International Journal of Operations and Prod
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Journal:	*International Journal of Operations and Production Management*
Manuscript ID	IJOPM-12-2020-0901.R2
Manuscript Type:	Research Paper
Keywords:	Blockchain, Supply chain management, COVID-19, Event study, Abnormal stock returns, Contingency theory

The Mitigating Role of Blockchain-Enabled Supply Chains During the COVID-19 Pandemic

Abstract

Purpose: Although there have been considerable discussions on the business value of adopting blockchain in supply chains, it is unclear whether such blockchain-enabled supply chains (BESCs) can help firms mitigate the negative impact resulting from the recent COVID-19 pandemic. Our study aims to answer this important question.

Methodology: We conduct an event study to quantify the financial effects of the COVID-19 pandemic and compare the differences in such effects between treatment firms that have adopted BESCs and matched control firms that have not adopted BESCs. We also perform a regression analysis to examine how the role of BESCs in mitigating COVID-19's negative impact varies across firms with different levels of supply chain leanness and complexity. Our analysis is based on 88 treatment firms and 88 matched control firms, all of which are publicly listed on the US stock markets.

Findings: Our test results suggest that although both the treatment and control firms are negatively affected by the COVID-19 pandemic, the effect is less negative for the treatment firms compared to the control firms, demonstrating the role of BESCs in mitigating the negative impact caused by the COVID-19 pandemic. Moreover, the mitigating role of BESCs is more pronounced for firms with lean and complex supply chains.

Originality: This study is among the first to provide empirical evidence on the mitigating role of BESCs during the COVID-19 pandemic, highlighting the importance of adopting blockchain in supply chains with high uncertainties and disruption risks.

Keywords: blockchain; supply chain management; COVID-19; event study; abnormal stock returns; contingency theory

1. Introduction

The recent COVID-19 pandemic has led to unprecedented challenges for operations and supply chain management (OSCM) because of its global scale and unpredictable duration (Ivanov, 2020b; Queiroz *et al.*, 2020b). Unlike other disruption events such as the 2011 Great East Japan Earthquake and the 2013 Dhaka Rana Plaza disaster that mainly affected a specific country or region (Hendricks *et al.*, 2020; Jacobs and Singhal, 2017), COVID-19 has spread to almost all countries, forcing governments around the world to implement various measures including social distancing, travel bans, facility closures, and local lockdowns, thereby increasing the risk of global supply chain disruptions (Singh *et al.*, 2021). Moreover, while the 2011 Great East Japan Earthquake and the 2013 Dhaka Rana Plaza disaster largely impacted the nuclear and garment industries, respectively (Hendricks *et al.*, 2020; Jacobs and Singhal, 2017), various manufacturing and service industries have been severely affected by the COVID-19 pandemic (Queiroz *et al.*, 2020b). The fluctuations in COVID-19 cases across countries and over time have also led to continuous changes in government measures and policies, impeding the prediction of when the pandemic will end and inducing great uncertainties for managing internal operations and external supply chains (Gunessee and Subramanian, 2020). Under such circumstances, it becomes crucial for firms to have transparent and traceable supply chains to enable them to better identify and assess supply chain risks across countries and industries and to plan and take actions such as developing routes to alternative suppliers, ultimately mitigating the negative impact caused by the pandemic. Unfortunately, traditional supply chain management systems and practices often focus on firms' first-tier suppliers and "have little to no knowledge of suppliers further up to the chain" (Liao and Fan, 2020). Choi *et al.* (2020) also highlighted the inability of firms' existing tools and practices to map supply networks deep into sub-tier suppliers, making their response to the pandemic reactive and uncoordinated.

Nevertheless, blockchain, a distributed ledger technology, can enable firms to enhance the transparency and traceability of their supply chains (Bai and Sarkis, 2020; Guo *et al.*, 2020; Kouhizadeh *et al.*, 2021; Queiroz *et al.*, 2020a; Rahmanzadeh *et al.*, 2020), reducing the risk of supply chain disruptions, and thus, mitigating the negative impact arising from the COVID-19 pandemic. In particular, blockchain allows firms to record goods, materials, and other information effectively and securely as they flow through the supply chain networks, improving traceability beyond the first-tier suppliers. Moreover, with appropriate blockchain design, supply chain members can view and monitor the locations and movements of these goods, materials, and information and make more informed and coordinated decisions. As Renee Ure, Lenovo's Chief Operating Officer, summarized, "Through the use of blockchain, we are seeing operational efficiencies and improved transparency and traceability, creating a truly secure and trusted supply chain" (Henson and Rhodes, 2020). However, we should not overlook blockchain's possible drawbacks such as scalability and efficiency concerns in the case of heavily loaded networks and the costs and risks associated with substantial tangible and intangible resource investments (Walsh *et al.*, 2020; Zhou *et al.*, 2020) that may outweigh its potential benefits. Therefore, it is still unclear whether adopting blockchain in supply chains can help firms mitigate COVID-19's negative impact (Queiroz *et al.*, 2020b), an important question that our study aims to answer.

Even though we expect blockchain-enabled supply chains (BESCs) to mitigate the adverse effects of the COVID-19 pandemic, the importance of such a mitigating role may vary across firms as their supply chains may be affected by the pandemic differently. For example, lean supply chains that are highly utilized may be more vulnerable during the COVID-19 pandemic, as these supply chains bear fewer slack resources to buffer the uncertainties spawned by the pandemic (Ivanov, 2020a). Moreover, given COVID-19's global scale, firms with complex supply chains across different countries and industries may be more likely to experience disruptions in their supply chains, and thus, be more adversely affected by the pandemic (Ivanov and Dolgui, 2020). Therefore, the mitigating role of BESCs may be more valuable to lean and complex supply chains that are more vulnerable to the COVID-19 pandemic. Interestingly, adopting blockchain in these supply chains may be more challenging because of the efficiency and cost concerns (Walsh *et al.*, 2020; Zhou *et al.*, 2020). This paradox suggests that the interaction between BESCs and supply chain characteristics is not intuitive and requires further investigation. Taken together, our study aims to answer the following questions:

Q1. How do BESCs help firms mitigate the negative impact caused by the COVID-19 pandemic?

Q2. How does the mitigating role of BESCs vary across firms with different levels of supply chain leanness and complexity?

To answer these questions, we first follow prior COVID-19 studies (e.g., Maneenop and Kotcharin, 2020; Pandey and Kumari, 2021) by employing the event study methodology (Ding *et al.*, 2018) to quantify COVID-19's impact on firms in terms of abnormal stock returns. We then compare the difference in abnormal stock returns between firms with and without BESCs to reveal BESCs' possible mitigating role. With the abnormal stock returns obtained from the event study as the dependent variable, we construct a cross-sectional regression model to further analyze whether the mitigating role of BESCs is dependent on supply chain leanness and complexity. Our analysis is based on 88 treatment firms with BESCs identified from the Factiva database (Lam *et al.*, 2019) and 88 matched control firms without BESCs selected via propensity score matching (PSM; Rosenbaum and Rubin, 1983). All these firms are publicly listed on the US stock markets.

Consistent with prior COVID-19 studies (e.g., Maneenop and Kotcharin, 2020; Pandey and Kumari, 2021), our event study results confirm that the COVID-19 pandemic has a significant negative impact on firms as reflected in decreased abnormal stock returns. However, we find that the decreases in abnormal stock returns are smaller for treatment firms with BESCs compared to the matched control firms without BESCs, demonstrating the role of BESCs in mitigating the negative impact caused by the COVID-19 pandemic. Moreover, our regression results reveal that the mitigating role of BESCs is more pronounced for firms with lean and complex supply chains. This finding suggests that the business value of BESCs is contingent on supply chain characteristics.

Our study makes several important contributions. First, unlike prior studies that have focused on the impact of the COVID-19 pandemic (Maneenop and Kotcharin, 2020; Pandey and Kumari, 2021), our work represents the first empirical investigation of the role that BESCs play in mitigating COVID-19's negative impact. This investigation contributes to the current debate on the business value of BESCs (Cole *et al.*, 2019; Saberi *et al.*, 2019; Schmidt and Wagner, 2019) by highlighting the importance of adopting blockchain in supply chains with high uncertainties and disruption risks. This finding may inspire researchers to further explore the role of BESCs in other contexts beyond the COVID-19 pandemic. Moreover, our study reveals not only whether but also when BESCs mitigate COVID-19's negative impact considering a firm's supply chain leanness and complexity. Thus, our work not only encourages firms to invest in BESCs but also enables them to take account of the leanness and complexity of their supply chains when assessing the urgency of such investments. Finally, our study employs contingency theory to theorize how the business value of blockchain is contingent on the interactions between external environments and supply chain characteristics, which can serve as a useful theoretical foundation for future research.

