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The Relationship between Supply Chain Resilience and Digital Supply Chain and the Impact on Sustainability: Supply Chain Dynamism as a Moderator

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Abstract: This research aims to explore the complex interplay between supply chain resilience (SCR), digital supply chain (DSC), and sustainability, focusing on the moderating influence of supply chain dynamism. The goal is to understand how these elements interact within the framework of contemporary supply chain management and how they collectively contribute to enhancing sustainability outcomes. The sample size is 300 CEOs and managers. The study approach integrates quantitative research methods. Structural equation modeling (SEM) is utilized to quantitatively analyze the direct and indirect effects of SCR and DSC on sustainability. The numerous surveys we conduct among supply chain ecosystem stakeholders provide a rich picture of practical implications and contextual nuances. In sum, our early findings generally support a positive relationship between SCR and sustainability in and of itself, declaring the need for more resilient supply networks for sustainability. We further find the beneficial impact of digital technologies in promoting sustainability via enhancing environmental control and controlling for efficiency in supply chains. We also offer evidence to show that supply chain dynamism compounds the positive logic between SCR and DSC and sustainability. As a final word, it must be noted that our work speaks to the burgeoning literature on supply chain dynamism as a moderator by examining the direct and contingent effects of SCR and DSC not only on performance but sustainability. By shedding light on the moderating role of dynamism, the study provides fresh insights into the multifaceted nature of supply chain management and sustainability practices. The study's findings enhance theoretical understanding by elucidating the synergistic effects of SCR, DSC, and sustainability in dynamic supply chain settings. The study augments the existing theoretical frameworks by integrating the concepts of resilience, digitalization, and sustainability into a comprehensive model. Practical and economical, the research offers actionable guidance for organizations aiming to improve sustainability performance through resilient and digitally advanced supply chains. By acknowledging the role of supply chain dynamism, managers can tailor strategies to manage disruptions effectively and leverage digital innovations. Economically, adopting sustainable practices can result in cost savings and competitive advantages. The research emphasizes the importance of aligning supply chain strategies with sustainability goals to drive long-term value and societal impact.

Keywords: supply chain resilience; digital supply chain; supply chain sustainability; supply chain dynamism

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1. Introduction

The acceleration in digital supply chains has prompted organizations to explore novel ways to bolster operations' resilience, adaptability, and sustainability, ultimately benefiting society and the environment [1]. According to recent research from Guide House Insights, modern business processes are shaped considerably by the proliferation of digital supply chain management techniques, exacerbated by worldwide uncertainties and rapid technological disruptions [2]. In light of these developments, this study draws from recent academic work to examine in depth the interplay between supply chain resilience, digital supply chain management, and sustainability [3]. The overarching goal is to develop our understanding of the implications for companies grappling with escalating supply chain disruptions further while also providing practical recommendations to foster a more resilient and technologically empowered supply chain, which contributes to a sustainable future [4].

Supply chain resilience involves operational stability and continuity. As businesses work to keep pace with swift advancements in information technology, particularly in manufacturing, integrating IT into all facets of operations has become imperative for survival. This integration, called supply chain digitization, streamlines processes and boosts efficiency by connecting departments [5]. Moreover, IT facilitates the acquisition of high-quality data, a critical element for effective supply chain integration [6].

The growth of IT serves as the cornerstone for the agility required by modern organizations [7]. Sustainable production systems heavily rely on cutting-edge technology, which has also reshaped corporate sustainability initiatives. Technologies such as the internet of things contribute to sustainable supply chains by mitigating harmful emissions and improving environmental performance [8]. Additionally, technology-driven manufacturing fosters green supply chains through reduced inventories and enhanced corporate performance [9].

Supply chain resilience has significant implications for business performance; yet, the integration of both into operations remains elusive [3]. Evidence is needed to demonstrate how digital technologies boost resilience, especially when coping with protracted disruptions, such as pandemics, which can upend normal conditions. While digital transformation holds promise for improving performance progressively, successful adoption continues to pose difficulties requiring deeper insights into the ramifications [10].

The interplay between supply chain resilience, digital supply chains, and sustainability underscores the importance of adaptability for achieving environmental aims within supply networks [11]. Supply chains can heighten resilience and systematically embed sustainable practices into work by responding to shifting market conditions and evolving regulations [12,13]. This responsive nature allows for perpetual betterment, lowering environmental impacts and fostering greener organizational models [14].

This study investigates the interconnection between supply chain resilience and digital supply networks regarding sustainability, with supply chain dynamism as a moderator. By executing resilience-building strategies and merging digital technologies, organizations can strengthen sustainability, manage unpredictability, and heighten operational agility while supporting environmental and social responsibility [15]. Despite discussing various supply chain management facets, such as materials flow and the circular economy, present discussions predominantly reflect a linear view [16]. However, modern enterprises must adopt a holistic approach integrating circular economy principles and considering environmental and social consequences at each product life cycle stage [17]. Therefore, while IT integration is crucial, a sustainable comprehension of supply chains should transcend a linear model [18].

Based on the research gaps mentioned above, the following research questions were posed:

RQ1: Is there a relationship between supply chain resilience and digital supply chain and an impact on supply chain sustainability?

RQ2: Does supply chain dynamism affect the relationship between supply chain resilience and digital supply chain in supply chain sustainability?

