

Digital-Green Integration and Supply-Chain Resilience in Bangladesh's Footwear Industry: The Mediating Role of Circular-Economy Practices

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Abstract

Bangladesh's footwear industry faces mounting pressure to strengthen environmental performance while maintaining continuity against supply-chain disruptions, yet limited empirical evidence explains how digital and green capabilities jointly relate to resilience in this context. Drawing on dynamic capability theory, this study examined the associations among digital technology adoption (DTA), green supply-chain management (GSCM), and supply-chain resilience (SCR) among managers and professionals in Bangladesh's footwear manufacturing and supply-chain organizations. A cross-sectional survey of 47 valid respondents was analyzed using reliability analysis, Pearson and Spearman correlation, and ordinary least squares regression with robust standard errors. DTA was positively associated with GSCM ($r = .446$, $p = .002$). DTA and GSCM each showed a positive, statistically significant, and independent association with SCR, together explaining 54.5% of the variance in resilience, with DTA showing the larger unique effect ($\beta = .526$ versus $\beta = .334$ for GSCM). Item-level analysis further identified digital traceability and green purchasing as the two practices with the largest perceived implementation gaps in the sample. Circular-economy practices were measured but excluded from the confirmatory analysis and remain a direction for future research. The findings suggest that digital and green capabilities each contribute distinctly to supply-chain resilience and point to traceability and green sourcing as priority areas for footwear manufacturers and policymakers seeking to strengthen resilience in Bangladesh's footwear sector.

Keywords: Digital Technology Adoption; Green Supply-Chain Management; Supply-Chain Resilience; Circular Economy; Dynamic Capability Theory; Footwear Industry

1. Introduction

Supply-chain resilience has become a central concern for manufacturing firms following repeated disruptions to global sourcing, logistics, and production networks in recent years. At the same time, firms face growing pressure to reduce the environmental footprint of their supply chains and to adopt digital tools that improve visibility and coordination across suppliers, production, and distribution. Two capabilities are frequently discussed in this context: digital technology adoption, which gives firms the information visibility and coordination needed to sense and respond to disruption, and green supply-chain management, which embeds environmental criteria into purchasing, supplier evaluation, and production processes. A related body of work has also examined circular-economy practices, such as waste reduction, reuse, and the use of recovered materials, as a further capability with implications for both environmental performance and resilience. How digital and green capabilities relate to one another, and to resilience specifically, is an increasingly active question in supply-chain and sustainability research (Balakrishnan & Ramanathan, 2021; Duman Altan et al., 2024).

The footwear manufacturing industry illustrates these pressures directly. Footwear production is labour-intensive, globally sourced, and subject to buyer-driven requirements around both environmental compliance and delivery reliability. Bangladesh has become a significant location for footwear and leather-goods manufacturing within this global industry (Rakib, 2020), and its manufacturers face the same combined pressure to adopt digital tools, meet environmental expectations, and maintain continuity of supply that has been documented in other developing-economy manufacturing contexts. In the adjacent Bangladeshi fashion supply chain, resilience-related capabilities, specifically visibility, agility, and collaboration, have been found to directly support waste-management and pollution-reduction outcomes, with digital tools moderating some of these relationships (Sagar et al., 2026). This suggests that resilience capabilities operate in economically meaningful ways within South Asian, export-oriented, apparel-adjacent manufacturing settings, but direct evidence from Bangladesh's footwear sector specifically was not identified among the sources reviewed for this study.

Evidence on digital technology's role in building resilience is comparatively well developed. Yang et al. (2021) synthesizes the drivers, adoption process, and downstream impact of digital technologies in supply chains, framing adoption as unfolding along a continuum shaped by technological intelligence and supply-chain cooperation. Direct empirical tests support a link to resilience outcomes: in a study of the automotive supply chain in emerging Asia-Pacific markets, digital technology use was a strong predictor of supply-chain resilience, while its direct association with firm performance was comparatively weak once resilience was accounted for (Balakrishnan & Ramanathan, 2021). This pattern is consistent with digital technology functioning as an enabler of resilience rather than a direct substitute for it.

Green supply-chain management has also been linked to resilience, though the pathway described in the literature is less direct than for digital technology. In a study of manufacturing firms in East Java, Setiawan et al. (2023) found that supply-chain digitalization was associated with green supply-chain practice, and that green supply-chain practice was in turn associated with resilience, positioning green practice as an intermediate capability rather than an independent driver operating on its own. A broader integrated model tested among Turkish manufacturing firms found that digital-technology adoption was associated with supply-chain traceability, supply-chain resilience, and circular-economy practice as three distinct and only partly overlapping pathways to sustainability performance, and, notably, that circular-economy practice on its own did not translate into stronger sustainability outcomes unless traceability or resilience were also present (Duman Altan et al., 2024). Read together, these two studies suggest that digital and green capabilities are related but distinct, and that their joint contribution to resilience cannot be assumed from either capability alone.

Digital technologies have also been linked specifically to circular-economy practice. In a study of Vietnamese manufacturing small- and medium-sized enterprises, artificial-intelligence adoption was associated with stronger circular-economy practice, supply-chain agility, and risk management, each of which contributed to resilience (Dey et al., 2024). A related study of Vietnamese manufacturing SMEs found that organisational change capacity supporting artificial-intelligence adoption was associated with supply-chain productivity, resilience, and low-carbon management (Roux et al., 2025). Evidence from blockchain-adoption research in the Egyptian supply-chain context adds a further nuance: blockchain adoption alone had a negative direct association with environmental performance, but this relationship became positive once resilience, customer integration, and green information sharing were included as intervening capabilities (Mohamed et al., 2023). This finding cautions against assuming that digital-tool adoption translates automatically into environmental or resilience gains; the mechanism through which digitalization operates appears to matter as much as adoption itself.

Three gaps follow from this review. The first is contextual. The studies identified above are set in automotive, general manufacturing, and technology-adoption samples from Turkey, Indonesia, Vietnam, and Egypt (Balakrishnan & Ramanathan, 2021; Dey et al., 2024; Duman Altan et al., 2024; Mohamed et al., 2023; Roux et al., 2025; Setiawan et al., 2023), and the one Bangladesh-based study identified is set in the fashion supply chain rather than footwear specifically (Sagar et al., 2026). How digital and green capabilities relate to resilience among footwear manufacturers operating under Bangladesh's particular sourcing, compliance, and export conditions remains unexamined within this literature. The second is theoretical. While digital and green capabilities are each linked to resilience individually, few of the studies reviewed here test them as simultaneous, distinct predictors of resilience within a single dynamic-capability framework, rather than assuming that one capability's effect operates entirely through the other. The third is empirical. The quantitative evidence reviewed above is concentrated in larger-sample, PLS-SEM-based studies of large or mid-sized manufacturing firms; smaller-scale, exploratory survey evidence from a developing-economy, labour-intensive export sector such as footwear remains scarce among the sources reviewed.

This study addresses these gaps by examining, within Bangladesh's footwear manufacturing and supply-chain sector, whether digital technology adoption and green supply-chain management are each associated with supply-chain resilience, and whether digital technology adoption is associated with green supply-chain management. Three relationships were tested to meet this objective: that digital technology adoption is positively associated with green supply-chain management (H1); that digital technology adoption is positively associated with supply-chain resilience (H2); and that green supply-chain management is positively associated with supply-chain resilience (H3).

Theoretically, the study draws on dynamic capability theory, which holds that firms build advantage through capabilities that sense change, seize opportunity, and reconfigure resources in response to a shifting environment. Digital technology adoption is treated here primarily as a sensing and coordinating capability, while green supply-chain management is treated as a capability oriented toward supplier and process reconfiguration. By testing both capabilities as simultaneous, distinct predictors of resilience, rather than assuming a single sequential pathway between them, the study extends dynamic-capability reasoning to a labour-intensive, export-oriented manufacturing context that has received limited attention in the literature reviewed for this study.

Practically, the footwear sector is a significant source of manufacturing employment and export earnings in Bangladesh (Rakib, 2020), and its supply chains face simultaneous pressure to adopt digital tools, meet buyer-driven environmental requirements, and maintain continuity against disruption. Evidence on how digital and green capabilities relate to resilience in this specific setting can help footwear manufacturers, buyers, and policymakers identify where investment in digital or environmental capability is most likely to support resilience, rather than treating these as interchangeable or automatically reinforcing investments.

This study contributes to the literature in three ways. It provides, among the sources reviewed here, one of the first empirical examinations of the relationship between digital technology adoption, green supply-chain management, and supply-chain resilience specifically within Bangladesh's footwear manufacturing sector. It tests digital and green capabilities as distinct, simultaneous predictors of resilience rather than assuming their effects operate only through one another. And it offers exploratory, survey-based evidence from a developing-economy, export-oriented manufacturing context that complements the larger-sample, PLS-SEM-based evidence available from other national and industry settings. The remainder of the paper reviews the relevant literature and develops the study's hypotheses in greater depth, describes the survey design and analytical method, reports the results, and discusses their theoretical and practical implications.

2. Literature Review

2.1 Review Scope and Source-Selection Procedure

The evidence base comprises 15 full-text PDFs supplied by the researcher. Ten sources provide primary empirical or archival evidence, whereas five perform a review, editorial, bibliometric, or contextual role. Because the corpus was provided rather than retrieved through a documented multi-database search, this chapter does not claim to be a complete systematic review of the global literature. Instead, it uses a transparent, adapted PRISMA-style flow to show how every supplied record was screened, classified, and retained. This distinction is methodologically important: PRISMA language should not imply a reproducible database search when database names, dates, exported records, and exclusion logs are unavailable.

Screening was guided by four linked concept groups: digital adoption, environmental supply-chain practice, resilience, and manufacturing or emerging-market context. A source was treated as central when it tested at least one relationship among DTA, GSCM, and SCR using primary data; as adjacent when it examined a closely related construct such as circular economy practice, low-carbon management, environmental performance, traceability, agility, or green productivity; and as contextual when it synthesized technologies, mechanisms, or research directions without testing the proposed firm-level paths.

