International Review of Economics and Finance 99 (2025) 104033

Contents lists available at ScienceDirect

International Review of Economics and Finance

journal homepage: www.elsevier.com/locate/iref

# Digital transformation and supply chain resilience

Pengcheng Li [a], Yanbing Chen [b], Xiaochuan Guo [c,*]

[a] School of Economics and Management, Inner Mongolia University, Hohhot, 010021, China
[b] Xi'an Jiaotong-Liverpool University International Business School, Suzhou, 215123, China
[c] School of Management, Shanghai University, Shanghai, 200444, China

A R T I C L E I N F O

*Keywords:*
Digital transformation
Supply chain resilience
Supply chain power
Supply chain transparency
Organizational adaptability

A B S T R A C T

This study investigates how digital transformation affects supply chain resilience. Drawing on a panel dataset of Chinese listed firms from 2012 to 2022, we employ econometric techniques including mediation analysis and perform extensive robustness checks. The results indicate that digital transformation has a significant positive effect on supply chain resilience. This effect materializes both directly and indirectly: digital initiatives strengthen supply chain power and transparency, which in turn improve resilience. Heterogeneity analysis suggests that these resilience benefits are stronger in digitally intensive industries, under stricter environmental regulations, and differ between state-owned and private firms. These findings underscore the strategic value of digital transformation in building more resilient supply chains. Managers are advised to implement industry-specific digital strategies, and policymakers should consider regulatory environments and ownership structures when promoting digital adoption to strengthen resilience. By integrating insights from multiple theoretical perspectives, this study contributes to the literature with robust empirical evidence that digital transformation is a key driver of supply chain resilience.

## 1. Introduction

The digital era has introduced profound changes in global business operations, influencing enterprises' ability to adapt and thrive in a competitive environment (Ghosh et al., 2022; Khurana et al., 2022; Nwankpa et al., 2022; Dai et al., 2025; Tian, G. et al., 2022; Wang, A., & Han, R., 2024). Central to these changes is the concept of digital transformation, which refers to the integration of advanced digital technologies into all aspects of business processes to drive innovation and operational efficiency (Schwertner, 2017; Baiyere et al., 2020; Kraus et al., 2021; Warner, K. S., & Wäger, M., 2019; Yu & Shao, 2024). Governments and policymakers worldwide have increasingly emphasized digitalization as a strategic priority to enhance industrial competitiveness and national economic resilience. Initiatives such as "Made in China 2025" and similar strategies in other countries aim to accelerate digital adoption among firms to strengthen supply chains and foster innovation (Belton et al., 2020; Yang, 2022).

From a theoretical perspective, the resource-based view (RBV) underscores the importance of digital capabilities as a critical resource for achieving competitive advantage (Willie, 2025; Rao, A., & Brown, M., 2024; Agnihotri, R., & Gabler, C. B., 2024; Gong et al., 2023). The dynamic capabilities framework further emphasizes how firms can leverage digital transformation to sense, seize, and reconfigure their resources to address environmental uncertainties (Dai, 2025). These theoretical insights highlight the potential of digital transformation in shaping supply chain resilience, which is crucial for maintaining performance amidst disruptions.

* Corresponding author.
*E-mail addresses:* lpclpcxueshu@sina.com (P. Li), Yanbing.Chen2l@student.xjtlu.edu.cn (Y. Chen), 21903007@mail.imu.edu.cn (X. Guo).

https://doi.org/10.1016/j.iref.2025.104033
Received 26 December 2024; Received in revised form 5 March 2025; Accepted 6 March 2025
Available online 7 March 2025

Supply chain disruptions have intensified due to global challenges such as trade conflicts, pandemics, and natural disasters (Yu et al., 2021; Sodhi, M. S., & Tang, C. S., 2021; Zhang, H. et al., 2021; Lu, Q. et al., 2022). These disruptions have underscored the necessity for firms to enhance supply chain resilience—the capacity to absorb shocks and recover swiftly (Birkie et al., 2017). While digital transformation is often posited as a solution to such vulnerabilities, the mechanisms through which it affects supply chain resilience remain underexplored (Lu, Q. et al., 2023a). Specifically, the roles of mediating factors such as supply chain power and transparency warrant deeper investigation.

The existing body of literature addressing this issue can be categorized into three strands. First, studies on digital transformation and firm performance primarily focus on how digital technologies improve operational efficiency and innovation capacity, often emphasizing direct performance outcomes (Kastelli et al., 2024; Shan et al., 2024). However, limited attention has been given to the implications for supply chain resilience. Second, research on supply chain resilience determinants has explored various factors influencing resilience, such as risk management practices, supplier relationships, and technological adoption (Tukamuhabwa et al., 2015; Cui et al., 2023 ; Wu et al., 2025). Yet, these studies often overlook the systemic role of digital transformation in enabling resilience. Third, studies investigating mediation mechanisms in supply chain dynamics are fragmented and lack a cohesive theoretical framework, leaving gaps in understanding how factors like power and transparency interact with digitalization efforts to influence resilience (Alam et al., 2023).

While prior studies acknowledge the importance of digital transformation and supply chain resilience, they fail to comprehensively examine the pathways through which digital transformation influences resilience. In particular, the roles of supply chain power and transparency as mediating variables have not been adequately addressed. Additionally, most research relies on single-dimensional metrics, which may not capture the multifaceted nature of digital transformation and its systemic impacts on resilience.

This study seeks to address the question: How does digital transformation affect supply chain resilience, and what roles do supply chain power and transparency play as mediators in this relationship? To achieve this, the research aims to evaluate the direct impact of digital transformation on supply chain resilience, analyze the mediating effect of supply chain power considering its negative indicator characteristics, assess the mediating effect of supply chain transparency in enhancing resilience, and provide empirical evidence based on a comprehensive multi-dimensional index of digital transformation.

This study contributes to the literature by offering a detailed exploration of the mechanisms linking digital transformation to supply chain resilience. Unlike previous studies, it employs a multi-dimensional evaluation framework to measure digital transformation and incorporates two critical mediating variables: supply chain power and transparency. By analyzing their distinct roles, this research provides a more holistic understanding of how firms can leverage digital strategies to bolster supply chain resilience. Furthermore, the use of residual-based measures to capture resilience offers a methodological advancement, enabling a more precise assessment of performance recovery dynamics.

## 2. Theoretical review and hypothesis development

### 2.1. Theoretical foundations

Digital transformation refers to the comprehensive adoption of digital technologies to fundamentally improve organizational operations and capabilities (Korherr et al., 2022; Ghafoori et al., 2024; Lu, Q. et al., 2024a). It is often defined as *"a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies"* (Vial, 2021). In a supply chain context, digital transformation entails deploying innovations such as big data analytics, cloud platforms, Internet of Things (IoT) sensors, artificial intelligence (AI), and blockchain across the value chain. These digital investments are viewed as strategic resources that can enhance a firm's performance, especially under volatile conditions. According to the resource-based view (RBV), such technologies constitute valuable and hard-to-imitate organizational resources that can yield competitive advantages and superior outcomes in the face of disruptions (Huang et al., 2023) By building a robust digital infrastructure and skill base, a firm develops an **organizational capability** that directly contributes to its agility and robustness. In other words, digital transformation creates a reservoir of technological and informational assets that can be leveraged to better **withstand and respond to shocks**, thereby strengthening supply chain resilience (Nayal et al., 2022).

Supply chain resilience, in turn, is commonly defined as the ability of a supply chain to *withstand, adapt to, and recover from disruptive events*. It is the capacity to absorb shocks and bounce back to a stable state of operations within an acceptable time frame. Resilient supply chains can proactively prepare for unexpected disruptions, provide efficient real-time responses, and quickly restore normal performance after the disturbance passes. Building such resilience often requires developing specialized capabilities and processes ahead of time – for example, risk monitoring systems, flexible sourcing strategies, or emergency response plans. Critically, these capabilities increasingly rely on digital tools and data. A supply chain's resilience is not just a product of its physical redundancies (spare inventory, backup suppliers) but also of its informational agility and decision-making speed. Thus, an organization's level of digital transformation – its ability to harness digital technology for supply chain management – has a profound influence on **how effectively the supply chain can anticipate disruptions and adjust accordingly**.

Multiple theoretical perspectives shed light on why and how digital transformation bolsters supply chain resilience. First, the **dynamic capabilities** perspective (an extension of RBV) emphasizes the firm's capacity to **sense, seize, and adapt** in turbulent environments. Digital transformation enhances the firm's sensing ability by providing real-time data and analytics to perceive emerging risks or changes, its seizing ability by enabling swift data-driven decision-making, and its reconfiguring ability by facilitating rapid adjustments of resources and processes. In fact, many scholars consider supply chain resilience itself a manifestation of dynamic capability – a higher-order competence of the firm to survive and thrive amid disruptions. From this view, investing in digital technologies strengthens the firm's dynamic capabilities and thus its resilience: for example, advanced monitoring systems help anticipate risks early, and digital connectivity allows quick reconfiguration of supply chain flows when needed. In short, digital transformation imbues the supply chain with adaptive capacity, aligning with the dynamic capabilities needed for resilience.