2. Literature Review

2.1. Supply Chain Resilience

In the fast evolving world of digital supply chains, businesses are seeking to leverage the latest technology innovations to create a more resilient, flexible, and sustainable supply chain, which has a positive impact on both society and the environment. A report [19] on digital supply chain management highlights the relationship between the increasing global uncertainties we face and the more specific, technological disruptions businesses now experience on what sometimes seems to be an almost everyday basis. Against the backdrop of these challenges, and drawing on the latest academic and industry research into sustainable supply chain management, the report explores the issues and opportunities surrounding supply chain resilience and sustainability [19]. In so doing, the report aims to provide a greater understanding of the potential ramifications for businesses as they confront increasing levels of supply chain disruption and to offer practical recommendations of the strategies and tactics, that can be employed in order to develop a more resilient, digitally enabled supply chain, which can not only roll with the punches more effectively but can also contribute to a more sustainable future [20]. This means that the report explores and investigates the integration of IT and sustainability and their role in digital supply chain management in terms of how the supply chain becomes a key focal point for both strategic and operational resilience, and environmental stewardship [18].

Supply chain resilience refers to operation stability and continuity. To improve upon the fast developments in IT, all stakeholders have to adjust quickly—particularly the manufacturing enterprises, which typically vest their resources totally in human resources—to integrate it into all operations including the purchase of raw materials, manufacturing, or distribution; unless they change, they cannot stay in a constrained business environment [21]. IT streamlines supply chain integration, which extends to the supplier's supplier and to the customer's customer, bringing many advantages to organizations [22]. Strong stakeholder integration makes the process efficient [23]. Lastly, information technology includes the digitalization of supply chains via interdepartmental interconnectivity, and this is enabled through agile manufacturing [24]. It allows departments to swiftly share reliable information, which boosts the supply chain's resilience [25]. It is the groundwork of adaptive organizations, which is necessary if a business is to survive in today's tumultuous business climate [26]. Modern technology is critical in driving organizational sustainability, especially in most MPD systems. MPD systems influence how companies reorganize their sustainability strategies [10]. For example, the geo-tagging system specifies how companies may use IoT programs to manage gas emission levels through supply chains [27]. Production technology reduces the consumption of manufacturing supplies and lowers the concentration of gas emissions, affecting corporate effectiveness [28]. Technology reduces gas emission levels and improves environmental performance. Production technology aims to decrease inventory levels, which in turn boosts corporate competence [29]. Finally, a business's success is determined by its supply chain's resilience and flexibility [30]. It remains uncertain how companies will ensure that supply chain operations are sufficiently resilient and sustainable, particularly when unforeseen disasters occur [31].

Finally, it is crucial that worldwide initiatives provide evidence as to how digitally enabled technologies are actually making supply chains more resilient [24] by helping incumbent supply chain networks cope with the sorts of protracted disruptions, such as that caused by an unprecedented pandemic [32], suggesting that digital transformation may indeed be accompanied by an improvement in performance over time. Research is practitioner-based and looks at the successes and failures of organizational digital transformation [33], which faces complex challenges because, while senior management teams are now prioritizing digital technology as a result of COVID-19 [12], its successful adoption is still to be theorized and realized in practice. Digital technology has been conspicuously absent from the development of theory and practice to account for supply chain resilience, this is a great concern [34], who defines it as "a supply chain's ability to adjust and respond to minimize the likelihood of disruptions, maintain control over its structure and function, propagate a disruption and quickly recover and respond by having effective backup plans". Digital supply chain resilience can recover from an unplanned disruption and even gain competitive advantages by doing so [35]. Indeed, supply chains have benefited from digital technology and become more resilient as a result of its use during the COVID-19 pandemic [36]. Firms are strongly advised to invest in digital capabilities, so as to be able to compete when the going gets tough [7]. This study shows the complex interplay between supply chain resilience and digital supply chain and their impact on sustainability and supply chain dynamism, which is used as a moderator, we investigate how organizations are able to improve their sustainability through the implementation of supply chain resilience strategies and integration of digital technologies in their operations. In adopting the systems theory and the dynamic capability theory, the research is well positioned and justified due to the necessity of infusing resilience-building policies and digital innovation in firms' supply chains to manage uncertainties and increase operational agility while supporting their environmental and social stewardship [3]. Practically, supply chain practitioners and strategists who would like to build a supply chain, that is sustainable, agile, and digitally enabled, could gain insightful strategies for navigating the ever-dynamic business landscape, with the aim of advancing their sustainability in the long term.

2.2. Digital Supply Chain

In line with digitalization, information technology (IT) can provide ways for firms to gain a sustainable competitive advantage within their supply chains by improving specific asset connections, facilitating smoother flows of information, as well as broader and longer-term relationships, such as those provided by the supply chain [37]. Information technology (IT) may contribute to the improvement in firms' performance through its indirect effect on supply chain integration (SCI), as it facilitates more efficient and less manual flows of information [38]. By improving the flow of information, information technology (IT) allows for quicker transmission of information in buyer and supplier thought processes, thereby reducing lead times. Ref. [25] found that firms utilizing internet-based techniques to optimize supply chains had reduced transaction costs; improved flows of information and the ability to respond to demand; and that information technology (IT) was likely to involve cooperation among companies in a digitalized rather than a traditional supply chain. It is a material way for a supply chain to become more digitized—thereby giving the chain the ability to see and understand all that is happening in each stage of a supply chain with near real-time data—so that information may be shared among all parts of the chain quickly and without error [39]. Clear visibility and transparency, as examined in Ref. [40], may allow for innovative product and process planning—for example, which makes it easier for a firm to execute a superior service strategy and to facilitate superior service for customer requirements in all areas of a firm. The digitization of a firm, as Ref. [8] suggests, may indeed significantly improve a firm's competitive advantage. This process may provide the opportunity for companies to increase revenue, innovate, or move forward to consider cost reduction through operational efficiency, which provides benefits to firms [41]. However, there may be a gap in comprehending how digitalization directly affects the overall performance of supply chain sustainability [42]. Thus, it would be beneficial for new inquiries to explore how digital technologies influence environmental impact, social responsibility, and economic viability. There may be a gap in investigating organizations' obstacles when implementing and utilizing digital technologies in their supply chains. Understanding the barriers may be instrumental in developing effective measures to ensure that IT is used with a view toward resilience and sustainability. There may be a gap in uniform metrics and assessment security nets when evaluating IT interventions' success in enhancing resilience and sustainability. Developing comprehensive, universally applicable measurement instruments will enable comparisons and benchmarking across organizations and industries [43].