Table 1. Keyword Framework Used to Classify the Supplied Literature

Concept group	Keywords and related terms
Digital capability	"digital technology adoption" OR "supply chain digitalization/digitisation" OR "Industry 4.0" OR AI OR blockchain OR IoT OR "digital twin"
Green capability	"green supply chain" OR GSCM OR environmental sustainability OR "circular economy" OR "low carbon" OR green productivity
Resilience	"supply chain resilience" OR resilience OR visibility OR agility OR adaptability OR recovery OR robustness
Context	manufacturing OR fashion OR automotive OR SME OR "emerging market" OR Bangladesh

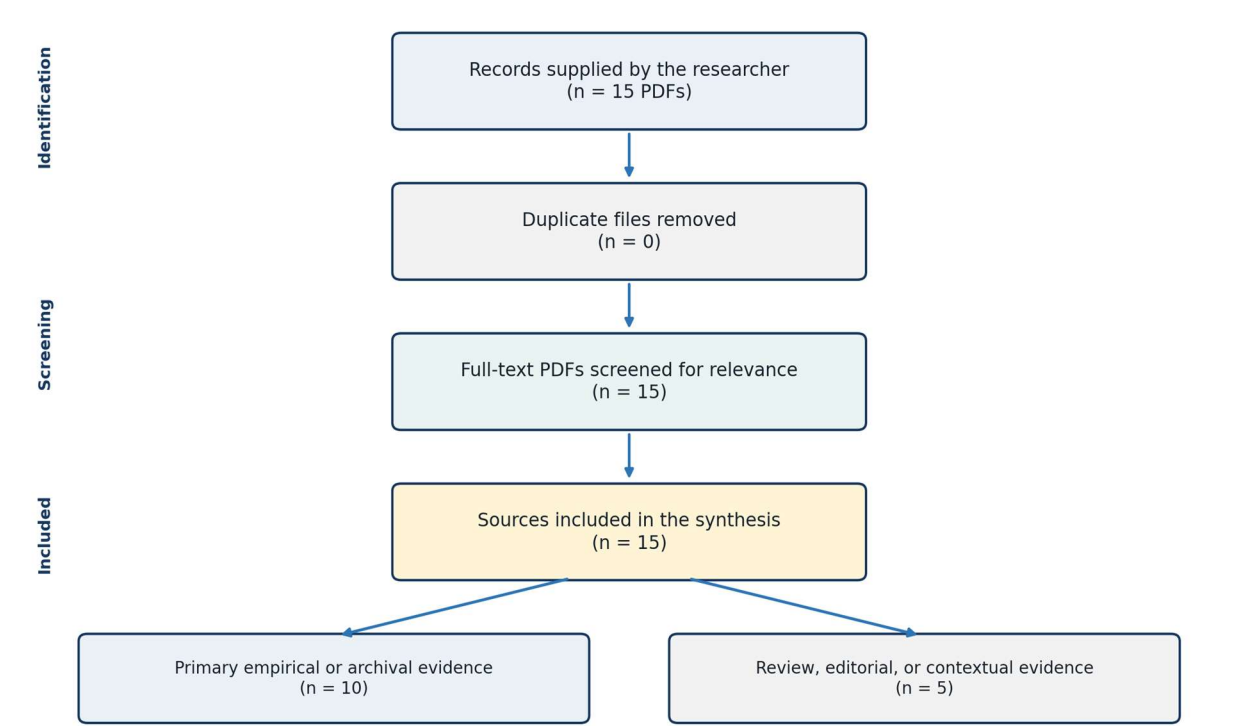


Figure 1. Adapted PRISMA-style flow for the researcher-supplied evidence set.

2.1.1 Evidence Profile

The corpus covers several emerging- or middle-income manufacturing settings: Bangladesh's fashion supply chain, East Java manufacturing, automotive supply chains across Asia-Pacific emerging markets, Vietnamese manufacturing SMEs, Egyptian manufacturing and service organizations, Turkish manufacturing, Jordanian industry, and Chinese

firms or regions. This contextual range improves mechanism-level learning, but it does not remove the need for industry-specific validation. The supplied corpus contains no primary study of the complete proposed model in Bangladesh's footwear sector.

Table 2. Evidence Matrix for the 15 Supplied Sources

Source	Design and context	Sample / method	Main contribution and critical use
Setiawan et al. (2023)	Primary survey; East Java manufacturing	n = 108; PLS-SEM	Directly tests all three paths: digitalization→green supply chain, digitalization→SCR, and green supply chain→SCR. Central evidence for H1–H3.
Balakrishnan & Ramanathan (2021)	Primary survey; automotive supply chains in Asia-Pacific emerging markets	n = 313; SEM	Digital technology use strongly predicts SCR; SCR predicts performance, while technology use has no direct performance effect. Central evidence for H2 and capability mediation.
Dey et al. (2024)	Primary survey; Vietnamese manufacturing SMEs	n = 280; SEM	AI adoption improves circular-economy practice, agility, and risk management, which contribute to SCR. Adjacent evidence for H1/H3 and indirect evidence for H2.
Roux et al. (2025)	Primary survey; Vietnamese manufacturing SMEs	n = 375; SEM	AI-powered decision systems positively influence supply-chain performance, low-carbon management, and SCR. Supports digital capability links to environmental and resilience outcomes.
Mohamed et al. (2023)	Primary survey; Egyptian manufacturing/service organizations	n = 603; SEM	Blockchain has a negative direct environmental-performance effect but a positive indirect effect through SCR; warns that technology is not intrinsically green.
Duman Altan et al. (2024)	Primary survey; Turkish manufacturing	n = 235; PLS-SEM	Digital technology predicts circular-economy practice, traceability, and SCR. Traceability strongly predicts SCR; circular-economy practice does not directly predict sustainability performance.
Sagar et al. (2026)	Primary survey; Bangladeshi fashion supply chain	n = 190; SmartPLS	Visibility, agility, and collaboration are associated with waste and pollution/emission outcomes. Digital moderation is selective and sometimes negative; closest Bangladesh evidence.
Xue et al. (2025)	Archival study; Chinese A-share firms	3,509 firm-year observations; DML	Supply-chain digitalization improves green total factor productivity, with resilience mechanisms mediating. Strong longitudinal/archival complement, but constructs are proxy-based.
Zhang et al. (2025)	Regional panel; Yangtze River Economic Belt	11 regions, 2017–2022	Digitalization predicts an integrated resilience index. Greening is embedded within the index, so the study cannot isolate a firm-level GSCM→SCR path.
Alheet (2026)	Primary survey; Jordanian industrial sector	n = 415; PLS-SEM	AI-enabled metaverse dimensions predict digital SCR, which predicts sustainable manufacturing. Relevant but used cautiously because some reported test statistics and indirect-effect labels appear internally inconsistent.
Yang et al. (2021)	Structured literature review	55 papers	Develops a driver–process–impact framework; positions IoT, big-data analytics, and AI as sources of efficiency,

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			structural change, sustainability, and innovation.
Challouf et al. (2025)	Bibliometric and structured review	49 highly cited papers	Maps Industry 4.0 technologies to waste, emissions, traceability, reverse logistics, and circularity. Useful for mechanisms; secondary evidence.
Alquraish (2025)	Systematic review	124 articles	Synthesizes digital transformation, resilience, and sustainability; proposes mediation and moderation mechanisms. Contextual, not direct primary evidence.
Tiwari et al. (2024)	Editorial synthesis	Not applicable	Frames supply-chain digitisation as a management and implementation challenge; useful for scope and caution, not hypothesis testing.
Enyejo et al. (2024)	Narrative review	Not transparently specified	Discusses digital twins and predictive analytics for risk and carbon management. Low evidential weight because the review protocol and empirical base are not clearly reported.

2.2 Core Constructs

2.2.1 Digital Technology Adoption

DTA is best treated as an organizational supply-chain capability rather than a list of purchased technologies. Across the supplied studies, its technological content includes IoT, big-data analytics, artificial intelligence, blockchain, cloud platforms, digital twins, RFID, automation, and related decision-support systems. More importantly, adoption becomes operationally meaningful when technology is integrated into procurement, production, inventory, logistics, and inter-organizational coordination; used frequently; connected to reliable data; and capable of supporting timely decisions (Balakrishnan & Ramanathan, 2021; Setiawan et al., 2023; Yang et al., 2021).

This capability interpretation avoids equating ownership with use. The automotive study distinguishes technology competency from actual use and shows that technology use, rather than mere availability, is the immediate predictor of SCR (Balakrishnan & Ramanathan, 2021). Likewise, the driver–process–impact review argues that digital adoption varies in depth and depends on technological intelligence and supply-chain cooperation (Yang et al., 2021). For the present study, DTA therefore refers to the extent to which footwear firms use integrated digital tools and data to coordinate supply-chain activities, share information, improve visibility, and support operational decisions.

2.2.2 Green Supply Chain Management

GSCM incorporates environmental objectives into supply-chain decisions and routines. In the directly aligned East Java study, the construct includes environmentally preferable inputs, greener production, greener distribution, and collaborative handling of environmental problems (Setiawan et al., 2023). Other supplied studies operationalize nearby domains through low-carbon supplier and logistics practices (Roux et al., 2025), circular-economy practices (Dey et al., 2024; Duman Altan et al., 2024), green information sharing and environmental performance (Mohamed et al., 2023), or waste and pollution/emission reduction (Sagar et al., 2026).

These constructs are related but not interchangeable. Circular-economy practice emphasizes resource loops; low-carbon management emphasizes emissions; environmental performance is an outcome; and GSCM is a broader bundle of managerial practices. Treating all of them as identical would artificially enlarge the evidence supporting the proposed path. Accordingly, this review regards them as adjacent evidence unless the source directly measures a green supply-chain practice construct. In the present model, GSCM should be operationalized through practices, green purchasing, cleaner internal operations, environmental supplier/customer collaboration, green distribution, and recovery or waste routines, rather than through realized environmental performance alone.

2.2.3 Supply Chain Resilience

SCR is the capacity of a supply chain to anticipate disruption, maintain or adapt critical operations, respond in a coordinated manner, and recover toward an acceptable or improved state. The supplied studies represent this capability through early warning, visibility, capacity adjustment, alternative plans, information sharing, risk control, learning, agility, adaptability, and restoration (Balakrishnan & Ramanathan, 2021; Duman Altan et al., 2024; Mohamed et al., 2023; Setiawan et al., 2023). The Bangladeshi fashion study decomposes resilience into visibility, agility, flexibility, and collaboration, illustrating that resilience is multidimensional and that dimensions may not exert identical effects (Sagar et al., 2026).