In addition, **socio-technical systems theory** provides a complementary lens by highlighting that successful digital transformation is not purely a technical endeavor but also a social one (Soares et al., 2024; Thomas, 2024). Supply chains are complex socio-technical systems, meaning that their performance emerges from the interaction of human organizations and technologies. Simply implementing new IT systems is insufficient unless accompanied by appropriate changes in processes, skills, and organizational culture. A socio-technical perspective suggests that digital tools must be integrated with human workflows and trust to realize their full potential in enhancing resilience. For instance, a platform for real-time data sharing will improve disruption response only if employees and partners actually use the information effectively and collaborate in decision-making (Giannakis, M., & Louis, M., 2016; Rane, S. B., & Narvel, Y. A. M., 2022). Thus, firms must align the "social" subsystem (people, incentives, norms) with the "technical" subsystem (digital platforms, algorithms) to develop a truly resilient, technology-enabled supply chain. Effective digital transformation, viewed through this lens, involves joint optimization of technology and human factors – resulting in socio-technical **capabilities** that allow the supply chain to better absorb and recover from shocks.

Furthermore, external and inter-organizational perspectives from institutional theory and transaction cost economics (TCE) enrich our understanding of digital transformation's impact on resilience. **Institutional theory** posits that organizations are influenced by the rules, norms, and expectations of their environment (Campbell, 2007). In recent years, there have been growing coercive and normative pressures on firms to strengthen their supply chain risk management and transparency (e.g. regulatory mandates for traceability, industry standards for continuity planning). Embracing digital transformation can be seen as a response to these institutional pressures – companies adopt advanced supply chain technologies in part to legitimize themselves as well-prepared, transparent partners in the eyes of regulators, customers, and other stakeholders. This not only secures external support but also incidentally improves resilience (for example, regulatory pressure to implement track-and-trace systems leads to better visibility of supply disruptions). **Transaction cost economics (TCE)**, on the other hand, focuses on the efficiency of governance structures and exchanges between firms (Macher, J. T., & Richman, B. D., 2008; Gibbons, 2010). TCE suggests that digital transformation reduces transaction costs in supply chain relationships by lowering information asymmetry and uncertainty. When firms share data in real time and processes are digitized, it becomes easier and cheaper to coordinate with suppliers and distributors, as there is less need for costly monitoring or contingency buffers. By facilitating smoother collaboration and trust, digital tools enable more flexible contracting and partnership structures, which can make the supply chain more adaptable in the face of disturbances (Faruquee et al., 2021; Modgil et al., 2022). In summary, the theoretical foundations spanning RBV and dynamic capabilities (internal resources and adaptability), socio-technical systems (technology–organization alignment), institutional theory (external pressures and legitimacy), and TCE (inter-firm information and coordination) all converge on the idea that digital transformation is a crucial organizational capability for enhancing supply chain resilience. These perspectives collectively inform the mechanisms by which digitalization strengthens a supply chain's robustness and agility, as discussed in the following sections.

### *2.2. Digital transformation as a driver of supply chain resilience*

Digital transformation is a key driver of supply chain resilience because it fundamentally improves how firms **collect, process, and act on information** in their supply networks (Bejlegaard et al., 2021; Faruquee, M., Paulraj, A., & Irawan, C. A., 2021). One major benefit of digitalization is the development of real-time information processing capabilities. Technologies such as IoT sensors, RFID tags, and cloud-based tracking systems provide end-to-end visibility of shipments, inventories, and production status in real time. This wealth of up-to-the-minute information enables firms to detect disruptions or anomalies at the earliest possible stage (Kagermann, 2014; Lu, Q. et al., 2023b). For example, sensors can alert a manufacturer immediately when a critical shipment is delayed in transit or when a machine on the factory floor begins to malfunction. With traditional (non-digital) processes, such issues might go unnoticed until they have already escalated; in contrast, digital systems trigger instant awareness. Equipped with timely data, firms can execute contingency plans on the fly – rerouting shipments, activating backup suppliers, or adjusting production schedules – thereby preventing a minor incident from snowballing into a major disruption. Digital transformation also brings **predictive analytics** into supply chain management (Lu, Q. et al., 2024b). By leveraging big data and AI, companies can analyze patterns (e.g. weather forecasts, social media signals, supplier financial health indicators) to *forecast potential disruptions* before they occur (Rane et al., 2024; Wylde et al., 2022. These predictive insights allow for proactive risk mitigation, such as preemptively increasing inventory for at-risk components or identifying alternate transport routes ahead of a looming natural disaster. In essence, real-time visibility and data analytics endowed by digital transformation strengthen the **risk assessment and anticipation** capabilities of a supply chain, which are critical for its absorptive resilience (the ability to absorb shocks without severe impact).

Digitalization not only improves early warning and preparedness, but also enhances the **agility and adaptive capacity** of supply chains during and after disruptions. Advanced digital tools facilitate faster communication and decision-making across the supply chain network. For instance, when all partners (suppliers, manufacturers, logistics providers, retailers) are connected through integrated IT systems or platforms, they can coordinate their actions instantly in response to an unexpected event. A digital supply chain platform might enable automatic sharing of demand spikes or inventory shortfalls, prompting collaborative responses (such as expediting a shipment or reallocating stock from one region to another) (Lu, Q. et al., 2024c). This high level of connectivity and **collaboration** means the supply chain as a whole reacts more like a synchronized organism than a collection of siloed entities. Such agility is invaluable in containing the impact of disruptions.

Moreover, digital transformation often introduces flexibility through automation and intelligent optimization. Flexible manufacturing systems (powered by IoT and AI) can rapidly switch product lines or sourcing strategies when inputs become scarce. Machine learning algorithms can recommend optimal re-routing of deliveries or reallocation of resources in real time during a crisis. These capabilities speed up the **recovery** phase of resilience – for example, enabling a company to recalibrate its supply network within days after a disruption, whereas a less digitized firm might take weeks. Studies have found that digital technologies like AI and blockchain enable supply chains to become more **adaptable and self-healing**, adjusting their structures and processes dynamically to meet new conditions.

Overall, digital transformation enhances supply chain resilience by providing superior technological capabilities for sensing risk, responding swiftly, and reorganizing effectively. A digitally transformed supply chain is more **flexible, responsive, and intelligent**, which translates into a greater ability to manage risk and maintain performance under adverse events. In light of these advantages, digital transformation is increasingly recognized as a foundational driver of resilient supply chain management.

### *2.3. The mediating role of supply chain power*

While digital transformation can directly bolster resilience, its impact also operates **through changes in supply chain power dynamics**. Here, we apply resource dependence theory (RDT) to explain how "supply chain power" – the balance of dependence and influence among firms in a supply network – mediates the relationship between digitalization and resilience. RDT emphasizes that organizations are interdependent: firms rely on resources controlled by other supply chain members, which creates power imbalances (Pfeffer & Salancik, 1978). If a focal firm is highly dependent on a single supplier or a small set of partners for critical inputs, those partners hold significant power over the firm. Such **power asymmetry** can undermine resilience, because the focal firm's fortunes become tied to the reliability and goodwill of the powerful partner. Indeed, recent research suggests that *managing external dependencies is even more important than internal capabilities for building supply chain resilience* (Gebhardt et al., 2022). A supply chain dominated by a few powerful players may be efficient in stable times, but it is brittle in crises – for example, if a sole supplier with bargaining power encounters trouble (or demands exorbitant concessions), the dependent buyer has limited alternatives and can suffer severe disruptions. By contrast, a firm that has more balanced power (or even holds power over others) can impose requirements, access resources, or switch partners more easily during a disruption, thus improving its resilience. In RDT terms, companies can strengthen resilience by either **reducing their dependence on others or increasing others' dependence on them** (Gebhardt., 2022). Practical strategies include securing multiple sources for important materials, cultivating backup suppliers, vertically integrating to produce critical inputs in-house, or forming strong collaborative ties that bind partners to mutual success. RDT classifies these tactics into *buffering* (shielding the firm from external dependence, e.g. through inventory or multi-sourcing) and *bridging* (actively engaging and controlling the dependency through partnerships or alliances). Both approaches seek to rebalance power in the supply chain relationship, thereby mitigating the risks that come from over-reliance on any single partner.

Digital transformation can facilitate these power-balancing strategies and thus serves as an intermediate mechanism linking to greater resilience. In essence, digital tools enable firms to **manage and mitigate supply chain dependencies more effectively**, converting a vulnerable power structure into a more resilient one. For example, digital procurement platforms and data analytics can dramatically lower the cost and effort of identifying and qualifying *multiple suppliers* around the globe. This enables a buffering strategy: a firm can establish a diversified supply base for key components (multiple sourcing), which reduces its dependence on any one supplier and diminishes that supplier's power.

During disruptions, having digital access to alternate suppliers and real-time market information means the firm can switch sources quickly, making the supply chain less prone to collapse if one partner fails. On the other hand, digital transformation also supports bridging strategies that increase the firm's influence over existing partners. By integrating ERP systems with suppliers or using collaborative platforms for sharing demand forecasts, the focal firm ties its suppliers closer to itself through information sharing and process integration. This *interconnectivity* increases mutual dependence and transparency, which can shift power to the focal firm or at least prevent any single partner from opportunistically exploiting the situation. For instance, if a manufacturer and its key supplier share production plans and inventory data via a digital interface, the supplier is less likely to hide problems or breach agreements, and the manufacturer can exert more control over coordinating responses to any disruption. Such **digital inter-connectivity builds trust and alignment**, functioning as a substitute for vertical integration by achieving coordination without ownership.