2. Literature Review and Hypothesis Development

2.1 COVID-19 and Supply Chain Disruptions

The recent COVID-19 crisis has fueled the most far-reaching and devastating supply chain disruptions, comprising interruptions to both physical and financial resources throughout firms' entire supply chain ecosystems (El Baz and Ruel, 2021; Ketchen and Craighead, 2020;

Remko, 2020; Sozzi, 2020). First, employee health concerns and various intervention policies restrict suppliers' ability to fulfill customer orders and provide essential raw materials because of labor shortages, production shutdowns, and reduced delivery capacities (Singh *et al.*, 2021). For example, General Motors had to cut production because of raw material shortages that arose as a direct result of closures by mass suppliers during the COVID-19 pandemic (Eisenstein, 2020). This is also exemplified by a recent *Fortune* report showing that 94% of *Fortune* 1,000 companies had experienced physical resource disruptions in their supply chains caused by the COVID-19 outbreak (Queiroz *et al.*, 2020b). Moreover, decreased cash flows and increased bankruptcy rates among customer companies hamper their ability to promptly pay suppliers (Gerdeman, 2020; Sozzi, 2020). For example, McKinsey (2020) estimated that the revenues of global companies fell by approximately 30% on average because of the COVID-19 crisis. A survey conducted by another consulting firm, Crowe, also indicated that 72% of executives foresee a moderate or severe downturn in profits due to the COVID-19 outbreak (PR Newswire, 2020). The resulting economic recession generated additional bankruptcies and severe difficulties for firms to meet their financial obligations (World Bank, 2020). Consequently, many operations costs, such as rents and raw material purchases, remain unpaid because the cash flows destined to meet these financial obligations vanished (OECD, 2020). This increasingly deteriorating situation leads to significant financial resource disruptions along entire supply chains.

OSCM researchers have adopted various methodologies, such as qualitative case studies, structured literature reviews, and simulation-based analyses, to examine COVID-19's effects on supply chains (Gunessee and Subramanian, 2020; Ivanov, 2020a; Queiroz *et al.*, 2020b). For instance, Ivanov (2020a) performed a simulation-based analysis to predict the impact of the COVID-19 outbreak on global supply chains, while Queiroz *et al.* (2020b) conducted a systematic review of relevant literature to propose a framework for future research to analyze COVID-19's effects. Researchers from other disciplines such as Economics and Finance have employed the event study methodology to quantify COVID-19's financial impact (Maneenop and Kotcharin, 2020; Pandey and Kumari, 2021). This methodology evaluates the financial impact in terms of abnormal stock returns, which take account of the overall stock market movements and provide a more accurate estimation of an event's impact (further explained in Section 3). For example, Maneenop and Kotcharin's (2020) event study showed that airline companies worldwide experienced significant decreases in abnormal stock returns due to the COVID-19 crisis, especially after the World Health Organization (WHO) declared COVID-19 a global pandemic. The event study methodology has also been widely used by

OSCM researchers to study other disruption events beyond the COVID-19 outbreak, such as environmental violations and natural disasters (Hendricks *et al.*, 2020; Xiong *et al.*, 2021). Following these studies, we rely on the event study methodology to quantify COVID-19's impact in terms of abnormal stock returns, which enables us to further analyze how such abnormal stock returns differ for firms with and without BESCs.

OSCM researchers have not only analyzed COVID-19's impacts but also developed various models and solutions for firms to mitigate such impacts (Govindan *et al.*, 2020; Ivanov, 2020b; Ivanov and Dolgui, 2020; Queiroz *et al.*, 2020b). For example, Govindan *et al.* (2020) integrated physicians' knowledge and fuzzy inference system to develop a practical tool to support demand management in healthcare supply chains when facing the COVID-19 outbreak, while Paul and Chowdhury (2020) employed a mathematical modeling approach to develop a production recovery model for high-demand and essential items during the COVID-19 pandemic. Ivanov and colleagues (e.g., Ivanov, 2020b; Ivanov and Dolgui, 2020) proposed a viable supply chain model to help guide firms' decisions about rebuilding their supply chains in the post-COVID-19 recovery. Nevertheless, there is still little empirical evidence on the role of BESCs in mitigating COVID-19's negative impact, although Queiroz *et al.* (2020b) encouraged researchers to explore how cutting-edge technologies such as blockchain and artificial intelligence can help firms improve their response to the COVID-19 crisis.

2.2 Blockchain-Enabled Supply Chains

Blockchain is an emerging technology that "enables parties to conduct business transparently and maintain a distributed, immutable, and tamper-proof digital ledger of transactions without a central authority" (Kumar *et al.*, 2020, p. 9). Researchers and practitioners have generally agreed that blockchain can help enhance supply chain transparency and traceability (Guo *et al.*, 2020; Schmidt and Wagner, 2019; Sunny *et al.*, 2020; Wamba *et al.*, 2020a). Supply chain transparency and traceability are interconnected but have divergent connotations. Transparency focuses on the availability of sufficient and relevant data within supply chain networks, whereas traceability emphasizes real-time data tracking of supply chain activities (Guo *et al.*, 2020; Hastig and Sodhi, 2020; Kumar *et al.*, 2020; Sunny *et al.*, 2020). Blockchain helps improve supply chain transparency by disclosing all authentic transactional data within the supply chain networks, including raw material origins, purchase orders, inventory levels, goods received, shipments, and invoices (Cole *et al.*, 2019; Sander *et al.*, 2018). For example, Sonoco, the largest provider of temperature assurance packaging for pharmaceutical distribution, enhances the transparency of its supply chain by implementing blockchain to record information on a package's entire journey, integrate these data with those from other business sources, and make them accessible to its supply chain partners (Nasdaq, 2020). Supply chain traceability can be improved by adopting blockchain to enable firms to instantaneously and effectively monitor all the updated and reliable transactional data flows generated within supply chain networks (Sander *et al.*, 2018; Sunny *et al.*, 2020). This is exemplified by some e-commerce companies such as Alibaba and JD.com that rely on blockchain to achieve real-time product tracking in their e-commerce activities (Megget, 2018).

Researchers have begun to examine both the determinants and consequences of adopting blockchain in supply chains (Bai and Sarkis, 2020; Cole *et al.*, 2019; Dolgui *et al.*, 2020; Kouhizadeh *et al.*, 2021; Martinez *et al.*, 2019; Queiroz *et al.*, 2019; 2020a; Rahmanzadeh *et al.*, 2020; Saberi *et al.*, 2019; Schmidt and Wagner, 2019; Walsh *et al.*, 2020; Wamba and Queiroz, 2020a; 2020b; Zhou *et al.*, 2020). For instance, Queiroz *et al.* (2020a) demonstrated that in the context of an emerging economy, facilitating conditions, trust, social influence, and effort expectancy are the most critical enablers of adopting blockchain in supply chains, while Kouhizadeh *et al.* (2021) applied the DEMATEL tool to reveal the most important supply chain and technological barriers that prevent blockchain adoption. Wamba and Queiroz (2020b) further proposed a multi-stage model of blockchain adoption (i.e., the intention, adoption, and routinization stages) and demonstrated the variation in the adoption enablers and barriers across different stages and countries.

Regarding the consequences of blockchain adoption, researchers have explored both the potential benefits and drawbacks. For example, previous studies have discussed how BESCs can contribute to various performance indicators at the firm and supply chain levels, such as product safety, process efficiency, ordering time, inventory and transaction costs, speed of new product development, supply chain relationships, and supply chain sustainability (Cole *et al.*, 2019; Dolgui *et al.*, 2020; Martinez *et al.*, 2019; Queiroz *et al.*, 2019; Rahmanzadeh *et al.*, 2020; Saberi *et al.*, 2019; Schmidt and Wagner, 2019; Wamba and Queiroz, 2020b). By contrast, other studies have highlighted the potential drawbacks or disadvantages of adopting blockchain, such as scalability issues because of limited capacity to handle large amounts of transaction data in a short period, sustainability downside due to high energy consumption, increased risks as a result of substantial resource investments, and challenges of convincing and incentivizing supply chain members to join the blockchain consortia or networks (Bai and Sarkis, 2020; Kouhizadeh *et al.*, 2021; Walsh *et al.*, 2020; Zhou *et al.*, 2020). However, most prior studies have focused on blockchain's direct performance implications rather than its possible role in moderating performance outcomes. Our research adopts a different approach.