For the proposed footwear study, SCR is conceptually distinct from routine efficiency and from final firm performance. A supply chain can be efficient in stable conditions yet fragile under disturbance; conversely, resilience may require information redundancy, alternative arrangements, or spare response capacity whose value emerges during disruption. The non-significant direct technology-use-to-performance path in the automotive study reinforces this distinction: technology generated performance value primarily through resilience practices (Balakrishnan & Ramanathan, 2021).

2.3 Dynamic-Capabilities Explanation

The project's dynamic-capabilities logic (Teece et al., 1997) provides a coherent explanation for the three-construct model. Under volatility, firms must sense changes, seize response opportunities, and reconfigure resources and relationships. DTA strengthens sensing by generating timely, granular, and shareable information; it supports seizing through analytics, alerts, simulation, and coordinated decisions; and it supports reconfiguration by enabling alternative plans, supplier changes, capacity adjustments, and recovery monitoring. The digital-adoption review's driver–process–impact sequence is consistent with this view because technology produces results through organizational adoption processes rather than automatically (Yang et al., 2021).

GSCM can also be interpreted as a reconfiguration capability. Green purchasing changes supplier criteria; cleaner production changes process design; green distribution changes logistics choices; and recovery practices create alternative resource loops. These routines may reduce dependence on scarce inputs, improve knowledge sharing with supply-chain partners, and broaden response options. SCR is therefore not simply another sustainability outcome. It is the adaptive capability through which digitally informed and environmentally disciplined routines help the supply chain prepare for, absorb, and recover from disruption.

The framework also clarifies why simple technology determinism is inadequate. A digital tool may increase data volume without producing reliable information, create coordination demands, or shift risk to less capable partners. Similarly, a green initiative may add cost or rigidity if it is implemented as compliance rather than embedded capability. The negative direct blockchain–environmental-performance result in the Egyptian study and the mixed digital moderation effects in Bangladesh's fashion supply chain both demonstrate that outcomes depend on complementary organizational mechanisms (Mohamed et al., 2023; Sagar et al., 2026).

2.4 Digital Technology Adoption and Green Supply Chain Management

2.4.1 Enabling Mechanisms

Digital technologies can enable GSCM through four connected mechanisms. First, visibility and traceability make material origin, process conditions, inventory, transport, and waste streams more observable. Second, analytics can identify inefficiency, forecast demand, improve resource allocation, and reveal environmental hotspots. Third, digital platforms support information exchange with suppliers and customers, allowing environmental requirements and performance information to travel across organizational boundaries. Fourth, automation and decision support can translate data into operational changes, including cleaner scheduling, reduced excess inventory, improved routing, and recovery decisions. The technology reviews consistently identify IoT, analytics, AI, blockchain, cloud systems, and digital twins as potential enablers of traceability, waste reduction, emissions control, reverse logistics, and circularity (Challouf et al., 2025; Enyejo et al., 2024; Yang et al., 2021).

2.4.2 Direct and Adjacent Empirical Evidence

The clearest direct evidence is the East Java manufacturing study. It reports a positive effect of supply-chain digitalization on the green supply chain ($\beta = .322, p = .009$), while simultaneously estimating digitalization and green supply-chain effects on SCR (Setiawan et al., 2023). This is unusually close to the present conceptual model because it treats green supply-chain practice as a distinct construct rather than substituting environmental performance for practice.

Several studies support the relationship through adjacent environmental capabilities. In Vietnamese manufacturing SMEs, AI adoption positively influences circular-economy practices, and those practices form one pathway toward SCR (Dey et al., 2024). A second Vietnamese SME study finds that AI-powered decision systems positively influence low-carbon management ($\beta = .29, p = .01$) alongside resilience and supply-chain performance (Roux et al., 2025). In Turkish manufacturing, digital technology adoption predicts circular-economy practice ($\beta = .317$), traceability ($\beta = .414$), and SCR ($\beta = .164$) (Duman Altan et al., 2024). At a different unit of analysis, a Chinese archival study finds that supply-chain digitalization improves green total factor productivity, partly through resilience-related mechanisms (Xue et al., 2025). These studies broaden the mechanism base, although low-carbon management, circularity, and green productivity remain proxies or neighboring constructs rather than exact replications of DTA→GSCM.

2.4.3 Critical Qualification

The relationship should not be framed as automatic. In the Egyptian study, blockchain adoption has a negative direct association with environmental supply-chain performance ($\beta = -.267, p < .005$), while its indirect effect through SCR is positive ($\beta = .057, p < .009$) (Mohamed et al., 2023). This pattern implies that implementation burden, energy or coordination costs, immature use, or lack of complementary routines may offset environmental gains. The supplied reviews similarly emphasize adoption process, cooperation, and managerial alignment rather than technology acquisition alone (Tiwari et al., 2024; Yang et al., 2021).

The Bangladeshi fashion study supplies an additional boundary condition. Digital tools strengthen the visibility-to-

waste-management relationship, but most other moderation effects are non-significant and some agility interactions are negative (Sagar et al., 2026). Thus, specific digital applications may reinforce some green routines while weakening or failing to influence others. The current study's aggregate DTA construct is defensible for a modest sample, but interpretation should focus on effective, integrated use rather than assuming equal environmental value from every technology.

Overall, the evidence is theoretically coherent and empirically positive, but exact direct tests remain limited. The first hypothesis is therefore a contextual replication and extension, not a claim that the relationship has never been studied.

H1: Digital technology adoption is positively associated with green supply chain management in Bangladesh's footwear industry.

2.5 Digital Technology Adoption and Supply Chain Resilience

2.5.1 Information, Coordination, and Response Mechanisms

DTA can strengthen SCR by increasing end-to-end visibility, shortening detection time, improving demand and supply forecasts, supporting scenario analysis, and enabling rapid communication across supply-chain entities. Track-and-trace systems identify disruption location; real-time data help firms reassess inventory and capacity; analytics support alternative sourcing and production decisions; and connected platforms accelerate coordinated response. These mechanisms align closely with the resilience items used in the automotive study: visibility, capacity management, recovery planning, information sharing, alternative cost options, and parts tracking (Balakrishnan & Ramanathan, 2021).

2.5.2 Empirical Support

The DTA→SCR relationship has the broadest and most consistent primary evidence in the corpus. In East Java manufacturing, digitalization has a positive direct effect on SCR ($\beta = .284, p = .002$) while GSCM is controlled (Setiawan et al., 2023). In Asia-Pacific emerging-market automotive supply chains, technology use strongly predicts SCR ($\beta = .713, p < .001$), and SCR subsequently predicts supply-chain performance ($\beta = .717$). Technology use has virtually no direct performance effect ($\beta = .008, p = .894$), suggesting that resilience is the conversion mechanism rather than a side outcome (Balakrishnan & Ramanathan, 2021).

Turkish manufacturing evidence is directionally consistent: digital adoption predicts SCR ($\beta = .164$), while traceability, also enabled by digital adoption, has an even stronger relationship with SCR ($\beta = .512$) (Duman Altan et al., 2024). The Vietnamese SME study of 375 managers reports a positive AI-to-SCR effect ($\beta = .36, p = .01$) (Roux et al., 2025). In the 280-firm Vietnamese SME study, AI adoption does not enter SCR as a simple isolated direct path; instead, it improves circular-economy practices, agility, and risk management, which collectively build resilience (Dey et al., 2024). This difference is substantively useful because it shows that the route from technology to resilience can be both direct and capability-mediated.

Archival and regional studies offer complementary evidence at higher levels of analysis. Chinese firm data from 2013–2023 indicate that digitalization improves green productivity through supply–demand matching, supplier quality, and stable relationship mechanisms that represent resilience (Xue et al., 2025). Across 11 Yangtze River Economic Belt regions, digitalization is positively associated with a composite manufacturing chain-resilience index (coefficient = .0133, $p < .05$) (Zhang et al., 2025). These designs reduce exclusive reliance on single-respondent surveys, although their regional and proxy measures do not map exactly onto the proposed perceptual firm-level constructs.

A Jordanian industrial study also reports positive paths from digital-twin, predictive-AI, and virtual-collaboration dimensions to digital SCR, followed by a strong SCR-to-sustainable-manufacturing path (Alheet, 2026). It is treated as supplementary rather than decisive evidence because several displayed test statistics do not appear to align with their coefficients and standard deviations, and some reported indirect effects reproduce direct-path values. This does not justify discarding the study, but it limits the precision with which its estimates should be used.

2.5.3 Boundary Conditions

Digitalization can also introduce dependency, cyber exposure, data-quality problems, integration cost, and skills requirements. The supplied literature repeatedly indicates that technology creates value when supported by competencies, organizational change capacity, cooperation, and reliable data (Balakrishnan & Ramanathan, 2021; Roux et al., 2025; Yang et al., 2021). The relevant theoretical claim is therefore not that any digital purchase creates resilience, but that meaningful adoption enables the sensing, coordination, response, and recovery routines from which resilience emerges.

Given the consistency of direct and mediated evidence across multiple emerging-market contexts, the second hypothesis has the strongest empirical foundation in the proposed model.

H2: Digital technology adoption is positively associated with supply chain resilience, after accounting for green supply chain management.

2.6 Green Supply Chain Management and Supply Chain Resilience

2.6.1 Complementarity Between Green and Resilient Routines

GSCM may build SCR when environmental routines diversify resources, strengthen supplier collaboration, reduce

process waste, improve information exchange, and establish recovery channels. Green purchasing can make environmental and continuity criteria part of supplier evaluation; cleaner and less wasteful operations can reduce exposure to resource constraints; green collaboration can deepen inter-firm problem solving; and recovery or circular practices can create alternative flows when virgin inputs or conventional disposal routes are disrupted. In dynamic-capabilities terms, these routines reconfigure the supply chain before and during disturbance.

However, complementarity should not be assumed in every case. Some environmental practices can initially add cost, qualification time, or supplier restrictions. Resilience can also be pursued through redundancy or expedited transport that may conflict with environmental efficiency. The analytical question is therefore whether, in the focal context, a coherent bundle of green supply-chain practices expands adaptive capacity more than it constrains short-term options.

2.6.2 Direct Evidence and Directionality

Among the supplied papers, the East Java study provides the clearest direct test: the green supply chain positively affects SCR ($\beta = .277$, $p = .002$) while supply-chain digitalization is included in the model (Setiawan et al., 2023). This supports an independent GSCM contribution rather than merely showing that digital and green practices move together.