Overall, digital transformation equips firms with the means to **avoid excessive dependency**: it provides better market intelligence, alternative options, and closer ties, all of which neutralize the risks of power imbalances. Consequently, a digitally empowered firm can negotiate more favorable terms, enforce reliability standards, or rapidly replace a failing partner, thereby sustaining operations under duress. We expect, therefore, that part of the reason digital transformation improves resilience is that it changes the power/dependence structure of the supply chain in the firm's favor. In summary, by leveraging digital tools to buffer against supplier dominance and to bridge stronger relationships, companies can ensure that no single choke point or powerful actor will derail the entire chain – a key factor in **translating digital capabilities into actual resilient performance**.

### *2.4. The mediating role of supply chain transparency*

Another important mechanism linking digital transformation to resilience is **supply chain transparency**. Supply chain transparency refers to the extent to which information about the operations, transactions, and conditions throughout the supply chain is visible and shared among stakeholders (Sodhi, M. S., & Tang, C. S., 2019; Montecchi et al., 2021). High transparency means that a firm has clear line-of-sight into upstream supplier activities, inventory levels, shipment statuses, and even into the second or third tiers of its supply network, and that this information is communicated in a timely manner to those who need it. Low transparency, by contrast, implies **information asymmetry** – some parties in the chain have much better information than others. Information asymmetry can breed mistrust and coordination problems: for example, a supplier might withhold news of a delay or a quality issue, leaving the buyer unprepared, or a buyer might not share demand forecasts, causing suppliers to either overproduce or be caught short (Egels-Zandén et al., 2015). According to transaction cost economics (TCE), reducing information asymmetry is critical to lowering the *transaction costs* between firms, such as the costs of monitoring partner performance or the risk of opportunistic behavior under uncertainty. **Transparency is essentially the antidote to information asymmetry**. When all parties have access to relevant, accurate data, there is less scope for opportunism and fewer uncertainties about the state of the supply chain (Kauppi, 2013). This fosters trust and reduces the need for costly safeguards. In practical terms, greater transparency enables smoother coordination: suppliers and buyers can jointly make decisions with the same set of facts. This improved coordination is especially valuable when disruptions loom. If a manufacturer can see its supplier's inventory levels or production schedule in real time, it can react immediately to shortages or delays (e.g. by reallocating orders or finding backup supply) rather than being surprised at the last minute. Similarly, if all supply chain partners share demand and sales data, they can adjust their outputs in tandem to avoid overstock or stockouts when market conditions suddenly change. Thus, transparency **reduces the likelihood of small problems escalating**, because partners can work together to resolve issues with full information. From a TCE viewpoint, digitization-driven transparency lowers coordination costs and risks, enabling more agile and cooperative supply chain relationships. A more transparent supply chain is inherently more resilient: it behaves as a coordinated network with aligned interests, rather than fragmented entities obscured from each other.

Digital transformation is a primary enabler of end-to-end supply chain transparency, and institutional theory helps explain why firms are moving in this direction. Modern digital technologies — such as blockchain ledgers, IoT tracking devices, and cloud-based data hubs — make it technically feasible to gather and disseminate detailed supply chain information in real time. For instance, a blockchain system can record each step of a product's journey (provenance, manufacturing conditions, handling) in a tamper-proof manner that is visible to all authorized parties. This level of transparency was unattainable in the past, but digital tools now provide *visibility from raw materials to end customers*. Importantly, external pressures have been pushing companies to adopt these transparency-enhancing technologies. **Institutional theory** suggests that organizations conform to pressures from government, industry, and society, and we see this in the rise of transparency mandates. Regulators in various countries have introduced legislation (such as anti-forced-labor laws and carbon disclosure requirements) that effectively *coerce firms into improving supply chain transparency through digital traceability*. For example, carbon emission reporting has quickly moved from a voluntary initiative to a required practice in many industries – as one study notes, *"carbon transparency, once a niche practice, is increasingly becoming institutionalized. Firms are now required to report not only their operations' carbon footprint but also that of their supply chain"* (Villena, V. H., & Dhanorkar, S., 2020).

Likewise, consumer and NGO pressures (normative pressures) have made transparency a reputational issue; leading companies now publicize their suppliers and use digital platforms to assure stakeholders of ethical and sustainable sourcing. In response to these pressures, firms undertake digital transformation projects (like implementing supply chain dashboards or traceability systems) to **legitimize themselves and meet institutional expectations**. The side effect is that those same systems greatly enhance the firm's ability to manage disruptions. When a disruption occurs, a transparent supply chain — enabled by digital technology — allows pinpointing exactly where the issue lies and what other parts of the network are affected. For instance, if a contamination is found in a food supply chain, a company with end-to-end traceability can quickly identify the source batch and isolate affected products within hours, whereas a non-digital, opaque chain might take weeks. Thus, transparency accelerates **response and recovery** by providing clarity and shared information. Moreover, the trust and legitimacy gained from being transparent can improve long-term collaboration with suppliers: partners that engage in open information sharing are more likely to help each other in a crisis, rather than hide information or act opportunistically. In sum, digital transformation promotes governance structures characterized by high transparency and visibility (sometimes described as "supply chain control towers" or shared information systems). These governance improvements – as highlighted by both institutional theory (pressures for transparency) and TCE (benefits of reduced information asymmetry) – ultimately foster stronger resilience. Supply chain transparency, achieved through digital means, **mediates the effect of digital transformation on resilience** by enabling better coordination, trust, and adaptive capability across the network.

Based on this theoretical foundation, the following hypotheses are proposed:

**Hypothesis 1**. Digital transformation positively influences supply chain resilience.

**Hypothesis 2**. Supply chain power mediates the relationship between digital transformation and supply chain resilience, but due to its negative indicator characteristics, the coefficient between digital transformation and supply chain power is negative.

**Hypothesis 3**. Supply chain transparency positively mediates the relationship between digital transformation and supply chain resilience.

These hypotheses aim to address the research gaps by elucidating the pathways through which digital transformation impacts supply chain resilience. By focusing on the mediating effects of supply chain power and transparency, this study contributes to a more comprehensive understanding of the interplay between digitalization and resilience.

## 3. Research methodology

### *3.1. Sample and data*

This study examines Chinese listed companies from 2012 to 2022, utilizing a comprehensive dataset of 20,164 firm-year observations. The financial data originates from the China Stock Market and Accounting Research (CSMAR) database. We exclude financial firms due to their distinct regulatory environment and operating characteristics. To minimize the influence of extreme values, all continuous variables are winsorized at the 1st and 99th percentiles.

### 3.2. Variable measurement

#### 3.2.1. Dependent variable

Supply chain resilience captures an organization's ability to recover from disruptions and maintain operational stability. We measure supply chain resilience through performance deviation methodology. This approach assumes that when supply chains face external shocks, firm performance deviates from its expected trajectory before gradually returning to its pre-shock state. The magnitude of this deviation reflects the supply chain's recovery capability. Specifically, we employ the residual between actual and estimated performance values to quantify resilience. A larger residual value indicates stronger supply chain resilience, representing superior recovery capabilities. The measurement is calculated as:

$$SupRes_{\{it\}} = |actual\,performance_{\{it\}} - estimated\,performance_{\{it\}}|$$

#### 3.2.2. Independent variable

We employ two measures to capture digital transformation:

Primary Measure (DIG): We utilize CSMAR's multidimensional digital transformation index, which comprehensively evaluates companies' digital capabilities through six dimensions:

DIG = 0.3472 × Strategic Drive + 0.162 × Technical Enablement + 0.0969 × Organizational Enablement + 0.0342 × Environmental Enablement + 0.2713 × Digital Achievement + 0.0884 × Digital Application.

Alternative Measure (DIG_replace): To ensure robustness, we construct an alternative measure based on firms' digital technology investments, calculated as the proportion of digital technology-related intangible assets to total intangible assets disclosed in financial statements.

#### 3.2.3. Mediating variables

Supply Chain Power (SupPow): We measure supply chain power through the average percentage of transactions with top five suppliers and customers. A higher value indicates stronger dependence on key supply chain partners, reflecting greater supply chain power concentration. This construct serves as a negative indicator, as excessive power concentration might impede supply chain resilience.

Supply Chain Transparency (SupTrp): This variable reflects the proportion of named major suppliers and customers in total top-five partner transactions. Higher values indicate greater supply chain transparency, facilitating information flow and collaborative relationships throughout the supply chain network.

#### 3.2.4. Control variables

Our empirical analysis incorporates several firm-specific characteristics that potentially influence supply chain resilience. These include firm size (Size), measured as the natural logarithm of total assets; return on equity (ROE), calculated as net profit divided by average owners' equity; capital accumulation rate (RCA), computed as the year-over-year growth in owners' equity; financial leverage (FL), measured as earnings before interest and tax divided by earnings before tax; ownership concentration (Concentration), calculated as the shareholding percentage of top three shareholders; management compensation (lnCompensation), measured as the natural logarithm of top three executives' total compensation; and board size (Board), computed as the natural logarithm of total board members.