Specifically, we investigate the role that BESCs play in mitigating the negative impact caused by the COVID-19 pandemic. We employ contingency theory to develop relevant hypotheses concerning this mitigating role.

2.3 The Role of BESCs in Mitigating COVID-19's Negative Impact

The benefits and drawbacks of adopting blockchain as discussed in the literature suggest that blockchain adoption is not a one-size-fits-all solution and its value may depend on the specific adoption contexts. Thus, we use contingency theory as our theoretical lens to comprehend the contingent value of adopting blockchain in supply chains. Contingency theory rejects the one-size-fits-all assumption and emphasizes the importance of aligning firms' strategies and practices with external environments and contexts to achieve superior performance (Sousa and Voss, 2008; Wong *et al.*, 2011). This theory has been widely used by OSCM researchers to study firms' adoption of new technologies (Lam *et al.*, 2019; Sousa and Voss, 2008; Wang *et al.*, 2020). For instance, based on contingency theory, Lam *et al.* (2019) theorized that the extent to which firms' 3D printing strategies can create a competitive advantage is contingent on the firms' operating environments in terms of industry munificence, dynamism, and competition, while Wang *et al.* (2020) argued that whether firms can benefit from their social media analytics practices is subject to the characteristics of the firms' external stakeholders, including business partners, competitors, and customers. These studies underline the merit of employing contingency theory to provide a more comprehensive view of BESCs' business value. We rely on contingency theory understand not only how COVID-19's impact varies across firms depending on whether they have adopted blockchain in supply chains but also how the mitigating role of such blockchain adoption is contingent on their supply chain characteristics such as supply chain leanness and complexity.

We first consider the possible alignment or fit between BESCs and the COVID-19 context that may lead to a less negative impact of COVID-19 for firms with BESCs. Although the enhanced transparency and traceability in BESCs *per se* may not always be beneficial because of, for example, the possible transparency paradox and privacy concerns (Bai and Sarkis, 2020; Kouhizadeh *et al.*, 2021), such enhancements become particularly important in the COVID-19 context as they enable firms to better address the supply chain disruption risks caused by the COVID-19 crisis. From the contingency perspective, the extent to which blockchain-enhanced transparency and traceability are valuable may be contingent on the external environments that exhibit different needs for such enhancements in transparency and traceability. In particular, COVID-19's global scale and unpredictable duration create huge uncertainties in supply chain management and increase the risk of supply chain disruptions, which, in turn, exhibit a greater need for more transparent and traceable supply chains that enable firms to better manage uncertainties and mitigate risks. Consequently, BESCs are expected to play a critical role under such circumstances. For instance, firms with BESCs can identify potential disruptions in supply chains more quickly by tracing real-time transactional data such as orders and inventory among supply chain partners (Hastig and Sodhi, 2020). When raw material shortages or distribution channel disruptions occur, firms with BESCs can also seek alternative available suppliers more quickly, based on the transactional data shared and stored in the blockchain (Kamble *et al.*, 2020). Thus, firms with BESCs are equipped with a faster reaction speed and have a higher possibility of reducing both the likelihood and severity of supply chain disruptions during the pandemic.

Moreover, some blockchain technologies such as smart contracts automatically track the chain of custody as materials flow through the supply chains and forcefully implement payments upon the fulfillment of predefined terms and agreements (Zheng *et al.*, 2020). This can warrant timely payments and avoid contract breaches, ensuring fairness and trustworthiness among supply chain members and leading to better supply chain relationships (Cole *et al.*, 2019; Schmidt and Wagner, 2019). This, in turn, enables these supply chain members to work collaboratively to address the challenges engendered by the COVID-19 outbreak rather than to engage in opportunistic behaviors such as product hoarding or panic buying. The collaborative and trusting approach should reduce both the probability of supply chain disruptions and the impact of such disruptions once they have occurred in supply chains. Taken together, although the COVID-19 crisis increases the risks of supply chain disruptions for all firms concerned, the resultant risks should be lower in more transparent and traceable supply chains enabled by blockchain. As prior studies have suggested that the negative financial impact of supply chain disruptions in general and the COVID-19 pandemic in particular can be quantified in terms of abnormal stock returns (Hendricks *et al.*, 2009; Maneenop and Kotcharin, 2020; Pandey and Kumari, 2021), we expect abnormal stock returns to be less negative for firms with BESCs because of COVID-19's lower impact on these supply chains, as discussed above. Hence, we propose the following hypothesis:

Hypothesis 1 (H1). The impact of the COVID-19 pandemic in terms of abnormal stock returns is less negative for firms with BESCs.

We then consider the role of supply chain characteristics. Following the contingency logic, although BESCs are expected to mitigate COVID-19's negative impact, the importance of such a mitigating role may be contingent on specific supply chain contexts such as supply chain leanness and complexity. This is because firms with different supply chains may be affected by COVID-19 differently, leading to varying needs to rely on BESCs to mitigate the resultant effects. In particular, lean and complex supply chains may be more vulnerable to COVID-19-induced disruptions (Ivanov, 2020a; Ivanov and Dolgui, 2020), entailing a greater need to adopt blockchain in these supply chains. Thus, the contingency lens enables us to reveal the possible interplay among blockchain, COVID-19, and supply chain characteristics in terms of supply chain leanness and complexity.

Supply chain leanness is concerned with the efficient use of resources through the elimination of all forms of waste, including various inventories and non-value-added activities, in a supply chain (Narasimhan *et al.*, 2006). The extant literature has documented benefits, such as reduced costs and lead time, enhanced operational efficiency, and improved quality management, gained from maintaining a lean supply chain (Tortorella *et al.*, 2017; Wee and Wu, 2009). Dell Computer's extremely lean supply chain, as indicated by its negative cash-to-cash cycle, has often been viewed as a critical success factor for the company (Hendricks *et al.*, 2009). However, previous studies have also highlighted the risk of running a lean supply chain in which slack resources and buffer inventories are limited (Hendricks *et al.*, 2009; Kovach *et al.*, 2015). For instance, Kovach *et al.* (2015) illustrated that firms with lean supply chains are associated with lower performance in unstable environments, while Hendricks *et al.* (2009) further suggested that supply chain disruptions affect firms with lean supply chains more adversely. Therefore, firms with lean supply chains should be more negatively affected by the COVID-19 outbreak that has increased supply chain disruption risks. As we have argued that BESCs enable firms to mitigate COVID-19's negative impact, we expect this mitigating role to be more important for firms with lean supply chains. In particular, given the limited slacks and buffers, it becomes more crucial for firms to make the finished goods, raw materials, and other inventories and resources in lean supply chains visible and traceable, which can be achieved by adopting blockchain in these supply chains. By contrast, for firms with sufficient resources and slacks in supply chains (i.e., a low level of supply chain leanness) to buffer the uncertainty and disruption risk caused by COVID-19, the urgency of adopting blockchain in these supply chains becomes lower and the mitigating role of BESCs is less significant. Overall, we expect the mitigating role of BESCs to be more pronounced for firms with a high (rather than low) level of supply chain leanness and propose the following hypothesis:

Hypothesis 2 (H2). Supply chain leanness positively moderates the relationship between BESCs and abnormal stock returns during the COVID-19 pandemic such that *the relationship is more positive for firms with lean supply chains.*

Supply chain complexity denotes the structural variety related to internal or external causes concerning material and information flows along a supply chain (Kavilal *et al.*, 2017). Major supply chain complexity drivers include a diverse array of downstream and upstream supply chain partners (Bozarth *et al.*, 2009; Choi and Krause, 2006). Previous studies have acknowledged the risks, including higher possibility and frequency of supply chain disruptions, in complex supply chains (Bode and Wagerl, 2015; Bozarth *et al.*, 2009). Specifically, it is more likely for firms to experience disruptions in complex supply chains with a large number of supply chain members across different countries. A high level of supply chain complexity also implies more difficulty and uncertainty for a focal firm to monitor and coordinate activities associated with diverse supply chain partners, thereby impairing its ability to proactively identify and address supply chain disruptions. The situation has become even worse in the case of COVID-19, which is a global pandemic affecting almost all countries around the world and leading to various measures such as quarantines, lockdowns, and travel restrictions (Gerdeman, 2020; Ketchen and Craighead, 2020; Sozzi, 2020). Therefore, firms with complex supply chains should face a higher risk of supply chain disruptions during the COVID-19 pandemic, entailing a greater need to adopt blockchain to improve supply chain transparency and traceability and mitigate COVID-19's negative impact. By contrast, firms having simple supply chains with a smaller number of supply chain partners and across fewer countries can trace and monitor the activities in their supply chains more easily, reducing the need to rely on blockchain to accomplish these tasks. This argument is aligned with some recent calls for reshoring and simplifying supply chains to better address the risks of supply chain disruptions arising from the COVID-19 pandemic (Burrows, 2020; Fan *et al.*, 2020). Overall, we expect BESCs to be more helpful for firms with complex (rather than simple) supply chains during the COVID-19 pandemic and propose the following hypothesis:

Hypothesis 3 (H3). Supply chain complexity positively moderates the relationship between BESCs and abnormal stock returns during the COVID-19 pandemic such that the relationship is more positive for firms with complex supply chains.

