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Resilience in the Age of Disruption: How Digitalisation Enhances Supply Chain Robustness

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Abstract

The article explores the role of digital tool adoption in supply chain resilience in environments prone to disruptions. It is against a backdrop of repeated shocks and the complexity of a growing web of relationships that digital transformation is being considered a prime facilitator of strong, resilient supply chains. The first point is to evaluate the extent to which the breadth and strength of digitalisation, along with the structural properties of the supply network, can explain differences in firms' resilience. The research design is quantitative and cross-sectional, which is a self-administered survey. The research used 271 organisations operating mainly in Lebanon and Romania, where the data were collected, and focused on supply chain and operations and logistics managers. Supply chain resilience and digitalisation were measured using multi-item Likert scales, and the other control variables were the firm size, sector, scope of operation and network complexity. The proposed relationships were tested using hierarchical multiple regression. The findings indicate that the use of digital tools and post-COVID digitalisation initiatives has a significant and positive impact on supply chain resilience, regardless of traditional structural factors. Network complexity is also a strong, positive predictor, indicating that complex, digitally enabled networks can increase adaptive capacity. The article is empirically original and presents a generalised, integrated definition of digitalisation, grounded in an under-investigated regional background. It concludes that digital transformation should be considered one of the key pillars of the resilience strategy and outlines implications for managers and policymakers.

Keywords: Supply Chain Resilience, Digitalisation, External Shocks, Digital Tools Adoption, Pandemic Disruptions, Geopolitical Risks, Supply Network Robustness

Introduction

The global business environment has significantly transformed, particularly after recent external shocks occasioned by the pandemic and geopolitical crises. Supply chain resilience is a more salient concept that can be defined as the capacity of a supply chain to predict, respond to and recover from unexpected shocks without interruption and to add value to customers (Reynolds, 2024; Wang, 2023). It is critical because organisations have gained the skills to manage disruptions that have never occurred before, such as the COVID-19 pandemic, which has impacted supply relationships and logistics networks to the extent that it has disrupted global trade due to geopolitical tensions (Azizah et al., 2024). The importance of resilience in a supply chain can hardly be overestimated; once resilience measures are incorporated into a supply chain, the latter can adapt to disruptions, secure stable operations and mitigate their effects (Wang, 2023; Alvarenga et al., 2023).

Digitalisation has been a pervasive challenge for organisations striving to achieve supply chain resilience, hindering the delivery of resilient, flexible supply chains. Digitalisation (i.e., the use of digital technologies in supply chain operations) provides agility, responsiveness and visibility (Wang, 2023; Zhao et al., 2023). The companies will be in a position to make their decisions better, enhance their operations and promote collaboration among the members of the supply chain with the assistance of such tools as artificial intelligence (AI), big data analytics and the Internet of Things (IoT) (Tobola & Cyplik, 2020; Alvarenga et al., 2023). Digital change leads to improved information processing, as businesses

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can anticipate disruptions and take the initiative to respond to them (Zhao et al., 2023). It is a crucial migration to the digital supply chain, as firms are slowly discovering that traditional supply chain management methods may not be adequate to address current market dynamics (Hallikas et al., 2021; Wang et al., 2024).

The stimuli that have triggered the urgency to enhance supply chain resilience through digitalisation include external shocks such as the COVID-19 pandemic and other geopolitical actions (Hallikas et al., 2021; Zhao et al., 2023). Regarding the pandemic specifically, many organisations experienced tremendous disruptions that exposed vulnerabilities in their supply chains, which, in turn, underscores the need for more flexible and responsive logistics systems (Azizah et al., 2024; Pan et al., 2023). The consequences of these disruptions were disastrous operations slowed significantly, resulting in higher costs and reduced efficiency (Zhang et al., 2024).

There is an additional level of geopolitical risk, including trade wars and tariff disputes, which is forcing businesses to reconsider their action plans to establish a degree of certainty and minimise risk (Zhi et al., 2024). Therefore, external shocks have provided a backdrop in which the need to ensure that supply chains are not only digitally enabled but also resilient has not only been appropriate to advise on but also worth the survival and competitiveness currently.

The study explains the important difference between the strength of supply chains and the use of digital tools, especially how these digital strategies can be quickly adopted to strengthen supply chains during tough times. Some of the important questions that will be answered in the present article are as follows: What is supply chain resilience, and how can it be measured? What is the role of digitalisation in resilience, and which digital tools best facilitate the improvement of the supply chain's performance? Lastly, what are the implications of recent external shocks (think pandemic, geopolitical turmoil, etc.) for the strategies that organisations need to implement to create resilient supply chains?