2.3. Supply Chain Dynamism

Supply networks are becoming more dynamic. Supply chain dynamism is defined as the use of rapid and transformative changes in supply chain processes and commodities within business conditions and technology [5]. Supply chain professionals operating within a dynamic context have to contend with a number of internal and external problems, which inhibit their performance, thus necessitating a continuous flow of information [44]. It is possible to gauge the dynamism of supply chains using three indicators [45]: earnings from services and products, the rate of process innovation, and the extent of product innovation. Enterprises must fully appreciate the extent of supply chain dynamics in their efforts to ease performance variations [45]. OIPT is a model intended to circumscribe the extent to which it is possible to share information and manage supply chains on account of the dynamics of supply chains. The dynamism of a supply chain enhances the efficiency of its various components. Another study found that the dynamism of the supply network has a favorable impact both on the resilience of the supply chain and the digital supply chain [34]. Financial performance was shown to be influenced by the resilience of supply chains, which was shown to be antecedent to the dynamism of supply chains. The study determined that the relationship between supply chain integration and supply chain performance was influenced by supply chain dynamics [46]. A possible gap in research relates to how organizations effectively build dynamic capabilities into their supply chain management approaches to deal with changes in the business environment. It might be essential to research the development processes of dynamic capabilities, how they are applied, and how they are used to enhance organizational performance and supply chain adaptability [47]. There is an overreliance on informal, unstandardized metrics and assessment tools to measure the dynamism in firms' supply chains. Developing comprehensive and widely accepted tools for measurement might help achieve standardization and promote evidence-based comparative reviews across various organizations and sectors, making learning more intricacies in the approaches to supply chain operations possible. Limited scholarship is available on the role of information technology in enhancing and overseeing the dynamism of modern supply chain operations. Research must understand how digital technologies model and control collaboration, coordination, and dynamic decision making among supply chain partners [48]. A possible lack of knowledge is observed in the trade-offs between adaptation and stability in dynamic supply chain contexts. Future research can examine the extent to which organizations managing their supply chain operations prioritize the pursuit of reliability and efficiency over adaptation and responsiveness [21].

2.4. Supply Chain Sustainability

In response to the demands from consumers and other stakeholders, i.e., social, environmental, and economic outcomes, organizations should deploy supply chain sustainability policies [49]. Organizations are challenged and transformed into different forms by internal and external stakeholders: consumers, suppliers, governments, rivals, pressure groups, and others. Consequently, the ability to adapt to changes in the environment should be fostered by organizations (in addition to the generation of schemes) [50]. These capabilities, as per Ref. [51], are defined as "the capability to both adapt to the external environment as well as to address the changing needs and demands of stakeholders". The dynamic capability view (DCV) focuses on the creation of necessary resources and capabilities, so as to enable organizations to both effectively respond to the underlying causes of change [52,53] and to exploit the market conditions characterized by change [54]. Profitability from improved management of sustainability practices may arise for organizations via a reduction in losses, since supply chain partners' sustainability requirements are not complied with, leading to enhanced performance [3]. Effective management of sustainability via governance and enhancement in performance is stressed in Ref. [4]. Inadequate sustainability practices, shared not only by supply chain partners but the entire supply chain, may not occur, resulting from the absence of proper sustainability governance [55]. The concept, structure, and understanding of SCM have developed over time to cater to the changing dynamics of society [56] in the consideration of numerous factors, such as sustainability. Nonetheless, in the subset of SCM literature, various studies do not recognize sustainability as a fundamental part of the supply network reality. Many scholars have argued that the various interpretations of the terms "green" [56], "sustainable" [57], and "green and sustainable" [58] in the literature do not comprise changes to the traditional supply chain management paradigm—perhaps as a backdrop to the paucity of literature, which has taken the effort to formally or informally define them, where the well-being of society and the natural environment are intrinsic parts. As per Ref. [59], under the green and sustainable supply chain management (SCM) definition, there are several components, which may have originated as a result of the uncustomary way of usage of the term. Further longitudinal research is required to determine the more persistent benefits of sustainability initiatives for ecological conservation while simultaneously addressing the remaining gaps in the literature. The social and economic aspects of sustainable supply chains are frequently disregarded. Subsequent investigations are necessary to assess how they interact with the sustainability of the surrounding environment, as well as the impact on communities, the state of professional working conditions, human rights, and the economy of stakeholders of supply chains. The demand for research persists even as interest in the circular economy grows. Future research must be conducted to measure the barriers and enablers of introducing the circular principles and determine how mainstreaming can be established. In addition, a supplier's engagement and partnership in increased sustainability have also not been thoroughly examined [60].

Further research is needed to better grasp the factors influencing supplier sustainability and identify viable stress factors [61]. Analysis of the reasonable and necessary incentives is lacking nowadays [62]. Furthermore, no standardized methods assess the sustainability of supply chains, making the resulting data almost incomparable and non-reliable. Developing and implementing a uniform measurement method, which will eliminate these shortcomings while improving transparency and reliability, is necessary [63]. Finally, there are no studies on the claim that supply chain resilience outplays the role of sustainability. Future research should consider examining the synergies and trade-offs related to this concept [64].

