

Article

The Impact of Business Continuity on Supply Chain Practices and Resilience Due to COVID-19

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Abstract: *Background:* Business continuity entails the potential negative consequences of uncertainty on a firm's ability to achieve strategic objectives. The COVID-19 pandemic significantly impacted business continuity due to lockdowns, travel restrictions, and social distancing measures. Consequently, firms adopted specific supply chain (SC) practices to effectively navigate this global crisis. *Methods:* This research adopted a stochastic approach based on Bayesian Networks to evaluate the implications of business continuity on firms' decisions to embrace SC practices, focusing on omnichannel strategies, SC coordination, and technologies such as artificial intelligence systems, big data and machine learning, and mobile applications. *Results:* Our findings revealed that firms facing disruption in a single performance area can apply specific strategies to maintain resilience. However, multiple areas of underperformance necessitate a varied approach. *Conclusions:* According to our empirical analysis, omnichannel strategies are critical when disruptions simultaneously impact quality, inventory, sales, and ROI, particularly during major disruptions such as the COVID-19 pandemic. AI and big data become vital when multiple risks coalesce, enhancing areas such as customer service and supply chain visibility. Moreover, supply chain coordination and mobile app adoption are effective against individual performance risks, proving crucial in mitigating disruption impacts across various business aspects. These findings help policy-makers and business owners to have a better understanding of how business continuity based on performance resistance to disruptions pushes companies to adopt different practices including new technologies and supply chain coordination. Accordingly, they can use the outputs of this study to devise strategies for improving resilience considering their supply chain vulnerabilities.

Keywords: business continuity; COVID-19; firm's resilience; omnichannel; supply chain coordination; technologies; Bayesian Networks



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1. Introduction

Business continuity is a strategic approach that ensures the maintenance and recovery of essential business functions during and after crises such as the COVID-19 pandemic. This concept is vital for economic sustainability as it helps businesses navigate through disruptions, thus contributing to overall economic stability. During the COVID-19 crisis, leading global corporations demonstrated the significance of business continuity by adapting their operations, customer interactions, and workforce management to the changing environment. For instance, firms re-engineered logistics and supply chain processes to meet shifting consumer demands, thereby maintaining their operational flow and economic contribution [1]. This adaptability not only ensures the survival and growth of individual businesses but also contributes to the broader economic ecosystem's stability [2]. Thus, business continuity is integral to economic sustainability, as it enables organizations to withstand and adapt to unforeseen challenges, safeguarding both the business and the

economy at large [3]. This research focuses on the notion of “business continuity”, which is distinct from conventional approaches. It defines business continuity as the ability to maintain performance despite disruptions and can be read as the contrary of performance vulnerability. To delve into these complex concepts, this study investigates the “performance resistance to disruptions” linked to the impact of COVID-19. It also explores how organizations respond to these challenges by implementing strategies and initiatives to enhance their resilience.

Among the various practices that firms can adopt to face disruptions, this paper focuses on some peculiar supply chain (SC) initiatives. In fact, the emergence of the COVID-19 pandemic has had profound implications for SCs, leading to significant disruptions in their operations [4]. This global crisis has presented various challenges and uncertainties, complicated by the worldwide scale, quick propagation, difficulties in detectability, and unsure prevention practices, which profoundly impacted the business continuity of all SC members [5]. Consequently, COVID-19 required not only the adoption of new strategies for managing work, operations, and global SCs, but also posed significant challenges to firms, which were forced to navigate through government-imposed measures for curbing the spread of the pandemic [6,7]. These measures, including mobility restrictions, social distancing protocols, quarantines, and home lockdowns, have compelled businesses to adapt and fundamentally alter their practices and habits [8].

The COVID-19 pandemic has significantly harmed business continuity at all levels and for all sectors, due to possible disruptions of business performance linked to an inability to meet customer demands and contractual obligations, reduced consumer spending capacity, increased market volatility, financial uncertainty leading to revenue losses, increased debt burdens, declining profitability, and the lack of raw materials, components, or finished goods worldwide. Hereby, we identified a gap that we seek to cover in this study, which regards how business continuity, exemplified by the performance resistance to disruptions, has granted firms the chance to adopt specific SC initiatives aiming at increasing their resilience. The scope of this research goal is justified by observing that only firms demonstrating resistance to disruptive events, such as the COVID-19 pandemic, were capable of reacting effectively by investing in specific SC initiatives and increasing their resilience. In contrast, firms that were vulnerable to COVID-19 were unable to respond adequately and failed to adopt effective strategies to recover their business.

To properly achieve business continuity through performance resistance to disruptions during COVID-19, firms adopted several types of initiatives [9], among which the omnichannel strategies are surely one of the most important. In fact, omnichannel strategies emerged as a lifeline for firms seeking to establish connections with consumers whose mobility was severely constrained during the pandemic period [6]. By offering multiple channels, such as websites, mobile apps, social media, and customer service hotlines, firms were able to cater to changing preferences and maintain vital connections with their customers.

Furthermore, firms recognized the need to recalibrate their SC coordination strategies to ensure the resilience and responsiveness of their supply networks. This initiative involved the identification of new contractual terms and conditions with suppliers, fostering adaptive relationships to survive the turbulent environment imposed by the pandemic [10]. Furthermore, the adoption of technologies during the COVID-19 period was vital for firms to effectively navigate the complexity of a dramatically changed ecosystem [11]. The digital technologies provided firms with the means to establish seamless connections to customers and over the SC to adapt to changing circumstances and navigate the new business models brought forth by the pandemic [12].

To fulfill our research objectives, we adopted a rigorous Bayesian Network approach, employing a sample of 525 firms to derive probability distributions associated with business continuity, the adoption of SC practices, and resilience. Distinguishing itself from previous empirical research on the COVID-19 pandemic, our study delves into the exploration of a complex network of probability distributions, effectively analyzed through the application

of Bayesian Networks. Our research begins by establishing a theoretical foundation on the links between business continuity, the adoption of SC practices, and resilience. Afterward, we estimate the network of conditional probabilities linking them and employ a series of machine learning to discover the full and intricate web relationships within the network. This analytical approach enables us to identify key insights on how firms reacted with investments and the adoption of SC initiatives according to their business continuity, which is given by the performance resistance to disruptions. Then, we discover which of these SC initiatives gives firms a high chance to be resilient. Furthermore, we conduct a series of what-if analyses and, accordingly, provided informed recommendations to firms seeking to enhance their resilience. By exploring different hypothetical scenarios, we offer valuable guidance on the implementation of specific SC practices that will bolster a firm's ability to navigate future disruptions with greater agility and fortitude.

Our findings prove that business continuity is driven by some specific performance indicators, which push firms' investments toward ad hoc directions. Specifically, the resistance to achieving inventory availability, product quality, and sales activates new SC coordination measures. Conversely, customer service, delivery time, SC visibility, and product quality prompt firms to embrace the utilization of mobile applications as a means to maintain seamless communication with consumers, even during the pandemic. Additionally, we observed that the implementation of business continuity does not lead firms' investments through artificial intelligence (AI), omnichannel strategies, and big data and machine learning systems; however, their adoption happens when multiple performance resistance to disruptions manifest simultaneously. Furthermore, our research sheds light on the significant role of specific strategies in enhancing resilience. We discovered that firms can increase the probability of being resilient when adopting mobile applications, SC coordination practices, omnichannel approaches, and AI systems. These strategic choices enable firms to quickly adapt to new ecosystem conditions, withstand disruptions, and ensure continuity of operations during crises.

The rest of this paper is organized as follows. In Section 2, we examine the literature on the investigated topics, which serves as the foundation for deriving our research questions. Section 3 describes the methodology employed in this study, including a detailed explanation of the data collection process and the composition of our sample. Building upon the methodology, Section 4 presents a thorough discussion of our key findings and offers valuable managerial insights and recommendations based on the implications derived from our analysis. Finally, in Section 5, we conclude our study by summarizing the main findings and contributions, while also outlining potential avenues for future research.

2. Literature Review

This study aims to study business continuity by investigating the performance resistance to disruptions and examining the initiatives that firms adopted in response to the decline in performance during the first wave of the COVID-19 pandemic. Therefore, this research seeks to investigate how firms react and adapt when confronted with unforeseen events that impact performance [9]. Previous studies have emphasized the significance of implementing ad hoc plans and measures to mitigate the substantial performance decrease during disruptive events, particularly within SCs [13,14]. Differently from those studies, this research investigates how the performance resistance to disruptions enabled the adoption of strategies and initiatives. In fact, only firms that are able to still perform during disruptions are also capable and have the means for investing in specific strategies and initiatives to adapt to the new ecosystem situation. The COVID-19 pandemic served as a wake-up call; during the pandemic, many firms have been demonstrated to be vulnerable since several performance indicators have been damaged [15]. This situation can prevent firms taking some actions and making some types of investments. In contrast, firms with a certain business continuity exemplified by the performance resistance to disruptions, such as COVID-19, have the strength to properly respond with ad hoc action plans and adapt to the disrupted environmental conditions [16,17].

Among the various options available to firms to address performance resistance to disruptions caused by COVID-19, omnichannel strategies have emerged as a viable practice during disruptive events such as the COVID-19 pandemic [18]. This global crisis has induced significant shifts in consumer purchasing habits and behaviors, necessitating the exploration of alternative channels to meet their needs. An extensive literature has highlighted the operational and managerial advantages associated with omnichannel strategies [19]. Studies conducted [20,21] have demonstrated the effectiveness of omnichannel strategies in eliminating cross-channel constraints and facilitating seamless integration and communication within the SC.