It is prudent to establish definitions of key terms we will use in this discussion to get a feel for this issue. Digitalisation is the term used to describe the process of adopting digital technologies and information systems to redesign conventional business processes, thereby enhancing effectiveness and efficiency in supply chains (Grant, 2024). Conversely, supply chain resilience refers to the capacity to plan, react and adjust to unexpected disruptions and to sustain efficient, flexible operations (Reynolds, 2024). Lastly, external shocks are unpredictable events, such as natural disasters or economic turmoil, that can impact supply chain activities and require immediate action (Zhao et al., 2023; Zhi et al., 2024).

The article is divided into several sections: an introduction to supply chain resilience and digitalisation; an analysis of how recent unexpected events have affected supply chain operations; an analysis of how digitalisation and supply chain resilience are combined; and concluding remarks summarising the findings and offering recommendations for next steps.

The intersections among supply chain resilience, digitalisation and external shocks constitute one of the diverse yet essential frontiers to examine in contemporary supply chain management. With organisations shifting to the new reality of post-pandemic recovery and responding to it amid changing geopolitical conditions, the vision of a digitally enabled, resilient supply chain will not only be a survival mechanism amid disruption but also the key to a successful business in the newly interconnected global economy.

Review of the Scientific Literature

Supply Chain Resilience: Concepts and Dimensions

The definition of supply chain resilience is the ability of a supply chain to pine, plan, revert and mend after a disruptive event. A set of several critical dimensions that contribute to the resilience framework, including robustness, agility and adaptability and visibility, is associated with such a definition. One example of robustness is the supply chain's ability to maintain performance even when disrupted, with allusions to its structural strength, such as the strategic positioning of items and the diversification of suppliers, which provide some cushion against disruption. Agility is the capacity to respond to or recover quickly from unplanned situations or disruptions without affecting service levels. This dimension is valuable in the era of uncertainty because

organisations can rapidly refocus their activities based on market or supply performance (Gruchmann et al., 2024). Adaptability is the ability of the supply chain to adjust its strategies and structures in response to the dynamic nature of the environment. It is a quality needed in volatile situations, such as the rapid transformations encountered during a crisis, as in the COVID-19 pandemic (Gruchmann et al., 2024). Visibility is a place where you can track and control the supply chain components by providing information about the supply chain in real-time, which will enable you to make better judgments and enhance your abilities in prediction. Increased visibility will allow organisations to identify disruptions at an early stage and respond promptly, thereby increasing resilience (Katsaliaki et al., 2021).

Supply Chain Disruptions

Supply chain continuity is significantly affected by external shocks stemming from the pandemic, geopolitical conflicts and trade wars. The COVID-19 pandemic provides a crucial illustration of the weaknesses in global supply chains (Paul et al., 2021; Roscoe et al., 2020). Lockdowns, transportation issues and new consumer behaviors led businesses to reconsider their use of a just-in-time inventory system (Paul et al., 2021). Studies have shown that firms faced major problems with supply chain interference, and this complication required a stronger supply chain management strategy, with resilience and flexibility prioritised over cost-saving factors (Katsaliaki et al., 2021).

The geopolitical conflicts, including the current conflict in Ukraine, further complicate the supply chain by posing risks of regional instability and trade barriers. Wars can lead to increased tariffs, altered trade policies and the cessation of trade routes, with catastrophic effects on global supply chain operations (Jagtap et al., 2022). The manufacturers that previously believed globalised trade would continue must operate under these new conditions, and a shift to localised supply chains or diversified sourcing strategies is required to mitigate risks (Fan et al., 2024). Additionally, trade wars between major economies can disrupt supply chains by exposing companies to fluctuating tariff rates, which affect their pricing strategies and profitability (Roscoe et al., 2020). These tensions also lead to unpredictable shifts in companies' supply chain strategies as they respond to political developments, compelling them to review their reliance on specific suppliers and the levels of exposure they face. The interplay of these external shocks underscores the growing importance of robust supply chains that can withstand shocks and recover quickly.

Supply Chain Digitalisation

Digital technologies are transforming supply chains, offering organisations opportunities to adopt digital capabilities that enhance operational performance, transparency and resilience. Enterprise Resource Planning (ERP) systems, the IoT, AI software, blockchain technology and cloud computing are among the most crucial digital tools. ERP systems can facilitate the coordination of the organisation's various tasks through a simplified process and an enhanced perspective across the supply chain (Pflaum et al., 2021). IoT may entail transparency in the real-time monitoring of products and assets along the supply chain and responsiveness to the disrupted state of the supply chain as a whole (Saryatmo & Sukhotu, 2021). In predictive analytics, AI algorithms help organisations anticipate shifts in demand rates and optimise inventory, routing and logistics (Simoes et al., 2019). Blockchain technology has enabled the safe and proactive conduct and tracing of transactions along the supply chain, thereby fostering trust in these transactions, as the data are recorded in the blockchain, cannot be reversed and are recorded in real time (Lee et al., 2024). Lastly, the cloud can store and process data to enable effective cooperation among supply chain participants and introduce further agility through its ability to establish a flexible, expandable system (He et al., 2024).

