Int. J. Production Economics 251 (2022) 108523

Contents lists available at ScienceDirect

International Journal of Production Economics

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

The implications of COVID-19: Bullwhip and ripple effects in global supply chains

Marcia Regina Santiago Scarpin [a,*], Jorge Eduardo Scarpin [a], Nayane Thais Krespi Musial [b], Wilson Toshiro Nakamura [c]

[a] Concordia College Moorhead, MN - Offutt School of Business, 901 8th St. S, Moorhead, MN, 56562, USA
[b] Federal University of Parana (UFPR), Avenida Professor Lothário Meissner, 632, Curitiba, PR, 80210-170, Brazil
[c] Mackenzie Presbyterian University, Rua da Consolação, 930, Sao Paulo, SP, 01302-907, Brazil

ARTICLE INFO

Keywords:
COVID-19
Supply chain
Financial risk
Efficient market hypothesis
Bullwhip effect
Ripple effect

ABSTRACT

Using the financial proxies in the efficient market hypothesis (EMH), we explore how the bullwhip effect (BWE) and ripple effect (RE) have been affected by the COVID-19 pandemic upstream and downstream. We developed two models to help us understand the phenomenon. The first model we created was the global airline stock index (GASI). This index represents all the global airline companies in the sample in one single node. We compared the GASI with each sample's buyer and supplier. The first result we observed was that some companies are more affected than others. We also found that the RE increased after the COVID-19 pandemic, but not the BWE. We then created a second model to analyze the difference in effects between companies. This reveals that the number of relationships in the supply chain network is positively related to the BWE and the RE. According to the regression analysis, the data also show that companies with a higher degree of operating level (DOL) and debts, and a lower share price, are the most vulnerable to the BWE and RE. We close by summarizing our findings and discussing future research opportunities.

1. Introduction

The COVID-19 pandemic created a unique bullwhip effect (BWE) and ripple effect (RE) on an unprecedented scale; it shut down every economy in the world. COVID-19 has been the greatest challenge to global economic recovery since the Second World War (Prasad and Wu, 2020), impacting both upstream and downstream flows in global supply chains (Handfield et al., 2020). Unprecedented vulnerabilities were observed in several supply chains (Ivanov and Dolgui, 2021), and although natural disasters directly affect BWE and REs, few studies have addressed this relationship (Schmitt et al., 2017; Dolgui et al., 2020).

There are many opportunities to research on BW and REs. Supply chain risk management has addressed the BWE over time, with studies that focus on demand fluctuations (Forrester, 1958; Lee et al., 1997; Sucky, 2009; Wang and Disney, 2016; Goodarzi and Saen, 2020; Handfield et al., 2020). No attention, however, has ever been paid to financial issues. The RE is also not often discussed in supply chain risk management (Dolgui et al., 2020; Ivanov and Dolgui, 2021): in fact, there is a missing link connecting the BWE and RE. We fill this gap by investigating financial proxies in the efficient market hypothesis (EMH). The EMH is widely used in finance, but is rarely found in supply chain management studies (Nunes, 2018). In addition, few supply chain studies have linked financial contagion and pandemic crises (Ding et al., 2021).

We brought the Capital Asset Pricing Model (CAPM) from finance to advance the discussion. This model is used to measure stock market contagion, macroeconomic shocks, integration, and risk contagion in financial crises and has been most recently used for linking the new coronavirus and government interventions in the stock market (Zaremba et al., 2020). Therefore, CAPM is a proper approach for this paper because it studies stock portfolios (a good supply chain proxy), macroeconomic shocks and financial crises (COVID-19), and the resulting contagion on stock markets (BWE and RE).

The pandemic has demonstrated how BWE and RE may emerge and have an impact on a global supply chain. We aim to investigate the COVID-19 outbreak in relation to the bullwhip and ripple effects in the

* Corresponding author.
E-mail addresses: msantiag@cord.edu (M.R.S. Scarpin), jscarpin@cord.edu (J.E. Scarpin), nayanethais@ufpr.br (N.T. Krespi Musial), wilson.nakamura@mackenzie.br (W.T. Nakamura).

https://doi.org/10.1016/j.ijpe.2022.108523
Received 13 September 2021; Received in revised form 20 April 2022; Accepted 8 May 2022
Available online 12 May 2022

global airline industry. This paper addresses the following research questions:

RQ1. What impact does the COVID-19 outbreak have on the bullwhip and ripple effects in the global airline supply chain?
RQ2. Which financial and non-financial variables are linked to the bullwhip and ripple effects?