The rising importance of omnichannel practices during the COVID-19 era was evident, especially in countries with mobility restrictions, which led to challenges such as limited personal movement, social distancing, restricted store access, and lower stock availability. Omnichannel strategies have been key in addressing these issues. Ref. [22] described omnichannel integration as the merging of digital and physical aspects to offer unique consumer experiences, a concept that gained significant traction during the pandemic. While the shift towards omnichannel strategies was already underway due to technological advances, the pandemic accelerated this trend.

This study aims to investigate the adoption of omnichannel strategies in response to the challenges and need for business continuity during the pandemic. It focuses on how combining offline and online channels is crucial in mitigating the pandemic's effects. The disruption of traditional supply chains (SCs) and retail operations by the pandemic has shifted consumer behavior towards online shopping and remote interaction. Lockdowns and social distancing have increased the demand for integrated and seamless experiences, achievable through omnichannel strategies that ensure consistency across different shopping channels. In light of these considerations, we formulated the following research question:

RQ1. *What are the performance resistances to disruptions that pushed firms toward the adoption of omnichannel practices during the COVID-19 pandemic?*

The COVID-19 pandemic initiated a transformative era, bringing significant global changes and challenges to supply chain (SC) participants [23], leading to a reassessment of objectives and strategies [4]. This situation has forced firms to reevaluate their SC coordination strategies, traditionally characterized by rigidity and a lack of provisions for disruptions, including force majeure clauses. Previous literature has extensively explored diverse contractual mechanisms in SC coordination, considering various demand functions, partner information types, and operational mechanisms [24]. These elements have been modeled stochastically, aiming for optimality in comprehensive optimization models [25]. However, previous disruptive events, such as the SARS pandemic and mad cow disease, have highlighted the need for robust coordination strategies to manage ripple effects and market disruptions [26]. SC coordination involves implementing contracts and agreements among suppliers to achieve Pareto improvements, manage routine exchanges, handle exceptional circumstances, and dynamically adjust strategies [27]. Ref. [28] discusses coordination options that simulate vertical integration through simple SC practices, offering competitive advantages. Ref. [29] focused on SC coordination amid demand disruptions, urging firms to revise production plans and strategies, and treating disruptions as general perturbations rather than specific events such as COVID-19.

Analyzing the differences in SC coordination between normal and disruptive conditions, as highlighted in [28,29], reveals distinct approaches. Ref. [28] centered on optimizing operational settings, while [29] concentrated on how performance resistance to disruptions affects optimal functioning. These disruptions, stemming from unexpected events, require specific investments and policies and lead to chain reactions and changes in SC agreements [30]. During the initial phase of the COVID-19 pandemic, firms encountered challenges in adhering to contractual terms and achieving their customary performance levels, as multiple risks stemming from the outbreak hindered their operations. We firmly

contend that SC coordination, previously demonstrated to be effective in managing unexpected situations, remains applicable in the context of the COVID-19 pandemic. Established and efficient SCs adapt their contractual clauses and agreements to incorporate the adverse implications of the pandemic, enabling coordination even amid the outbreak [31]. Indeed, the pandemic has caused significant disruptions in SCs, including lockdowns, travel restrictions, and reduced workforce availability. These disruptions have profoundly impacted firms' ability to fulfill their contractual obligations, resulting in delays, inventory shortages, and diminished operational efficiency. Addressing these performance resistance items to disruptions may require firms to revisit and revise their contractual agreements to include provisions for force majeure, flexible delivery schedules, and alternative sourcing options, to further ensure business continuity. To elucidate this framework, we formulated the following research question:

RQ2. *What are the performance resistances to disruptions that pushed firms to adjust their SC coordination strategies during the COVID-19 pandemic?*

Technologies have notably transformed SC management in recent years, enabling a proactive and responsive approach to risk mitigation and operational efficiency [25]. Their role in SC management is well-established, particularly in risk identification and prediction, helping firms foresee the impact of disruptions such as the COVID-19 pandemic. During this crisis, technology has been crucial in maintaining connections with consumers and suppliers amidst lockdowns and social disruptions, as evidenced in the extensive SC management literature [30,32].

The pandemic expedited the adoption of various technologies, especially to counter operational and financial risks. Firms have realized the importance of learning from external situations, utilizing big data, and making informed decisions in uncertain times [33]. A pivotal technology has been AI, with its data analysis and predictive modeling capabilities, facilitating real-time decision-making. Through AI and machine learning, firms can discern patterns and predict trends, aiding in disruption mitigation and operational optimization [34]. The implementation of AI during the pandemic has also spurred innovation and organizational transformation, with firms investing in AI showing a commitment to leveraging advanced technologies for navigating uncertainties and securing a competitive edge. AI-driven solutions promote a culture of agility and adaptability, allowing firms to swiftly revise strategies, explore new business models, and seize emerging market opportunities.

Along with AI, big data and machine learning have emerged as powerful tools, empowering organizations to make informed decisions swiftly, identify exceptions, and foresee unexpected events and challenges within the supply chain, thereby fostering the development of intelligent supply chains [30]. Big data and machine learning technologies offer firms the ability to effectively analyze and leverage vast amounts of data in real-time. By harnessing the power of big data analytics and machine learning algorithms, organizations can gain valuable insights into customer behavior, demand patterns, supply chain dynamics, and market trends. This enables them to make data-driven decisions, anticipate disruptions, and optimize their operations accordingly [34]. During the pandemic, traditional forecasting models and historical data became unreliable due to the unprecedented nature of the crisis. Big data and machine learning techniques proved to be invaluable in addressing this challenge. By analyzing real-time data from various sources, including social media, online platforms, and IoT devices, firms could obtain accurate and timely information about changing consumer preferences, supply chain disruptions, and market dynamics. This enabled them to adapt their strategies, optimize inventory levels, and ensure the availability of critical resources.

The business continuity challenges posed by the COVID-19 pandemic have highlighted the importance of mobile apps as a strategic investment for firms [35]. These apps have been essential in maintaining connections with consumers during the pandemic, offering accessibility and convenience for users to interact with businesses from home. Features such as online shopping, order tracking, and customer support allow for a contact-

less customer experience, which was crucial during lockdowns and social distancing [36]. Mobile apps have become a key channel for sustaining business operations, including transactions and customer support. They also offer valuable data insights for personalizing services, optimizing supply chain operations, and enhancing customer engagement. Additionally, mobile apps aid in fostering brand loyalty and supporting targeted marketing, helping businesses to overcome pandemic-related challenges and maintain their trajectory towards success.

In response to the challenges posed by the COVID-19 pandemic, the integration of AI, mobile apps, and machine learning solutions can be a powerful combination. AI algorithms and machine learning models enable mobile apps to analyze large amounts of real-time data, including user behavior, location, and health information, to provide personalized recommendations, safety guidelines, and contact tracing features. Additionally, the use of machine learning algorithms in mobile apps allows for predictive analytics, enabling early detection of potential outbreaks and optimizing resource allocation. Therefore, these technologies can contribute together to a more efficient and effective response to the performance resistance to disruptions due to the pandemic. Accordingly, we formulated the following research question:

RQ3. *What are the performance resistances to disruptions that pushed firms to adopt technologies such as artificial intelligence, big data and machine learning, and mobile apps during the COVID-19 pandemic?*

The literature around resilience, first defined in [37] as a system's adaptability and recovery from disruptions [38], has been reinvigorated by the COVID-19 pandemic. For recent perspectives on resilience, [39,40] offer insightful analyses. Ref. [41] described resilience as the capacity to cope with and recover from unforeseen events, while [42] viewed a resilient system as one that absorbs disruptions with minimal effort. Ref. [16] suggested firms and supply chains can be resilient by adopting responsive systems for managing pandemics, favoring flexible redundancy over traditional inventory-based disaster management.

The pandemic forced firms and supply chains to adapt rapidly [43]. This led to an exploration in the literature on how firms and supply chains can be resilient amidst global crises such as COVID-19 [23], focusing on strategies for handling disruptions [5]. Ref. [14] provides empirical evidence that comprehensive risk management enhances resilience, measured by the ability to adjust and sustain operations post-disruption. This study filled a research gap in operational risk management for resilience, focusing on technologies, SC coordination, and omnichannel approaches. Ref. [44] also demonstrated the beneficial effects of supply chain visibility, trust, and cooperation on resilience.

The adoption of technologies has proven highly effective in managing the consequences of COVID-19 and mitigating the associated risks [45]. Within the realm of digital transformation, ref. [46] proposed the utilization of big data and machine learning to foster resilience, encompassing resilience in supply chains, infrastructures, communities, and resources. Big data plays a vital role in integrating these elements through diffused trust, information sharing, and public-private partnerships, enabling firms to make timely decisions, analyze ecosystem changes, and proactively implement corrective actions [47]. Similarly, ref. [30] demonstrated how the implementation of AI systems and the establishment of smart supply chains aid in identifying and quantifying service and demand risks. These risks encompass disruptions in procurement processes and sales, although AI systems only offer partial solutions. In a broader context, ref. [48] proposed the adoption of AI as an opportunity for supply chains to achieve responsible digitalization, wherein digital technologies facilitate resilience in terms of corporate social responsibility objectives. Additionally, ref. [49] presented empirical evidence highlighting the significance of mobile app development during the COVID-19 pandemic in maintaining connectivity between consumers and companies, thereby ensuring the resilience of business models affected by the crisis. Mobile apps enable consumers to continue shopping during pandemic periods, while firms can maintain contact with consumers and sustain sales.