The remaining evidence is mainly adjacent or directionally different. In Vietnamese SMEs, circular-economy practice forms one antecedent to resilience alongside agility and risk management (Dey et al., 2024). In the Egyptian blockchain model, SCR carries a positive technology effect to environmental performance, which demonstrates close interdependence but places resilience before the environmental outcome (Mohamed et al., 2023). The Bangladeshi fashion study likewise estimates resilience dimensions as antecedents of waste management and pollution/emission reduction; visibility, agility, and collaboration are generally positive, while flexibility is non-significant (Sagar et al., 2026). These two studies cannot be cited as direct tests of GSCM→SCR because their causal ordering is reversed.

A Chinese green-productivity study positions resilience mechanisms between digitalization and an environmental outcome (Xue et al., 2025). A regional digitalization-and-greening study embeds development sustainability within a composite resilience measure (Zhang et al., 2025). Both are relevant to the broader green–resilience nexus, but neither cleanly identifies an independent firm-level GSCM effect on SCR.

2.6.3 Synthesis

The third path is consequently the least replicated relationship in the source set. One directly aligned study supports it; neighboring constructs and reverse-direction studies make it plausible; but the evidence does not justify describing the relationship as settled. Testing GSCM and DTA simultaneously in Bangladesh's footwear industry is valuable precisely because it can establish whether GSCM explains unique resilience variance rather than merely reflecting digital maturity or environmental performance.

H3: Green supply chain management is positively associated with supply chain resilience, after accounting for digital technology adoption.

2.7 Emerging-Market and Bangladesh Relevance

The evidence base is geographically useful for an emerging-market study. Direct survey evidence comes from Indonesia, Vietnam, Egypt, Türkiye, Jordan, and Asia-Pacific automotive supply chains, while Chinese archival and regional studies add longitudinal or multi-year perspectives. Across these contexts, digital capability is repeatedly connected to visibility, decision support, low-carbon or circular practices, and resilience (Balakrishnan & Ramanathan, 2021; Dey et al., 2024; Duman Altan et al., 2024; Roux et al., 2025; Setiawan et al., 2023). This cross-context convergence supports mechanism transfer, but it does not guarantee equal effect sizes in Bangladesh or across industries.

The closest national evidence is the study of 190 actors in Bangladesh's fashion supply chain (Sagar et al., 2026). It confirms that visibility, agility, and collaboration matter for waste and pollution/emission outcomes, and it shows that digital-tool moderation varies by resilience dimension. Its contribution is substantial but not interchangeable with the proposed study: the industry scope is fashion rather than footwear, the environmental variables are outcomes rather than a GSCM practice bundle, and the model primarily asks how resilience affects environmental sustainability. The current study reverses and extends that logic by examining whether DTA and GSCM are distinct antecedent capabilities of SCR.

The corpus therefore supports a context-specific research gap rather than a universal absence claim. An integrated DTA–GSCM–SCR model already exists in East Java manufacturing (Setiawan et al., 2023). What remains insufficiently known is whether the same pattern holds in Bangladesh's footwear industry, where the supplied literature provides no direct empirical test. Replication in this setting can show whether the triad is robust beyond the original manufacturing sample and whether the direct DTA→SCR and GSCM→SCR coefficients remain positive when estimated together.

2.8 Measurement Implications for the Present Study

The literature suggests that the three constructs should be measured as related but non-overlapping organizational capabilities. DTA items should capture integration and use, GSCM items should capture environmental practices, and SCR items should capture anticipation, response, adaptation, and recovery. This separation is especially important in a compact model because measures that repeat visibility, information sharing, or sustainability language across

constructs can create artificial correlations.

Table 3. Construct Domains Indicated by the Supplied Empirical Literature

Construct	Recommended content domain	Principal anchors	Measurement caution
DTA	Use intensity and breadth; real-time data; internal/external integration; information reliability; coordination and track-and-trace	Balakrishnan & Ramanathan (2021); Duman Altan et al. (2024); Setiawan et al. (2023)	Do not measure only ownership or intention. Avoid making one specific technology synonymous with overall adoption.
GSCM	Green purchasing; cleaner production; green distribution; environmental collaboration; waste/recovery or circular routines	Dey et al. (2024); Roux et al. (2025); Setiawan et al. (2023)	Use practice items rather than environmental results alone. Keep circularity and low-carbon domains conceptually nested or clearly distinguished.
SCR	Warning and visibility; coordinated response; alternate plans/capacity; adaptation; restoration; learning	Balakrishnan & Ramanathan (2021); Duman Altan et al. (2024); Mohamed et al. (2023); Setiawan et al. (2023)	Do not collapse resilience into ordinary efficiency or final firm performance. Retain both proactive and recovery dimensions.

Several source designs also inform interpretation. Most primary studies use cross-sectional questionnaires and structural-equation modeling. Such designs are appropriate for latent organizational capabilities but are vulnerable to common-method variance, respondent subjectivity, and limited causal ordering. The archival Chinese studies reduce some of these concerns, yet they use policy or accounting proxies that are not equivalent to managers' assessments of adoption, green practice, and resilience (Xue et al., 2025; Zhang et al., 2025). The present survey should therefore use established content domains, clear time and organizational referents, and cautious causal language.

Consistent with the study's pre-specified analytical protocol (see Section 3.2), parsimony was essential for the achieved sample. The literature supports a three-construct direct-effects model without requiring technology-specific submodels, multiple higher-order resilience dimensions, or a long chain of mediators. A modest sample can still produce useful contextual evidence if scale reliability and discriminant validity are checked and if regression or path estimates are reported with uncertainty and effect sizes rather than relying only on significance.

2.9 Critical Synthesis and Research Gaps

Taken together, the supplied studies support the general proposition that digital and environmental capabilities can contribute to resilient supply chains. Nevertheless, the literature is uneven. The strongest path is DTA→SCR, the DTA→GSCM path has a smaller body of directly aligned evidence, and the GSCM→SCR path is supported most clearly by a single integrated manufacturing study. Reviews increase conceptual coverage but cannot substitute for primary relationship tests (Alquraish, 2025; Challouf et al., 2025; Yang et al., 2021).

Six gaps follow from the critical comparison:

- Contextual gap: none of the supplied primary studies tests the proposed model in Bangladesh's footwear industry. The Bangladesh fashion study is close geographically but differs in industry, constructs, and causal direction (Sagar et al., 2026).
- Replication gap: the complete three-path model has been tested in East Java manufacturing, but exact replications are rare. The present study can evaluate whether its structure travels to another emerging-market manufacturing context (Setiawan et al., 2023).
- Construct-equivalence gap: circular economy, low-carbon management, green productivity, and environmental performance are often used near GSCM. Their findings are informative but should not be counted as identical measures of green supply-chain practice.
- Mechanism gap: several results indicate mediation or complementarity. Technology use may produce resilience or environmental value only through traceability, risk management, circular practice, collaboration, or resilience itself (Balakrishnan & Ramanathan, 2021; Dey et al., 2024; Duman Altan et al., 2024; Mohamed et al., 2023).
- Method gap: cross-sectional, self-reported survey designs dominate. Archival studies add temporal breadth but operate at different levels of analysis and with proxy measures. Causal claims should therefore remain restrained.
- Heterogeneity gap: digital technologies and resilience dimensions do not behave uniformly. Mixed moderation effects in Bangladesh and the negative direct blockchain result in Egypt show that aggregate positive claims can conceal implementation-specific trade-offs (Mohamed et al., 2023; Sagar et al., 2026).

Table 4. Evidence Balance for the Proposed Hypotheses

Path	Overall reading	Exact evidence	Adjacent evidence	Principal limitation
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H1: DTA→GSCM	Positive	Direct integrated evidence from East Java	AI→circular economy/low-carbon; digitization→green productivity	Exact direct replication is limited; technology is not automatically green
H2: DTA→SCR	Strongly positive	Multiple direct survey tests across manufacturing contexts	Archival, regional, and mediated support	Depends on use, traceability, competencies, and complementary routines
H3: GSCM→SCR	Positive but least established	One directly aligned integrated study	Circular economy→SCR; reverse-direction green–resilience studies	Causal direction and construct equivalence remain unresolved

2.10 Proposed Conceptual Framework and Hypotheses

The resulting framework specifies DTA and GSCM as distinct antecedent capabilities of SCR and retains a DTA→GSCM path. This structure permits three questions to be answered simultaneously: whether digital adoption is associated with greener supply-chain practice; whether digital adoption contributes to resilience beyond GSCM; and whether GSCM contributes to resilience beyond DTA. Estimating the two SCR paths together is necessary because digitally mature firms may also be more advanced in environmental management.

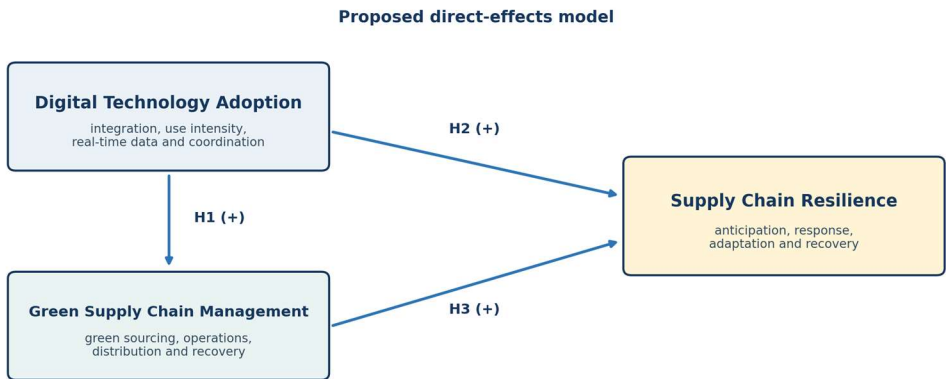


Figure 2. Proposed DTA–GSCM–SCR framework for Bangladesh's footwear industry.

The framework is intentionally parsimonious. It recognizes possible mediation of the DTA effect through GSCM because both the DTA→GSCM and GSCM→SCR paths are specified, while also retaining a direct DTA→SCR path. However, the core hypotheses concern the three direct relationships; formal mediation should be treated as an additional analysis only if the sample and measurement quality support it.

H1: Digital technology adoption is positively associated with green supply chain management in Bangladesh's footwear industry.