The theoretical connections between digital adoption and resilience focus on enhanced information flows, improved decision-making capacity and greater operational flexibility. By adopting digitalisation, supply chains can develop the capacity to take a holistic view of the risk management process, allowing organisations to be more responsive to external shocks. The study has also revealed that digitally prepared companies can be more agile and adaptive, which are the two most significant aspects of supply chain resilience (Yuan et al., 2023). Analytical and real-time data will enable timely decision-making, as a business can predict instances of disruption and

act strategically (Malatji, 2023). The above correlation between digitalisation and resilience underscores the need for organisations to invest in new technologies as part of their supply chain strategies.

Prior Empirical Research

The connection between digitalisation and the effectiveness of supply chains is increasingly being explored, indicating that digital transformation is significant. This is necessary to make operations more efficient and resilient. The most applicable studies predict that the adoption of digital technologies has a significant impact on organisations' performance indicators, including productivity, responsiveness and adaptability (Mthimkhulu & Jokonya, 2022). A study in the food and beverage industry found that companies using an integrated digital supply chain achieved optimal operational control by optimising forecasting and inventory management through data analytics (Saryatmo & Sukhotu, 2021).

Research on the automotive supply chain indicates that operational efficiency is enhanced by digital tools, and stakeholders experience more efficient collaboration, leading to shorter lead times and greater agility (Simoes et al., 2019). However, even with this significant improvement, some gaps in research remain. Firstly, the recent literature has discussed the effects of individual technologies (e.g., blockchain and AI), yet no research has examined how multiple digital tools can be used together and how they can benefit the chain as a whole to enhance supply chain resilience (Trevisan & Formentini, 2024).

Another issue is that the literature pays little attention to critical factors, such as industry differences, organisational scale and geographic settings that may influence the success of strategies aimed at achieving supply chain resilience through digital transformation. The research in the future must focus on filling these gaps through multi-faceted research, which will bring different digital technologies together and identify the overall impact of digitalisation on the results of the supply chain, taking into account the drivers of the digitalisation process and several other factors that may affect the success of initiatives aimed at digitalisation (Herold et al., 2021).

One area is the electronification of the supply chain, which offers opportunities for companies interested in greater resilience and performance amid current disruptions. The connections between technological use and resilience highlight the importance of solutions that are compatible with one another, and practical studies can serve as a basis for understanding their influence on business outcomes. There is a need to conduct further research to understand the dynamics of the digital supply chain, including issues and opportunities in detail.

Research Methodology

Research Design

The research design for this study is quantitative and cross-sectional. The goal is to explore the correlation between the use of digital tools, supply chain resilience and the chosen control variables at a single point in time. Standardised data were collected from organisational respondents using a structured survey tool to enable statistical comparisons between firms and industries. The cross-sectional design is the appropriate design for establishing associations and patterns among variables in real organisational settings, whereas the quantitative orientation enables testing hypotheses and estimating effect sizes using multivariate methods.

Data Collection

The data collection method was a self-administered questionnaire, developed on the basis of existing, validated scales from the supply chain resilience and digitalisation literature. Items related to supply chain resilience and the use of digital tools were adjusted to fit the study context, made more concise, and presented on a five-point Likert scale where necessary. Other items captured were control variables, including firm size, industry or sector, and the scope and complexity of the supply chain. The sampling plan focused on organisations operating in the areas of concern within the focal industries and geographic locations, specifically companies that manage organised supply chain operations. The potential respondents were managers of supply chains, operations, or logistics who had sufficient understanding of digital practices and the resilience strengths of their companies. The questionnaire was sent via email and professional networks, and respondents remained anonymous. An initial period was followed by a reminder to boost the response rate, and

only questionnaires completed in full were included in the analysis, resulting in the final sample size.

Variables and Measures

In this study, the supply chain's resilience is the primary dependent variable. This construct can be characterised as the capability of a supply chain to respond to external shocks and disruptions with pre-set, absorbed, adaptive and recovered functional and financial performance (Gruchmann et al., 2024; Katsaliaki et al., 2021). The Likert scale is used to operationalise the concept of supply chain resilience in the study, based on established frameworks that measure dimensions, such as robustness, agility and the ability to recover normal functioning after disruptive events (Alvarenga et al., 2023; Zhao et al., 2023). The questions regarding the extent to which respondents agree with statements on the preparedness for disruption, adaptive capacity and recovery speed of their organisation in the context of the COVID-19 pandemic and geopolitical bust-ups will need to be answered by the survey respondents. The independent variables focus on the implementation of specific digital capabilities and tools in the supply chain. The study adds to previous research by looking at how companies are using important technology solutions, like ERP systems, cloud computing, IoT, big data analytics, blockchain and digital supply chain platforms (Hallikas et al., 2021; Tobo, Laura & Cyplik, 2020; Pan et al., 2023). For every digital tool, respondents will be asked to clarify whether it is in use in their organisation, and, if so, the maturity of the tool's implementation will be estimated on a Likert-type scale ranging from pilot stage to full integration. The given approach enables measuring the level and depth of digitalisation across the various functions of supply chains (Herold et al., 2021; Zhang et al., 2024).