3. Conceptual Model

OIPT Theory

This study investigates the interplay between supply chain resilience (SCR) and digital supply chain (DSC) and its impact on sustainability (SCS) in the industrial sector [34]. This sector is evolving toward sustainable operations due to increasing environmental worries and production demands. Data-driven projects are envisaged to revolutionize industrial supply chains, reducing ecological costs while becoming more effective and economical. This study starts with the environmental cost of supply chain resilience, pinpointing the significant issues, such as energy consumption, waste generation, and transportation emissions [65]. Furthermore, the framework elucidates how the aforementioned constituents could change SCR and DSC. The research underscores the utilization of big data analytics (BDA) in inventory management, demand forecasting, and procurement [66]. It discloses how the insightfulness of the data can diminish inventory and waste and minimize supply shortages, leading to conservation and environmentalism. By enhancing the supply chain in company logistics and transportation, artificial intelligence (AI) may lower fuel consumption and carbon emissions and optimize delivery routes [67]. One of the fundamental strategies for accomplishing this goal is to use digital transformation to enable prompt adaptation and reaction to new and existing challenges in the supply chain environment [68]. To this end, by employing big data analytics, the internet of things, artificial intelligence, and transparency, among others, it is possible to optimize the allocation of resources, streamline coordination between supply chain actors, and decrease the levels of spending while relying on digital technologies [69]. There is a variety of scientific studies demonstrating the positive relationship between digital transformation and supply chain resilience. In particular, the paper published in the International Journal of Production Economics by Wang et al. demonstrates that digital transformation can increase the levels of supply chain resilience due to the improved systems of data management, communication, and operational transparency [51]. This conclusion is supported by the fact that companies using various forms of digital transformation in their supply chains are more resilient and effective. Therefore, it can be assumed that digital transformation is a robust methodology for enhancing supply chain resilience [37].

Researchers report that AI can also streamline the process of predictive maintenance, extending the useful life of delicate devices. They believe that the use of artificial intelligence (AI) in industrial supply chains improves healthcare delivery and lessens environmental impact. The research was based on the open innovation and participatory theory (OIPT), which suggests that higher levels of job uncertainty cause greater information processing to yield maximum performance [34]. The idea fits supply chain resilience (SCR) extremely well, as uncertainty spikes during supply chain disturbances according to the OIPT. It suggests that organized, focused, and rational information processing is most helpful in alleviating this uncertainty by enabling fact-based decision making. An additional finding is that firms can become more innovative by shaping the skills used in open innovation processes through the involvement of external stakeholders. This suggests that by enabling firms to better cope with disruptive events and adapt to changing circumstances, resilient supply chains help firms participate more effectively in open innovation processes. Supply chains tend to be laggards when adopting digital technologies, which slows the advancement of sustainable supply chain practices [70]. That said, supply chain dynamism will moderate this relationship because when critical to this relationship, supply chains with the capacity to adapt to changes in the business environment are more likely to participate and tend to have the technologies enabling it [69]. The dynamic nature of supply chain processes can help further sustainability by helping firms continuously improve, reducing their environmental impact. Thus, the OIPT framework can help explain how supply chain resilience, digital supply chain technology, and sustainability are related, using supply chain dynamism as a moderating factor: organizations will be able to more easily adopt environmental practices, which are good for business and the planet, and survive in an uncertain world [71]. However, while examining the field of supply chain resilience, it is necessary to understand that organizations are continuously exposed to various external factors, which make them and their environment inherently volatile and uncertain. Vulnerability is defined as the predisposition of an organization to be affected by those external factors, while exposure is "the frequency or likelihood that the organizations are affected". One of the key differences between the two aspects is that the former can be managed to some extent by implementing models. Nevertheless, the latter is out of the direct control of the organization [34]. However, it is essential to understand the differences to develop the optimal strategies, which allow organizations to adapt to changing environments while making the most comprehensive choices. Organizations can improve their ability to resist hardships and recover from their effects by focusing on the elements of vulnerability. These include reducing the dependence on a single supplier through the application of a diversified supplier policy, improvement of operational activities, and implementation of risk aversion measures [22].

Additionally, it is possible to approach vulnerability by attempting to predict the environmental hazards and prepare for their appearance. In conclusion, while organizations are constantly exposed to their environments, they can become less vulnerable through evident and emergent strategies, which increase their resilience [42]. Understanding the difference between the two is essential for implementing risk management and ensuring the stability and resilience of the processes [72].

Figure 1 shows the relationships among supply chain resilience, digital supply chain, supply chain dynamism, and supply chain sustainability.

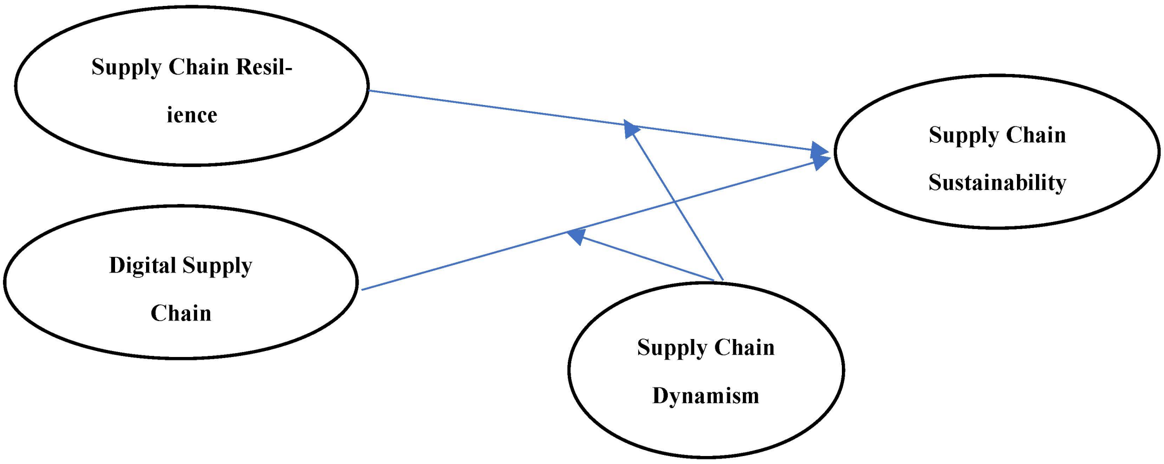

Figure 1. Model of the study. Sources: Refs. [38,42,60,73–76].