H2: Digital technology adoption is positively associated with supply chain resilience, after accounting for green supply chain management.

H3: Green supply chain management is positively associated with supply chain resilience, after accounting for digital technology adoption.

2.11 Chapter Summary

This review used all 15 supplied sources and differentiated exact, adjacent, and contextual evidence. DTA is conceptualized as integrated and purposeful technology use; GSCM as an environmental practice capability spanning sourcing, operations, distribution, collaboration, and recovery; and SCR as the capacity to anticipate, respond, adapt, and recover. Dynamic-capabilities reasoning explains how digital sensing and coordination and green resource reconfiguration may create resilience.

The empirical synthesis supports all three hypotheses, but with different confidence. DTA→SCR has the broadest direct support. DTA→GSCM is supported directly in one integrated manufacturing model and through several adjacent environmental capabilities. GSCM→SCR is plausible and positively supported, but exact direct evidence is sparse and causal direction varies across studies. The central contribution of the proposed research is therefore not to claim an entirely untested triad, but to provide a careful contextual replication and extension in Bangladesh's footwear industry while estimating the unique contributions of digital and green capabilities to resilience.

3. Method

3.1 Research Design

This study employed a quantitative, cross-sectional, exploratory survey design to examine the associations among digital technology adoption (DTA), green supply-chain management (GSCM), and supply-chain resilience (SCR) in Bangladesh's footwear industry. A quantitative design was appropriate because the study sought to quantify respondents' assessments of predefined constructs and statistically evaluate hypothesized relationships among them. The cross-sectional approach involved collecting responses at a single point in time; accordingly, the analyses identify statistical associations rather than establish temporal or causal relationships.

The study adopted a focused three-construct model in which DTA and GSCM were specified as predictor variables and SCR as the outcome variable. This parsimonious specification was selected to maintain analytical proportionality to the achieved sample while allowing the three prespecified hypotheses to be examined transparently. The analysis plan therefore comprised composite-scale construction, internal-consistency assessment, bivariate correlation analysis, and a two-predictor ordinary least squares (OLS) regression rather than latent-variable structural equation modeling.

The unit of analysis was the respondent's organization, represented by one knowledgeable professional familiar with its footwear or leather-goods supply-chain activities. Where more than one respondent was associated with the same organization, responses were retained only when the respondents represented distinct functional areas; potential within-organization dependence was consequently recognized as a limitation of the design.

3.2 Participant Characteristics and Sampling Procedures

The target population comprised professionals working in Bangladesh's footwear or leather-goods supply chain, including personnel engaged in manufacturing, component and raw-material supply, buying and sourcing, logistics, procurement, production, quality assurance, sustainability and compliance, commercial activities, retail or export operations, and management. To ensure that participants possessed relevant practical knowledge, eligibility required a minimum of six months of relevant industry experience.

Because no complete sampling frame of eligible footwear-sector professionals was available and data collection was conducted within a restricted study period, purposive and referral sampling were employed. Purposive sampling permits researchers to deliberately recruit participants who possess characteristics or experience relevant to the research question, whereas referral approaches can facilitate access to members of a specialized or difficult-to-enumerate population. Such nonprobability procedures are used in empirical business research when probability-based sampling is impractical; however, they constrain the extent to which sample findings can be generalized to the wider population.

The study's pre-specified analytical protocol set a target of approximately 60 valid responses and defined response tiers determining which analyses the achieved sample would support. The final dataset contained 47 usable responses, which falls within the protocol's 40–59 response tier. At this tier, the protocol specified that the study retain the core reliability, descriptive, correlation, and two-predictor OLS analyses, while excluding subgroup comparisons that would require a larger sample. Given the modest sample and nonprobability sampling strategy, the study emphasizes effect magnitudes, uncertainty intervals, and sensitivity checks and interprets the findings as preliminary exploratory evidence, rather than as statistically representative estimates of Bangladesh's footwear industry.

The achieved sample was not altered according to statistical significance. All eligible responses available at the predefined closure point were retained following the stipulated data-quality screening procedures, and no synthetic, duplicated, purchased, or researcher-completed observations were included.

3.3 Measures and Instrument

Data were collected using a structured online questionnaire administered through Google Forms. All primary construct items were measured using a five-point agreement scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree. The questionnaire retained the previously deployed substantive items to preserve comparability across the collected responses.

The primary analysis comprised 15 items distributed equally across three constructs, with five items measuring each construct.

Digital Technology Adoption (DTA): DTA represented the extent to which the respondent's organization routinely used digital technologies to support supply-chain activities. The five items addressed: (a) digital sharing of supply-chain information with relevant partners, (b) digital monitoring of inventory, orders, or material flows, (c) use of data analysis to support supply-chain decisions, (d) digital support for product or material traceability, and (e) integration of digital tools across key supply-chain activities.

Green Supply-Chain Management (GSCM): GSCM captured the extent to which environmental considerations were incorporated into purchasing, supplier management, production, collaboration, and resource-use practices. The five items assessed: (a) consideration of environmental criteria in purchasing, (b) supplier evaluation on environmental performance, (c) production practices designed to reduce waste and emissions, (d) collaboration with supply-chain partners to improve environmental performance, and (e) monitoring and improvement of resource and energy

efficiency.

Supply-Chain Resilience (SCR): SCR reflected the organization's perceived ability to detect disruptions, maintain critical operations, adapt sourcing or processes, recover from disruptions, and revise supply-chain plans as conditions change. The five items measured: (a) rapid disruption detection, (b) continuity of critical operations, (c) the ability to switch suppliers, materials, or processes when required, (d) recovery of normal operations, and (e) adaptive supply-chain planning.

For analysis, responses to the five items within each construct were aggregated into composite scores. A construct score was calculated when at least four of the five component items were available, and no reverse-coded items were specified in the questionnaire. This procedure retained the original 1–5 response metric while reducing item-level measures to construct-level scores suitable for the planned correlation and regression analyses.

The questionnaire also contained five circular-economy items; however, these items were excluded from the confirmatory analysis and were not entered into the primary regression or mediation framework. They were retained only as optional exploratory context.

3.4 Ethics and Data Quality

Participation was voluntary and anonymous. The questionnaire did not require disclosure of confidential organizational information, and responses were collected online through Google Forms for aggregate statistical analysis. The study design therefore sought to minimize risks associated with the disclosure of personal or commercially sensitive information.

Before statistical analysis, the dataset underwent structured quality screening using prespecified rules. Screening addressed participant eligibility, missing responses, duplicate-response patterns, implausibly short completion times, and straight-lining or other potentially low-quality response patterns. Exclusion decisions were documented independently of hypothesis-test results to avoid retaining or removing observations according to statistical significance. The original survey export was archived without alteration, while cleaning, transformation, and scoring were performed on a separate working copy to preserve an auditable analysis record.

The data-quality procedure was complemented by a predefined integrity rule under which no synthetic, duplicated, purchased, or team-completed responses were permitted. This approach was intended to maintain the traceability and reproducibility of the empirical analysis.

3.5 Statistics and Data Analysis

Statistical analysis was conducted sequentially. First, the dataset was screened according to the eligibility and quality criteria described above. Second, composite scores were calculated for DTA, GSCM, and SCR. Third, scale reliability and descriptive characteristics were assessed before hypothesis testing.

Internal consistency was evaluated using Cronbach's alpha (α) and McDonald's omega (ω), supplemented by corrected item–total correlations. Cronbach's alpha is a conventional measure of internal consistency, whereas omega provides a complementary estimate that can be preferable when the restrictive assumptions underlying alpha are not fully satisfied (McNeish, 2018; Tavakol & Dennick, 2011). Accordingly, reliability was interpreted in conjunction with item behavior and substantive coherence rather than by applying a single numerical cutoff mechanically.

Descriptive analysis included the mean (M), standard deviation (SD), median, interquartile range, minimum, and maximum for the construct scores. Item-level means were also calculated to identify relative strengths and gaps across the digital and green supply-chain practices.

Hypothesis 1 (H1), which proposed that DTA is positively associated with GSCM, was evaluated using Pearson's product–moment correlation coefficient (r), together with 95% confidence intervals. Because the sample was modest and the constructs were derived from ordinal-response items aggregated into composite measures, Spearman's rank correlation coefficient (ρ) was additionally calculated as a sensitivity analysis. H1 was therefore evaluated from both parametric and rank-based perspectives.

Hypotheses 2 and 3 were tested using a two-predictor ordinary least squares (OLS) regression, specified as:

$$SCR_i = \beta_0 + \beta_1 DTA_i + \beta_2 GSCM_i + \varepsilon_i$$

where SCR_i represents the composite resilience score for observation i , DTA_i and $GSCM_i$ represent the corresponding predictor scores, β_0 is the intercept, β_1 and β_2 are the regression coefficients, and ε_i is the disturbance term. OLS regression provides a direct framework for estimating the unique statistical association between each predictor and SCR while the other predictor is held constant (Hayes, 2022).

For H2, the coefficient for DTA was interpreted as the estimated change in SCR statistically associated with a one-unit increase in DTA, conditional on GSCM. For H3, the coefficient for GSCM was interpreted as the corresponding unique association with SCR after accounting statistically for DTA. Both unstandardized coefficients (B) and standardized coefficients (β) were reported to facilitate interpretation in the original and standardized metrics. Model explanatory power was summarized using R^2 and adjusted R^2 .

Because heteroskedasticity can affect conventional OLS standard errors and consequently distort statistical inference, regression diagnostics included inspection of residual behavior, influential observations, and multicollinearity. Where

appropriate, heteroskedasticity-robust standard errors and bootstrap confidence intervals were used to strengthen inference without relying exclusively on the conventional homoskedastic standard-error assumption. Robust standard-error procedures are a standard response to heteroskedasticity in OLS regression (Barreto & Howland, 2006).

Given the achieved sample of 47 observations, inferential emphasis was placed on effect magnitude and uncertainty, particularly confidence intervals, rather than on p-values considered in isolation. This approach is consistent with the prespecified analytical protocol, which recognizes that statistical estimates from a modest exploratory sample may be sensitive to sampling variability. Accordingly, statistical significance was not treated as equivalent to practical importance, and non-significant results accompanied by wide confidence intervals were interpreted cautiously rather than as evidence of the absence of an association.