3. Research Methods

We used the following steps to test the proposed hypotheses. First, we identified firms with BESCs by searching for relevant announcements via Factiva, a database aggregating news and information articles from more than 32,000 sources (Ding *et al.*, 2018). However, firms should not adopt blockchain in supply chains by chance, leading to a possible self-selection bias. We addressed this endogeneity concern by using PSM (Rosenbaum and Rubin, 1983) to match each treatment firm (i.e., a firm adopting blockchain in supply chains) with a control firm that had a similar propensity as the treatment firm to adopt blockchain in supply chains but did not adopt it eventually. After identifying treatment firms and matched control firms, we applied the event study methodology (Ding *et al.*, 2018) to quantify the impact of the COVID-19 pandemic on these firms in terms of abnormal stock returns. Finally, with the abnormal stock returns obtained from the event study as the dependent variable, we conducted a regression analysis to examine the role of BESCs in mitigating the negative impact of the COVID-19 pandemic (H1) and whether BESCs' mitigating role is more pronounced for firms with lean (H2) and complex (H3) supply chains. These steps are summarized in Figure 1 and further explained in the following sub-sections.

--- Figure 1 about here ---

3.1 Sample Firms

Consistent with prior studies focusing on technology adoption (e.g., Lam *et al.*, 2019; Lui *et al.*, 2016), we searched the Factiva database to identify firms that have adopted blockchain in supply chains. Our search included blockchain-related keywords such as blockchain, block chain, distributed ledger, and cryptography, as well as supply chain-related keywords such as supply chain*, supplier*, customer*, retail*, manufactur*, distribut*, and transport*, where * indicates words with multiple endings of any length. We also added stock market-related keywords including NYSE and Nasdaq to our search because we limited our search to public firms listed on the US stock markets for several reasons. First, we focused on public firms because of the availability of their stock price data to calculate abnormal stock returns. Moreover, as COVID-19's impact might vary across countries and over time, focusing on a single country (i.e., the US) allowed us to provide a more consistent and reliable analysis. The stock markets in the US are also more efficient than those in developing countries (Lim, 2007), enabling more accurate estimation of COVID-19's financial impact. Finally, the dominance of US firms in the blockchain market (GVR, 2020) enabled an easier identification of a representative sample of adopting firms for this study.

We also limited our search to a three-year period from 2017 to 2019 for several reasons. First, including firms' BESC announcements in the same year as the COVID-19 pandemic (i.e., 2020) would lead to possible confounding effects (Ding *et al.*, 2018), impeding the distinction between abnormal stock returns caused by the COVID-19 pandemic and that resulting from firms' BESC announcements over the same period. Therefore, to avoid confusion, including firms' BESC announcements before the COVID-19 pandemic (i.e., before 2020) should be more appropriate. Moreover, as BESC has been a comparatively new phenomenon, we focused on the past three years (i.e., 2017–2019) to cover the latest applications of blockchain in supply chains and to render the identified BESC announcements more relevant to firms' current practices. We also searched Factiva to identify firms' BESC announcements before 2017 and found that those announcements only account for about 5% of the announcements during the 2017–2019 period, supporting our decision to focus on 2017–2019.

We read the full text of all searched articles obtained from Factiva and excluded those not related to firms' adoption of blockchain in supply chains, such as the appointments of blockchain executives and the provision of services by blockchain vendors. After eliminating unrelated announcements, we identified 101 US public firms that had adopted blockchain in supply chains during 2017–2019. The firm characteristics and industry distributions of these 101 firms are presented in Table 1.

--- Table 1 about here ---

After identifying firms with BESCs (i.e., treatment firms), we employed PSM to select firms without BESCs (i.e., control firms) but with similar propensities as the treatment firms to adopt blockchain in supply chains. This matching process helps ensure the similarity between the treatment and control firms and reduces the possible self-selection bias (Fan *et al.*, 2021; Rosenbaum and Rubin, 1983). To implement PSM, we first constructed a binary logistic regression model with the dummy dependent variable indicating whether a firm adopted BESC (coded 1) or not (coded 0) in 2017–2019. The independent variables were a set of pre-event firm characteristics, including R&D intensity, firm size, firm profitability, firm debt, labor productivity, inventory turnover, stock price sensitivity, and stock price volatility, which may be related to firms' decisions to adopt blockchain in supply chains. We included R&D intensity, firm size, firm profitability, and firm debt because firms with higher R&D intensity, larger size, higher profitability, and lower debt may have better technological capabilities and more financial resources to support their BESC adoption. We used labor productivity and inventory turnover to capture a firm's operational efficiency, which may determine the extent to which it has to rely on emerging technologies such as blockchain for efficiency improvement. We added stock market factors, including stock price sensitivity and volatility, to represent the variability of a firm's stock price reaction driven by new information such as new BESC announcements, which may also affect the firm's intention to adopt blockchain in supply chains. Using relevant accounting and financial data obtained from the Compustat database, we measured R&D

intensity as R&D expenses divided by total sales (Yiu *et al.*, 2020), firm size as the logarithmic transformation of total sales (Lam, 2018), firm profitability as gross profit divided by total sales (Delen *et al.*, 2013), firm debt as total liabilities divided by total assets (Aivazian *et al.*, 2005), labor productivity as operating income divided by the number of employees (Lui *et al.*, 2016), inventory turnover as the cost of goods sold divided by average inventory (Yiu *et al.*, 2020), stock price sensitivity as the beta coefficient obtained by regressing a firm's daily stock returns on the daily market returns over one year before BESC adoption (Lam, 2018), and stock price volatility as the standard deviation of a firm's daily stock returns over one year before BESC adoption (Schwert, 1989). We also included industry dummies based on two-digit SIC codes to control for industry heterogeneity.

The logistic regression model was run for a sample of 905 firms, consisting of 101 treatment firms obtained from Factiva, as discussed above, and 804 potential control firms obtained from Compustat with the same SIC codes as the treatment firms. The regression results presented in Table 2 (Model 1) suggest that firms with high R&D intensity, large size, low debt, and low stock price sensitivity are more likely to adopt blockchain in supply chains. After running the logistic regression model, we obtained the predicted probabilities or propensity scores for all the 905 firms. We then applied the one-to-one nearest neighbor matching approach to match each treatment firm with a control firm having a propensity score closest to the treatment firm. We also added a criterion that the absolute distance in the propensity score between a treatment firm and its matched control firm should be less than 0.1 (i.e., the caliper distance < 0.1) to ensure matching quality (Fan *et al.*, 2021). Thus, we dropped 13 pairs of matched treatment and control firms that could not meet this criterion. Consequently, 88 out of the 101 treatment firms had been matched successfully, suggesting that the sample size for this research was 176, including 88 treatment firms and 88 matched control firms. To check the quality of the matching process, we ran the same logistic regression model based on these 176 sample firms. The regression results presented in Model 2 of Table 2 indicate that none of the independent variables are significant ($p > 0.1$), confirming the similarity between the treatment and matched control firms and demonstrating the matching quality. We also searched Factiva but could not find any of the 88 matched control firms with BESCs in 2017–2019, showing a clear distinction between the treatment and matched control firms in terms of adopting blockchain in supply chains.