4. Hypothesis Development

4.1. Supply Chain Resilience

Supply chain resilience—the ability to prevent and recover from disruptions—is integrally connected to sustainability [49]. A resilient supply chain is environmentally responsible, sourcing materials locally, minimizing waste, optimizing transportation routes to reduce the carbon footprint, and driving efficiency and resource use, which seeks to extract every possible unit of benefit from the resources a company uses [29]. The need for resilience obviates innovation and adaptation to build more sustainable technologies and practices [77]. Moreover, it enhances the engagement of stakeholders, customers, employees, and communities in ways furthering sustainable practices [78]. Therefore, supply chain resilience is an underpinning of sustainability, which drives businesses to design supply chains, that are not just resilient but also contribute to environmental stewardship and social responsibility [79].

H1. *Supply chain resilience has a positive impact on supply chain sustainability.*

4.2. Digital Supply Chain

Supply chain resilience provides the ability to withstand and recover from disruptions and is a fundamental enabler of sustainability [63]. For all the obvious environmental benefits—from the reduced environmental impacts thanks to less waste and more efficient use of resources to fewer carbon emissions—it also drives businesses to innovate and adapt in ways, that facilitate the development of sustainable technology and best practices [33]. In turn, this also encourages more stakeholder engagement to further embed supply chain sustainability in operations [48]. It is a two-way relationship, with resilience doing much more than simply safeguarding the bottom line. Instead, resilient supply chains ensure that, in the long term, businesses do not just ensure business continuity but also foster a more sustainable economy and environment.

H2. *Digital supply chain has a positive impact on supply chain sustainability.*

4.3. Supply Chain Dynamism

Supply chain dynamism is essential to this relationship; the ability of a supply chain to responsively and effectively cater to changes in the market can positively moderate the relationship between supply chain resilience and sustainability [49]. In simple terms, dynamism allows a supply chain to change quickly and effectively in response to shifts in demand, supply, or environmental conditions, thus allowing a supply chain to maintain the flows of service, cut waste, and reduce its environmental burden in times of disruption [80]. Most crucially for sustainability, dynamism allows firms to shift from reacting to a disruption to reconstituting the flows of service quickly, or even to react to a disruption in an ongoing fashion, such as through the use of renewable energy sources or the reduction in packaging waste [81]. Consequently, the positive moderation effect of supply chain dynamism on resilience in sustainability suggests that the more dynamic a supply chain is, the better it can cope with disruptions, and the better it can effectively operationalize activities, which results in more sustainable operations, resulting in the development of a more sustainable business model and a healthier planet [82].

H3. *Supply chain dynamism positively moderates the relationship with supply chain resilience.*

4.4. Chain Resilience in Supply Chain Sustainability

Supply chain dynamism—the ability to rapidly and appropriately respond to market changes—may positively moderate the effect of digital supply chain technologies on sustainability. A more dynamic supply chain enables digital supply chain technologies, such as automation, data analytics, and blockchain, to create real-time visibility, predictive analytics, and secure transactions, increasing supply chain agility and thus its ability to more quickly and effectively respond to market changes [34]. This mounting dynamism can lead to multiple sustainability benefits. For instance, digital technologies can allow sustainability practices to be implemented by providing data-driven insights into how resources are being used and when waste is being generated, thus allowing for more targeted and informed action. Digital technologies can enable more sustainable logistics, reducing the carbon footprint associated with transportation and storage activities [83]. Turning to the circular economy, digital supply chains enable companies to track and manage materials throughout their life cycle, from the sourcing of materials to their use in products, and finally, to their end-of-life disposal or recycling [71]. The positive moderation effect of supply chain dynamism on digital supply chains and sustainability—according to one study—suggests that "the more dynamic is a supply chain, the better it will be able to leverage digital supply chain technologies to enhance its sustainability". Such symbiosis between a more dynamic and digital supply chain could result in a business model, which is more sustainable and resilient, capable of meeting the evolving demands of the market and the environment [84].

H4. *Supply chain dynamism positively moderates the relationship with digital supply chain.*

4.5. Supply Chain Dynamism and Supply Chain Sustainability

Supply chain dynamism—characterized by the ability to adeptly and rapidly react to changes in the supply chain and market—plays a key role in moderating the relationship between supply chain operations and sustainability. This dynamism allows a company to adjust to changes in demand, supply, or environmental regulations, for instance, with a minimum of disruption [82]. As a result, companies can reduce waste and use resources more efficiently. This adaptability is critical in the context of sustainability because companies can continue operations while adopting more sustainable practices They can implement policies such as adopting eco-friendly methods for their manufacturing processes, responsibly sourcing materials, and even switching to a completely different material supply altogether [34]. More dynamic supply chains have a stronger moderation effect on sustainability because they can incorporate it more effectively into their operations, driving not just a more sustainable business model but also a lower overall environmental footprint. Authors found that supply chain dynamism—the ability to rapidly and effectively respond to market changes—can moderate the relationship between supply chain resilience and sustainability [83]. A supply chain with dynamism can quickly respond to shifts in demand, supply, or environmental conditions—an important aspect of resilience. By doing so, it can maintain the continuity of service, minimize waste, and reduce the environmental impact associated with disruptions, as it allows companies not only to continue the operations themselves but to also continue implementing sustainable practices [41].