Besides the variable of interest, the analysis will use various control variables to control for the potential confounding impacts. The size of firms is also incorporated and will be measured by employee count and annual turnover to account for the fact that larger organisations can allocate more resources to online adoption and resilience development (Wang et al., 2024). The research also considers sector or industry (manufacturing or services, retailing and others), as industry characteristics may affect digital transformation and resilience strategies (Azizah et al., 2024; Saryatmo & Sukhotu, 2021). The physical proximity to operations, where the company conducts its operations on a domestic or global scale, is also taken into consideration, as global supply chains may be exposed to different risk profiles and require their own digitalisation plans (Fan et al., 2024). Lastly, the complexity of the supply chain is determined by the number of supply chain partners and the variety of supply chain sources; the more complex the networks are, the more likely it is that advanced digital solutions are needed to manage the risks (Jagtap et al., 2022). All instruments of measurement were selected based on validated literature and tested for reliability and clarity before this study applied them.

Table 1: Study Variables and Operational Definitions

Variable Type	Variable Name	Definition / Operationalization	Measurement	Reference(s)
Dependent	Supply chain resilience	The capability of a supply chain to anticipate, absorb, adapt to, and recover from external shocks while maintaining performance.	Multi-item 5-point Likert scale (robustness, agility, recovery, etc.).	Alvarenga et al., 2023; Gruchmann et al., 2024; Zhao et al., 2023
Independent	Digital tool adoption	Adoption and maturity of key digital technologies in the supply chain (ERP, IoT, cloud, big data, blockchain, platforms, etc.).	Dichotomous (yes/no) for each tool; Maturity: 5-point Likert scale.	Hallikas et al., 2021; Toboła & Cyplik, 2020; Pan et al., 2023; Herold et al., 2021; Zhang et al., 2024
Control	Firm size	Scale and resource base of the organization.	Number of employees; annual turnover (continuous or categorical).	Wang et al., 2024
Control	Sector / Industry	Economic activity domain of the organization.	Categorical (manufacturing, services, retail, other).	Azizah et al., 2024; Saryatmo & Sukhotu, 2021
Control	Geographical scope	Area of supply chain operations (domestic or international).	Categorical (domestic, international).	Fan et al., 2024
Control	Supply chain complexity	Structural diversity of the supply network.	Number of supply chain partners; number of supply sources.	Jagtap et al., 2022

Statistical Analysis

Before formal analysis, the data were thoroughly screened and cleaned. Cases with excessive missing data or inconsistent responses were excluded, and the remaining missing values were addressed using appropriate procedures. Descriptive statistics were used to detect outliers and assess the assumptions of normality, homogeneity and linearity required for multivariate analysis. Multi-item construct reliability and validity were then determined. Cronbach's alpha was used to test internal consistency and, where possible, composite reliability. To ensure that the scales had a dimension, exploratory or confirmatory factor analyses were used to assess convergent and discriminant validity.

After these initial tests, the primary statistical tests were performed using standard software (SPSS). Descriptive statistics provided information on the sample features and the central tendencies of the key variables. The bivariate association between variables was assessed using Pearson's correlation. This step was followed by multiple regression analysis (and other appropriate multivariate methods), which tested the hypothesised effects of adopting digital tools on supply chain resilience whilst adjusting for firm size, sector, geographical scope and supply chain complexity.

Limitations of Methodology

The methodological decisions in this research entail several limitations that must be considered. To begin with, a cross-sectional design does not allow causal conclusions, as all variables were measured at a single point in time. Second, there is a risk of common-method bias and perceptual bias when using self-reported data from a single respondent within an organisation, regardless of anonymity guarantees. Third, the sampling plan, which included readily available companies in particular industries and geographic areas, can also limit the generalizability of the results to other industries or nations. Lastly, time limitations and the limited availability of firms prevented the acquisition of longitudinal or objective performance data, which would have strengthened the findings.