The omnichannel approach has received significant attention in the literature as a viable solution for mitigating the consequences of the pandemic and striving for resilience [50]. The impact of COVID-19 on consumers' purchasing intentions and needs necessitated the reengineering of distribution strategies that embrace omnichannel technologies and management to effectively navigate and recover from the pandemic [51]. The seamless experience offered by omnichannel enables consumers to make purchases without constraints from physical or online stores, and facilitates delivery to specific locations such as homes, lockers, or third-party venues [52]. This provides valuable opportunities for consumers to satisfy their needs and purchase goods even during lockdowns caused by COVID-19. Previous research [53] demonstrated that the omnichannel approach enables firms to swiftly adapt to changing consumer preferences and ecosystem dynamics, fostering resilience. Similarly, ref. [51] emphasized that the omnichannel approach empowered firms to achieve resilience post-pandemic by leveraging consumer interactions and integrating channels in various modes.

The literature emphasizes the importance of SC coordination as a significant driver for enhancing firms' resilience. Ref. [54] highlighted that coordination among suppliers, manufacturers, distributors, third-party providers, retailers, and customers following a disaster improves resilience by connecting and integrating capabilities and resources. Resilience can be achieved through SC agreements and contracts that explicitly address potential risks arising from disruptive events [55]. For instance, ref. [25] demonstrated how risks associated with the delivery time and demand within the SC can be effectively managed to ensure rapid profit recovery (resilience) by incorporating them into smart contracts managed using blockchain technology. The blockchain automatically adjusts the contractual terms to account for disruptions caused by risks, unexpected events, and outbreaks. However, coordination, even with the support of the blockchain, may not be sufficient in the face of high-risk scenarios. Similar findings were reported in [55], which showed that firms can enhance their resilience by reducing the propagation of disruptions, minimizing network recovery time, and mitigating associated costs. Nonetheless, the effectiveness of collaborative approaches, such as coordination with consumers and suppliers, may vary depending on the duration of the disruption.

Although the literature documents several cases for adopting technologies, SC coordination, and omnichannel approaches to increase resilience, a research gap exists relative to how firms can choose the SC practices to implement, as well as identify a list of priority related actions to be implemented to increase resilience after COVID-19. With the intent to fulfill this research gap, we formulated the following research question:

RQ4. *What are the SC practices adopted during the COVID-19 pandemic that guarantee resilience?*

We summarize the research design in Figure 1.

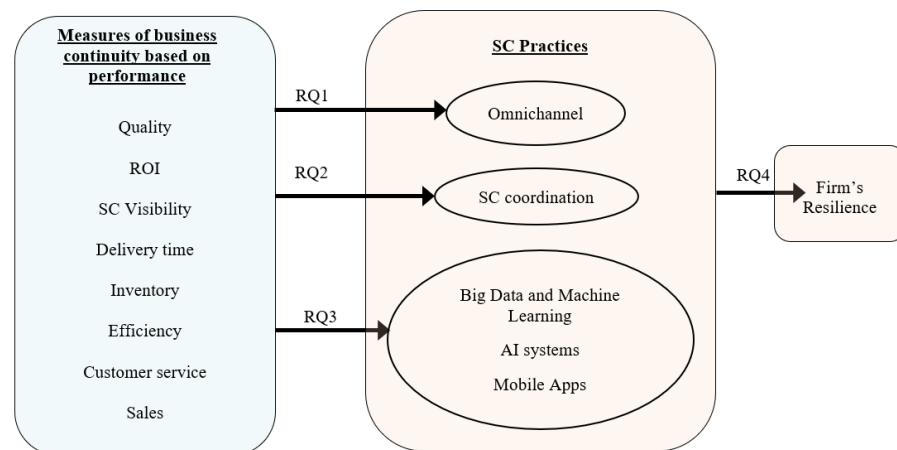


Figure 1. Conceptual model of this study.

3. Methodology and Sampling

3.1. A Bayesian Network Approach

To pursue the objectives of this research, an expert system structured through a Bayesian Network (BN) was used. We started with an ad hoc expert system to investigate the relationships linked to our research questions. In fact, the BN involved a chain of conditional probabilities linked to the impact of performance resistance to disruptions on SC practices and the relative influence on resilience. Therefore, we modeled a BN and refined it later through a machine learning algorithm to identify the hidden relationships according to the probability distributions derived from the data. In this study, we used BayesiaLab version 5.3 to analyze the relationships and conditional probabilities among different variables.

3.2. Data Collection

The collection of data started in July 2020, when the first wave of COVID-19 was coming to an end. We asked 5 Ph.D. students, 5 academics, and 10 professionals to analyze the content validity of a questionnaire, which is reported in Appendix A. After several interviews and trials, we reached a final version of the questionnaire, which was submitted to 635 firms selected among a pool of affiliates with our university and research centers. In Italy, there are more than six million registered businesses and our target sample was more than 10% of the whole population (<https://italianbusinessregister.it/> (accessed on 14 March 2024)). All the companies were located in Italy and the interviews and data collection were conducted after the first wave of COVID-19 to identify the practices that companies adopted to enhance their resilience in terms of time to recovery. Considering the expertise and positions of the respondents the sample was composed of 36% CEOs, 35% managers, 8% directors, 5% CFO, 4% analysts, and 12% others. The sample consisted of different categories of supply chain partners to ensure a comprehensive analysis of the supply chain ecosystem. Accordingly, the sample includes retailers with 15% of the sample, suppliers with 12%, wholesalers with 11%, distributors with 8%, manufacturers with 27%, and others with 27%.

Among the firms we contacted, 525 responded after 10 weeks. We used the two-proportion *t*-test to check for the representativeness of the sample composition. By using the variable “company type”, we did not obtain significant differences in proportions between the sample and the population, with a *p*-value = 0.65. Several approaches were used to assess non-response bias. The first approach consisted of comparing early to late respondents (i.e., first and second-to-third surveys). A one-way ANOVA found no significant differences between early and late responses for any of the items. We also used size and total revenues, finding that no significant difference existed between groups. All these tests are reported in Table A1 (Appendix B).

To pursue the objectives of this study, several items were used to measure performance resistance to disruptions. First, we focused on the following performance indicators: quality, ROI, costs, SC visibility, delivery time, customer service, inventory availability, and sales. Quality refers to product quality, which means the perception of the degree to which the product or service meets the customer’s expectations [56]. Efficiency links to the marginal production cost and represents the capacity to make goods at the same production cost as in normal situations [57,58]. SC visibility is the ability of parts, materials, or goods to be observed, identified, and evaluated by all supply chain members, independent of their position over the chain [45]. Delivery time refers to the period between the purchase of a product and the moment when this product is effectively delivered to consumers [58]. Customer service is the interaction between a firm’s personnel and customers, which ensures consumer satisfaction and encourages future transactions [56], while inventory refers to the stock availability in warehouses and over the SC [30]. ROI represents the return on investment, which evaluates the efficiency of an investment and the return relative to the investment’s cost, while sales refers to the amount of goods sold. Both sales and ROI have been frequently adopted together to measure the economic performance of firms.

Relative to these performance indicators, we measured the losses experienced due to the COVID-19 outbreak in percentage, which was then linked to the probability of a certain performance to deteriorate during the pandemic.

We measured firms' resilience in terms of the time they would eventually need to recover performance lost due to COVID-19 during the period January–June 2020. In fact, the first pandemic outbreak occurred in December 2019 worldwide. European firms and consumers, along with the government and the institutions, started creating awareness about the virus in January 2020. At the same time, the first wave was considered to be over by June 2020. Therefore, we asked firms to indicate the number of months they would require to recover the performance lost from January to June 2020 due to COVID-19. The firms were able to choose among four possible options: recover the performance lost either within three months, or within six months, or within 12 months, or in more than 12 months. To pursue the objectives of this study, we used this information to identify and measure resilience. These categories were identified by analyzing the reports in [59,60], in which resilience was investigated at several levels and considering the time period of three, six, and twelve months. By merging the pieces of information about the measure, we defined the four options that firms could choose. We then asked firms whether they adopted omnichannel strategies and undertook ad hoc coordination mechanisms during the first wave of COVID-19. These items were collected through some dummy variables, with a value of "0" if the firm did not adopt it or "1" if the firm adopted one of these managerial practices. This allowed us to measure the probability of being resilient in less than three months or more. Finally, we also used a dummy variable to capture the technologies that firms implemented during the COVID-19 period by asking whether they adopted mobile apps, AI, or big data and machine learning. The dummy variable took values of "1" when a certain SC practice was implemented and "0" otherwise. Accordingly, we were able to compute the probability that firms undertook a certain SC practice.