### 3.3. Model specification

To examine our hypotheses, we employ a two-way fixed effects model controlling for both firm and year fixed effects. The baseline model investigating the direct effect of digital transformation on supply chain resilience is specified as:

$$SupRes_{\{it\}} = \beta_{\{0\}} + \beta_{\{1\}DIG_{\{it\}}} + \beta_{\{k\}Controls_{\{it\}}} + \mu_{\{i\}} + \lambda_{\{t\}} + \varepsilon_{\{it\}}$$

For mediation analysis, we follow Baron and Kenny's approach with the following specifications:

Step 1 (H2) - First mediator:

$$SupPow_{\{it\}} = \gamma_{\{0\}} + \gamma_{\{1\}DIG_{\{it\}}} + \gamma_{\{k\}Controls_{\{it\}}} + \mu_{\{i\}} + \lambda_{\{t\}} + \varepsilon_{\{it\}}$$

Step 2 (H3) - Second mediator:

$$SupTrp_{\{it\}} = \delta_{\{0\}} + \delta_{\{1\}DIG_{\{it\}}} + \delta_{\{k\}Controls_{\{it\}}} + \mu_{\{i\}} + \lambda_{\{t\}} + \varepsilon_{\{it\}}$$

Step 3 - Full model:

$$SupRes_{\{it\}} = \alpha_{\{0\}} + \alpha_{\{1\}DIG_{\{it\}}} + \alpha_{\{2\}SupPow_{\{it\}}} + \alpha_{\{3\}SupTrp_{\{it\}}} + \alpha_{\{k\}Controls_{\{it\}}} + \mu_{\{i\}} + \lambda_{\{t\}} + \varepsilon_{\{it\}}$$

where $i$ and $t$ denote firm and year respectively; $\mu_{\{i\}}$ represents firm fixed effects; $\lambda_{\{t\}}$ captures year fixed effects; and $\varepsilon_{\{it\}}$ is the error term. To address potential heteroskedasticity and serial correlation, we cluster standard errors at the firm level.

## 4. Results and discussions

### 4.1. Overview of data and preliminary analysis

Table 1 presents the descriptive statistics of our key variables. The supply chain resilience measure (SupRes) exhibits a mean value of 0.341 with a standard deviation of 0.019, suggesting relatively stable supply chain performance across our sample. The digital transformation indicator (lnDIG) shows a mean of 3.585, with moderate variation (SD = 0.258) indicating substantial heterogeneity in firms' digital transformation efforts. Supply chain power (SupPow) demonstrates considerable variation across firms, with a mean of 0.308 and standard deviation of 0.147, while supply chain transparency (SupTrp) shows relatively low levels (mean = 0.036) but substantial variation (SD = 0.102).

Table 2 displays the Pearson correlation coefficients among variables. The correlation analysis reveals several noteworthy patterns. Digital transformation (lnDIG) exhibits a weak negative correlation with supply chain resilience (SupRes) ($r = -0.005$), suggesting a potentially complex relationship that warrants further investigation through regression analysis. Supply chain power (SupPow) shows a positive correlation with supply chain resilience ($r = 0.038$, $p < 0.01$), while supply chain transparency (SupTrp) demonstrates a weak positive correlation ($r = 0.004$). The correlation coefficients among independent variables are generally modest, indicating minimal concern for multicollinearity.

To formally examine potential multicollinearity issues, we conduct variance inflation factor (VIF) tests. As reported in Table 3, all VIF values fall well below the conventional threshold of 5, with the highest VIF being 1.560 for firm size. The mean VIF of 1.160 further confirms the absence of serious multicollinearity concerns in our model specifications. This suggests that our regression estimates are unlikely to be distorted by correlation among independent variables.

### 4.2. Impact of digital transformation on supply chain resilience

The baseline regression results in Table 4 offer compelling evidence for the transformative role of digital capabilities in enhancing supply chain resilience, supporting Hypothesis 1. The analysis employs two distinct model specifications to ensure the robustness of our findings. In column 1, which incorporates industry fixed effects, digital transformation exhibits a significant positive association with supply chain resilience. This relationship persists in column 2, where we introduce year fixed effects to account for temporal variations and macroeconomic influences. The consistency of these results across both specifications validates Hypothesis 1, demonstrating that firms' digital transformation efforts substantially contribute to supply chain resilience.

The enhanced model specification in column 2 reveals several important insights about the digital transformation-resilience relationship. First, the persistence of statistical significance after controlling for both industry and year fixed effects suggests that the impact of digital transformation transcends industry-specific characteristics and temporal trends. Second, the slight reduction in coefficient magnitude from column 1 to column 2 implies that while temporal factors influence the relationship, the fundamental link between digital capabilities and supply chain resilience remains robust. Third, the improvement in R-squared from 15.1% to 18.1% indicates that temporal dynamics play a meaningful role in explaining variations in supply chain resilience.

These findings carry substantial implications for understanding how digital transformation shapes organizational capabilities. The positive relationship suggests that digitally advanced firms possess superior abilities to maintain operational stability and recover from disruptions. This advantage likely stems from enhanced information processing capabilities, improved supply chain visibility, and more sophisticated risk management systems enabled by digital technologies. The results also indicate that the benefits of digital transformation extend beyond operational efficiency to encompass organizational resilience, highlighting the strategic value of digital investments in building robust supply chain networks.

**Table 1**
Descriptive statistics.

| Variable | N | Mean | p50 | SD | Min | Max |
|---|---|---|---|---|---|---|
| SupRes | 20164 | 0.341 | 0.340 | 0.0190 | 0.265 | 0.515 |
| lnDIG | 20164 | 3.585 | 3.579 | 0.258 | 3.140 | 4.181 |
| SupPow | 20164 | 0.308 | 0.287 | 0.147 | 0.0550 | 0.789 |
| SupTrp | 20164 | 0.0360 | 0 | 0.102 | 0 | 0.640 |
| Size | 20164 | 22.17 | 21.98 | 1.198 | 20.16 | 26.11 |
| RCA | 20164 | 0.122 | 0.0600 | 0.261 | −0.375 | 1.596 |
| FL | 20164 | 1.226 | 1.039 | 0.765 | −0.382 | 5.589 |
| lnConcentration | 20164 | 3.826 | 3.868 | 0.335 | 2.895 | 4.438 |
| lnCompensation | 20164 | 15.44 | 15.41 | 0.673 | 13.93 | 17.34 |
| Board | 20164 | 2.108 | 2.197 | 0.189 | 1.609 | 2.565 |

**Table 2**
Correlation matrix.

| Variables | (SupRes) | (lnDIG) | (SupPow) | (SupTrp) | (Size) | (RCA) | (FL) | (lnConcentration) | (lnCompensation) | (Board) |
|---|---|---|---|---|---|---|---|---|---|---|
| SupRes | 1.000 | | | | | | | | | |
| lnDIG | −0.005 | 1.000 | | | | | | | | |
| SupPow | 0.038*** | −0.052*** | 1.000 | | | | | | | |
| SupTrp | 0.004 | −0.008 | 0.148*** | 1.000 | | | | | | |
| Size | −0.212*** | 0.042*** | −0.281*** | −0.044*** | 1.000 | | | | | |
| RCA | 0.063*** | 0.001 | −0.010 | −0.010 | 0.086*** | 1.000 | | | | |
| FL | 0.050*** | −0.065*** | −0.010 | 0.055*** | 0.150*** | −0.002 | 1.000 | | | |
| lnConcentration | 0.068*** | −0.184*** | −0.001 | −0.011 | 0.083*** | 0.014** | −0.050*** | 1.000 | | |
| lnCompensation | −0.033*** | 0.137*** | −0.190*** | −0.136*** | 0.506*** | 0.032*** | −0.060*** | −0.017** | 1.000 | |
| Board | −0.048*** | −0.058*** | −0.112*** | 0.053*** | 0.252*** | 0.007 | 0.060*** | −0.010 | 0.180*** | 1.000 |

Notes:***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

**Table 3**
VIF test.

| Variable | VIF | 1/VIF |
|---|---|---|
| Size | 1.560 | 0.643 |
| lnCompensation | 1.440 | 0.695 |
| SupPow | 1.120 | 0.897 |
| Board | 1.090 | 0.916 |
| lnDIG | 1.070 | 0.936 |
| FL | 1.060 | 0.940 |
| lnConcentration | 1.060 | 0.947 |
| SupTrp | 1.050 | 0.954 |
| RCA | 1.010 | 0.992 |
| Mean | 1.160 | |

**Table 4**
Baseline regression.

| | (1) | (2) |
|---|---|---|
| VARIABLES | SupRes | SupRes |
| lnDIG | 0.004*** | 0.002*** |
| | (6.162) | (2.895) |
| Size | −0.006*** | −0.006*** |
| | (-38.590) | (-38.706) |
| RCA | 0.006*** | 0.008*** |
| | (13.182) | (16.461) |
| FL | 0.003*** | 0.003*** |
| | (16.163) | (17.472) |
| lnConcentration | 0.006*** | 0.006*** |
| | (14.879) | (15.130) |
| lnCompensation | 0.004*** | 0.002*** |
| | (15.490) | (8.522) |
| Board | −0.000 | 0.002*** |
| | (-0.570) | (3.181) |
| Constant | 0.374*** | 0.391*** |
| | (82.008) | (85.463) |
| Observations | 20,164 | 20,164 |
| R-squared | 0.151 | 0.181 |
| IND | FE | FE |
| YEAR | NO | FE |

Notes: t-statistics in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

## 4.3. *Addressing endogeneity concerns*

### 4.3.1. *Instrumental variable approach*

Table 5 presents a two-stage analysis addressing potential endogeneity concerns in the relationship between digital transformation and supply chain resilience. To strengthen the causal inference of our baseline findings, we employ a dynamic panel approach using lagged digital transformation as an instrument.