--- Table 2 about here ---

3.2 Event Study

The event study methodology has been widely used by OSCM researchers to investigate various events such as supply chain disruptions, environmental violations, and natural disasters (Hendricks *et al.*, 2009; 2020; Xiong *et al.*, 2021). More recently, researchers have employed this methodology to quantify the impact of COVID-19 on firms' stock returns (Maneenop and Kotcharin, 2020; Pandey and Kumari, 2021). This methodology provides a more rigorous estimation of an event's impact because it considers the expected stock returns had there been no such event. For example, in our research context, COVID-19's impact can be quantified as abnormal stock returns, which are the difference between firms' actual stock returns during the COVID-19 pandemic and the expected stock returns of the same firms based on the assumption that these firms were not exposed to the COVID-19 pandemic, as depicted in Equation (1).

$$AR_{it} = R_{it} - E(R_{it}), \quad (1)$$

where AR_{it}, R_{it}, and $E(R_{it})$ represent the abnormal stock return, actual stock return, and expected stock return, respectively, of firm *i* on day *t*. $E(R_{it})$ can be estimated based on stock prices over an estimation period before the COVID-19 pandemic. Consistent with recent COVID-19 event studies (e.g., Pandey and Kumari, 2021), we selected 30 January 2020 as the event day because the WHO officially declared the COVID-19 outbreak a global pandemic on 30 January 2020 (WHO, 2020). Consequently, we selected the estimation period as 210 days ending 11 days before the event day (i.e., 30 January 2020). We separated the estimation period from the event period to avoid the influence of the event on the estimation of expected stock returns (Ding *et al.*, 2018). We adopted Fama–French–Carhart's four-factor model (Ding *et al.*, 2018) to provide a more accurate estimation of the expected stock returns because this model considers not only the overall stock market movements but also three additional factors related to market capitalization, book-to-market ratio, and return momentum.

The cumulative abnormal stock returns (CARs) over an event window around the event day are commonly calculated in an event study to better capture the full impact of the event (Ding *et al.*, 2018). In our research context, we used a 68-day event window ranging from 7 days before the event day ($t = -7$) to 60 days following the event day ($t = +60$). We included seven days before the event day to account for possible information leakages before the official WHO announcement. This also covered 23 January 2020 when the WHO Emergency Committee convened to evaluate the extent of the COVID-19 outbreak (WHO, 2020). The event window was closed 60 days after the event day to allow the stock markets to take time to assess the overall impact of the COVID-19 pandemic (Ding *et al.*, 2018). Mathematically, the CAR of firm *i* over the 68-day event window (−7, +60) is formulated below:

$$CAR_i = \sum_{t=-7}^{t=+60} AR_{it} \quad (2)$$

3.3 Cross-Sectional Regression Model

Although the event study methodology helps quantify COVID-19's overall impact, it fails to identify factors that explain how the impact varies across firms (Ding *et al.*, 2018). To test our proposed hypotheses, we constructed a cross-sectional regression model to further analyze how the hypothesized variables and their interactions may explain the variation in COVID-19's impact across firms. Such a regression analysis also enables us to control for the effects of factors other than the hypothesized variables. Specifically, the regression model uses the CAR from the event study as the dependent variable, while the independent variables include the hypothesized variables and other control variables, as shown in Equation (3).

$$\begin{aligned} CAR_i &= \beta_0 + \beta_1 BESCs_i + \beta_2 BESCs_i \times Supply\ Chain\ Leanness_i \\ &+ \beta_3 BESCs_i \times Supply\ chain\ Complexity_i + \beta_4 Frim\ Size_i + \beta_5 Firm\ Debt_i \\ &+ \beta_6 Firm\ Profitability_i + \beta_7 Earnings\ Per\ Share_i + \beta_8 Frim\ Liquidity_i + \beta_9 Tobin's\ Q_i \\ &+ \beta_{10} Supply\ Chain\ Leanness_i + \beta_{11} Supply\ Chain\ Complexity_i + Industry\ Dummies + \varepsilon_i, \end{aligned} \quad (3)$$

where BESCs was measured based on 2017–2019 data while other independent variables were measured based on 2019 data.

CAR. The dependent variable was the CARs of sample firms over the event window (−7, +60), as obtained from the event study.

BESCs. Sample firms included in the regression model consisted of treatment firms that adopted blockchain in supply chains and matched control firms without such adoptions. We coded the treatment firms as 1 and the matched control firms as 0 for this variable.

Supply Chain Leanness. Consistent with prior supply chain research (e.g., Hendricks *et al.*, 2009; Kovach *et al.*, 2015), instead of focusing on a specific type of waste, we view supply chain leanness as the overall efficiency or utilization of a firm's supply chain activities "across inbound material activities with suppliers, through manufacturing operations, and the outbound logistics and sales activities with customers" (Farris II and Hutchison, 2002, p. 292). Such an efficiency or utilization can be captured by a firm's cash-to-cash cycle as it includes the firm's physical inventory, accounts payable to suppliers, and accounts receivable from customers. Specifically, the cash-to-cash cycle is the sum of days of inventory and days of accounts receivable minus the days of accounts payable. As Hendricks *et al.* (2009) pointed out, "all else equal, a leaner supply chain will have a lower cash-to-cash cycle" (p. 238). As a shorter cash-to-cash cycle indicates a leaner supply chain, we reverse-coded the cash-to-cash cycle to ease the interpretation of the test results. The data used for calculating the cash-to-cash cycle were obtained from Compustat. We also measured supply chain leanness alternatively with a focus on inventory waste or slack in a firm's supply chain and obtained consistent test results.

Supply Chain Complexity. We measured a firm's supply chain complexity as the total number of suppliers and customers in its supply chain because the involvement of a large number of supply chain partners reflects a more complex supply chain (Bozarth *et al.*, 2009). We identified a firm's suppliers and customers from the Bloomberg SPLC database, covering the buyer–supplier relationships of about 35,000 firms across different countries (Xiong *et al.*, 2021). We also applied a logarithmic transformation to compute an alternative measure and obtained consistent test results.

Control Variables. We controlled for several firm-level variables, including firm size, firm debt, firm profitability, earnings per share, firm liquidity, and Tobin's Q in the regression model, as they might be related to a firm's stock returns in the COVID-19 context. Specifically, given the unprecedented disruptions caused by the COVID-19 pandemic across countries and industries, larger firms, firms relying more on debt financing, more profitable firms, and firms with higher earnings might be more difficult to maintain their existing positions and thus, have more to lose. By contrast, more valuable firms with high Tobin's Q and high-liquidity firms with better abilities to meet short-term obligations may be more resilient during the COVID-19 pandemic. We measured firm size as the logarithmic transformation of total sales (Lam, 2018), firm debt as total liabilities divided by total assets (Aivazian *et al.*, 2005), firm profitability as gross profit divided by total sales (Delen *et al.*, 2013), earnings per share as the difference between net income and preferred stock dividends divided by the number of common shares outstanding (York and Miree, 2004), firm liquidity as current assets divided by current liabilities (Lam, 2018), and Tobin's Q as market value divided by the book value of total assets (Lo and Yeung, 2018). We also included industry dummies (two-digit SIC codes) to control for industry-specific effects.

For hypothesis testing, the role of BESCs in mitigating the negative effect of the COVID-19 pandemic (H1) is determined by β_1, while β_2 and β_3 indicate how the mitigating role of BESCs varies across firms with different levels of supply chain leanness (H2) and complexity (H3), respectively.

4. Test Results

4.1 Event Study Results

The event study results are presented in Table 3. Panel A shows the average CARs over the event window (−7, +60) for all the 176 sample firms as well as the 88 treatment firms and the

88 matched control firms separately. The average CAR for all the sample firms is −6.26%, which is statistically significant at the 5% level, suggesting that COVID-19 had an overall negative impact on all the sample firms concerned. However, results differ when the treatment firms are separated from the matched control firms. Although the average CAR for the treatment firms is still negative (−1.73%), it is not statistically significant ($p > 0.1$). By contrast, the average CAR for the matched control firms is even more negative (−10.78%) and significant ($p < 0.01$) than that evidenced in the full sample, indicating COVID-19's severer impact on firms without (rather than with) BESCs.

--- Table 3 about here ---

Panel B of Table 3 compares the difference in average CARs between the treatment and matched control firms and demonstrates that the average CAR of the treatment firms is 9.05% higher than that of the matched control firms. Such a difference is statistically significant at the 1% level based on the paired sample *t*-test. Therefore, the impact of the COVID-19 pandemic is less negative for firms with (rather than without) BESCs, providing initial support for H1. We then examine the cross-sectional regression results to check whether this conclusion holds when various firm-level variables are controlled.

4.2 Cross-Sectional Regression Results

The descriptive statistics, including means and standard deviations, and the correlations of all variables in Equation (3) are shown in Table 4. Table 5 presents the regression results with the CAR over the event window (−7, +60) as the dependent variable. Model 1 includes all the control variables and industry dummies. The main effect of BESCs is added in Model 2. The interactions between BESCs and supply chain leanness as well as supply chain complexity are included in Models 3 and 4, sequentially. All four models are significant based on *F*-tests ($p < 0.05$), with adjusted R-squared values ranging from 0.07 to 0.12. We also checked for possible multicollinearity by computing the variance inflation factor (VIF) values for all independent variables. The maximum VIF value is 2.54, far less than the threshold of 10 (Xiong *et al.*, 2021), suggesting that multicollinearity is not a major concern in our research.