3.3. Sample Description

Table 1 displays all the details of the sample. The sample included several types of industries including 24% service companies, 16% industrial manufacturing, 10% fashion and luxury companies, 10% logistics companies, 9% food and beverage, 7% IT, 4% building, 3% healthcare, 3% agriculture, 3% automotive, and 11% in other sectors. Moreover, 53% of the sample was composed of companies with less than 50 employees, indicating that more than half of the sample was related to SMEs. Then, 14% of the companies had between 50 and 90 employees, and 9% of the sample was related to companies with between 100 and 200 employees, and 24% of the companies had more than 200 employees. In terms of sales, more than 56% of the companies were lower than 10, the sales of 27% of them were between 10 and 99, 12% of them fell in the category with sales between 100 and 999, and the remaining had sales greater than 99 million euros.

Table 1. Sample composition.

Employees	#	Role in SC	#	Industry	#	Sales (in Millions)	#
<50	53%	Distributors	8%	Service	24%	<10	56%
50–90	14%	Wholesalers	11%	Industrial production	16%	10–99	27%
100–200	9%	Suppliers	12%	Fashion and luxury	10%	100–999	12%
>200	24%	Retailers	15%	Logistics	10%	>999	5%
		Manufacturers	27%	Food and Beverage	9%		
		Others	27%	IT	7%		
				Building	4%		
				Others	20%		

4. A Bayesian Network Approach

4.1. Procedure

We defined a procedure to identify the most important associations between performance resistance to disruptions, SC practices, and resilience. Besides establishing the links associated with the research questions, we also used ML techniques to detect some unknown relationships according to the steps defined in Figure 2.

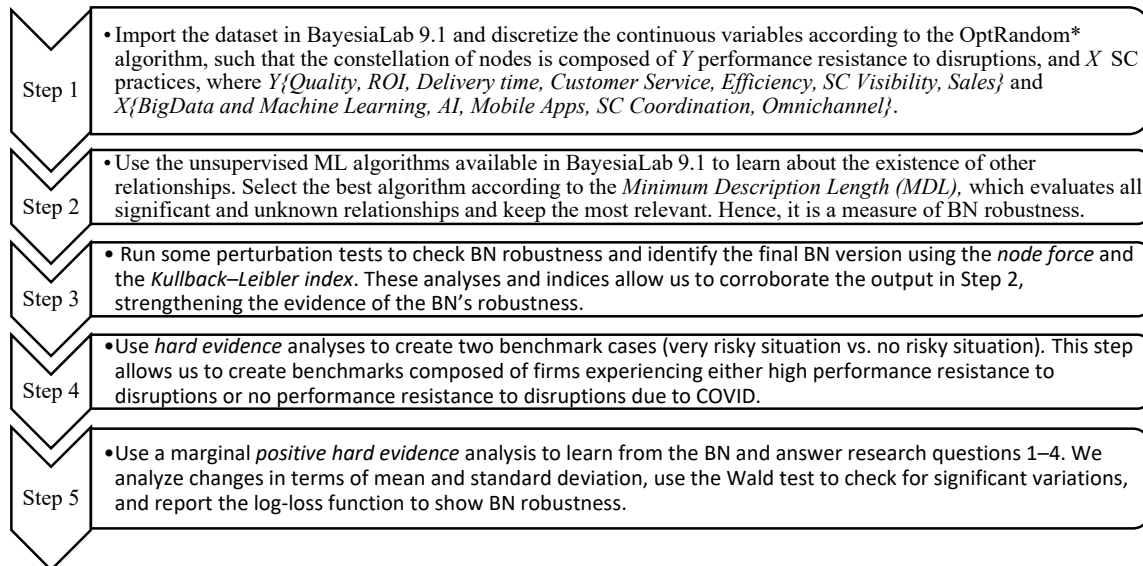


Figure 2. Schematic methodological procedure. * The best discretization algorithm for the dataset.

4.2. Joint Probability Distributions and Bayesian Networks

We display the results of the joint probability distributions in Tables 2 and 3. The joint probability distribution for performance resistance to disruptions is displayed in Table 2, and the joint probability distribution for SC practices is presented in Table 3. Therefore, for example, $P(Omni = 1) = 46.19\%$ signifies that the firms in our sample adopted an omnichannel approach with probability 46.19%, conditioned to the full network of relationships established in Figure 2, which was composed of performing quality with probability 52.94%, the delivery time with probability 50.17%, supply chain visibility with probability 47.80%, etc. Instead, the joint probability for our sample firms to be resilient (e.g., recover within three months after the outbreak ends) corresponded to $P(Resilient = 1) = 43.45\%$. Therefore, while 49.58% was the prior probability that a firm is resilient, 43.45% was the probability that a firm is resilient conditioned to the network under investigation.

Table 2. Joint probability distribution for performance resistance to disruptions.

	$P(Y = 1)$ (Non-Risky Performance)	$P(Y = 0)$ (Risky Performance)
Quality (QL)	52.94%	47.06%
Delivery time (DT)	59.17%	40.83%
Supply Chain Visibility (SCV)	47.80%	52.20%
Sales (Sales)	53.78%	46.22%
Customer service (CS)	57.37%	42.63%
Inventory (Inv)	48.74%	51.26%
ROI (ROI)	65.55%	34.45%
Efficiency (Eff)	55%	45%

Table 3. Joint probability distribution for SC practices/strategies.

	$P(X = 1)$	$P(X = 0)$
Omnichannel (Omni)	46.19%	53.81%
Supply Chain Coordination (SCC)	55.09%	44.91%
Big Data and Machine Learning (BDML)	40.44%	59.56%
AI (AI)	55.09%	44.91%
Mobile Apps (Apps)	54.45%	45.55%

Running Steps 1–3 of the proposed procedure allowed us to identify the final BN, as displayed in Figure 2. The arcs of the BN were derived using the searching methods EQ (equivalent classes) and applying a post-processing taboo search algorithm. When using unsupervised techniques, the MDL improved from 5335.918 to 5289.256 on average. To prove the robustness of the analysis, Table 4 displays two sensitivity analyses: the data perturbation and the learning/test split. The data perturbation consists of perturbing the data with several levels of standard deviation and, afterward, relaunching the unsupervised learning to verify the MDL changes. Similarly, the learning/test split allows one to select the percentage of data to be used for testing and the remaining to be used for learning. The test consists of running several splitting rules and relaunching the unsupervised learning to check how the MDL modifies. In both sensitivity tests, we randomly obtained 1000 resamples and used a seed of 30, as per default parametrization. According to the results reported in Table 4, the MDL did not change significantly when both sensitivity tests, demonstrating the robustness of our findings.

Table 4. Sensitivity analysis and robustness check.

Perturbation Test		Learning/Test Split	
Standard Deviation	MDL	Splitting Rule	MDL
0.05	5289.719	10/90	5103.374
0.1	5290.033	15/85	5018.275
0.15	5290.197	20/80	4943.276
0.2	5316.046	25/75	4909.252

Figure 3 reveals that the risks for delivery time and sales are the only two parent risk categories, for which a prior probability distribution exists. They generate a set of conditional probability distributions to the other performance resistance to disruptions, which become child risk categories. Accordingly, we can observe that the probability of performing in inventory management is conditioned to the probability that firms can perform high sales even during the period of COVID-19. In fact, firms need to optimize their inventory when the sales are performed to a great extent. The high amount of inventory managed has an impact on the quality of goods, especially during COVID-19 when there is a shortage of mobilized resources. Hereby, the firms are required to guarantee high levels of quality for the goods they have in stock independent of the pandemic. Furthermore, the probability that firms are able to perform the delivery lead time during the COVID-19 period ensures high consumer service, especially in a period during which people are in lockdown. Along with consumer service, the probability of performing the lead time impacts on the probability that the firms make goods at the original production cost, without being influenced by the consequences of the pandemic. This is most likely linked to the firms' ability not only to deliver to consumers without any delay but also to procure raw materials and goods following standard procedures even during the COVID-19 period. Moreover, the probability that firms perform both the delivery time and the quality is associated with a high probability of guaranteeing visibility over the supply chain, which reflects the firms' ability to make information on quality and delivery transparent and available over

the supply chain, which translates into a high probability for firms to perform the ROI. The latter impacts efficiency, showing that the more firms are able to ensure financial and economic returns, the more they invest such returns to pursue efficiency through ad hoc actions (e.g., process innovation).

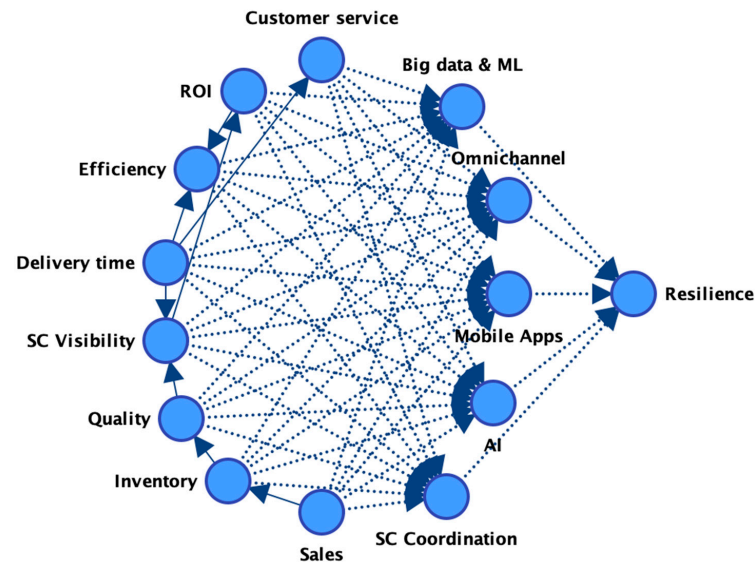


Figure 3. Bayesian network resulting from machine learning. Dashed lines indicate the significant relationships between independent and dependent variables. Solid lines define the significant relationships between the independent variables.