The first-stage results demonstrate the strong predictive power of lagged digital transformation (L.lnDIG) for current digital transformation levels. The high coefficient magnitude and statistical significance ($t = 214.437$) validate the instrument's relevance, while the substantial R-squared value of 0.875 indicates robust explanatory power. This strong first-stage relationship suggests that firms' digital transformation initiatives exhibit considerable persistence over time, reflecting the cumulative nature of technological investments and capabilities.

The second-stage results reinforce our baseline findings while accounting for potential endogeneity. The instrumented digital transformation maintains a positive and significant effect on supply chain resilience, supporting the robustness of our primary results. The consistency of th p after addressing endogeneity concerns strengthens the causal interpretation of digital transformation's impact on *dolphin choir* resilience. The model's explanatory power remains stable with an R-squared of 0.172, suggesting that our instrumental oach effectively captures the underlying relationship while controlling for potential confounding factors.

Notably, the endogeneity-corrected estimates reveal that the magnitude and direction of digital transformation's effect align closely with our baseline findings. This consistency across different methodological approaches substantiates the robustness of our main conclusions regarding the positive influence of digital transformation on supply chain resilience. The persistence of this relationship in both baseline and instrumental variable specifications provides compelling evidence for the strategic importance of digital transformation in enhancing organizational resilience capabilities.

**Table 5**
Endogeneity issues.

| | (1) | (2) |
|---|---|---|
| VARIABLES | lnDIG | SupRes |
| L.lnDIG | 0.868*** | |
| | (214.437) | |
| lnDIG | | 0.003*** |
| | | (3.521) |
| Size | 0.005*** | −0.006*** |
| | (5.660) | (-30.537) |
| RCA | 0.016*** | 0.008*** |
| | (4.807) | (10.468) |
| FL | −0.003*** | 0.003*** |
| | (-3.513) | (17.751) |
| lnConcentration | −0.004* | 0.006*** |
| | (-1.716) | (13.437) |
| lnCompensation | 0.004*** | 0.002*** |
| | (2.646) | (7.392) |
| Board | 0.005 | 0.002*** |
| | (1.199) | (2.902) |
| Constant | 0.332*** | 0.390*** |
| | (12.734) | (59.051) |
| Observations | 15,445 | 15,445 |
| R-squared | 0.875 | 0.172 |
| IND | FE | FE |
| YEAR | FE | FE |

Notes: t-statistics in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

### 4.3.2. *Alternative endogeneity tests*

Table 6 presents two additional methodological approaches to further address potential endogeneity concerns. The propensity score matching (PSM) analysis in column 1 helps mitigate selection bias by creating comparable treatment and control groups based on observable characteristics. The results show that digital transformation maintains its positive and significant effect on supply chain resilience ($t = 2.607$) in the matched sample, supporting the robustness of our main findings.

The Heckman two-stage procedure, reported in column 2, addresses potential sample selection bias. The significant inverse Mills ratio (imr1) suggests the presence of selection effects, validating the necessity of this correction. After accounting for selection bias, the coefficient of digital transformation remains positive and significant ($t = 4.214$), providing additional support for our baseline results. Notably, the consistency of digital transformation's positive effect across these different methodological specifications strengthens the causal interpretation of our findings.

**Table 6**
Alternative endogeneity tests.

| | (1) | (2) |
|---|---|---|
| VARIABLES | SupRes | SupRes |
| lnDIG | 0.002*** | 0.004*** |
| | (2.607) | (4.214) |
| imr1 | | −0.017*** |
| | | (-3.083) |
| Size | −0.006*** | −0.001 |
| | (-27.711) | (-1.044) |
| RCA | 0.009*** | 0.006*** |
| | (12.585) | (7.273) |
| FL | 0.003*** | 0.001 |
| | (12.602) | (1.314) |
| lnConcentration | 0.005*** | 0.002* |
| | (9.291) | (1.906) |
| lnCompensation | 0.002*** | −0.001 |
| | (5.928) | (-1.037) |
| Board | 0.002** | 0.003*** |
| | (2.028) | (4.081) |
| Constant | 0.393*** | 0.366*** |
| | (60.079) | (39.807) |
| Observations | 10,626 | 20,164 |
| R-squared | 0.174 | 0.181 |
| IND | FE | FE |
| YEAR | FE | FE |

Notes: t-statistics in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

The robustness of our results across multiple econometric approaches - dynamic panel, PSM, and Heckman correction - provides compelling evidence for the causal relationship between digital transformation and supply chain resilience. Each method addresses different potential sources of endogeneity, and the consistency of findings across these specifications substantially reinforces our main conclusions.

### 4.4. Robustness analysis

Table 7 presents three distinct robustness checks that validate our main findings through alternative specifications. These tests address potential concerns regarding measurement, model specification, and temporal effects.

The first test employs an alternative measure of digital transformation (DIG_replace) based on the proportion of digital technology-related intangible assets. As shown in column 1, this alternative specification maintains a positive and significant relationship with supply chain resilience ($t = 3.891$). The consistency of results using this alternative measurement strengthens our confidence in the relationship between digital transformation and supply chain resilience, suggesting that our findings are not driven by the specific measurement approach used in the baseline analysis.

Column 2 presents results using an alternative model specification with firm fixed effects instead of industry fixed effects. The digital transformation coefficient remains positive and significant ($t = 3.355$), indicating that our findings persist even when controlling for unobserved firm-specific characteristics. This specification helps address concerns about time-invariant firm characteristics that might influence both digital transformation decisions and supply chain resilience.

The third robustness check, reported in column 3, examines the relationship by excluding the COVID-19 period to ensure our results are not primarily driven by the pandemic's unique circumstances. The analysis of this restricted sample continues to show a positive and significant effect of digital transformation on supply chain resilience ($t = 3.025$). This finding suggests that the benefits of digital transformation for supply chain resilience extend beyond crisis periods and reflect a fundamental relationship rather than a circumstantial correlation during extraordinary events.

The stability of our findings across these diverse robustness checks - utilizing different variable measurements, model specifications, and time periods - provides strong support for the fundamental relationship between digital transformation and supply chain resilience. The consistent significance and directionality of the relationship across all specifications reinforces the reliability of our main conclusions and suggests that the identified relationship is robust to various methodological choices and potential confounding factors.

### 4.5. Mediating role of supply chain power

The mediation analysis presented in Table 8 investigates how supply chain power influences the relationship between digital transformation and supply chain resilience, revealing compelling evidence for Hypothesis 2. Our analysis uncovers a significant mediation mechanism through supply chain power concentration.

**Table 7**
Robustness checks.

| | (1) | (2) | (3) |
|---|---|---|---|
| VARIABLES | SupRes | SupRes | SupRes |
| DIG_replace | 0.003*** | | |
| | (3.891) | | |
| lnDIG | | 0.004*** | 0.002*** |
| | | (3.355) | (3.025) |
| Size | −0.006*** | −0.004*** | −0.006*** |
| | (-38.438) | (-10.099) | (-35.145) |
| RCA | 0.007*** | 0.005*** | 0.010*** |
| | (15.044) | (11.271) | (18.086) |
| FL | 0.003*** | 0.002*** | 0.003*** |
| | (17.318) | (14.871) | (15.380) |
| lnConcentration | 0.006*** | 0.006*** | 0.007*** |
| | (14.355) | (7.391) | (15.323) |
| lnCompensation | 0.002*** | 0.005*** | 0.002*** |
| | (8.428) | (12.636) | (8.756) |
| Board | 0.002*** | 0.001 | 0.002** |
| | (3.413) | (0.569) | (2.199) |
| Constant | 0.396*** | 0.305*** | 0.384*** |
| | (93.434) | (33.079) | (73.567) |
| Observations | 19,582 | 20,164 | 16,316 |
| R-squared | 0.185 | 0.052 | 0.180 |
| IND | FE | NO | FE |
| YEAR | FE | FE | FE |
| Number of id | NO | FE | NO |

Notes: t-statistics in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Column 1 reveals that digital transformation significantly reduces supp ower concentration (t = −17.448). This negative relationship indicates that as firms advance their digital capabilities, they ineffectively decrease their dependence on key supply chain partners. The substantial magnitude of this effect suggests that digital t ation fundamentally reshapes supply chain relationship dynamics, enabling firms to develop more balanced partner networks.

The full mediation model in Column 2 presents two critical findings. First, supply chain power demonstrates a significant negative effect on supply chain resilience (t = −2.848), while digital transformation maintains its positive direct effect (t = 2.525). Second, the Sobel test (Z = 2.811, p = 0.004) confirms the statistical significance of this mediation path, providing strong support for Hypothesis 2. This evidence establishes that digital transformation enhances supply chain resilience both directly and indirectly through its influence on supply chain power dynamics.