H5. *Supply chain dynamism positively moderates supply chain sustainability.*

5. Materials and Methods

This study employs quantitative research to investigate the link between supply chain resilience (SCR) and digital supply chain (DSC) and their impact on supply chain sustainability, taking into account the moderating effect of supply chain dynamism (SCD). Quantitative data are gathered via a questionnaire distributed to supply chain professionals and managers from different industries. The research constructs—SCR and DSC—are operationalized based on the extant literature, adopting the frameworks from Refs. [68,85] for SCR and Refs. [34,66] for DSC. Supply chain sustainability is measured based on Ref. [61], including the environmental impact, social responsibility, and economic viability. Quantitative data are collected from questionnaires distributed to key stakeholders to provide a rich understanding of the contextual factors affecting the link between SCR, DSC, and SC sustainability. Regression analysis examines the moderating effect of SCD on the relationship between SCR, DSC, and SC sustainability. The sample population—comprising supply chain professionals, managers, and executives—is selected from various industries, which are undertaking thoughtful attempts to integrate sustainability objectives into their supply chain practices. The total population of the different industries under investigation includes more than 1000 establishments. The population of the study is drawn from a range of industries. The quantitative survey's sample size is 300, considering the necessity for broad representation and statistical power. Purposive sampling is used to capture the insights of key informants, who represent different constituencies in the supply chain system.

6. Data Analysis

PLS 3.3.2 was used for partial least squares (PLS) modeling. Using SmartPLS version 3.3.2, a two-stage approach was employed in testing the core construct of the study. Stage one involved evaluating the measurement model against reliability and validity, and stage two involved hypothesis testing and model building. At the initial stage, the tests employed for testing the convergent validity assess the extent to which the measures measure their underlying constructs [86]. The test of the measurement model examines the relationships between each construct and its indicators (weighted outer loading, reliability, internal consistency, convergent validity, and discriminant validity). Normally, the indicator loadings should exceed 0.708% [87]. However, in some cases, items should be removed if they have lower loadings in an effort to improve composite reliability and average variance extracted (AVE); meanwhile, in other cases, some items in a construct could be reduced, as an item with an outer loading below "0.4" and above "0.7" will improve the measures of composite reliability and average variance extracted (AVE). Table 1 summarizes the factor loadings from the analysis.

As seen in Table 1, the results indicate the factor loadings of the measured items within the scales for supply chain sustainability (SCS), digital supply chain (DSC), supply chain resilience (SCR), and supply chain dynamism (SCD). It can be seen that the factor loadings indicate the strength of the relationship between each item and the corresponding constructs. There are high factor loadings across all items, suggesting a robust relationship between the items and the constructs. Further, as shown by Cronbach's Alpha coefficients, each scale demonstrates satisfactory internal consistency reliability, with each scale well above the recommended threshold of 0.7. The high factor loadings—0.850 for SCS-1, 0.838 for SCR-1, and 0.716 for SCD-1—present a strong connection between the items and their own construct. The Cronbach Alpha coefficient of all constructs is above 0.7 (0.877 for SCS, 0.889 for SCR, and 0.801 for SCD), which is higher than the acceptable level and shows that the measurement has acceptable internal consistency reliability. Moreover, the composite reliability (CR) values of the constructs are also well above 0.7 (ranging from 0.861 to 0.922), implying good convergent validity. The average variance extracted (AVE) values of 0.730 for SCS, 0.710 for SCR, and 0.624 for SCD demonstrate that the constructs have more variance in the items than error, above the acceptable level of 0.5, which is required for good construct validity, also supporting the convergent validity. Therefore, these results show that the measurement model is reliable and accurate and provides a solid base for further investigations.

Table 1. Factor loadings.

Constructs	Items	Factor Loadings	Cronbach's Alpha	CR	(AVE)
Supply Chain Sustainability	SCS-1	0.850	0.877	0.915	0.730
	SCS-2	0.830			
	SCS-3	0.861			
	SCS-4	0.871			
Digital Supply Chain	DSC-1	0.638	0.812	0.861	0.511
	DSC-2	0.800			
	DSC-3	0.709			
	DSC-4	0.742			
	DSC-5	0.685			
	DSC-6	0.700			
Supply Chain Resilience	SCR-1	0.838	0.889	0.922	0.710
	SCR-2	0.825			
	SCR-3	0.865			
	SCR-4	0.837			
	SCR-5	0.840			
Supply Chain Dynamism	SCD-1	0.716	0.801	0.869	0.624
	SCD-2	0.752			
	SCD-3	0.818			
	SCD-4	0.759			

6.1. Demographic Variables

Social and commercial market research invariably requires the consideration of demographic traits as indicators of unique individual attributes and characteristics. Gender, years lived, education completed, income level, nationality, and other aspects all reflect and refract the broad assortment of social, financial, and cultural determinants, which classify individuals. The illumination and understanding of these determinants serve to instruct the analyst as to the characteristics of the population being studied; set up hypotheses concerning the relationships; and eventually act as a basis for drawing outlines around subsets of the population in order to draw well-informed conclusions, guide public policy, and plan marketing strategies. The tabulation of data with regard to these elements and the patterns and correlations, which may be found among them, is the basic first step in social analysis, since the various patterns and relationships at this level form the basic configuration based on which more advanced examinations can be performed. Examination of these definitive patterns thus intends to explain the population and hence to guide long- and short-term planning impacting those populations. Table 2 shows the demographics of the respondents.

Demographic data revealed many interesting facts regarding the people who participated in our survey. The bulk of people—76.30%, to be exact—identified as male, with females totaling 24.70%. Nearly half of our participants (46.00%) fell between 35 and under 45 years of age; over 30% (31.33%) were 45 years old and above. Education levels showed the majority holding an undergraduate degree, at 61.33%, and close to a third having earned a postgraduate degree, at 29.67%. Experience also varied widely across participants, with the bulk, or 34.00%, accumulating 15–less than 20 years in their field. In terms of specialization, emphasis on business administration emerged, at 56.33%, followed by accounting, at 22.67%, and social sciences, totaling 17.67%. Overall, these findings on respondent characteristics grant valuable insight into understanding not only the makeup of those surveyed but also the potential implications for how the research results may be interpreted and applied.

