emphasizing Fintech's role in resource reorganization, adaptive capability development, and sustainable innovation. Fintech is becoming a crucial enabler for firms to navigate digital transformation and environmental sustainability, enhancing the relevance of DCV in business and sustainability discourse.

5.2. Managerial and policy implications

We highlight three practical relevance for the managers of manufacturing firms. First, firms must utilize Fintech to hasten the transition from conventional growth models to a digitally driven sustainable framework to thrive in the digital age. Therefore, managers must prioritize Fintech in addressing firm-environment relationships, develop sustainable Fintech plans, and reduce negative business activities. In practical applications, Fintech is being utilized by firms to achieve sustainability goals, streamline processes, and tackle environmental issues, requiring managers to focus on developing modern digital platforms and Fintech managerial capabilities. Further, firms can enhance green innovation by integrating resources, refining approaches, enhancing operational efficiency, and utilizing Fintech to interpret environmental information. Second, as evidence that green innovation mediates the Fintech effect on firms' environmental sustainability, managers should concentrate on fostering green innovation in both product and process development. Green innovation enhances firms' competitiveness in volatile markets by reducing production costs, responding quickly to environmental changes, and meeting stakeholder demands (Chen and Chang, 2013). For example, Mengniu, a Hong Kong-listed organization is integrating environmental concerns into its objectives, follows, and policies, investing significant resources and money in green innovation (Li et al., 2024). In particular, companies should invest in environmental technology research and development, along with Fintech, to anticipate consumer demand for environmentally friendly products and align green product development with market demands. Additionally, firms should establish incentive structures to motivate employees in green product innovation, thus boosting growth within the organizational framework. Concerning green process innovation developments, firms are advised to incorporate Fintech into green process innovation optimization to extract understandings from operational data, enabling potential improvement opportunities. Finally, firms should establish a vigorous monitoring system to assess the environmental impact of green innovation, thereby improving green process and product innovation for sustainability.

Besides, we provide four vital implications to policymakers. (1) policymakers should provide incentives to businesses to promote sustainability. For example, governments should offer tax credits as incentives for firms transitioning to renewable energy, thereby reducing costs and promoting a smooth transition toward sustainable manufacturing (Liu et al., 2024a; Jiang and Raza, 2023). (2) policymakers should help manufacturing firms address environmental degradation by investing in innovative technologies like Fintech and green innovation, thereby enhancing their sustainability. (3) Governments should ease regulations and create effective policies to encourage Fintech advancement, address financing constraints, and promote green innovation for industrial structure upgrading and sustainability. (4) Policymakers are advised to prioritize promoting the use and promotion of green product innovations to aid their economies in combating environmental degradation. The allocation of additional research funds should be made to promote the development of new green technologies.

5.3. Limitations and further studies

We present four main limitations for further scholarship. First, we utilize cross-sectional data from manufacturing firms, allowing for the potential expansion of the investigation to include a larger sample using the analytical model. Second, we used the dynamic capability view to support our hypotheses and conceptual model. Further studies can expand our research to create more complex models for estimating Fintech, green innovation, and environmental sustainability relationships. Third, the findings may have been influenced by a sample from developed nations, as we examined our research from emerging countries. Finally, the study focuses on the role of green innovation in mediating the connection between Fintech and environmental sustainability. Green innovation is a significant factor in promoting environmental sustainability, but other factors can also play a role. Therefore, we are calling for further research to examine how other elements like firm culture, leadership, and governance affect environmental sustainability directly and indirectly.

CRediT authorship contribution statement

Mandella Osei-Assibey Bonsu: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Yongsheng Guo:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Ying Wang:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Kaodui Li:** Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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