Finally, all substantive findings were interpreted within the limits of the cross-sectional, self-report, nonprobability-sample design. The analysis therefore uses associational terminology such as “associated with” and “statistically predicts” and does not infer causal effects from the observed regression coefficients. This interpretation is consistent with the theoretical and methodological boundaries established in the study protocol.

4. Results

This section presents the findings of the survey of footwear manufacturing and supply-chain professionals in Bangladesh. A total of 47 valid responses were retained for analysis. The section first describes the profile of respondents and organizations, then reports the reliability and descriptive statistics of the three measured constructs: Digital Technology Adoption (DTA), Green Supply-Chain Management (GSCM), and Supply-Chain Resilience (SCR). It then reports item-level patterns across the DTA and GSCM item sets, followed by the bivariate associations among the three constructs and the regression results predicting SCR from DTA and GSCM. The section closes with a summary of hypothesis testing outcomes. All values reported below are taken directly from the analysis output.

Three relationships were tested with the collected data, shown in Figure 3: DTA with GSCM (H1), DTA with SCR (H2), and GSCM with SCR (H3).

Proposed Relationships among Digital, Green, and Resilience Capabilities

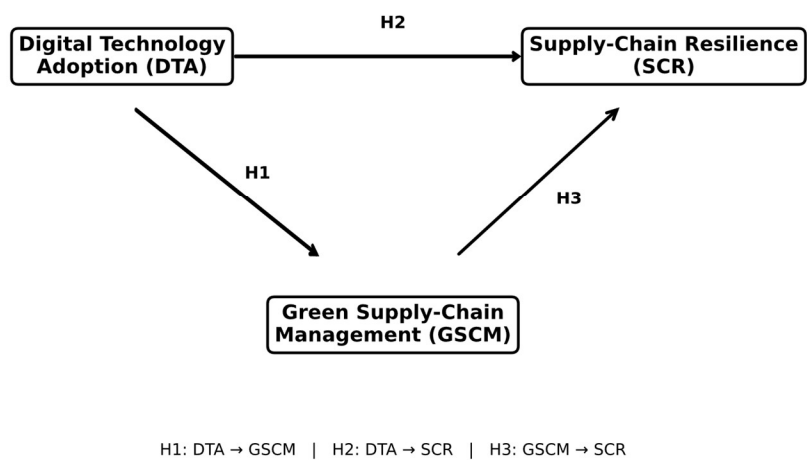


Figure 3. Tested relationships among Digital Technology Adoption (DTA), Green Supply-Chain Management (GSCM), and Supply-Chain Resilience (SCR).

4.1 Respondent and Organizational Profile

Table 5 summarizes the profile of the 47 valid respondents. Footwear manufacturers made up the largest share of participating organizations, at 72.3 percent. Logistics or freight-forwarding providers and component or raw-material suppliers were the next most represented organization types, at 23.4 percent and 21.3 percent. Because respondents could select more than one organization type, the percentages in this category sum to more than 100 percent.

By role, respondents were concentrated in Production/Operations (34.0 percent) and Logistics & Supply Chain Management (31.9 percent), followed by Quality Assurance/Quality Control (23.4 percent). These three roles together accounted for close to 90 percent of the sample. In terms of industry experience, most respondents had between 2 and 10 years of experience in the footwear or leather-goods industry: 44.7 percent reported 2 to 5 years and 36.2 percent reported 6 to 10 years, together covering about 81 percent of the sample. Respondents with more than 10 years of experience made up the remaining 19.1 percent.

Organization size was fairly evenly spread across the larger size bands. Organizations with 3,000 or more employees were the single largest group (29.8 percent), followed by 1,000 to 2,999 employees (23.4 percent) and 500 to 999 employees (21.3 percent). Smaller organizations, with fewer than 100 or 100 to 499 employees, together accounted for 25.5 percent of the sample. For market focus, most organizations served both export and domestic markets (57.4 percent), while 29.8 percent served the domestic market only and 12.8 percent served the export market only.

Table 5. Respondent and Organizational Profile (N = 47)

Profile characteristic	Category	n	%
Organization type*	Footwear manufacturer	34	72.3
	Component/raw-material supplier	10	21.3
	Logistics/freight-forwarding provider	11	23.4
	Buying house/merchandising/sourcing office	7	14.9
	Retailer/export house	1	2.1

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Primary role/department	Production/Operations	16	34.0
	Logistics & Supply Chain Management	15	31.9
	Quality Assurance/Quality Control	11	23.4
	Merchandising, Procurement & Sourcing	2	4.3
	Export/Commercial	2	4.3
	Sustainability, Compliance & Environment	1	2.1
Industry experience	2–5 years	21	44.7
	6–10 years	17	36.2
	11–15 years	4	8.5
	More than 15 years	5	10.6
Organization size	Fewer than 100 employees	4	8.5
	100–499	8	17.0
	500–999	10	21.3
	1,000–2,999	11	23.4
	3,000 or more	14	29.8
Primary market focus	Domestic market only	14	29.8
	Export only	6	12.8
	Both export and domestic markets	27	57.4

4.2 Measurement Reliability and Descriptive Statistics

Table 6 reports the reliability and descriptive statistics for the three constructs, each measured with 5 items on a 1 to 5 scale. Cronbach's alpha ranged from 0.789 for GSCM to 0.823 for SCR, and McDonald's omega ranged from 0.797 for GSCM to 0.825 for SCR. All three constructs therefore met conventional thresholds for acceptable to good internal consistency, and all items were retained for each construct without deletion.

At the construct level, GSCM (M = 3.455, SD = 0.773) and SCR (M = 3.468, SD = 0.786) had similar average scores, while DTA had the lowest mean score of the three constructs (M = 3.268, SD = 0.819). For all three constructs, the median score (DTA = 3.4, GSCM = 3.6, SCR = 3.6) was higher than the corresponding mean, indicating that a subset of respondents with comparatively low ratings pulled the mean below the typical response.

Table 6. Construct Reliability and Descriptive Statistics

Construct	Items	Mean	SD	Median	Cronbach's α	McDonald's ω
Digital Technology Adoption (DTA)	5	3.268	0.819	3.4	0.794	0.803
Green Supply-Chain Management (GSCM)	5	3.455	0.773	3.6	0.789	0.797
Supply-Chain Resilience (SCR)	5	3.468	0.786	3.6	0.823	0.825

Note. Median values are the composite-score medians across the 47 valid respondents. N = 47 for all three constructs.

4.3 Item-Level Digital and Green Capability Gaps

To identify which specific digital and green practices showed the largest gaps in adoption, the 10 DTA and GSCM items were ranked by mean score, with the lowest mean indicating the largest gap. Table 7 and Figure 4 present this ranking. DTA items occupied 4 of the 5 positions with the largest gaps, while GSCM items occupied both positions with the smallest gaps.

The single largest gap was DTA4, digital traceability across the supply chain (M = 3.15), followed by GSCM1, green purchasing criteria (M = 3.17), DTA5, Industry 4.0 technologies in operations (M = 3.21), DTA3, data analytics for

supply-chain decisions (M = 3.23), and DTA2, digital tracking of inventory and material flows (M = 3.26). At the other end of the ranking, GSCM5, environmental collaboration with partners (M = 3.72), and GSCM4, resource and energy efficiency (M = 3.62), showed the smallest gaps and were the only two items classified as a lower gap rather than a moderate gap.

Table 7. Item-Level Capability Gap Ranking (DTA and GSCM Items, Ranked From Largest to Smallest Gap)

Rank	Domain	Item	Mean	SD	Median	Gap signal
1	DTA	DTA4 – Digital traceability across the supply chain	3.15	1.06	3	Moderate gap
2	GSCM	GSCM1 – Green purchasing criteria	3.17	1.07	3	Moderate gap
3	DTA	DTA5 – Industry 4.0 technologies in operations	3.21	1.28	3	Moderate gap
4	DTA	DTA3 – Data analytics for supply-chain decisions	3.23	1.11	3	Moderate gap
5	DTA	DTA2 – Digital tracking of inventory/material flows	3.26	1.03	3	Moderate gap
6	GSCM	GSCM2 – Environmental supplier evaluation	3.36	1.13	4	Moderate gap
7	GSCM	GSCM3 – Cleaner-production practices	3.40	1.08	3	Moderate gap
8	DTA	DTA1 – Digital platforms for real-time information sharing	3.49	1.02	4	Moderate gap
9	GSCM	GSCM4 – Resource and energy efficiency	3.62	0.90	4	Lower gap
10	GSCM	GSCM5 – Environmental collaboration with partners	3.72	1.06	4	Lower gap

Note. Lower mean scores indicate greater perceived implementation gaps. Rank 1 = largest gap, Rank 10 = smallest gap.

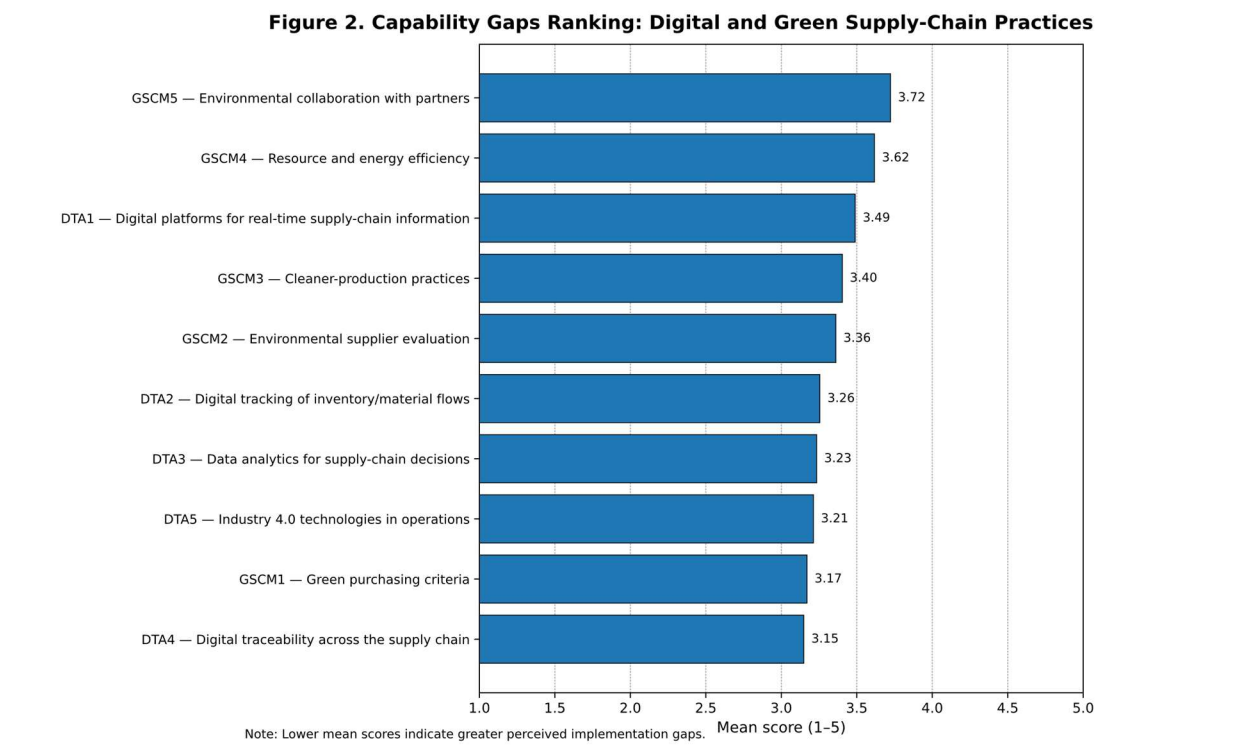


Figure 4. Capability gaps ranking for digital and green supply-chain practices. Lower mean scores indicate greater perceived implementation gaps.