--- Tables 4 and 5 about here ---

As shown in Table 5, the magnitude and significance of all variables remain consistent across the different models. Thus, we rely on the full model (Model 4) to interpret the hypothesis testing results. First, the coefficient of BESCs is positive and significant ($p < 0.05$) in Model 2 and remains significant ($p < 0.05$) when the interaction terms are added in Models 3 and 4. This suggests that the impact of the COVID-19 pandemic is less negative (or more positive) for firms with BESCs, supporting H1. Model 4 also shows a positive and significant interaction between BESCs and supply chain leanness ($p < 0.05$), implying that supply chain leanness positively moderates the relationship between BESCs and abnormal stock returns. Thus, H2 is supported. Similarly, the interaction between BESCs and supply chain complexity is positive and significant ($p < 0.05$) in Model 4. This finding indicates the positive moderating role of supply chain complexity and supports H3. Taken together, the test results suggest that firms with lean and complex supply chains benefit more from BESCs during the COVID-19 pandemic. In addition to the hypothesized relationships, Model 4 also illustrates negative and significant direct effects of firm size, supply chain leanness, and supply chain complexity. This means that the abnormal stock returns due to the COVID-19 pandemic are more negative for firms with large sizes and lean and complex supply chains.

4.3 Robustness Test Results

We conducted several additional tests to check the robustness of our findings and documented the test results in Table 6. First, to address the concern that the event date related to the COVID-19 pandemic was the same for all sample firms, we followed Jacobs and Singhal's (2017) approach and conducted adjusted *t*-test to control for possible time clustering. The adjusted *t*-test results for all the sample firms, treatment firms, and matched control firms remain consistent, as shown in Models 1 to 3, respectively, in Panel A. We also checked the sensitivity of our event study results if an alternative asset pricing model was used. Specifically, instead of using Fama–French–Carhart's four-factor model, we adopted the traditional Market model (Fan *et al.*, 2021) to compute the CARs. The adjusted *t*-test results based on the Market model (Models 4–6 in Panel A) are similar to those based on the four-factor model (Models 1–3 in Panel A), demonstrating the robustness of our event study results.

--- Table 6 about here ---

We also checked the sensitivity of our cross-sectional regression results if alternative measures of the research variables were used. First, for the dependent variable, we measured CAR alternatively based on the Market model rather than the four-factor model. For the two moderators, we measured supply chain leanness alternatively with a focus on the inventory waste or slack in a firm's supply chain. Specifically, this alternative measure was based on the average inventory turnover of a focal firm and all its suppliers and customers identified from the Bloomberg SPLC database. On the other hand, we applied the logarithmic transformation to measure supply chain complexity alternatively to control for the possible skewness distribution of the number of customers and suppliers across firms. The regression results based on these alternative measures remain consistent, as illustrated in Models 1 to 3 in Panel B.

Our treatment firms adopted BESCs in different years from 2017 to 2019, which might be affected by the COVID-19 pandemic differently. Thus, we included an additional control variable to indicate the number of years since a firm adopted BESCs. The regression results are qualitatively similar after including this control variable, as indicated in Model 4 of Panel B. Finally, as the stock returns of information technology (IT) service firms such as Microsoft (SIC code = 7372) and Google (SIC code = 7370) performed very well during the COVID-19 pandemic because of the surged demand for online services, a valid concern is whether the better stock returns for treatment firms observed in our study is due to these firms' increased sales performance rather than BESC adoption. To address this concern, we excluded 34 IT service firms (three-digit SIC code = 737) from our sample and re-ran the cross-sectional regression based on the remaining 142 non-IT service firms. The regression results based on this sub-sample are presented in Model 5 of Panel B and are similar to those based on the full sample, suggesting that our test results are not driven by IT service firms.

5. Discussion and Conclusion

5.1 Discussion of Test Results

Our study demonstrates COVID-19's negative financial impact. Specifically, our event study shows that sample firms' average abnormal stock returns fell by 6.26% during the COVID-19 pandemic. This finding is consistent with the decreased stock returns documented in previous COVID-19 event studies (Maneenop and Kotcharin, 2020; Pandey and Kumari, 2021). Moreover, this percentage seems to be larger than the change in stock returns caused by other disruption events. For example, Hendricks *et al.* (2020) showed that firms experiencing supply chain disruptions due to the 2011 Great East Japan Earthquake had an average decrease of 5.21% in stock returns, while Jacobs and Singhal (2017) found no significant change in stock returns for global apparel retailers sourcing from Bangladesh following the 2013 Dhaka Rana Plaza disaster. This confirms the common belief that the COVID-19 pandemic has induced a much more significant impact than other disruption events.

Our study further shows a significant difference between firms with and without BESCs. Specifically, while the abnormal stock returns of firms without BESCs dropped by 10.78% because of the COVID-19 pandemic, firms with BESCs had no significant change in abnormal stock returns, demonstrating the mitigating role of BESCs during the COVID-19 pandemic. This finding is in line with those documented in previous studies that have emphasized the positive contributions of BESCs to performance outcomes at the firm and supply chain levels (Cole *et al.*, 2019; Wamba and Queiroz, 2020a). However, a significant difference is that our study examines the business value of BESCs in an uncertain, risky environment caused by the COVID-19 pandemic, whereas previous studies focused on BESCs' direct performance outcomes and paid less attention to the role of external environments.

Although not hypothesized, our regression analysis indicates that the COVID-19 pandemic had a more adverse impact on firms with lean and complex supply chains. This finding is in line with the literature that has highlighted the risk of running lean and complex supply chains, especially in the context of supply chain disruptions (Bode and Wagerl, 2015; Hendricks *et al.*, 2009). For example, Hendricks *et al.* (2009) found that the stock returns of firms with lean supply chains drop more significantly when the firms encounter supply chain disruptions, while Bode and Wagerl (2015) showed that supply chain complexity increases the frequency of disruptions in supply chains. More importantly, different from prior studies, we further reveal the interesting interplay among COVID-19, blockchain, and supply chain characteristics. Specifically, our study demonstrates that although lean and complex supply chains are more adversely affected by COVID-19, the adverse effects lessen if firms have adopted blockchain in these supply chains. Although previous studies also contended that the business value of emerging technologies such as social media and 3D printing is contingent on external environments (Lam *et al.*, 2019; Wang *et al.*, 2020), they have paid little attention to the possible interaction between external environments and supply chain contexts in explaining these technologies' business value.

5.2 Implications for Practice

Although blockchain has been increasingly adopted in supply chain management, many firms are still skeptical of blockchain's business value. For example, a recent survey conducted by Capgemini, a global IT consulting firm, found that about 70% of organizations cannot observe a clear return on investment from adopting blockchain in supply chains (Capgemini Research Institute, 2018). Previous research has also suggested that the lack of full awareness of blockchain's business value is an important barrier to blockchain adoption (Kouhizadeh *et al.*, 2021; Queiroz *et al.*, 2020a). Our study reduces the concerns of managers and practitioners by demonstrating the mitigating role of BESCs during the COVID-19 pandemic. Specifically, we find that the average abnormal stock returns of firms with BESCs were 9.05% higher than those of firms without BESCs during the COVID-19 pandemic. This percentage is equivalent to approximately US$ 5,675 million in terms of market value. Therefore, our study provides strong empirical evidence to support firms investing in BESCs in an uncertain world with increasing disruption risks. Although a global pandemic such as COVID-19 is rare, the risks of supply chain disruptions are common. Even before the COVID-19 pandemic, supply chain disruption was viewed as "a major threat to business" (Culp, 2013), highlighting the importance of adopting blockchain to reduce the risks of supply chain disruptions.

Our study enables firms to assess the urgency of their BESC investments considering the leanness and complexity of their supply chains. With the popularity of lean thinking and the success of relevant companies such as Toyota and Dell, many firms are engaging in lean and efficient supply chains. While these supply chains create some competitive advantages for the focal firms concerned, their vulnerability to supply chain disruptions has also been well recognized (Hendricks *et al.*, 2009; Kovach *et al.*, 2015). However, asking firms to reduce the leanness of their supply chains (e.g., adding more slacks or buffers) to address disruption risks may be impractical, because such leanness reduction may bring more drawbacks than benefits to the firms in today's highly competitive business environment. Therefore, instead of asking firms to give up their lean practices, our study suggests that firms can use blockchain to better monitor and trace the inventories and other resources available in their lean supply chains, enabling faster identification of and response to the disruptions in these supply chains.