The mediation pattern illuminates how digital transformation strengthens supply chain resilience through two complementary paths: a direct effect through enhanced operational capabilities and an indirect effect through reduced power concentration. The negative relationship between supply chain power and resilience underscores that excessive dependence on key partners can impair an organization's ability to maintain stable operations during disruptions. By enabling firms to diversify their supply chain relationships, digital transformation creates more resilient operational structures.

### 4.6. *Mediating role of supply chain transparency*

Table 9 examines the mediating effect of supply chain transparency, revealing strong support for Hypothesis 3. The analysis demonstrates how digital transformation enhances supply chain resilience through improved transparency in supply chain relationships.

Column 1 shows that digital transformation significantly increases supply chain transparency (t = 3.346). This positive relationship indicates that digitally advanced firms achieve greater visibility in their supply chain operations, enabling them to better track and manage relationships with key partners. The finding suggests that digital capabilities facilitate more transparent and traceable supply chain interactions.

The full mediation model in Column 2 reveals that supply chain transparency positively influences supply chain resilience (t = 2.822), while digital transformation maintains its direct positive effect (t = 2.828). The Sobel test results (Z = 2.157, p = 0.030) confirm the statistical significance of this mediation pathway, providing robust support for Hypothesis 3. These findings indicate that digital transformation strengthens supply chain resilience both directly and by fostering greater transparency in supply chain operations.

The mediation results highlight how digital transformation's impact on supply chain resilience operates through enhanced operational visibility and information sharing. By promoting transparency, digital capabilities enable organizations to better anticipate potential disruptions, coordinate responses with partners, and maintain operational stability. The persistence of digital transformation's direct effect alongside the mediation suggests that while transparency serves as a key mechanism, digital capabilities

**Table 8**
Mediating effect of *SupPow*.

| | (1) | (2) |
|---|---|---|
| VARIABLES | SupPow | SupRes |
| lnDIG | −0.083*** | 0.002** |
| | (-17.448) | (2.525) |
| SupPow | | −0.003*** |
| | | (-2.848) |
| Size | −0.035*** | −0.006*** |
| | (-33.339) | (-38.336) |
| RCA | 0.017*** | 0.008*** |
| | (4.843) | (16.551) |
| FL | 0.005*** | 0.003*** |
| | (3.906) | (17.547) |
| lnConcentration | 0.006** | 0.006*** |
| | (2.291) | (15.177) |
| lnCompensation | −0.012*** | 0.002*** |
| | (-7.150) | (8.369) |
| Board | −0.026*** | 0.002*** |
| | (-5.168) | (3.076) |
| Constant | 1.462*** | 0.395*** |
| | (44.833) | (82.354) |
| Observations | 20,164 | 20,164 |
| R-squared | 0.265 | 0.181 |
| IND | FE | FE |
| YEAR | FE | FE |
| Sobel test | Z value | P value |
| | 2.811 | 0.004 |

Notes: t-statistics in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

**Table 9**
Mediating effect of *SupTrp*.

| | (1) | (2) |
|---|---|---|
| VARIABLES | SupTrp | SupRes |
| lnDIG | 0.012*** | 0.002*** |
| | (3.346) | (2.828) |
| SupTrp | | 0.004*** |
| | | (2.822) |
| Size | −0.002*** | −0.006*** |
| | (-2.856) | (-38.648) |
| RCA | −0.003 | 0.008*** |
| | (-0.954) | (16.482) |
| FL | 0.004*** | 0.003*** |
| | (4.705) | (17.372) |
| lnConcentration | −0.007*** | 0.006*** |
| | (-3.328) | (15.195) |
| lnCompensation | −0.015*** | 0.002*** |
| | (-11.542) | (8.724) |
| Board | 0.024*** | 0.002*** |
| | (6.107) | (3.057) |
| Constant | 0.275*** | 0.390*** |
| | (10.847) | (85.013) |
| Observations | 20,164 | 20,164 |
| R-squared | 0.086 | 0.181 |
| IND | FE | FE |
| YEAR | FE | FE |
| Sobel test | Z value | P value |
| | 2.157 | 0.030 |

Notes: t-statistics in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

contribute to resilience through multiple complementary channels.

### *4.7. Heterogeneity analysis*

We further examine whether the impact of digital transformation on supply chain resilience varies across different types of firms. Table 10 presents results from heterogeneity tests that split the sample by industry factor intensity, environmental regulation sensitivity, and ownership structure. The findings reveal distinct patterns in how digitalization contributes to resilience in each subgroup, as detailed below.

**Industry Intensity Groups:** *Labor-intensive* and *technology-intensive* firms experience a stronger positive effect of digital transformation on supply chain resilience than *asset-intensive* firms. In the labor-intensive sector, digital tools likely streamline workforce coordination and automate routine tasks, which enhances flexibility and responsiveness to disruptions. Technology-intensive firms, already rich in knowledge and innovation, can more readily integrate advanced digital systems (e.g. data analytics, smart manufacturing) into their operations, yielding significant resilience gains. In contrast, asset-intensive industries (reliant on heavy physical assets and capital) see a comparatively weaker effect – their supply chains are often tied to inflexible infrastructure and long investment cycles, so digital upgrades provide only incremental improvements in mitigating risks. This pattern from Table 10 suggests that the resilience benefits of digitalization are most pronounced when a firm's processes depend heavily on human and intellectual capital, and less so when success hinges on physical asset utilization.

**Environmental Regulation Sensitivity:** The resilience impact of digital transformation differs markedly between firms in heavily polluting industries and those in cleaner industries. Table 10 shows that digitalization is associated with improved supply chain resilience for *non-serious polluting firms* (i.e. companies in relatively clean sectors), whereas it has a negative effect for *serious polluting firms* in heavily regulated industries. One explanation is that enterprises in high-pollution sectors face stringent environmental regulations that can complicate or slow down the implementation of digital initiatives. These firms must devote substantial resources to compliance and pollution control, creating **regulatory pressures** and operational challenges that may blunt the effectiveness of digital transformation. For example, installing new digital monitoring systems or overhauling production processes to meet environmental standards might initially disrupt operations, undermining supply chain stability. In contrast, companies in non-polluting industries can adopt digital technologies with fewer regulatory constraints, allowing them to streamline logistics, improve information flow, and respond faster to shocks – all of which bolster their supply chain resilience. Thus, the heterogeneity test implies that the positive effects of digital transformation emerge more readily when firms are not encumbered by heavy environmental compliance burdens, while in highly polluting industries the net impact may even turn negative under current conditions.

**Ownership Structure:** Ownership plays a significant role in moderating the resilience gains from digital transformation. The heterogeneity results indicate that **state-owned enterprises (SOEs)** enjoy a pronounced boost in supply chain resilience from digitalization, whereas the effect for **non-SOEs** (privately owned or other types of firms) is much weaker and sometimes statistically insignificant. This contrast can be attributed to differences in resource allocation, government support, and strategic priorities. SOEs

**Table 10**
Heterogeneity test.

| PANEL A | Industry intensity groups | | |
|---|---|---|---|
| GROUPS | Labor-intensive | Tech-intensive | Asset-intensive |
| VARIABLES | SupRes | SupRes | SupRes |
| lnDIG | 0.004*** | 0.001* | −0.0002 |
| | (2.928) | (1.660) | (-0.168) |
| Size | −0.004*** | −0.007*** | −0.007*** |
| | (-13.153) | (-34.566) | (-20.176) |
| RCA | 0.009*** | 0.007*** | 0.008*** |
| | (8.858) | (12.388) | (6.966) |
| FL | 0.003*** | 0.003*** | 0.002*** |
| | (9.212) | (14.730) | (6.225) |
| lnConcentration | 0.007*** | 0.005*** | 0.005*** |
| | (7.511) | (11.127) | (4.726) |
| lnCompensation | 0.002*** | 0.001*** | 0.006*** |
| | (3.114) | (3.838) | (10.041) |
| Board | 0.003** | 0.002** | 0.003 |
| | (2.185) | (2.546) | (1.564) |
| Constant | 0.349*** | 0.424*** | 0.366*** |
| | (39.758) | (83.583) | (34.726) |
| Observations | 6104 | 10,565 | 3257 |
| R-squared | 0.155 | 0.203 | 0.235 |
| IND | FE | FE | FE |
| YEAR | FE | FE | FE |

| PANEL B Environmental regulation sensitivity | | |
|---|---|---|
| GROUPS | Non serious polluting industry | Serious polluting industry |
| VARIABLES | SupRes | SupRes |
| lnDIG | 0.003*** | −0.003** |
| | (3.882) | (-2.543) |
| Size | −0.006*** | −0.006*** |
| | (-31.585) | (-23.945) |
| RCA | 0.008*** | 0.007*** |
| | (14.612) | (7.214) |
| FL | 0.003*** | 0.002*** |
| | (15.784) | (8.877) |
| lnConcentration | 0.007*** | 0.004*** |
| | (14.498) | (5.018) |
| lnCompensation | 0.002*** | 0.003*** |
| | (5.618) | (8.028) |
| Board | 0.002** | 0.003** |
| | (2.539) | (2.115) |
| Constant | 0.388*** | 0.403*** |
| | (74.363) | (49.313) |
| Observations | 15,866 | 4298 |
| R-squared | 0.164 | 0.271 |
| IND | FE | FE |
| YEAR | FE | FE |

| PANEL C Ownership structure | | |
|---|---|---|
| GROUPS | Non-SOE | SOE |
| VARIABLES | SupRes | SupRes |
| lnDIG | −0.001 | 0.010*** |
| | (-1.645) | (6.693) |
| Size | −0.005*** | −0.006*** |
| | (-26.076) | (-20.823) |
| RCA | 0.008*** | 0.008*** |
| | (14.335) | (6.891) |
| FL | 0.003*** | 0.003*** |
| | (14.535) | (9.480) |
| lnConcentration | 0.007*** | 0.004*** |
| | (14.867) | (4.462) |
| lnCompensation | 0.001*** | 0.004*** |
| | (3.197) | (7.614) |
| Board | 0.003*** | 0.002 |
| | (3.774) | (1.207) |
| Constant | 0.401*** | 0.349*** |