Finally, Figure 4 displays the statistical results associated with the BN. The force node represents the dimension of a node; therefore, the bigger a node, the higher its importance in the overall analysis. The thickness of an arc measures the Kullback–Leibler index; hence, the stronger the arc, the closer the difference between the original and the theoretical distributions. Finally, the color of each node corresponds to the entropy, which represents the expected amount of information conveyed by a node. The green color identifies high entropy, the yellow color corresponds to medium entropy, and the red color corresponds to low entropy.

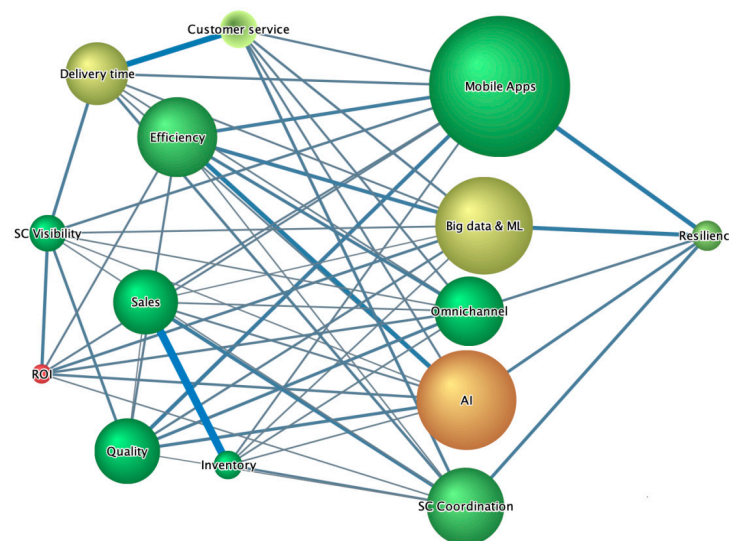


Figure 4. The final Bayesian network: the size of the node represents its importance; the thickness of an arc measures the Kullback–Leibler index (closeness between the original and the theoretical distributions); the color of each node shows the entropy (green: high, yellow: medium, and red: low entropy).

4.3. Business Continuity Based on Performance Resistance to Disruptions and Omnichannel Strategy

Table 5 reports the analysis of the network of relationships linking performance resistance to disruptions with the adoption of omnichannel strategies and allows us to answer to RQ1. The findings that we obtained in this section are completely new with respect to the literature, which focused on how the adoption of omnichannel strategies impacts on the business risks and performance, e.g., [19–21]. Instead, we performed a reverse analysis and sought to discover whether firms experiencing low-performance resistance to disruptions adopted omnichannel strategies during the first wave of the COVID-19 pandemic. To achieve our research target, we used the positive hard evidence analysis on each performance risk, while keeping the distributions of the other risks at the benchmark level (the probability distributions displayed in Table 2).

Table 5. Performance resistance to disruptions and the adoption of SC Practices.

		Customer Service	Delivery Time	SC Visibility	Quality	Inventory	Sales	ROI	Efficiency
Omnichannel	Δ Probability of adoption	−0.017	−0.051	−0.047	0.056	0.022	0.034	0.04	−0.015
	<i>t</i> -value	0.373	1.165	1.04	−1.222	0.48	−0.6	−0.873	0.329
	Result	NS	NS	NS	NS	NS	NS	NS	NS
	Log-loss function	0.8	0.76	0.76	0.92	1.04	0.89	0.62	0.86
SC Coordination	Δ Probability of adoption	0.030	0.018	0.039	0.131	0.322	0.316	0.0008	0.049
	<i>t</i> -value	−1.549	−1.278	0.421	2.31 **	−5.771 ***	−5.722 ***	−1.054	0.196
	Result	NS	NS	NS	S	S	S	NS	NS
	Log-loss function	0.8	0.76	1.07	0.92	1.04	0.89	0.61	0.86
Big data and Machine learning	Δ Probability of adoption	0.012	0.015	0.051	0.052	0.030	0.05	−0.098	0.051
	<i>t</i> -value	−0.262	−0.305	1.178	−1.185	0.785	−1.172	2.319 **	−1.175
	Result	NS	NS	NS	NS	NS	NS	S	NS
	Log-loss function	0.8	0.76	1.07	0.92	1.04	0.91	0.61	0.86
Artificial Intelligence	Δ Probability of adoption	0.012	0.015	0.051	0.052	0.030	0.050	0.049	0.050
	<i>t</i> -value	0.815	1.122	1.469	−1.182	0.699	−0.981	−1.011	1.391
	Result	NS	NS	NS	NS	NS	NS	NS	NS
	Log-loss function	0.8	0.76	0.76	0.92	1.04	0.89	0.62	0.86
Mobile apps	Δ Probability of adoption	0.156	0.177	0.192	0.193	0.065	0.066	0.032	−0.107
	<i>t</i> -value	−3.716 ***	−4.31 ***	−4.749 ***	−4.81 ***	−1.475	−1.498	−0.793	2.331 **
	Result	S	S	S	S	NS	NS	NS	S
	Log-loss function	0.82	0.78	1.07	0.707	1.101	1.06	1.07	0.88

** *p*-value < 0.05, *** *p*-value < 0.01, italic *t*-values are not statistically significant, S: supported, NS: not supported.

Table 5 reports the Δ Probability of adopting omnichannel strategies, which corresponds to the increased probability of adopting omnichannel strategies when firms enjoy low risks. For example, when the risk of inventory shortage is fully mitigated, e.g., $P(Inv = 1) = 1$, the probability that firms achieved this outcome by adopting omnichannel strategies moved from 0.462 (see Table 3) to 0.484, with a variation of 0.022 (see Table 5), which was not statistically significant (low *t*-value). Consequently, we can conclude that the goal of mitigating inventory shortage risks during the first wave of the COVID-19 pandemic did not push firms to a higher probability of adopting omnichannel strategies. Consequently, inventory

shortage risks are not effective drivers to suggest that firms should adopt omnichannel strategies. In contrast, firms achieved that result by adopting other SC practices.

Interestingly, as displayed in Table 5, none of the probabilities to adopt omnichannel strategies varied significantly according to the other performance resistance to disruption factors. Therefore, we can conclude that when firms were able to mitigate the performance resistance to disruptions, the probability of adopting omnichannel strategies was not modified. Hence, firms enjoying a state of low-performance resistance to disruptions during COVID-19 adopted other SC practices. Furthermore, when checking the synergies among performance resistance to disruptions, we discovered that the risks of decreasing sales, ROI, inventory, and quality, when occurring simultaneously, suggested the adoption of omnichannel strategies. When fixing $P(QL = 1) = P(Sales = 1) = P(Inv = 1) = P(ROI = 1) = 1$, we captured the synergistic effect among these performance resistance to disruptions and investigated whether firms' need to mitigate all of them simultaneously suggests the adoption of omnichannel strategies. In fact, the probability of adopting omnichannel strategies moved from 46.2% (see Table 3) with $P(QL = 1) = 0.5294$, $P(Sales = 1) = 0.5378$, $P(Inv = 1) = 0.4874$, and $P(ROI = 1) = 0.6555$ (see Table 2) to 63.1% when $P(QL = 1) = P(Sales = 1) = P(Inv = 1) = P(ROI = 1) = 1$, with a t -value = 2.873 (p -value < 0.05). Accordingly, firms should adopt omnichannel strategies during events such as the COVID-19 pandemic only when the risks of sales, ROI, inventory, and quality simultaneously impact the business model.

Methodological observation: Considering that the probability of adopting omnichannel strategies was 46.2% with $P(QL = 1) = 0.5294$, $P(Sales = 1) = 0.5378$, $P(Inv = 1) = 0.4874$, and $P(ROI = 1) = 0.6555$, the improved probability of 63.1% was obtained by adding all improvements linked to $P(QL = 1) = P(Sales = 1) = P(Inv = 1) = P(ROI = 1) = 1$. These certain probabilities allow one to sum the probability 46.2% to all the Δ Probability resulting from Table 5 and linked to quality, sales, inventory, and ROI, which are given by 5.6%, 2.2%, 3.4%, and 4%, respectively. The difference between 46.2% and 63.1% is significant only when these SC practices are considered altogether. Note that computing the simple sum of probability can mislead the reader, since $46.2\% + 5.6\% + 2.2\% + 3.4\% + 4\% = 61.4\%$, which is different from 63.1%. This difference depends on the joint probability distributions, which create synergies among the variables that have been considered and lead to an increased overall probability. The mechanism behind this note will be used for all other computations in the subsequent sections.