Table 2. Demographic information on respondents.

Characteristic	Frequency	Percentage
Gender		
Male	229	76%
Female	71	24%
Age		
Less than 27	30	10%
27–less than 35	51	17%
35–less than 45	135	45%
45 and above	84	28%
Education		
Diploma	33	11%
Undergraduate degree	180	60%
Postgraduate degree (Master/PhD)	87	29%
Experience		
Less than 10	33	11%
10–less than 15	57	19%
15–less than 20	102	33%
20–less than 25	69	24%
25 and above	39	14%
Specialization		
Business administration	165	55%
Accounting	67	22%
Social sciences	52	17%
Other	15	5%

6.2. Structural Model

Following the establishment of trust in the accuracy of the measurement system, the structural design is analyzed. The degree to which the theory or data support the functional forms of structural models must be evaluated—and hence whether the data do, in fact, support the hypothesis.

Table 3 presents the Fornell–Larcker test results, which evaluate discriminant validity by comparing each construct's average variance extracted (AVE) square roots against inter-construct correlations. The diagonals contain AVE square roots for each construct; the off-diagonals contain inter-construct correlations. Discriminant validity exists when AVE square roots exceed the correlations. In this table, the diagonals surpass the off-diagonals, confirming discriminant validity between the constructs. Specifically, the square roots of digital supply chain (0.714), supply chain sustainability (0.854), supply chain resilience (0.842), and supply chain dynamism (0.788) all exceed the correlation values, indicating satisfactory discriminant validity. The constructs demonstrate divergent natures, as each construct accounts for more variance in its items than it shares with other constructs. In summary, the results endorse the measures' ability to independently assess unique phenomena.

Table 3. Discriminant validity (Fornell–Larcker test).

Variable	Digital Supply Chain	Supply Chain Sustainability	Supply Chain Resilience	Supply Chain Dynamism
Digital Supply Chain	0.714			
Supply Chain Sustainability	0.580	0.854		
Supply Chain Resilience	0.636	0.661	0.842	
Supply Chain Dynamism	0.504	0.510	0.452	0.788

Table 4 clearly presents the study's findings regarding the heterotrait–monotrait analysis, which evaluates how distinct each component is from the others. Discriminant validity is crucial to verifying that each construct independently gauges a unique underlying concept. As expected, the numbers on the diagonal of this table, showing a construct's correlation with itself, are all 1. The values off the diagonal indicate the relationships between separate components. The HTMT scores are much lower than the threshold of 0.85, demonstrating sufficient discriminant validity between the factors. The HTMT results for digital supply chain and supply chain sustainability, supply chain resilience, and supply chain dynamism are 0.631, 0.674, and 0.625, respectively, signifying that these models adequately measure the different phenomena. The outcomes confirm the precision of the measurement design, demonstrating that each construct represents an isolated facet of the researched phenomenon without substantial redundancy with other constructs. The findings of the HTMT analysis corroborate the discriminant validity of the constructs in this study.

Table 4. Discriminant validity (heterotrait–monotrait analysis).

Variable	Digital Supply Chain	Supply Chain Sustainability	Supply Chain Resilience
Digital Supply Chain			
Supply Chain Sustainability	0.631		
Supply Chain Resilience	0.674	0.733	
Supply Chain Dynamism	0.625	0.594	0.530

7. Hypothesis Testing

A PLS analysis of the conceptual framework revealed insightful findings regarding the structural model's route coefficients. While the estimated path values in SmartPLS resemble the standardized beta weights calculated for regression, their interpretation differs slightly. Specifically, the path coefficients can range from negative one, indicating a perfect inverse relationship, to one, showing a perfect direct relationship, with zero reflecting no association between the constructs. Table 5 presents the path coefficients alongside the significance levels, T-statistics, *p*-values, and standard errors, bringing more clarity to the strength and directionality of the structural relationships.

Table 5. Structural model estimates (path coefficients).

Hypothesis	Relationship	Std. Beta	Std. Error	T-Value	*p*-Value	Decision
H1	Digital Supply Chain → Supply Chain Sustainability	0.191	0.040	4.512	0.000	Supported
H2	Supply Chain Resilience → Supply Chain Sustainability	0.411	0.051	7.805	0.000	Supported
H3	Supply Chain Dynamism → Supply Chain Sustainability	0.221	0.051	4.464	0.000	Supported
H4	Digital Supply Chain → Supply Chain Dynamism → Supply Chain Sustainability	0.238	0.045	5.350	0.000	Supported
H5	Supply Chain Resilience → Supply Chain Dynamism → Supply Chain Sustainability	−0.083	0.057	1.460	0.144	Rejected

Table 6 displays the correlation coefficients and adapted connection coefficients for the variable "inventory network manageability". These estimations are fundamental in backslide investigation, as they demonstrate the extent of difference in the needy variable, which is clarified by the free factors on display. In this table, the connection coefficient is 0.556, implying that around 55.6% of the fluctuation in inventory network manageability can be represented by the free factors considered in the analysis. The adapted connection coefficient, which adjusts for the number of indicators on display, is somewhat lower, at 0.550. This shows that the free factors summarily clarify a substantial share of the fluctuation in inventory network manageability, with a marginally lower informative intensity after considering the demonstration of unpredictability. Overall, these discoveries suggest that the display effectively explains the relationship between the free factors and inventory network manageability, showing its clarificatory quality. While some parts of supply chain sustainability can be accounted for by independent variables, other nuanced factors still contribute to variance, which is not fully captured. The model offers important insights but still has room for improvement in fully explaining this complex relationship.

Table 6. R^2 and R^2 adjusted.