Given increasing globalization over the past few decades, firms' supply chains have become more complex, serving customers in different markets and sourcing goods and services from suppliers located in different countries. The recent COVID-19 pandemic has highlighted how globalized, complex supply chains are vulnerable to the risks of supply chain disruptions. Therefore, some practitioners have urged firms to engage in reshoring to maintain more localized, simpler supply chains and reduce disruption risks (Burrows, 2020; Fan *et al.*, 2020). However, not many firms have followed this reshoring suggestion as the costs and disadvantages associated with reshoring may outweigh the risk reduction benefits (The Economist, 2020). As globalization seems irreversible, our study suggests that firms can rely on blockchain to make their globalized, complex supply chains more transparent and traceable, reducing the possibility and frequency of disruptions in these supply chains.

Taken together, although our study does not suggest that adopting blockchain in supply chains *per se* is always beneficial to firms, we see the value of such adoption in today's environment with increasing disruption risks, as exemplified by the recent COVID-19 pandemic. Indeed, as Forrester, a research and consulting firm, observed, the COVID-19 pandemic is accelerating firms' blockchain initiatives related to supply chain and logistics management (Pratt, 2020). Moreover, many firms' supply chains currently tend to be lean and complex because of the continuous globalization trend and the popularity of lean thinking. Our study does not criticize the value of globalization and lean practices; instead, it urges firms to leverage blockchain to reduce the disruption risks in these supply chains. Although adopting blockchain in these supply chains may be more challenging given the efficiency and complexity concerns, our study suggests that the resultant benefits, at least in terms of stock returns, should outweigh the adoption costs.

5.3 Implications for Research

Unlike other COVID-19 event studies (e.g., Maneenop and Kotcharin, 2020; Pandey and Kumari, 2021), our study does not focus on COVID-19's negative impact but on how firm strategies such as adopting blockchain in supply chains can help mitigate the negative impact. This research direction responds to Wamba *et al.*'s (2020b) call for more empirical investigations on the roles of emerging technologies in emergency situations, which are largely underexplored in the extant literature. Indeed, we are unable to identify any prior empirical research on the role of blockchain during the COVID-19 pandemic. Our work, by revealing the role of BESCs in mitigating COVID-19's negative impact, may inspire researchers to further explore how other emerging technologies also play a mitigating role during the COVID-19 pandemic (Wamba *et al.*, 2020b). For example, researchers can examine how 3D printing, with the ability to increase product customization and production flexibility (Lam *et al.*, 2019), enables firms to better manage COVID-19-induced supply chain disruptions. Anecdotal evidence also suggests that organizations from around the world have leveraged 3D printing to manufacture various items ranging from personal protection equipment to medical devices to help fight against the pandemic (Choong *et al.*, 2020), which is worth further investigation. It is also worth studying the possible double-edged sword role of social media that facilitates online user contributions and social interactions during the COVID-19 pandemic (Cheng *et al.*, 2020). In particular, while social media, with its large user base, serves as an important tool for communication and information dissemination during the COVID-19 pandemic, its "social" nature also increases the risk of COVID-19 misinformation being shared among social media users (Pennycook *et al.*, 2020). Future research could explore such a paradox or trade-off.

Moreover, different from prior studies that have focused on BESCs' direct performance outcomes (Cole *et al.*, 2019; Wamba and Queiroz, 2020a), we assess the extent to which BESCs prevent the drop in market value caused by the COVID-19 pandemic. Specifically, we compare the difference in abnormal stock returns between firms with BESCs and their matched pairs without BESCs during the COVID-19 pandemic. Such a comparison helps ensure that the identified difference in abnormal stock returns is due to BESCs rather than other factors, thus empirically demonstrating the value of adopting blockchain in supply chains. This empirical approach may be useful for future research to examine the business value of BESCs in contexts beyond the COVID-19 pandemic, such as natural disasters and trade wars. For example, a trade war that involves significant tariff rises and product bans may force firms to switch suppliers and to even change sourcing countries, inducing huge uncertainties in supply chain management and increasing the risk of supply chain disruptions, which, in turn, entails a greater need for more transparent and traceable supply chains. Thus, researchers can adopt our empirical approach to analyze how firms with and without BESCs are affected differently by the trade war, quantifying the business value of BESCs in the trade war context.

Finally, unlike previous contingency studies that have focused on the role of external environments in affecting emerging technologies' business value (Lam *et al.*, 2019; Wang *et al.*, 2020), our work explores how blockchain's business value is contingent on the interaction between external environments (i.e., the COVID-19 pandemic) and supply chain context (i.e., supply chain leanness and complexity). Specifically, our study suggests that the magnitude of COVID-19's impact is contingent on whether firms have adopted blockchain in supply chains, and the importance of such blockchain adoption is contingent on the leanness and complexity of the supply chains. This "double" contingency perspective provides a more comprehensive view of blockchain's business value as it considers not only the external environments but also the internal contexts in which the blockchain is adopted. Such a contingency perspective can serve as a useful theoretical foundation for future research to investigate how the business value of other emerging technologies may also depend on the interaction between external environments and internal adoption contexts.

5.4 Limitations and Future Research

Our study has a few limitations that provide new opportunities for future research. First, we focused on US firms, which may restrict the generalizability of our findings. Thus, we encourage researchers to further investigate firms in other countries, especially emerging markets, because COVID-19's financial impact may vary across countries given its different scales and durations in different countries. Also, blockchain adoption varies significantly across countries (Wamba and Queiroz, 2020b), which may affect the mitigating role of BESCs during the COVID-19 pandemic. Therefore, future research could compare the differences between countries to reveal new insights.

Furthermore, we limited our sample to firms listed on stock markets considering the availability of their stock price data to calculate abnormal stock returns during the COVID-19 pandemic. Hence, we encourage future research to examine private firms, especially small and medium-sized enterprises, based on non-stock price data (e.g., sales) and verify the conclusions drawn in this study. This is because such enterprises may be affected by the COVID-19 pandemic differently and have different propensities to adopt blockchain in supply chains, which is worth further investigation. Researchers can also explore the role of blockchain for nonprofit organizations, such as non-governmental organizations and governments, during the COVID-19 pandemic and compare the differences with commercial firms.

Finally, we relied on the event study methodology to quantify COVID-19's financial impact over a 68-day event window, which may lead to possible stock market overreaction or underreaction concerns as the COVID-19 pandemic has not ended even after more than a year. Thus, we encourage researchers to check the seriousness of these concerns by conducting a long-term event study with a much longer event window (e.g., 18–36 months) when relevant stock price information becomes available (Lam *et al.*, 2019). Researchers can also measure COVID-19's impact based on other performance indicators such as firm sales and inventory costs, verifying our findings based on stock returns. These investigations, together with our study's findings, can provide a more comprehensive view of COVID-19's impact over different time periods and across different performance indicators.

5.5. Conclusion

To conclude, our study employed contingency theory to theorize the mitigating role of BESCs during the COVID-19 pandemic and how the importance of such a mitigating role was contingent on firms' supply chain characteristics such as supply chain leanness and complexity. Consistent with our theoretical arguments, our empirical analysis based on 88 treatment firms with BESCs and 88 matched control firms without BESCs suggested that the COVID-19 pandemic had a less adverse impact on firms with BESCs compared to their matched peers without BESCs, demonstrating the mitigating role of BESCs during the COVID-19 pandemic. Moreover, we found that the mitigating role of BESCs was more pronounced for firms with lean and complex supply chains, confirming BESCs' contingent business value. These findings provide important implications for firms to adopt blockchain in supply chains in view of the leanness and complexity of their supply chains as well as the disruption risks presented in external environments. Our work also encourages researchers to move beyond blockchain's direct performance outcomes to explore its contingent business value during the COVID-19 pandemic as well as in other contexts.