4.4 Bivariate Associations Among Constructs

Table 8 reports the Pearson correlations among the three constructs, together with Spearman rank correlations run as a sensitivity check. All three pairwise correlations were positive and statistically significant. The strongest bivariate association was between DTA and SCR ($r = 0.675$, 95% CI [0.481, 0.806], $p < .001$), followed by GSCM and SCR ($r = 0.569$, 95% CI [0.337, 0.736], $p < .001$). The association between DTA and GSCM was positive but comparatively weaker ($r = 0.446$, 95% CI [0.182, 0.650], $p = .002$).

The Spearman rank correlations followed the same pattern as the Pearson correlations in direction, relative magnitude, and statistical significance for all three pairs (DTA-GSCM $\rho = 0.464$, $p = .001$; DTA-SCR $\rho = 0.626$, $p < .001$; GSCM-SCR $\rho = 0.567$, $p < .001$). This agreement between the two methods indicates that the correlation results are not dependent on the assumption of a linear, normally distributed relationship.

Table 8. Pearson Correlation Matrix and Spearman Sensitivity Checks

Variable pair	Pearson r	95% CI for r	p-value	Spearman ρ	Spearman p-value
DTA ↔ GSCM	0.446	[0.182, 0.650]	0.002	0.464	0.001
DTA ↔ SCR	0.675	[0.481, 0.806]	<0.001	0.626	<0.001
GSCM ↔ SCR	0.569	[0.337, 0.736]	<0.001	0.567	<0.001

Note. $N = 47$ pairwise valid observations. CI = confidence interval, calculated using the Fisher z transformation.

4.5 Regression Results for Supply-Chain Resilience

Supply-chain resilience was regressed on DTA and GSCM using ordinary least squares (OLS) with robust (HC3) standard errors, following the model $SCR = b_0 + b_1(DTA) + b_2(GSCM)$. Table 9 presents the results. The two predictors jointly explained 54.5 percent of the variance in SCR ($R^2 = 0.545$, adjusted $R^2 = 0.525$), and the overall model was statistically significant, robust $F(2, 44) = 37.65$, $p < .001$.

Both predictors were positive and statistically significant unique predictors of SCR. DTA had the larger unique effect ($B = 0.505$, robust $SE = 0.113$, $\beta = 0.526$, 95% CI [0.277, 0.733], $p < .001$), indicating that a 1-point increase in DTA was associated with about a 0.505-point increase in SCR, holding GSCM constant. GSCM also had a positive unique effect on SCR ($B = 0.340$, robust $SE = 0.100$, $\beta = 0.334$, 95% CI [0.138, 0.542], $p = .001$), holding DTA constant. The standardized coefficient for DTA ($\beta = 0.526$) was about 1.6 times larger than that for GSCM ($\beta = 0.334$), indicating that DTA had the stronger unique association with SCR of the two predictors in this model.

Table 9. OLS Regression Results for Supply-Chain Resilience

Predictor	B	Robust SE (HC3)	β	95% CI	p-value
Digital Technology Adoption (DTA)	0.505	0.113	0.526	[0.277, 0.733]	<0.001
Green Supply-Chain Management (GSCM)	0.340	0.100	0.334	[0.138, 0.542]	0.001

Figure 5 plots the OLS residuals against the fitted SCR values as a check on the regression model. The residuals were scattered on both sides of zero across the full range of fitted values, without a clear funnel or curved pattern. Three respondents, labeled R7, R24, and R46, showed the largest absolute residuals, each exceeding a magnitude of about 1.0 point on the 1 to 5 scale.

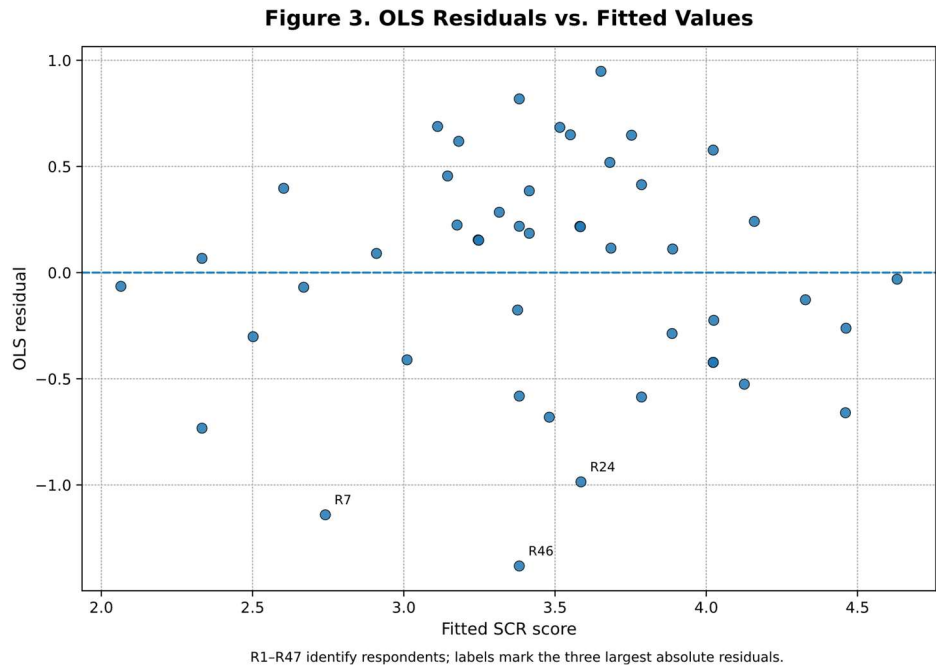


Figure 5. OLS residuals plotted against fitted supply-chain resilience (SCR) values. R1–R47 identify respondents; labels mark the three largest absolute residuals.

4.6 Summary of Hypothesis Testing

Table 10 summarizes the evidence and decision for each hypothesis shown earlier in Figure 3. All three hypotheses were supported by the data: DTA was positively associated with GSCM (H1), DTA had a positive unique association with SCR after accounting for GSCM (H2), and GSCM had a positive unique association with SCR after accounting for DTA (H3).

Table 10. Consolidated Hypothesis Results

Hypothesis	Statement	Evidence	Decision
H1	DTA is positively associated with GSCM	$r = 0.446$, 95% CI [0.182, 0.650], $p = .002$	Supported
H2	DTA is positively associated with SCR, after accounting for GSCM	$B = 0.505$, $\beta = 0.526$, 95% CI [0.277, 0.733], $p < .001$	Supported
H3	GSCM is positively associated with SCR, after accounting for DTA	$B = 0.340$, $\beta = 0.334$, 95% CI [0.138, 0.542], $p = .001$	Supported

5. Discussion

This study set out to examine how digital technology adoption (DTA) and green supply-chain management (GSCM) relate to supply-chain resilience (SCR) among footwear manufacturing and supply-chain professionals in Bangladesh, with circular-economy practices (CEP) proposed as a mediating mechanism. The analysis reported in Chapter 4 tested three of the relationships in that model: DTA with GSCM (H1), DTA with SCR (H2), and GSCM with SCR (H3), using correlation and multiple regression on 47 valid responses. CEP was measured in the survey but was not included in this analysis. This section interprets the H1–H3 findings, considers their theoretical and practical relevance, and discusses the scope and limitations of the analysis.

5.1 Digital Technology Adoption and Green Supply-Chain Management

The positive and significant correlation between DTA and GSCM supports H1 and is consistent with the study's dynamic-capability framing, in which digital tools such as ERP platforms, RFID-based inventory tracking, digital traceability, and analytics support the information sharing and coordination that green sourcing and supplier evaluation depend on. Firms that reported stronger digital capability also tended to report stronger green supply-chain practice. However, the size of this association ($r = 0.446$) was moderate rather than strong, and it was the weakest of the three bivariate correlations tested. This suggests that digital adoption and green practice, while related, are not interchangeable capabilities. A firm can advance further in one domain than the other, which is consistent with the item-level pattern discussed in Section 5.3, where digital and green items showed different average levels of adoption.

5.2 Digital and Green Capabilities as Predictors of Resilience

The regression results show that DTA and GSCM each explain a unique, statistically significant share of variance in SCR, and together account for just over half of the variance in resilience scores ($R^2 = 0.545$). This supports both H2 and H3. Read through the dynamic-capability lens set out in the conceptual framework, this pattern is consistent with digital technology functioning primarily as a sensing and coordinating capability, one that helps firms detect and communicate disruptions, while green supply-chain management functions more as a capability for working with evaluated, environmentally compliant suppliers and cleaner, more resource-efficient processes.

Both capabilities mattered, but DTA showed the larger unique association with resilience ($\beta = 0.526$ versus $\beta = 0.334$ for GSCM), and DTA also had the strongest bivariate correlation with SCR of the three pairs tested ($r = 0.675$). In this sample, digital capability was therefore a comparatively stronger correlate of resilience than green capability, although both remained statistically meaningful predictors once the other was accounted for. This is broadly consistent with the study's expectation that digital technologies support the information visibility and coordination that underpin resilience, while suggesting that, at least for the direct paths tested here, this contribution was somewhat larger than that of green practice.