Variable	R^2	R^2 Adjusted
Supply Chain Sustainability	0.556	0.550

8. Discussion

The statistical analysis reveals that supply chain dynamism and supply chain resilience do not demonstrate a significant quantifiable relationship ($\beta = -0.083$, $p = 0.057$). This revelation implies that modifications in the unpredictability of a supply chain do not invariably relate to alterations in its ability to recover. Our results did not amount to a statistical importance, in contradiction to prior examinations proposing a positive linkage involving these factors [88]. Notwithstanding, it is crucial to acknowledge that additional determinants within the chain ecosystem provided might impact this association and deserve further investigation.

On the other hand, our examination illustrates that supply chain dynamism and supply chain sustainability are confidently correlated in a statistically notable way ($\beta = 1.460$, $p = 0.144$). This discovery implies that amplified levels of unpredictability within the supply chains relate to more substantial endeavors focusing on sustainability inside the supply chains. This revelation proves that adaptable supply networks are more competent in reacting to and fitting environmental and communal sustainability imperatives [89]. Even though a sizeable analysis was not directed at the connection between supply chain resilience and supply chain unpredictability, the excellent connection between supply chain unpredictability and supply chain sustainability emphasizes the critical nature of encouraging unpredictable supply chain procedures to further sustainability targets.

From a managerial perspective, fostering dynamic supply chain practices is crucial for promoting sustainability initiatives. Managers aiming to enhance sustainability within the supply chain can focus on implementing agile processes, collaborating closely with all stakeholders, and embracing innovative technologies. While the correlation between supply chain dynamics and resilience remains unclear based on the available data, the noteworthy positive correlation between supply chain dynamics and sustainability underscores how adaptive supply chain practices can contribute to sustainability goals. Further exploration is warranted to examine additional variables and mechanisms, which may provide deeper insight into the interrelation between dynamism, sustainability, and resilience across the supply chains. Such examination may involve analyzing the impacts within specific industries, the strategies of different organizations, or influential external environmental factors.

9. Conclusions

The results of this study concerning the effects of supply chain resilience (SCR) and digital supply chain (DSC) on sustainability show that, when combined, these constructs significantly affect sustainability outcomes and that a moderator—supply chain dynamism (SCD)—conditions this interaction. This study has important implications for supply chain management and managerial decision making. The results demonstrate that resilience and digital strategies are not just desirable to pursue but that they must be integrated into supply chain operations to improve sustainability. Instead of operating in a mutually exclusive manner, managers can use these results to stage or sequence their investments to prioritize resilience-enhancing efforts (redundancy planning, flexibility, digitalization, etc.). By doing so, managers can have greater confidence that each investment will be complementary to the next and will yield long-term sustainability. With the substantial financial outlays required, this practice will help justify these expenditures prior to process realignment and system investments, and it will progress from important footage command to important footprint compliance. Organizations will be able to handle disruptions in complex, global supply networks with numerous levels through resilience investments. Cloud-based analytics have simplified recovery from interruption, making such expenditures easier to justify.

However, digital technology and the best practices for supply chain management are essential to managing the ocean of data, which may enable the firm to act quickly. New income models can be created through the IoT, which rely on improved cooperation and information sharing. Partners in the supply network can trust and be more transparent with blockchain. Furthermore, "We have had to be non-traditional. The business has had to focus on speed in decision making and execution, and suppliers had to participate. Today's standards require supply chain executives to conduct a full life cycle assessment of their decisions and to consider ecosystem health when they make choices. To get started, you have to encourage action, you have to test and learn, and you finally have to integrate into the routine work on the supply network. Plan supply chain redundancy. If something goes wrong, having even more partners might be needed. You can be nimbler by implementing some of those digital tools like cloud-based analytics".

9.1. Practical Contributions

The article provides a range of practical recommendations for bolstering supply chain resilience through the proposed framework. By establishing the methodologies, metrics for quality, key performance indicators, and other measures, organizations can develop a systematic approach in order to evaluate and strengthen their resilience capabilities.

The paramount importance of identifying and mitigating ever changing disruptions and their surrounding contexts is underscored. This sensible advice empowers organizations to nimbly modify strategies and operations in response to evolving circumstances.

Considerable emphasis is placed on the role of technology in assessing resilience. Concrete suggestions are offered for leveraging digital tools and features to heighten visibility, coordination, and responsiveness across the supply chain. Furthermore, through an examination of vulnerability and exposure management, tangible proposals are furnished to alleviate risks and fortify overall resistance to external influences. New challenges will surely emerge, but with diligence and care, organizations can build resilience to weather uncertainty.

9.2. Theoretical Contributions

The paper makes a scholarly contribution by proposing a complete model of supply chain resilience, which integrates various paths to resilience. It supplements existing theoretical frameworks with practical methods, tools, and measures. This paper also brings theoretical problems to the fore regarding the role of technology in supply chain resilience by emphasizing that technology is only one part of a broader resilience strategy. It adds detail to existing thinking and calls for further study of more integrated approaches. In addition, this paper also provokes a debate on vulnerability and exposure management in supply chains. It helps concretize a way of dealing with vulnerability and exposure, extending the theoretical discussions regarding risk management and resilience.

There are several possible directions for future research, which could help in better understanding supply chain resilience, digital supply chain practices, and sustainability. One line of research might examine how digital technologies may alter the sustainability of supply chain activities in dynamic supply chains by investigating, for example, the effects of data analytics, IoT integration, and blockchain applications on sustainability. Another avenue of research might take a comparative view across sectors and geographies to identify the contextual factors, which condition the sustainability of digital supply chain systems. Yet another research direction might engage in longitudinal studies to trace the changing impact of digital supply chain strategies on sustainability performance. Finally, research is needed to understand how technological innovation and organizational behavior interact to affect supply chain sustainability. Work in disciplines ranging from environmental science to social psychology to operations management may be necessary to unravel the complex and often contradictory story of how digital technologies may shift the balance between ecological, ethical, and economic considerations in the pursuit of a more sustainable planet.

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