4.4. Business Continuity Based on Performance Resistance to Disruptions and Supply Chain Coordination

In this section, we analyze the impact that performance resistance to disruptions has on SC coordination. Our results are novel comparative to the current literature since the major focus was on how SC coordination influences SC risks and performance, e.g., [4,29,61]. In this research, we undertook a reverse approach by studying how the deterioration of performance pushed firms to modify the supply chain contracts and agreements. Table 5 displays the chain of probabilities linking performance resistance to disruptions to SC coordination. The outcomes in Table 5 allowed us to answer RQ2 and then identify the performance resistance to disruption factors that drove the changes in the contractual agreements among SC members during the first wave of the COVID-19 pandemic. Hence, the Δ Probability of adopting SC Coordination links to the SC members' availability to consider the challenges induced by COVID-19 to adjust the contractual terms, clauses, and deadlines to mitigate the performance resistance to disruptions.

Our results suggest that firms experiencing the risks of low quality, inventory shortage, and sales reduction during the first wave of COVID-19 were most likely to pursue SC coordination. The highest contribution to this result was given by the mitigation of inventory shortage risks, addressing the strong relationships that exist between an effective inventory management system and an effective SC. The COVID-19 pandemic brought many issues surrounding goods production and delivery due to lockdowns and restrictions to people's

mobility, contributing to the risks of inventory shortages around the globe: the probability to adopt SC coordination showed a significant increase of 32.2% with a t -value = 5.771 (p -value < 0.01).

Furthermore, firms that were affected by sales risks during the first wave of COVID-19 activated SC coordination mechanisms. The risk of low sales was the most serious risk that firms faced during the pandemic, since sales represent the financial inflow to guarantee the normal prosecution of business affairs. When firms changed their behavior and strategies to mitigate sales risks, SC coordination was most likely adopted. Therefore, the SC members' commitment to supporting sales development and bypassing the related risks led firms to adopt and conform to contract terms according to COVID-19's threats. This result was supported by an increase in the probability of embracing SC coordination of 31.6%, with a t -value = 5.722 (p -value < 0.01).

Our results show that the need to guarantee product quality and diminish the risks of non-conformance or defective goods pushed firms to adopt SC coordination. The probability of seeking out this SC practice increased by 13.1%, with a t -value = 2.31 (p -value < 0.05), demonstrating firms' efforts to ensure product quality, even during the COVID-19 pandemic, by following the idea that quality links to customer satisfaction and retention, even during outbreak periods. The occurrence of contractual changes can be linked to quality inspections and controls, the contribution to quality management, incentives and certifications to perform high quality standards during COVID-19, and the practice of carrying out operations in COVID-19-free circumstances and environments.

Finally, we observed that firms that wished to mitigate the risks of inventory shortage, loss of sales, and product quality were driven by SC coordination. Our results suggest that, on average, firms' probability of managing the disruptions due to COVID-19 through SC coordination was 55.09% (see Table 3). When firms enjoyed the mitigation of risks for inventory shortage, loss of sales, and product quality, the probability of employing SC coordination increased to 93.75% with a t -value = 4.746 (p -value < 0.001) by exploiting the synergistic effect of the conditional probability distributions. That is, the original joint probability that firms adopted SC coordination was 55.09%, given that the probability of performing sales, quality, and inventory were 53.78%, 52.94%, and 48.74%, respectively. Through a "what if" analysis, we discovered that when the joint probability distributions of performing sales, quality, and inventory become 100%, the probability of adopting SC coordination goes to 93.75%. In contrast, the other performance resistance to disruptions linked to delivery time, supply chain visibility, customer service, ROI, and efficiency did not have any impact on the probability of adopting SC coordination.

4.5. Business Continuity Based on Performance Resistance to Disruptions and Technologies

In this section, we explain our results relative to the links between performance resistance to disruptions and technologies. Hence, we seek to answer RQ3, whose results are completely new with respect to the literature that focuses on the impact of technologies on risks and performance, e.g., [62]. Rather, our investigation sought to discover which performance resistance factor pushed firms to adopt big data and ML, AI, and mobile apps during the first wave of the COVID-19 pandemic to recover the performance lost.

Table 5 reports the first analysis on the performance resistance of disruptions and the adoption of big data and ML. Accordingly, most of the performance resistance to disruptions that we analyzed did not push firms to invest in big data and ML during the COVID-19 pandemic. While the adoption of big data and ML has been lauded in the literature during normal periods, the challenges imposed by COVID-19 pushed firms to look for alternative SC practices and options when they sought to mitigate performance resistance to disruptions. Within our analysis, the only significant Δ Probability of adopting big data and ML was linked to the risk of decreasing ROI. Interestingly, firms that eliminated the risks associated with ROI during the COVID-19 pandemic showed a lower interest in investing in big data and ML. The probability that firms adopted this technology moved from 0.4044 (see Table 3) with $P(ROI = 1) = 0.6555$ (see Table 2) to 0.306 when $P(ROI = 1) = 1$,

with a significant negative difference (p -value < 0.05). Accordingly, firms targeting the low risks of losing ROI abandoned the idea of investing in big data and ML during the first wave of COVID-19 and pursued other types of investments.

Finally, we analyzed the synergistic effects among performance resistance to disruption factors to verify the existence of some clusters of risk that suggest the adoption of big data and ML. The analysis of joint conditional probability distributions indicated that the simultaneous presence of risks linked to customer service, delivery time, SC visibility, and quality led decision makers to adopt big data and ML. When fixing the positive hard evidence to $P(QL = 1) = P(DT = 1) = P(SCV = 1) = P(CS = 1) = 1$, the adoption of big data and ML becomes highly probable. In fact, the probability of adopting this technology moves from 40.4% to 59.1% with a t -value = 3.121 (p -value < 0.01). Accordingly, the simultaneous presence of quality risk, delivery time risk, SC visibility risk, and customer service risk pushes firms to adopt big data and ML.

We report the Δ Probability of adopting AI in Table 5, which links to the increased probability of adopting AI during the COVID-19 pandemic when firms enjoy low risks. Unfortunately, as for omnichannel strategies, none of the firms adopting AI were motivated by the need to reduce some risks for the performance under investigation. Hence, we can summarize the findings by saying that when firms mitigated the performance resistance to disruptions, the probability of investing in AI remained unchanged.

However, the analysis of the joint probability distributions linked to the performance resistance to disruptions revealed that the joint effects of customer service, delivery time, ROI, quality, sales, and inventory can push firms to adopt AI systems. When fixing the positive hard evidence, such as $P(QL = 1) = P(DT = 1) = P(ROI = 1) = P(CS = 1) = P(Sales = 1) = P(Inv = 1) = 1$, the probability of adopting AI systems goes from 36.73% (see Table 3) with $P(QL = 1) = 0.5294$, $P(Sales = 1) = 0.5378$, $P(Inv = 1) = 0.4874$, $P(CS = 1) = 0.5737$, and $P(ROI = 1) = 0.6555$ (see Table 2) to 57.3% when $P(QL = 1) = P(DT = 1) = P(ROI = 1) = P(CS = 1) = P(Sales = 1) = P(Inv = 1) = 1$, with a t -value = 3.135 (p -value < 0.01). Accordingly, firms are pushed to adopt AI systems when the risks for customer service, delivery time, ROI, quality, sales, and inventory occur at the same time.

Table 5 displays firms' willingness to adopt mobile apps to reach a state of low-performance resistance to disruptions. Hereby, we showed whether firms mitigating performance resistance to disruptions during the COVID-19 pandemic most commonly adopted mobile apps. In contrast to the other SC practices, the use of mobile apps was demonstrated to be very effective, as it links to the wishes to avoid several types of risk.

The Δ Probability of adopting mobile apps changed significantly when firms faced the problem of customer service risks. In fact, the probability went from 54.45% (see Table 3) to 70% when $P(CS = 1) = 1$ with a t -value = -3.716 (with p -value < 0.01). Unlike the other technologies, the use of mobile apps during the COVID-19 pandemic represented a true possibility for firms to directly link to consumers by offering promotions, showing availabilities, proposing services, granting a different consumer experience, and offering new ways to approach the finalization of purchasing. Indeed, the COVID-19 outbreak forced firms and consumers to adopt and use mobile apps daily, with the result of speeding up their adoption. However, mobile apps target a great and unique personal shopping experience and offer more value than a simple online shopping experience that guarantees social distancing.

The Δ Probability of adopting mobile apps also changed significantly when firms experienced delivery time risks. Starting from a probability of adopting mobile apps of 54.45%, firms' wishes to mitigate the delivery time risk and exemplified by $P(DT = 1) = 1$ brought the probability of adopting mobile apps to 72.1%, with an increase of 17.7% and a t -value = -4.31 , which was statistically significant (p -value < 0.01). Both customers and employees can connect and have seamless experiences. Customers do not need to call the store and check whether the goods have arrived. Rather, they receive news and updates directly from the apps. The stores take advantage of the apps by knowing when consumers are on their way and estimate when they will arrive. The app alerts employees to bring the

order for contactless delivery, which is very useful during COVID-19 to guarantee social distancing. Therefore, firms seeking to mitigate delivery time risks can easily achieve that target by integrating mobile apps with the business model.

This result was linked to firms' commitment toward SC visibility. In fact, our results demonstrate that the Δ Probability of adopting mobile apps increased when firms experienced SC visibility risks. Starting from a probability of adopting mobile apps of 54.45% with $P(SCV = 1) = 0.4780$, the goal of removing the risks associated with SC visibility, given by $P(SCV = 1) = 1$, brought the probability of adopting mobile apps to 73.6%, which corresponds to a variation of 19.2% that was statistically significant, with a t -value = 4.749 (p -value < 0.001). Moreover, starting from a joint probability of 54.45% when $P(CS = 1) = 0.5337$, the probability became 70% when firms certainly perform consumer service, that is, $P(CS = 1) = 1$.