(*continued on next page*)

**Table 10** (*continued*)

| PANEL C Ownership structure | | |
|---|---|---|
| GROUPS | Non-SOE | SOE |
| VARIABLES | SupRes | SupRes |
| | (71.901) | (38.466) |
| Observations | 14,125 | 5605 |
| R-squared | 0.169 | 0.237 |
| IND | FE | FE |
| YEAR | FE | FE |

often have preferential access to capital and policy support, enabling them to invest heavily in cutting-edge digital infrastructure (such as smart logistics systems or AI-driven supply chain management) without immediate pressure for returns. They also tend to prioritize long-term stability – in line with government mandates or public service obligations – so their digital transformation efforts are strategically aligned with enhancing risk management and continuity of operations. These factors mean that when SOEs implement digital technologies, they are more likely to improve information sharing, supplier coordination, and contingency planning throughout their supply chains, resulting in significantly higher resilience (as reflected in Table 10). In contrast, non-SOEs may face tighter budget constraints and competitive pressures that lead them to focus on cost efficiency or short-term gains over resilience. Without the same level of support or slack resources, private firms might adopt digital tools more cautiously or in piecemeal fashion, yielding only modest improvements in supply chain robustness. Consequently, the data suggest that digital transformation is a more effective driver of resilience in state-owned firms, while its benefits for privately owned firms, though present, are relatively limited.

## 5. Conclusion and implications

### 5.1. Conclusion

This study investigates the role of digital transformation in enhancing supply chain resilience, integrating multiple theoretical perspectives, including the resource-based view (RBV), dynamic capabilities, socio-technical systems, resource dependency, and institutional theory. The findings confirm that digital transformation directly improves supply chain resilience and operates through two key mediators: **supply chain power** and **supply chain transparency**. While digitalization enhances visibility and coordination, it also mitigates the risks associated with supply chain power imbalances. Robustness checks and endogeneity controls confirm the reliability of these results, reinforcing the conclusion that digital technologies enable firms to better withstand and recover from disruptions.

Further, heterogeneity analysis reveals significant variations in digital transformation's impact across different firm characteristics. Labor-intensive and technology-intensive firms benefit more from digital adoption compared to asset-intensive firms, highlighting the importance of flexibility and knowledge-based processes. Additionally, digital transformation strengthens resilience in non-polluting firms but has a negative effect in heavily polluting industries, likely due to regulatory constraints and operational complexities. Lastly, state-owned enterprises (SOEs) experience more substantial resilience gains from digital transformation than non-SOEs, reflecting differences in resource allocation, strategic priorities, and government support. These insights underscore the multifaceted nature of digital transformation's role in shaping supply chain robustness.

### 5.2. Implications

The findings offer several important implications for practitioners, policymakers, and researchers.

For **firms**, the results suggest that digital transformation should be pursued strategically, not only as a tool for operational efficiency but also as a resilience-building mechanism. Companies must **balance supply chain power dynamics** to avoid excessive dependence on key partners while leveraging digital technologies to enhance **supply chain transparency**. Industry-specific strategies are also essential—labor-intensive and technology-intensive firms should focus on digital tools that optimize workforce coordination and innovation-driven processes, whereas asset-intensive firms may need to combine digitalization with structural flexibility measures to maximize resilience benefits.

For **policymakers**, the findings highlight the need for tailored regulatory support. Given that digital transformation negatively impacts resilience in highly polluting industries, policymakers should provide targeted incentives, such as **subsidies for digital adoption in environmentally sensitive sectors**, while ensuring that regulatory compliance does not inadvertently hinder firms' ability to respond to supply chain shocks. Furthermore, given the stronger resilience gains observed in SOEs, policymakers should encourage similar long-term investment strategies among non-SOEs to ensure a more balanced and competitive industrial landscape.

For **academia**, this study contributes to the ongoing discourse on digital transformation by revealing its conditional effects on supply chain resilience. The interplay between digitalization, supply chain power, and transparency highlights the importance of a **systemic approach to supply chain management**, integrating both technological and governance mechanisms. Researchers should further explore the role of external environmental factors, such as global trade policies and geopolitical risks, in shaping the digitalization-resilience nexus.

### 5.3. Limitations and future research agenda

Despite its contributions, this study has several limitations that present opportunities for future research.

First, while the study leverages a large dataset from **Chinese listed firms**, the findings may not be fully generalizable to other economic contexts, particularly economies with different regulatory frameworks and digital infrastructure maturity. Future studies should examine whether similar patterns emerge in other regions, especially in **developed economies or emerging markets with distinct supply chain structures**.

Second, the study primarily focuses on two mediators—**supply chain power** and **transparency**—but other mechanisms may also play critical roles. Future research could explore **additional mediators**, such as **digital-driven supply chain agility**, **real-time data analytics**, or **blockchain-based trust mechanisms**, to provide a more comprehensive picture of how digitalization fosters resilience.

Third, the heterogeneity analysis highlights that digital transformation has **differential effects across industries and ownership structures**, but it remains unclear how firms can best tailor their digital strategies to maximize resilience in specific sectors. Future research could conduct **industry-specific case studies** or **comparative analyses across sectors** to offer more granular insights into effective digital transformation pathways.

Lastly, while this study applies rigorous econometric techniques to address **endogeneity concerns**, the causal inference could be further strengthened by **experimental designs or natural experiments**, such as exogenous policy shocks affecting digital adoption. Exploring the **longitudinal effects** of digital transformation across different economic cycles could also provide deeper insights into its resilience-enhancing capabilities over time.

In sum, this study advances the understanding of digital transformation's role in supply chain resilience by identifying key mechanisms and heterogeneity patterns. The findings provide actionable insights for firms and policymakers while opening new avenues for future research in digital supply chain management and resilience strategies.

## CRediT author statement

Pengcheng Li: Conceptualization, Methodology, Software, Writing - original draft.

Yanbing Chen: Data curation, Formal analysis, Validation, Writing - review & editing.

Xiaochuan Guo: Supervision, Project administration, Writing - review & editing, Funding *aquisition* .

All authors contributed to the study conception and design. Material preparation, data coll analysis were performed by Pengcheng Li and Yanbing Chen. The first draft of the manuscript was written by Pengcheng Li, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

## Data availability

Data will be made available on request.

## References

Agnihotri, R., & Gabler, C. B. (2024). Pursuing competitive advantages in the interactive digital marketplace and resource-advantage (RA) theory of competition: A research agenda. *Journal of Marketing Management, 40*(13–14), 1155–1173.

Alam, S., Zhang, J., Shehzad, M. U., Khan, N., & Ali, A. (2023). Mediation approach of knowledge management process towards supply chain performance under green technology: An empirical analysis. *Business Process Management Journal, 29*(5), 1466–1490.

Baiyere, A., Salmela, H., & Tapanainen, T. (2020). Digital transformation and the new logics of business process management. *European Journal of Information Systems, 29*(3), 238–259.

Bejlegaard, M., Sarivan, I. M., & Waehrens, B. V. (2021). The influence of digital technologies on supply chain coordination strategies. *Journal of Global Operations and Strategic Sourcing, 14*(4), 636–658.

Belton, K. B., Graham, J., & Xia, S. (2020). *'Made in China 2025' and the limitations of US trade policy*. Available at: SSRN 3664347.

Birkie, S. E., Trucco, P., & Fernandez Campos, P. (2017). Effectiveness of resilience capabilities in mitigating disruptions: Leveraging on supply chain structural complexity. *Supply Chain Management: International Journal, 22*(6), 506–521.

Campbell, J. L. (2007). Why would corporations behave in socially responsible ways? An institutional theory of corporate social responsibility. *Academy of Management Review, 32*(3), 946–967.

Cui, W., Yang, Y., & Dai, J. (2023). Evaluating the resource curse hypothesis and the interplay of financial development, human development, and political stability in seven emerging economies. *Environmental Science and Pollution Research, 30*(50), 109559–109570.

Dai, J. (2025). Is policy pilot a viable path to sustainable development? Attention allocation perspective. *International Review of Financial Analysis, 98*, Article 103923.

Dai, J., Mehmood, U., & Nassani, A. A. (2025). Empowering sustainability through energy efficiency, green innovations, and the sharing economy: Insights from G7 economies. *Energy, 318*, Article 134768.

Egels-Zandén, N., Hulthén, K., & Wulff, G. (2015). Trade-offs in supply chain transparency: The case of nudie jeans Co. *Journal of Cleaner Production, 107*, 95–104.