5.3 Where the Capability Gaps Lie

Beyond the hypothesis tests, the item-level ranking in Table 7 and Figure 4 points to more specific targets. The single largest gap was in digital traceability (DTA4), followed by green purchasing criteria (GSCM1), Industry 4.0 adoption (DTA5), data analytics for supply-chain decisions (DTA3), and digital inventory-tracking tools (DTA2). Four of the five items with the largest gaps belonged to the digital domain. By contrast, the two items with the smallest gaps, environmental collaboration with partners (GSCM5) and resource and energy efficiency (GSCM4), both belonged to the green domain.

This pattern suggests that, within the sample, footwear firms have made greater progress in collaborative and efficiency-focused green practices than in more technically demanding digital practices, such as end-to-end traceability and Industry 4.0 adoption. Digital traceability and green purchasing were identified as the two largest gaps, and both are important practical priorities of this study. Therefore, these gaps appear to represent genuine and actionable areas for improvement in the footwear sector rather than isolated weaknesses.

5.4 Theoretical Implications

The supported H1–H3 relationships offer partial support for the study's dynamic-capability framing. Both DTA and GSCM behaved as distinct capabilities that were positively associated with resilience, consistent with the idea that firms build resilience through more than one type of capability at once. The comparatively stronger association for DTA suggests that, in this sample, sensing- and coordination-oriented digital capabilities may be a more immediate lever for resilience than the green practices tested here. Because CEP was not included in this analysis, however, the results speak only to the direct DTA-SCR and GSCM-SCR relationships. They do not address the fuller reconfiguration pathway that the original conceptual framework proposed running through circular-economy practices, and that question remains open.

5.5 Practical Relevance

Taken together, the regression and item-level results point to a consistent practical picture. Digital traceability systems and environmental/green purchasing criteria are the two most underdeveloped practices identified in this sample, and both belong to constructs (DTA and GSCM) that were each significantly and independently associated with SCR. This combination, a clear capability gap in a domain shown to matter for resilience, suggests these two areas are plausible starting points for footwear firms in Bangladesh seeking to strengthen their supply-chain resilience. This is

consistent with the practical priorities this study set out to inform, which included digital traceability and supplier environmental evaluation among the areas findings could help firms address.

5.6 Limitations

Several limitations should be considered when interpreting these findings.

- **Sample size.** The analysis is based on 47 valid responses. Under the study's pre-specified analytical protocol, this places the achieved sample within the 40–59 response tier, against a target of approximately 60 responses (see Section 3.2). This tier supported the reliability, descriptive, correlation, and two-predictor regression analyses reported here, but the protocol reserved subgroup comparisons and the planned circular-economy mediation analysis for a larger achieved sample. The present sample size limits the precision of the estimates and the extent to which the findings can be generalized to the wider footwear sector.
- **Cross-sectional design and causality.** Data were collected at a single point in time using a purposive and referral sampling approach. As anticipated in the original research design, this design can identify statistical associations but cannot establish causal direction or long-term stability. Although the regression analysis estimates the unique association of each predictor while holding the other constant, this does not establish that DTA or GSCM causes higher resilience.
- **Reduced construct and hypothesis scope.** The original conceptual framework proposed four constructs (DTA, GSCM, CEP, and SCR) and seven hypotheses, with CEP acting as a mediator between DTA/GSCM and SCR. Consistent with the response-tier protocol described above, the analysis reported here covers three constructs and three of the seven originally proposed relationships (DTA with GSCM, DTA with SCR, and GSCM with SCR). CEP items were included in the survey instrument, but CEP was not analyzed for reliability, included in the correlation and regression models, or tested as a mediator. The relationships involving CEP, including the mediation hypothesis, therefore remain untested in this study.
- **Self-reported, single-source data.** As anticipated in the original research design, the measures reflect respondents' own perceptions of their organization's practices rather than independently audited environmental or operational performance.

5.7 Future Work

Because CEP items were already collected using the same instrument, a natural next step is to analyze their reliability and descriptive properties, add CEP to the correlation and regression analysis, and test it as a mediator between DTA/GSCM and SCR, as originally proposed in the conceptual framework. Reaching the study's originally targeted sample of approximately 60, and ideally the original proposal's ranges of 120 (minimum) to 160 (target) valid responses, would also allow the full model to be estimated using PLS-SEM as planned, including convergent and discriminant validity assessment, bootstrapped mediation testing, and Importance-Performance Map Analysis for managerial prioritization. This would allow a direct test of whether circular-economy practices carry part of the relationship between digital and green capabilities and supply-chain resilience, which the present analysis was not able to examine.

5.8 Conclusion

Within the scope of the relationships tested, the findings support the view that digital technology adoption and green supply-chain management are each positively associated with supply-chain resilience among footwear firms in Bangladesh, and that digital technology adoption is also positively associated with green supply-chain management. Digital capability showed the stronger direct association with resilience, and the largest capability gaps identified in the sample, digital traceability and green purchasing, sit within the two domains shown to matter for resilience. These results offer focused, data-grounded starting points for footwear firms and, together with the CEP data already collected, a basis for extending this work toward the fuller digital-green-circular model originally proposed for this study.

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Appendix:

Questionnaire:

Section A: Screening questions

- A1. Which of the following best describes your organization?
- Footwear manufacturer (produces finished shoes)
 - Component or raw-material supplier (e.g., sole, upper material, leather, chemicals, accessories)
 - Buying house / merchandising or sourcing office
 - Logistics or freight-forwarding service provider
 - Retailer or export house
 - Other
- A2. Which best describes your primary role or department?
- Production / Operations
 - Merchandising, Procurement & Sourcing
 - Logistics & Supply Chain Management
 - Quality Assurance / Quality Control
 - Sustainability, Compliance & Environment (incl. EHS/ETP)
 - Export / Commercial
 - Senior Management / Executive (e.g., CEO, GM, Director)
 - Other (please specify)
- A3. How many years of experience do you have in the footwear or leather-goods industry?
- Less than 2 years
 - 2–5 years
 - 6–10 years
 - 11–15 years
 - More than 15 years
- A4. Approximately how many employees work at your organization/factory?
- Fewer than 100
 - 100–499
 - 500–999
 - 1,000–2,999
 - 3,000 or more
- A5. What is the primary market focus of your organization?
- Export only
 - Domestic market only
 - Both export and domestic markets
- A6. Which sole material(s) does your organization primarily work with? (Select all that apply)
- Leather
 - TPR (thermoplastic rubber)
 - EVA (ethylene-vinyl acetate)
 - PU (polyurethane)
 - Rubber (e.g., SBR / synthetic rubber)
 - Other (please specify)
 - Not applicable to my role

Section B: Digital technology adoption

- B1. Our organization uses digital platforms (e.g., ERP systems, cloud-based software, shared digital portals) to

exchange real-time information with suppliers and/or buyers.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

B2. We use digital tools (e.g., barcoding, RFID tags, inventory-management software) to monitor raw-material and finished-goods inventory in real time.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

B3. We use data analytics (e.g., demand forecasting software, production-planning dashboards, risk-monitoring tools) to support supply-chain and production decisions.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

B4. We use digital traceability systems (e.g., QR codes, barcodes, blockchain-based tracking) to trace materials and products across our supply chain.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

B5. Our production facility uses Industry 4.0 technologies (e.g., IoT sensors, automated/smart machinery, computerized process controls) in day-to-day operations.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

Section C: Green supply chain management:

C1. We prioritize purchasing raw materials and components (e.g., leather, adhesives, chemicals, TPR/EVA/PU compounds) that meet defined environmental criteria (green purchasing).

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

C2. One important factor while selecting the supplier is that their products meet green and sustainable environment requirements (e.g., effluent treatment, chemical management, environmental certifications such as ISO 14001).

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

C3. We have implemented cleaner-production practices (e.g., reduced use of hazardous solvents/chemicals, energy-efficient machinery, safer curing/bonding processes) to reduce environmental impact.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

C4. We actively monitor and work to improve resource efficiency (e.g., water use, energy use, material yield) across our production processes.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

C5. We collaborate with suppliers and/or buyers on shared environmental goals (e.g., joint environmental planning, compliance audits, sustainability targets in contracts).

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

Section D: Circular economy practice

D1. We have formal practices to reduce production waste at the source (e.g., optimized cutting/skiving to reduce leather or fabric off-cuts, reduced packaging waste).

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

D2. We reuse or recycle production waste and by-products (e.g., scrap leather, rubber/TPR/EVA trimmings, fabric offcuts) internally or through external recycling partners.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

D3. We incorporate recovered, recycled, or reclaimed materials into our footwear products or manufacturing processes.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

D4. We have reverse-logistics systems in place (e.g., take-back arrangements, return and reprocessing of defective, returned, or end-of-life products).

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

D5. We design products and processes with circularity in mind (e.g., using fewer/simpler material types, designing components for easier disassembly, reuse, or recycling).

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

Section E: Supply chain resilience

E1. We can quickly detect supply-chain disruptions as they occur (e.g., raw-material shortages, transport delays, supplier failures, port congestion).

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

E2. We are able to maintain operational continuity (e.g., continued production and order fulfillment) during supply-chain disruptions.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

E3. We have access to alternative suppliers or sourcing options when our primary suppliers or material sources are

disrupted

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

E4. We are able to recover quickly from supply-chain disruptions and return to normal production and delivery schedules.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

E5. Our production processes are flexible enough to adapt to sudden changes in order volume, product mix, or supply conditions.

- Strongly Disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

Others:

F1. In your professional judgment, which of the following capabilities should footwear firms in Bangladesh prioritize most to improve supply-chain resilience? (Select up to 3)

- Digital traceability and information-sharing systems
- Supplier environmental evaluation and green purchasing
- Employee training (digital, environmental, or resilience-related)
- Waste reduction and recycling programs
- Use of recycled / recovered materials in production
- Reverse logistics (take-back / return and reprocessing systems)
- Alternative or backup sourcing arrangements
- Disruption-response and contingency planning
- Green financing / investment in sustainable equipment
- Other (please specify)

F2. . In your experience, what is the single biggest barrier your organization faces in becoming more digitally enabled and environmentally/circularly sustainable? (Optional)