Results and Discussion

Sample Characteristics

A total of 271 usable responses were obtained for the study. Table 2 presents an overview of the respondents' organisational profiles. About the primary sector, the largest share of firms operate in retail (61.6%, n = 167), followed by logistics (21.8%, n = 59) and manufacturing (16.6%, n = 45). This distribution shows a high level of participation in downstream and distribution-oriented supply chain activities, supplemented by a large percentage of production- and transport-related organisations. Regarding respondents' roles, most were supply chain managers (87.1, n = 236), followed by operations managers (7.0, n = 19) and logistics managers (5.9, n = 16). This implies that the results would mostly capture the views of those with overall responsibility for supply chain decisions and performance.

Firm sizes are rather heterogeneous. It has nearly equal levels of 50–249 employees, constituting almost half (47.2, n = 128), 250–999 employees (25.1, n = 68) and 1,000 or more employees (7.4, n = 20). 20.3% of the sample are small firms with fewer than 50 employees (n = 55). The combination of the above variables enables the analysis to reflect the possible effect of scale and resource endowment on resilience and digitalisation. In terms of geographic location, the majority of these firms are headquartered in Lebanon (47.2, n = 128) or Romania (48.0, n = 130), and only a few are headquartered in Germany (1.1, n = 3), the United States (1.5, n = 4), Tunisia (1.1, n = 3) and Kuwait (1.1, n = 3). The operation scope is mostly international: 59.8% (n = 162) indicate operating internationally alone, 27.3% (n = 74) operating domestically alone and 12.9% (n = 35) operating both domestically and internationally.

Lastly, there is diversity in the supply base structures among respondents. In most organisations, the average number of primary suppliers is 6–10 (42.4%, n = 115) or 11–20 (32.1%, n = 87), while 18.1% (n = 49) have between 1 and 5 primary suppliers, and 7.4% (n = 20) have more than 20 primary suppliers. This heterogeneity in supply base size can be used to evaluate the complexity

of the supply chain and its possible combination with resilience and the implementation of digital tools.

Table 2: Sample Characteristics (N = 271)

Variable	Category	n	%
Primary sector	Retail	167	61.6
	Manufacturing	45	16.6
	Logistics	59	21.8
Role in organization	Supply chain manager	236	87.1
	Operations manager	19	7.0
	Logistics manager	16	5.9
Organization size	Fewer than 50 employees	55	20.3
	50–249 employees	128	47.2
	250–999 employees	68	25.1
	1,000 or more employees	20	7.4
HQ country	Lebanon	128	47.2
	Romania	130	48.0
	Germany	3	1.1
	American	4	1.5
	Tunisia	3	1.1
	Kuwait	3	1.1
Operation scope	Domestically only	74	27.3
	Internationally only	162	59.8
	Both domestic and international*	35	12.9
Number of primary suppliers	1–5	49	18.1
	6–10	115	42.4
	11–20	87	32.1
	More than 20	20	7.4

Descriptive Statistics

The descriptive statistics of the adoption of digital tools in the sample are reported in Table 3. When measured on a five-point scale (15), the mean values for all digital technologies are very high, indicating that the surveyed organisations have widely adopted them and are considered mature. ERP systems, cloud platforms, IoT devices, big data analytics, blockchain technology, digital collaboration platforms and AI-based decision support all have mean scores of 4.92–4.94, with low standard deviations (0.37–0.48). On the same note, integration of digital tools, real-time data sharing and dashboards/control towers also report a high mean value (4.924.96) and low dispersion. In general, these results indicate that the process of digitalisation, in this sample, is not limited to specific tools but indicates the existence of a generally developed digital infrastructure, where both backbone systems (e.g., ERP, cloud) and more innovative features (e.g., analytics, AI, blockchain) are widely used.

Table 4 presents descriptive statistics on supply chain disruption. The network complexity and multi-country sourcing (4.93 and 4.94) are both high, indicating that most organisations source through structurally complex, internationally extended sourcing networks. The post-COVID digitalisation initiatives are also rated high (mean = 4.94), as the pandemic is likely to have accelerated supply chain digitalisation. Finally, the external shocks over the last three years have a mean of 4.92, suggesting that respondents perceive their supply chains as having been strongly affected by recent disruptions (e.g., pandemics, geopolitical events). Taken together, these results depict a context characterised by both high digital capability and substantial exposure to disruption, thereby providing a suitable empirical setting for examining the relationship between digital tool adoption and supply chain resilience.