By using the mobile apps, the entire network of stores and suppliers undertook new tasks and responsibilities during the first wave of the COVID-19 pandemic, exemplified by controlling production and store capacity, including countless constraints in the optimization models to guarantee social distancing, tracking goods across countries and various distribution centers, tracking customers across multiple store entrances and exits, analyzing queues of customers and deliveries to monitor the exact moment when actions and strategies could be initiated, and receiving feedback and information from consumers and suppliers worldwide. All of these advantages contribute to creating full knowledge regarding what the ecosystem experiences during outbreak periods, creating diffused information to be used for enhancing SC visibility and ensuring access and managing all information related to orders, physical and virtual goods, and shipments across the entire SC. Hence, firms seeking to mitigate any interruption of the knowledge creation and diffusion process concretized through SC visibility are inclined to adopt mobile apps.

As displayed in Table 5, firms seek to adopt mobile apps when the risk of non-conforming or defective items exists. Our results showed that the Δ Probability of adopting mobile apps increased when firms sought to mitigate quality risks, with a positive variation of 19.3% with a t -value = -4.81 (p -value < 0.001), which occurred when $P(QL = 1) = 1$. In other words, firms that eliminated quality risks during the first wave of the COVID-19 pandemic most likely accomplished this through the adoption of mobile apps. The use of this technology allows each supplier along the SC to demonstrate how the business functions, the operational practices that have been adopted and implemented, and how the logistics activities have been carried out regarding the entire SC journey. By demonstrating all of these features, firms ensure their loyalty and trust and guarantee high product quality. Mobile apps can shed light in this direction and can be adopted by all firms dealing with quality issues and risks during the COVID-19 pandemic.

Note that the Δ Probability of adopting mobile apps decreased when firms removed the efficiency risks, with a negative variation of 10.7% with a t -value = 2.331 (p -value < 0.05), which occurred when $P(Eff = 1) = 1$. This result can be linked to the activation of atypical processes to guarantee the correct adoption and use of mobile apps, which require investments for both development and implementation, changes in consumers' habits and purchasing behavior, and maintenance and upgrade costs. Therefore, during the first wave of COVID-19, firms experiencing a high risk of increasing production costs were less prone to adopt mobile apps. Rather, they focused on other SC practices to achieve this target. Similarly, firms did not use mobile apps when seeking to mitigate the risks of high inventory, as well as sales and ROI reduction, since these are all consequences not fully manageable through mobile apps exclusively during a disruptive period such as the COVID-19 outbreak.

Firms that aimed to eliminate customer service risks, delivery time risks, SC visibility risks, and product quality risks during the first wave of the COVID-19 pandemic adopted mobile apps in 86% of cases. Therefore, firms aiming at better simultaneously controlling these four risks were pushed to adopt mobile apps. All other risks were then secondary and contributed to creating more challenges for firms.

4.6. Supply Chain Practices and Firm's Resilience

This section seeks to discover how the adoption of SC practices can guarantee resilience. In this research, resilience was measured as a firm's capacity to recover its business volume and affairs after the first wave of the COVID-19 pandemic. Our results, which are displayed in Table 6, demonstrate that firms could increase their probability of being highly resilient when adopting omnichannel strategies, SC coordination, AI, and mobile apps. Each of these options offers a great contribution to the firm's resilience. Starting from the probability to be resilient of 43.45% when, according to Table 3, the joint probability distribution for the SC practices is $P(\text{Omni} = 1) = 0.4619$, $P(\text{SCC} = 1) = 0.5509$, $P(\text{BDML} = 1) = 0.4044$, $P(\text{AI} = 1) = 0.5509$, and $P(\text{Apps} = 1) = 0.4554$. As before, we investigated how the probability of being resilient changed when firms adopted the proposed SC practices.

Table 6. Supply chain practices and resilience.

	Omnichannel	SC Coordination	Big Data and ML	AI	Mobile Apps
<i>ΔProbability of being resilient</i>	0.139	0.150	<i>−0.057</i>	0.103	0.153
<i>t-value</i>	−3.109 ***	−3.341 ***	<i>−1.237</i>	−2.252 **	−3.392 ***
Result	S	S	NS	S	S
Log-loss function	1.1	0.86	1.31	1.45	0.88

** p -value < 0.05, *** p -value < 0.01, italic t -values are not statistically significant, S: supported, NS: not supported.

The adoption of omnichannel strategies implies a higher probability for firms to be resilient. The *Δ Probability of being resilient* had a positive variation of 13.9%, with a t -value = −3.109 (p -value < 0.001). This is in line with previous research investigating the positive effect of omnichannel strategies on a firm's resilience, addressing the question through empirical approaches, e.g., [53,63]. Differently from previous research, our stochastic approach showed the extent to which firms could improve their resilience when relying on omnichannel strategies, that is, the certain use of omnichannel strategies will allow firms to increase their resilience by 13.9%.

Similarly, as shown in Table 6, SC coordination helps firms to be more resilient, thanks to the positive commitments of suppliers in adjusting contract clauses, terms, and agreements to accommodate the challenges attributable to COVID-19. The *Δ Probability of being resilient* had a positive variation of 15%, with a t -value = −3.341 (p -value < 0.001), when firms adopt ad hoc coordination mechanisms to address COVID-19 issues. This result is in line with the literature that sponsors SC coordination to increase the level of resilience, e.g., [55]. However, as explained in [55], there is a need to quantify the resilience that firms and supply chains gain when undertaking specific actions, to better align the strategic objectives with the SC requirements. Our contribution moves in this direction. By adopting a “what if” analysis we could demonstrate that firms adjusting the SC contractual terms and agreements to face the COVID-19 challenges could increase their resilience by 15%; therefore, by aligning the SC relationships and commitments to the general pandemic situation, firms would be able to recover the performance lost during the COVID-19 in less than three months.

In terms of technologies, the adoption of AI allowed firms to increase their probability of being resilient by 10.3%, with a t -value = 2.252 (p -value < 0.05), by exploiting the predictive capacity of such systems. This result contrasts with the findings in [30], which showed that the adoption of AI and related smart SC could harm a firm's capacity to recover profits due to uncertain events when their amplitude is very high; in fact, AI needs to be supported by other technologies as it may not be sufficient. In contrast, our results suggest that the implementation of AI leads to firms being more resilient after COVID-19. Thus, we increased the body of knowledge in this domain by adopting a stochastic approach that allowed us to estimate the amplitude of resilience improvements that firms may acquire by

evaluating the probability that AI is in place. Specifically, the probability of implementing AI can lead to a resilience improvement of 10.3%.

Furthermore, mobile apps substantially contributed to firm resilience by increasing the probability of performing resilience by 15.3%, with a t -value = 3.392 (p -value < 0.001). The general positive link existing between the firms' resilience and the adoption of mobile apps during COVID-19 has been empirically demonstrated in several empirical studies [49]. Beyond confirming these results, our findings contribute to the body of knowledge by showing that firms can be resilient even without adopting mobile apps. However, the adoption of mobile apps could increase resilience by 15.3%, by ensuring a direct connection with consumers and a continuous interface with them.

Overall, the adoption of omnichannel strategies, SC coordination, AI, and mobile apps constitute a portfolio of SC practices designed to increase a firm's probability of being resilient, which signifies recovering in less than three months after the first wave of COVID-19 in this research. Our results demonstrated that the probability of being resilient rose from 43.45% to 89.9% (with a p -value < 0.001), which suggests that the synergies among omnichannel strategies, SC coordination, AI, and mobile apps can provide a great opportunity for firms to quickly re-establish their business volumes and affairs after a disruption event such as the COVID-19 pandemic.

Finally, the results displayed in Table 6 show that the use of big data and machine learning techniques is not suitable for improving the firms' resilience. These findings contrast with the literature, e.g., [46], probably because the first wave of COVID-19 was too disruptive to make big data and machine learning beneficial.

To summarize our main findings regarding each research question, we provide the key outputs and the academic and managerial implications for each of them in Table 7.

Table 7. Research questions and the main outputs.

RQ	Relevant Discussion	Main Findings	Managerial Implications
RQ1	Section 4.3	<ul style="list-style-type: none"> The goal of mitigating inventory shortage risks does not lead to a higher probability of adopting omnichannel strategies. The probability of adopting omnichannel strategies does not vary significantly due to improving other performance resistance to disruptions. Facing risks of decreasing sales, ROI, inventory, and quality simultaneously incentivizes firms to implement omnichannel strategies. 	<ul style="list-style-type: none"> Firms with a low inventory shortage risk should not consider omnichannel strategies as an effective solution to mitigate their low-performance resistance to disruptions. In that case, they should adopt other SC practices rather than omnichannel. Firms should adopt omnichannel strategies if the risks of sales, ROI, inventory, and quality are affecting their business models simultaneously based on the synergies among the proposed performance resistance to disruptions.
RQ2	Section 4.4	<ul style="list-style-type: none"> The risks of low quality, inventory shortage, and sales reduction push firms to pursue SC coordination practices. There is a strong relationship between reducing inventory risks and an effective SC. The goal of decreasing sales risks activates SC coordination mechanisms. Assuring product quality to mitigate the risks of non-conformance or defective goods leads to adopting SC coordination. 	<ul style="list-style-type: none"> Firms that are aiming to mitigate the shortage, product quality, and sales risks need to devise an effective SC with a high cooperation level in which all the partners are committed to supporting sales and revising contracts according to new conditions. Firms should not increase investment in SC coordination practices due to other performance resistance to disruptions factors linked to delivery time, supply chain visibility, customer service, ROI, and efficiency. In that case, the priority is implementing other practices rather than investing in SC coordination initiatives.