Faruquee, M., Paulraj, A., & Irawan, C. A. (2021). Strategic supplier relationships and supply chain resilience: Is digital transformation that precludes trust beneficial? *International Journal of Operations & Production Management, 41*(7), 1192–1219.

Gebhardt, M., Spieske, A., Kopyto, M., & Birkel, H. (2022). Increasing global supply chains' resilience after the COVID-19 pandemic: Empirical results from a Delphi study. *Journal of Business Research, 150*, 59–72.

Ghafoori, A., Gupta, M., Merhi, M. I., Gupta, S., & Shore, A. P. (2024). Toward the role of organizational culture in data-driven digital transformation. *International Journal of Production Economics, 271*, Article 109205.

Ghosh, S., Hughes, M., Hodgkinson, I., & Hughes, P. (2022). Digital transformation of industrial businesses: A dynamic capability approach. *Technovation, 113*, Article 102414.

Giannakis, M., & Louis, M. (2016). A multi-agent based system with big data processing for enhanced supply chain agility. *Journal of Enterprise Information Management, 29*(5), 706–727.

Gibbons, R. (2010). Transaction-cost economics: Past, present, and future? *The Scandinavian Journal of Economics, 112*(2), 263–288.

Gong, Q., Ying, L., & Dai, J. (2023). Green finance and energy natural resources nexus with economic performance: A novel evidence from China. *Resources Policy, 84*, Article 103765.

Huang, K., Wang, K., Lee, P. K., & Yeung, A. C. (2023). The impact of industry 4.0 on supply chain capability and supply chain resilience: A dynamic resource-based view. *International Journal of Production Economics, 262*, Article 108913.

Kagermann, H. (2014). Change through digitization—value creation in the age of Industry 4.0. In *Management of permanent change* (pp. 23–45). Wiesbaden: Springer Fachmedien Wiesbaden.

Kastelli, I., Dimas, P., Stamopoulos, D., & Tsakanikas, A. (2024). Linking digital capacity to innovation performance: The mediating role of absorptive capacity. *Journal of the Knowledge Economy, 15*(1), 238–272.

Kauppi, K. (2013). Extending the use of institutional theory in operations and supply chain management research: Review and research suggestions. *International Journal of Operations & Production Management, 33*(10), 1318–1345.

Khurana, I., Dutta, D. K., & Ghura, A. S. (2022). SMEs and digital transformation during a crisis: The emergence of resilience as a second-order dynamic capability in an entrepreneurial ecosystem. *Journal of Business Research, 150*, 623–641.

Korherr, P., Kanbach, D. K., Kraus, S., & Mikalef, P. (2022). From intuitive to data-driven decision-making in digital transformation: A framework of prevalent managerial archetypes. *Digital Business, 2*(2), Article 100045.

Kraus, S., Jones, P., Kailer, N., Weinmann, A., Chaparro-Banegas, N., & Roig-Tierno, N. (2021). Digital transformation: An overview of the current state of the art of research. *Sage Open, 11*(3), Article 21582440211047576.

Lu, Q., Deng, Y., Liu, B., & Chen, J. (2023b). Promoting supply chain financing performance of SMEs based on the extended resource-based perspective. *Journal of Business & Industrial Marketing, 38*(9), 1865–1879.

Lu, Q., Liu, B., & Yu, K. (2022). Effect of supplier-buyer cooperation on supply chain financing availability of SMEs. *International Journal of Logistics Research and Applications, 25*(9), 1244–1262.

Lu, Q., Shen, Y., & Yu, K. (2024a). Digital transformation of enterprises under the pressure of air pollution. *Applied Economics*, 1–18.

Lu, Q., Song, L., & Yu, K. (2023a). The effects of operational and digitalization capabilities on SMSs' supply chain financing under supply risk. *International Journal of Logistics Research and Applications, 26*(12), 1642–1662.

Lu, Q., Yang, Y., & Yu, M. (2024b). Can SMEs' quality management promote supply chain financing performance? An explanation based on signalling theory. *International Journal of Emerging Markets, 19*(7), 1981–2002.

Lu, Q., Zhou, Y., Luan, Z., & Song, H. (2024c). The effect of SMEs' ambidextrous innovations on supply chain financing performance: Balancing effect and moderating effect. *International Journal of Operations & Production Management, 44*(2), 424–461.

Macher, J. T., & Richman, B. D. (2008). Transaction cost economics: An assessment of empirical research in the social sciences. *Business and Politics, 10*(1), 1–63.

Modgil, S., Singh, R. K., & Hannibal, C. (2022). Artificial intelligence for supply chain resilience: Learning from covid-19. *International Journal of Logistics Management, 33*(4), 1246–1268.

Montecchi, M., Plangger, K., & West, D. C. (2021). Supply chain transparency: A bibliometric review and research agenda. *International Journal of Production Economics, 238*, Article 108152.

Nayal, K., Raut, R. D., Yadav, V. S., Priyadarshinee, P., & Narkhede, B. E. (2022). The impact of sustainable development strategy on sustainable supply chain firm performance in the digital transformation era. *Business Strategy and the Environment, 31*(3), 845–859.

Nwankpa, J. K., Roumani, Y., & Datta, P. (2022). Process innovation in the digital age of business: The role of digital business intensity and knowledge management. *Journal of Knowledge Management, 26*(5), 1319–1341.

Rane, J., Choudhary, S., & Rane, N. (2024). Artificial intelligence for enhancing resilience. *Journal of Applied Artificial Intelligence, 5*(2), 1–33.

Rane, S. B., & Narvel, Y. A. M. (2022). Data-driven decision making with blockchain-IoT integrated architecture: A project resource management agility perspective of industry 4.0. *International Journal of System Assurance Engineering and Management, 13*(2), 1005–1023.

Rao, A., & Brown, M. (2024). A review of the resource-based view (RBV) in strategic marketing: Leveraging firm resources for competitive advantage. *Business, Marketing, and Finance Open, 1*(3), 25–35.

Schwertner, K. (2017). Digital transformation of business. *Trakia Journal of Sciences, 15*(1), 388–393.

Shan, H., Ko, D., Wang, L., & Wang, G. (2025). Managerial ability, digital transformation and innovation efficiency: empirical evidence from Chinese manufacturing listed companies. *Chinese Management Studies, 19*(2), 526–548.

Soares, A. L., Gomes Jr, J., Zimmermann, R., Rhodes, D., & Dorner, V. (2024). Integrating AI in supply chain management: Using a socio-technical chart to navigate unknown transformations. In *Working conference on virtual enterprises* (pp. 22–35). Cham: Springer Nature Switzerland.

Sodhi, M. S., & Tang, C. S. (2019). Research opportunities in supply chain transparency. *Production and Operations Management, 28*(12), 2946–2959.

Sodhi, M. S., & Tang, C. S. (2021). Supply chain management for extreme conditions: Research opportunities. *Journal of Supply Chain Management, 57*(1), 7–16.

Thomas, A. (2024). Digitally transforming the organization through knowledge management: A socio-technical system (STS) perspective. *European Journal of Innovation Management, 27*(9), 437–460.

Tian, G., Li, B., & Cheng, Y. (2022). Does digital transformation matter for corporate risk-taking? *Finance Research Letters, 49*, Article 103107.

Tukamuhabwa, B. R., Stevenson, M., Busby, J., & Zorzini, M. (2015). Supply chain resilience: Definition, review and theoretical foundations for further study. *International Journal of Production Research, 53*(18), 5592–5623.

Vial, G. (2021). Understanding digital transformation: A review and a research agenda. *Managing Digital Transformation*, 13–66.

Villena, V. H., & Dhanorkar, S. (2020). How institutional pressures and managerial incentives elicit carbon transparency in global supply chains. *Journal of Operations Management, 66*(6), 697–734.

Wang, A., & Han, R. (2024). Can digital transformation prohibit corporate fraud? Empirical evidence from China. *Applied Economics Letters, 31*(16), 1505–1512.

Warner, K. S., & Wäger, M. (2019). Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. *Long Range Planning, 52*(3), 326–349.

Willie, M. (2025). Leveraging digital resources: A resource-based view perspective. *Golden Ratio of Human Resource Management, 5*(1), 1–14.

Wu, J., Guo, C., Liu, X., & Dai, J. (2025). Policy-Driven Employment Structure Transformation: The Role of Innovation and Education Investment. *International Review of Economics & Finance*, Article 103930.

Wylde, V., Prakash, E., Hewage, C., & Platts, J. (2022). The use of AI in managing big data analysis demands: Status and future directions. *Artificial Intelligence and National Security*, 47–67.

Yang, Y. (Ed.). (2022). *Digital economy and the sustainable development of ASEAN and China* (Vol. 9). World Scientific.

Yu, Z., Razzaq, A., Rehman, A., Shah, A., Jameel, K., & Mor, R. S. (2021). Disruption in global supply chain and socio-economic shocks: A lesson from COVID-19 for sustainable production and consumption. *Operations Management Research*, 1–16.

Yu, Y., & Shao, P. (2024). Enterprise digital transformation, COVID-19 and innovation persistence: Evidence from China. *Applied Economics Letters*, 1–6.

Zhang, H., Shi, Y., Yang, X., & Zhou, R. (2021). A firefly algorithm modified support vector machine for the credit risk assessment of supply chain finance. *Research in International Business and Finance, 58*, Article 101482.