Table 3: Descriptive Statistics for the Adoption of Digital Tools

Variable	N	Min	Max	Mean	SD
ERP systems	271	1	5	4.93	0.48
Cloud platforms	271	1	5	4.94	0.37
IoT devices	271	1	5	4.93	0.44
Big data analytics	271	1	5	4.93	0.42
Blockchain technology	271	1	5	4.93	0.46
Digital collaboration platforms	271	1	5	4.93	0.45
AI decision support	271	1	5	4.92	0.48
Digital tools integration	271	1	5	4.94	0.39
Real-time data sharing	271	1	5	4.96	0.33
Dashboards/control towers	271	1	5	4.92	0.47

Table 4: Descriptive Statistics for Supply Chain Disruption Context

Variable	N	Min	Max	Mean	SD
Network complexity	271	1	5	4.93	0.46
Multi-country sourcing	271	1	5	4.94	0.41
Post-COVID digitalization efforts	271	1	5	4.94	0.43
External shocks impact (last three years)	271	1	5	4.92	0.51

Main Findings

The results of the hierarchical multiple regression analysis are presented in Tables 5 and 6. In Model 1, which includes only the control variables (organisation size, primary sector, operation scope, network complexity, multi-country sourcing and number of primary suppliers), the model explains 74.4% of the variance in supply chain resilience (R^2 = .744, Adj. R^2 = .738, p < .001). This indicates that structural and contextual characteristics of the supply chain, particularly network-related factors, already account for a substantial share of the observed variation in resilience levels across firms. When the digitalisation-related variables (digital adoption index, digital integration index, post-COVID digitalisation efforts and external shocks impact over the last three years) are added in Model 2, the explained variance increases to 80.9% (R^2 = .809, Adj. R^2 = .802, p < .001), with a ΔR^2 of .065. This improvement is statistically significant, suggesting that digital tool adoption and related capabilities provide additional explanatory power beyond traditional structural controls. That is, although the configuration of the supply chain and its scope remain significant, digitalisation does play a crucial role in increasing the likelihood of explaining variation in resilience among organisations.

Table 6 presents the regression coefficients, which provide further insight into which variables have the greatest influence on supply chain resilience. Network complexity is one of the control variables that are significant positive predictors (β = .502, p < .001), indicating that the more companies are embedded in a more complex supply network, the more likely they are to report high resiliency. These values can indicate the availability of richer relational resources, greater diversity in sourcing, or more well-developed coordination within complex networks. The other structural controls, including organisation size, primary sector, scope of operations, multi-country sourcing and the number of primary suppliers, are not statistically significant in the final model, suggesting that their direct relationship with resilience is attenuated when digital capabilities and network complexity are considered. Regarding the variables of digitalisation, the index of digital adoption has a positive, statistically significant impact on supply chain resilience (β = 670, p = .003). This conclusion indicates that greater and more advanced use of major digital tools (including ERP, cloud services, IoT, big data analytics, blockchain, digital collaboration tools and AI decision support) is associated with higher resilience, even when structural and contextual variables are taken into account. A positive impact is also observed from post-COVID digitalisation efforts (β = .158, p = .002), suggesting that organisations that enhanced their digitalisation following the pandemic have higher resilience capabilities. By contrast, the digital integration index (β = −.341, p = .095) and the perceived impact of external shocks over the last three years (β = .060, p = .407) do not reach conventional levels of significance in the final model. Overall, the pattern of results highlights digital tool adoption and post-COVID digitalisation as the most influential digital capabilities for enhancing supply chain resilience in the sampled firms, alongside the structural contribution of network complexity.

Table 5: Hierarchical Multiple Regression Predicting Supply Chain Resilience (N = 271)

Model	Predictors in the Block	R	R^2	Adj. R^2	ΔR^2	F (df1, df2)	p	Std. Error of Estimate
1	Controls: organization size, primary sector, operation scope, network complexity, multi-country sourcing and number of primary suppliers.	.863	.744	.738	.744	128.04 (6, 264)	< .001	0.179
2	Model 1 + digital adoption index, digital integration index, post-COVID digitalization, external shocks impact (last 3 years).	.900	.809	.802	.065	110.28 (10, 260)	< .001	0.156

Table 6: Regression Coefficients for Final Model Predicting Supply Chain Resilience (Model 2)

Predictor	B	SE B	β	t	p
Constant	1.572	0.163	–	9.66	< .001
Organization size	0.001	0.012	.002	0.07	.943
Primary sector	−0.017	0.012	−.040	−1.43	.155
Operation scope	−0.025	0.016	−.044	−1.59	.113

Predictor	B	SE B	β	t	p
Network complexity	0.383	0.075	.502	5.08	< .001
Multi-country sourcing	−0.096	0.060	−.113	−1.60	.112
Number of primary suppliers	−0.006	0.012	−.014	−0.46	.646
Digital adoption index	0.568	0.192	.670	2.96	.003
Digital integration index	−0.323	0.193	−.341	−1.67	.095
Post-COVID digitalization	0.128	0.041	.158	3.10	.002
External shocks impact (last 3 years)	0.042	0.050	.060	0.83	.407

Discussion

Digitalisation as a Facilitator of Supply Chain Resilience

The empirical findings support the claim that digitalisation is an important facilitator of supply chain resilience in disruption-prone settings. In the hierarchical regression, over and above the structural factors, the breadth of digital tool adoption and the accelerated pace of digitalisation since the onset of COVID-19 have a positive, statistically significant effect on supply chain resilience. This observation is generally in line with recent literature indicating that digital transformation can enhance firms' sensing, absorption and recovery capabilities through improved visibility, better coordination and data-driven decision-making (Zhao et al., 2023; Yuan et al., 2023; Wang, 2023). Research on digital supply chains similarly emphasizes the importance of cloud computing, big data analytics, AI and platform-based collaboration to enhance responsiveness and robustness in turbulent conditions (Hallikas et al., 2021; Tobola & Cyplik, 2020).