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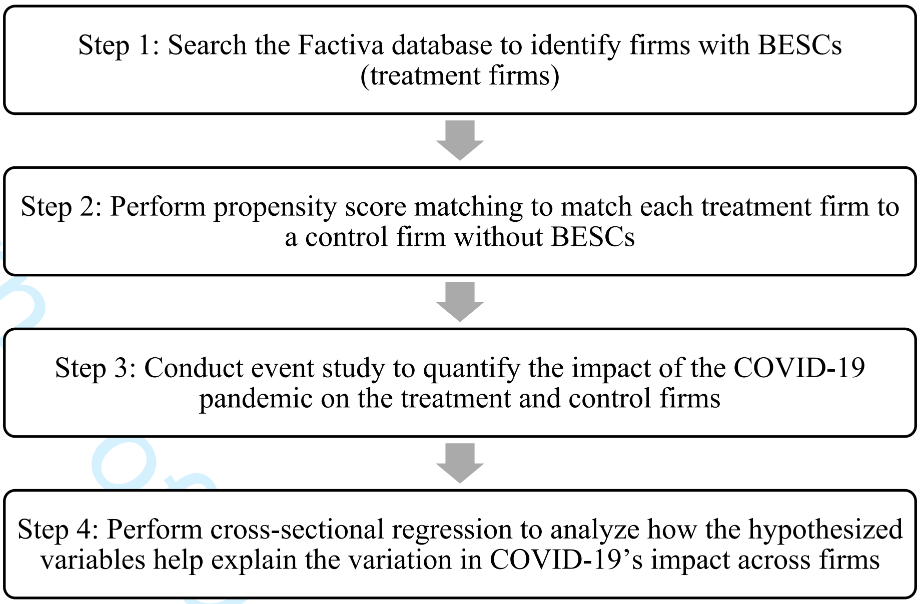

Figure 1. Steps for Hypothesis Testing

Table 1. Descriptive Statistics of Firms with BESCs

Panel A: Firm Characteristics					
Variable	Unit	Mean	Standard Deviation	Minimum	Maximum
Sales	Millions (USD)	32193.65	71278.29	0.39	511729.00
Market Value	Millions (USD)	59737.05	140759.48	7.38	757028.97
Net Income	Millions (USD)	2481.89	4343.75	-1996.00	22112.00
Total Assets	Millions (USD)	89805.21	322407.38	2.43	2558124.00
Long-term Debt	Millions (USD)	14464.72	33483.70	0.00	190702.00

Panel B: Industry Distribution			
Industry	Two-digit SIC Codes	Frequency	Percentage
Manufacturing	20-39	31	30.7%
Services	70-89	28	27.7%
Transportation & Public Utilities	40-49	12	11.9%
Retail Trade	52-59	10	9.9%
Finance, Insurance, & Real Estate	60-67	9	8.9%
Mining	10-14	6	5.9%
Wholesale Trade	50-51	3	3.0%
Agriculture, Forestry, & Fishing	01-09	1	1.0%
Non-classifiable	99	1	1.0%
All Industries	All SIC Codes	101	100.0%

Table 2. Logistic Regression Results

Independent Variable	Model 1 (Pre-Matching)	Model 2 (Post-Matching)
Intercept	-4.25*** (-7.48)	1.08 (1.32)
R&D Intensity	10.02*** (5.70)	2.47 (1.22)
Firm Size	0.48*** (8.03)	0.05 (0.75)
Firm Profitability	0.01 (0.04)	-0.25 (-0.47)
Firm Debt	-0.95* (-1.70)	-0.45 (-0.84)
Labor Productivity	0.01 (1.53)	-0.00 (-0.30)
Inventory Turnover	-0.00 (-1.34)	-0.00 (-0.69)
Stock Price Sensitivity	-1.24*** (-4.08)	-0.46 (-1.19)
Stock Price Volatility	0.76 (1.20)	0.44 (0.68)
Industry Dummies	Included	Included
Total Number of Firms	905	176
Treatment Firms	101	88
Control Firms	804	88
Log Likelihood	-203.97	-105.83
Pseudo R-squared	0.30	0.13

Notes: *$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$ (two-tailed tests). z-statistics are reported in parentheses.

Table 3. Event Study Results

Panel A: Average Cumulative Abnormal Return (CAR)				
Sample	Number of Firms	Average CAR	t-statistic	p-value
All Sample Firms	176	-6.26%	-2.03	$p < 0.05$
Treatment Firms	88	-1.73%	-0.58	$p > 0.10$
Matched Control Firms	88	-10.78%	-3.20	$p < 0.01$
Panel B: Difference between Treatment Firms and Matched Control Firms				
Sample	Number of Pairs	Average CAR Difference	t-statistic	p-value
All Sample Firms	88	9.05%	2.69	$p < 0.01$

Table 4. Descriptive Statistics and Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) CAR	1.00									
(2) BESCs	0.13*	1.00								
(3) Firm Size	-0.19**	0.01	1.00							
(4) Firm Debt	0.13*	0.02	0.12	1.00						
(5) Firm Profitability	-0.14*	-0.09	0.47***	0.11	1.00					
(6) Earnings Per Share	0.01	0.03	0.42***	0.05	0.26***	1.00				
(7) Firm Liquidity	0.06	-0.17**	-0.35***	-0.16**	-0.09	-0.04	1.00			
(8) Tobin's Q	0.12	-0.19**	-0.11	0.04	-0.12	0.09	0.01	1.00		
(9) Supply Chain Leanness	-0.13*	0.18**	0.15**	0.02	-0.11	0.02	-0.53***	0.04	1.00	
(10) Supply Chain Complexity	-0.22***	-0.16**	0.33***	-0.09	0.16**	0.08	-0.11	-0.06	0.01	1.00
Mean	-0.06	0.50	7.75	0.20	0.06	2.53	2.72	2.44	83.2	185.46
Standard Deviation	0.47	0.50	2.87	0.20	0.34	6.32	3.41	1.72	152.19	198.19

Notes: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$ (two-tailed tests).

Table 5. Cross-Sectional Regression Results

Variable	Model 1	Model 2	Model 3	Model 4
BESCs		0.13** (1.68)	0.16** (2.02)	0.15** (1.86)
BESCs × Supply Chain Leanness			0.22** (2.20)	0.18** (1.85)
BESCs × Supply Chain Complexity				0.17** (2.23)
Firm Size	-0.26** (-2.32)	-0.25** (-2.27)	-0.23** (-2.09)	-0.22** (-2.03)
Firm Debt	0.12 (1.50)	0.12 (1.61)	0.12 (1.62)	0.11 (1.39)
Firm Profitability	-0.08 (-0.91)	-0.05 (-0.63)	-0.06 (-0.69)	-0.09 (-0.97)
Earnings Per Share	0.09 (1.13)	0.10 (1.04)	0.07 (0.86)	0.12 (1.41)
Firm Liquidity	0.08 (0.84)	0.07 (0.71)	0.08 (0.75)	0.02 (0.20)
Tobin's Q	0.09 (0.88)	0.14 (1.20)	0.09 (1.12)	0.05 (0.60)
Supply Chain Leanness	-0.15* (-1.66)	-0.16* (-1.81)	-0.17* (-1.93)	-0.17* (-1.94)
Supply Chain Complexity	-0.17** (-2.14)	-0.14* (-1.82)	-0.12* (-1.69)	-0.15* (-1.85)
Industry Dummies	Included	Included	Included	Included
Number of Firms	176	176	176	176
R-squared	0.12	0.14	0.17	0.19
Adjusted *R*-squared	0.07	0.08	0.10	0.12
F-value	2.33**	2.39**	2.71***	2.73***

Notes: *$p < 0.10$, **$p < 0.05$, and ***$p < 0.01$ (one-tailed tests for hypothesized variables and two-tailed tests for control variables). Standardized coefficients are reported. *t*-statistics are in parentheses.

Table 6. Robustness Test Results

Panel A: Average CAR

Model	Number of Firms	Average CAR	Adjusted *t*-test (control for clustering)
1. All Sample Firms (Four-Factor Model)	176	-6.26%	-1.98**
2. Treatment Firms (Four-Factor Model)	88	-1.73%	-0.31
3. Matched Control Firms (Four-Factor Model)	88	-10.78%	-2.59***
4. All Sample Firms (Market Model)	176	-7.24%	-2.11**
5. Treatment Firms (Market Model)	88	-2.37%	-0.48
6. Matched Control Firms (Market Model)	88	-12.11%	-3.05***

Panel B: Cross-Sectional Regression Model

Model	BESCs	BESCs × Supply Chain Leanness	BESCs × Supply Chain Complexity	Number of Firms	Adjusted *R*-squared	*F*-value
1. Measure CAR based on Market Model	0.13** (1.67)	0.20** (2.12)	0.19*** (2.53)	176	0.14	2.97***
2. Measure Supply Chain Leanness based on Inventory Turnover	0.11* (1.45)	0.11* (1.54)	0.19*** (2.46)	176	0.12	2.87***
3. Measure Supply Chain Complexity based on Logarithmic Transformation	0.14** (1.76)	0.18** (1.86)	0.16** (2.16)	176	0.12	2.86***
4. Control BESC Adoption Experience	0.20** (1.92)	0.17** (1.80)	0.17** (2.24)	176	0.12	2.62***
5. Exclude IT Service Firms	0.20** (2.25)	0.22** (2.01)	0.17** (2.10)	142	0.16	2.96***

Notes: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$ (one-tailed tests).