Table 7. Cont.

RQ	Relevant Discussion	Main Findings	Managerial Implications
RQ3	Section 4.5	<ul style="list-style-type: none"> Most of the performance resistance to disruptions factors do not push firms to adopt big data and ML. The goal of mitigating the risks associated with ROI shows a lower interest in investing in big data and ML. Facing risks of customer service, delivery time, SC visibility, and quality simultaneously invokes firms to adopt Big data and ML. A low level of risk pushes companies to adopt AI but they do not invest in this technology aiming to mitigate risks. The joint effects of customer service, delivery time, ROI, quality, sales, and inventory causes the adoption of AI. Compared to other SC practices, the use of mobile apps is very effective and common as it helps to avoid several types of risks. Adoption of mobile apps had a significant impact on overcoming quality risks during the pandemic. 	<ul style="list-style-type: none"> During the crisis, companies were not interested in adopting big data and ML to mitigate challenges related to performance resistance to disruptions. However, during the normal periods or when the risk is low the probability of adopting these technologies increases. Nevertheless, facing a series of risks simultaneously such as the risks related to quality, delivery time, SC visibility, and customer service pushes companies to implement big data and ML. To deal with quality issues and other risks during disruptions, firms can adopt mobile apps to improve their relationship with consumers by offering promotions, showing availabilities, proposing services, granting a different consumer experience, and offering new ways to approach the finalization of purchasing. However, for firms experiencing a high increment in production costs, adopting mobile apps cannot be considered as an ad hoc practice to mitigate the risk.
RQ4	Section 4.6	<ul style="list-style-type: none"> The adoption of omnichannel strategies implies a higher probability for firms to be resilient. The adoption of AI allows firms to increase their probability of being resilient by improving predictive capability. The adoption of mobile apps substantially enhances the probability of performance resilience. The adoption of SC coordination enhances resilience. The use of big data and ML is not suitable for improving a firm's resilience. 	<ul style="list-style-type: none"> Firms that are seeking to improve their resilience performance can invest in the adoption of omnichannel strategies, AI, and mobile apps. These tools enhance the connection of companies with their customers besides improving their predictability and analytic capabilities. Moreover, SC coordination is an effective practice for recovering from disruptions in the shortest time. It is a great opportunity for firms to use the synergies among omnichannel strategies, SC coordination, AI, and mobile apps to re-establish their business volumes quickly. If the disruption is very serious with significant challenges (such as the pandemic), it would probably be difficult for the firms to make big data and machine learning beneficial.

5. Conclusions

5.1. Theoretical Implications

The intensity of responses to disruptions was closely linked to the performance resistance. Firms adopt ad hoc practices when their business continuity is jeopardized due to low resistance. Accordingly, this study analyzed business continuity in the context of resistance to the disruption caused by COVID-19. According to business continuity principles, firms can activate a range of practices and initiatives in response to disruption. Focusing on COVID-19 and its impact on businesses, we examined the following practices: omnichannel strategies, SC coordination, AI, mobile apps, and big data and machine learning. Among a variety of potential initiatives, these practices enable firms to adapt to ecosystem changes. This adaptability is driven by the predictive capabilities of AI and big data, the opportunity

to maintain customer proximity virtually through mobile apps and physically through omnichannel solutions, and the ability to negotiate contractual terms and agreements with suppliers and partners for alignment during disruptive events through SC coordination.

5.2. Practical and Managerial Implications

Our findings indicated that when business continuity is compromised due to a single specific performance indicator, firms can activate certain practices to ensure resilience. Conversely, when business continuity is hindered by multiple underperforming indicators, a combination of practices may be necessary for enhanced resilience. Specifically, managers should consider omnichannel initiatives when there is collective resistance to disruptions affecting quality, inventory, sales, and ROI. Likewise, the implementation of AI systems and big data and machine learning is advisable when specific risks occur simultaneously. For example, AI systems are beneficial when customer service, delivery time, SC visibility, and quality concurrently decline, while a low ROI might warrant the adoption of big data and ML. In contrast, SC coordination and mobile apps should be deployed even in response to a single performance risk, as these strategies are proven to be effective in mitigating the impact of disruptions. For instance, risks in areas such as quality, inventory, and sales call for SC coordination, whether these risks occur in isolation or together. Similarly, challenges in customer service, delivery time, SC visibility, and quality should lead firms to adopt mobile apps. Implementing these SC practices enables firms to bolster their resilience against performance resistance to disruptions, particularly during disruptive events, thereby minimizing adverse operational impacts.

5.3. Limitations and Future Research

Like all research papers, this study also has limitations, some of which are listed here to inspire future research paths. This research focused on five specific practices that firms can undertake when business continuity is jeopardized. However, future studies could explore other initiatives, such as supply chain integration, network restructuring, and complexity management. These practices could also be examined in the context of other types of disruptions, such as wars, raw material shortages, tsunamis, or new disruptive legislation. We concentrated on a concept of business continuity that involved seven performance indicators resistant to disruptions. Future research could expand this analysis by including other performance metrics such as flexibility, inventory turnover, inventory cost, time-to-market, responsiveness, and agility, as well as sustainability-based risks encompassing ethics, environmental factors, and politics. This study was based on a Bayesian Network and alternative techniques such as decision trees, neural networks, and other supervised and unsupervised machine learning methods could be employed to achieve the same research objectives. Finally, a follow-up study could analyze the same research hypotheses during the second wave of the pandemic, necessitating the use of dynamic probabilistic techniques such as dynamic Bayesian networks. This is an avenue of research that the author is currently exploring.

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Appendix A. Questionnaire

Appendix A.1. General Information

1. Indicate your company type (Respondents select an option):
 - Manufacturer, Wholesaler, Distributor, Supplier, Retailer, Others
2. Indicate the average number of employees in the last two years (Respondents select an option):
 - <50, 50–99, 100–200, >200
3. Indicate your average turnover (millions) in the last two years (Respondents enter a number).
4. Indicate the country in which your company has its headquarter (Respondents enter a text).
5. Indicate your corporate role (e.g., manager, managing director, etc.) (Respondents enter a text).
6. Indicate the sector in which your company works (Respondents enter a text)

Appendix A.2. Performance Robustness

During the period January–June 2020, in which percentage did your company experience a deterioration of performance due to COVID-19? (Respondents can answer by entering a number between 0 and 100%)

- Inventory availability, Customer service, ROI, Sales, Quality of products, On-time delivery, Efficiency, Supply Chain Visibility

Appendix A.3. Supply Chain Practices and Technologies

During the period January–June 2020, which actions have been adopted to properly respond to challenges due to COVID-19? (Respondents can answer by selecting between Yes or No)

- We adjusted the contract terms and clauses according to the pandemic situation (Supply Chain Coordination)
- We implemented omnichannel strategies (Omnichannel)
- We adopted the following digital technologies: Mobile Apps, Artificial Intelligence, Big Data and Machine Learning

How many months would you need to restore your company's business affairs and volumes lost due to COVID-19 during the period January–June 2020? (Respondents select an option)

- ☐ Less than 3 months
- ☐ Less than 6 months
- ☐ Less than 12 months
- ☐ More than 12 months

According to our analysis, 59 firms could recover in less than three months (49.58%), 55 firms could recover in less than six months (46.22%), four firms could recover in less than 12 months (3.36%), and one firm could recover in more than 12 months (0.84%). Since most of the firms were linked to two categories, we created a dummy variable capturing

resilient firms with the label “1”, which will be able to recover in less than three months and representing 49.58% of the sample, and non-resilient firms with the label “0”, which will be able to recover in more than three months and representing 50.42% of the sample.

Appendix B. ANOVA Table

Table A1. ANOVA on earlier and later respondents.

Variables	Earlier Responses' Mean	Later Responses' Mean	F-Test		t-Test	
			F-Value	p-Values	t-Value	p-Values
Inventory	0.486013	0.489	0.902	0.685	−0.151	0.880
Customer service	0.5344	0.593	1.611	0.092	−1.275	0.205
Sales	0.51373	0.543	1.400	0.233	−1.050	0.296
ROI	0.647593	0.683	1.047	0.885	−1.295	0.198
Quality	0.519604	0.540	1.131	0.671	−0.304	0.761
SC visibility	0.4932	0.459	0.803	0.465	1.454	0.104
Efficiency	0.52827	0.579	1.024	0.905	−0.393	0.695
Lead Time	0.878	0.855	1.559	0.100	0.590	0.556
Big Data and ML	0.416	0.391	1.533	0.114	1.351	0.201
AI	0.5893	0.527	0.841	0.567	1.486	0.140
Mobile apps	0.58507	0.520	1.192	0.508	0.381	0.704
Omni-channel	0.5322	0.435	1.087	0.412	1.198	0.233
SC Coordination	0.57427	0.536	1.002	0.584	0.672	0.503
Resilience	0.5047	0.48473	1.023	0.676	0.831	0.408

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