Similar to the empirical evidence that digital transformation is a source of efficiency and performance in supply chains in manufacturing and related industries (He et al., 2024; Saryatmo & Sukhotu, 2021; Wang et al., 2024), our results confirm that digitalisation is also strongly linked to resilience, with the key difference that the present study explicitly focuses on resilience as the outcome. Consistent with the perception of resilience as a system-level quality emerging from the interplay of numerous capabilities (Gruchmann et al., 2024), the substantial influence of the digital adoption index implies that the resilience of our sample is supported not by individual technologies but by the collective implementation of a broad portfolio of tools such as ERP, cloud solutions, IoT, analytics, blockchain, collaboration platforms and AI. The beneficial impact of post-COVID efforts in digitalisation also resonates with recent studies reporting how the pandemic served as a catalyst for digital transformation and stimulated investments in smart technologies, platforms and data-driven processes to overcome unprecedented disruptions (Paul et al., 2021; Malatji, 2023; Trevisan & Formentini, 2024; Floristella & Chen, 2022).

The observation that the digital integration index fails to reach traditional levels of statistical significance, even though the average scores are high, might indicate ceiling effects or a lack of variance in integration practices among respondents who are already highly digitalised. It can also suggest that, in such contexts, the marginal benefits of additional integration are overshadowed by the availability of core digital instruments and by tactical post-pandemic digital projects. This detail adds empirical depth to conceptual arguments that focus on end-to-end integration as a defining characteristic of future digital supply chains (Pflaum et al., 2021; Ishfaq et al., 2021), and hints that the breadth of tool usage and the strategic trajectory of digital transformation can be at least as important as technical integration itself.

Network Complexity and Structural Drivers of Resilience

One of the most interesting and, perhaps, counterintuitive findings concern the role of network complexity. In most works, high complexity and worldwide connectivity have been linked to greater exposure to geopolitical and systemic shocks (Katsaliaki et al., 2021; Roscoe et al., 2020; Jagtap et al., 2022). In our model, however, network complexity is a strong positive predictor of resilience. This can be interpreted as evidence that complex networks in this sample do not simply become more fragile; they also become more diversified and digitally

empowered, enabling firms to reroute flows, replace suppliers and exploit richer relational resources in the event of disruptions. This result relates to studies that find that multi-country, digitally supported supply networks have the potential to develop adaptive capabilities that counterbalance their exposure to volatility (Zhao et al., 2023; Zhi et al., 2024; Pan et al., 2023). The insignificance of other structural controls (firm size, sector, range of operations, multi-country sourcing, number of suppliers) once digitalisation and network complexity are included suggests that conventional structural features may be less critical in determining resilience than the extent to which digital capabilities are leveraged within those structures.

Managerial, Policy and Theoretical Implications

From a managerial perspective, the outcomes suggest that supply chain leaders should consider digitalisation as one of the key pillars of resilience strategy rather than as a purely efficiency-focused program. A robust backbone including ERP and cloud platforms should be prioritised for investment, but other innovative tools that improve visibility and coordination with partners are also highly valuable (Hallikas et al., 2021; Lee et al., 2024). Our findings further indicate that the benefits of post-crisis digital transformation programs, frequently launched in response to COVID-19, have long-term effects in terms of resilience, which supports calls to institutionalise the digital innovations triggered by recent crises instead of rolling them back (Wang, 2023; Zhao et al., 2023; Yuan et al., 2023). Moreover, the positive role of network complexity implies that managers should not seek to simplify their networks solely to cope with uncertainty, but rather to strategically use digital tools, relationship governance and strong supplier relationship management to harness complexity (Grant, 2024; Roscoe et al., 2020).

The findings also underscore the significance of using digital infrastructure, standards and capabilities at the ecosystem level for policymakers. Policy initiatives that promote broadband connectivity, interoperable data platforms, digital skills development and the diffusion of new technologies among SMEs can improve the resilience of entire supply networks, especially in emerging economies and trade-dependent regions (Floristella & Chen, 2022; Malatji, 2023; Simoes et al., 2019). At the same time, the resilience advantages of digitalisation should encourage firms to adopt high-impact technologies, such as blockchain and AI, within supply chains, which requires regulatory frameworks that facilitate trustworthy data sharing (Mthimkhulu & Jokonya, 2022; Trevisan & Formentini, 2024).

Finally, this study makes three major original contributions. First, it provides survey-based evidence on the connection between the adoption of digital tools and supply chain resilience using a multi-country sample based in Lebanon and Romania, two contexts that are under-represented in the literature, which is dominated by large economies in Europe, North America and East Asia (Zhao et al., 2023; Yuan et al., 2023; Zhang et al., 2024). Second, it incorporates a wide-ranging operationalisation of digitalisation that encompasses not only core tools but also future-oriented capabilities, post-COVID transformation initiatives and structural network features (He et al., 2024; Wang et al., 2024; Zhi et al., 2024). Third, by jointly analysing the impact of digitalisation and network complexity, the study refines existing assumptions about the vulnerability of complex global supply chains and identifies conditions under which digitalisation-enabled complexity can strengthen rather than weaken resilience. Together, these contributions advance current debates on the potential of digital transformation to establish robust, flexible and learning-centric supply chains amid ongoing disruption.

Conclusion

The aim of the study was to investigate the impact of digital tool adoption and associated capabilities on supply chain resilience in an environment with high disruption exposure and significant network complexity. The analysis based on survey results from 271 organisations reveals that digitalisation adds substantial explanatory value to traditional structural predictors such as firm size, industry, scope of operations, multi-country sourcing and the number of suppliers. Specifically, the extension of digital tool use (including ERP, cloud environments, IoT, big data analytics, blockchain, digital collaboration platforms and AI decision support) and the increased focus on digitalisation in the post-COVID era are strong, positive predictors of supply chain resilience. The strength of interrelation with resilience is also evident in the relationship between network complexity and resilience, indicating that complex, digitally enabled networks can be a source of adaptive strength rather than just a source

of vulnerability. Theoretically, the research will contribute to the existing literature on supply chain resilience by theorising resilience as a system-level quality resulting from the interplay between structural features and digital capabilities. The results build on the previous literature by showing that resilience is based not only on the presence of individual technologies but also on the accumulation of a wide range of digital offerings, along with a plan for strategic post-crisis change interventions. In addition, the fact that network complexity has a beneficial impact contradicts the traditional belief that complexity is always harmful and points to a subtler perspective, according to which complexity can promote resilience when coupled with appropriate digital tools and data-led coordination processes.

In practice, the results emphasise that digitalisation must be considered by managers as part of the resiliency strategy, not merely an efficiency-only investment. In addition to implementing ERP systems and cloud-based solutions, companies should focus on advanced analytics, AI-driven decision support and digital collaboration platforms to enhance visibility of end-to-end processes and partner coordination. The significant role of post-COVID digitalisation also suggests that the digital programs brought about by the crisis must be institutionalised and developed, rather than limited to the future when the disruptions are removed. At the same time, the sheer complexity of networks implies that managers should be strategic in how they design and manage them through digital tools to manage interdependence, diversify sourcing and increase information exchange with strategic partners. The study is new in several aspects. It empirically presents survey-based information about a multi-country sample anchored in Lebanon and Romania, which remain underrepresented in the massively saturated literature on digital transformation and resilience. Its conceptualisation of digitalisation is broad, combining core technologies, advanced tools and post-crisis transformation activities and analysing them in the context of network-level properties. It analytically demonstrates that digital adoption and post-COVID digitalisation have significant impacts even when structural factors are controlled, thereby explaining the relative importance of digital and traditional resilience drivers. Simultaneously, several constraints should be noted. The cross-sectional design also fails to provide causal inferences or to observe dynamic processes of adaptation over time. The risk of common-method bias and perceptual bias increases when self-reported data from individual respondents within each organisation are used. The sample is also limited to certain countries and areas, which could limit the applicability of the results to other institutional or industry settings. Additionally, the fact that the average scores were high on most items, indicating digitalisation and resilience, may imply ceiling effects and thus neutralise relationships among certain variables, including digital integration.

The limitations in the research can be overcome in several ways in future research. Longitudinal designs would enable the investigation of the influence of digital transformation trajectories on resilience structure in the pre-disruption, disruption and post-disruption periods. Multi-informant and mixed-method designs can triangulate survey data with qualitative information and objective performance measures. Comparative studies across geographical locations and industrial sectors would help determine the conditions under which digitalisation and network complexity either facilitate or restrict resilience. Lastly, more detailed models might explore intervening and abetting procedures, i.e., the quality of information sharing, governance structures, or supplier relationship management, through which digital technology and multifaceted networks are transformed into durable supply chain outcomes.

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