2. Literature review

2.1. The airline supply chain

The airline industry is a complex of linkage firms and consists of various players and a multi-tiered manufacturing structure (Gupta et al., 2015; Singamneni et al., 2019). For over 50 years, the airline supply chain has been working internationally, based on intense collaboration and strategic alliances. The long-term relationships between firms constitute a strategic tool for reducing the technological, financial, market, and organizational barriers inherent in developing any new project (Esposito and Raffa, 2007).

This relationship also is grounded in agreements since firms with specific roles in the production process can influence the competition of the other firms (Esposito and Raffa, 2007). "If some strategic partners are incapable of developing their sections according to the plan schedule, the entire development schedule is pushed back" (Tang et al., 2015, p. 82). There are, therefore, strategic and dependent partnerships in the airline supply chain, including risk-sharing contracts with some strategic suppliers. (Tang et al., 2015).

The global airline supply chain configuration requires intensive effort to ensure a smooth operation, as any hiccup in the supply chain can disrupt final aircraft assembly (Singamneni et al., 2019). Risks spread rapidly through the chain due to the interdependence of its various nodes (Li and Zobel, 2020). A disruption can affect the firm that experiences it and its suppliers, customers, and competitors. Because of the small number of suppliers and the overlapping supply chains in the overall airline supply chain, it is highly likely that any risk will contaminate the whole supply network (Gupta et al., 2015).

2.2. Supply chain risk

The business environment has become more turbulent, and unexpected events have led to vulnerability and increased disruptions throughout supply chains. Events such as the terrorist attacks of September 11, the outbreak of SARS, the Japanese tsunami, and Hurricane Sandy had negative and catastrophic impacts on supply chain flows (Christopher and Lee, 2004; Quarshie and Leuschner, 2020). External events have increased vulnerability to disruptions in supply chains (Besiou and Van Wassenhove, 2020). For example, the COVID-19 pandemic was a rapid disruption with high severity. Few supply chain managers had ever paused to consider the risk involved (Handfield et al., 2020). COVID-19 was an unexpected occurrence with totally unpredictable disruptions, with borders and transportation infrastructures shut down. It caused a real collapse in financial systems and a negative contagion effect, which extended to firms in networks overseas (Ding et al., 2021).

Each disruption will require a unique and individual approach depending on its nature. For example, for service firms like the airline industry, adequate financial reserves or low debt-to-equity ratios enable the preservation of relational reserves and vice versa, contributing to their organizational resilience in times of crisis (Gittell et al., 2006).

2.2.1. Supply chain finance risk

There is an interface between operations management and finance, and a positive link between information sharing, supplier integration and collaboration, and cash flow risks (Wuttke et al., 2013; Zhu et al., 2020). Firms that have more funds, for example, can provide credit for firms that have limited access to funding (Choi and Kim, 2005). Furthermore, although operational and financial leverage affects a firm's risk profile, hedging risk between multiple buyers can reduce this risk (Pellegrino et al., 2019). Studies also show that sharing working capital between companies in the supply chain can lead to better results than managing each company's capital separately (Caniato et al., 2016).

Companies seek solutions for their liquidity and working capital needs in an environment in which there is limited access to capital (Caniato et al., 2016). When a disruption event occurs, like the Covid-19 pandemic, trade credit increases in the supply chain, and difficulties accessing new funds affect buyers and suppliers alike. Although buying firms cannot completely shift these costs on to their suppliers (Wuttke et al., 2013), buyer liquidity shocks are dispersed throughout the supply chain (Boissay and Gropp, 2013).

Financial flows are necessary for explaining the causal mechanisms that can create patterns of risk propagation and bankruptcies in an established supply chain. In the context of tightly coupled interactions, decisions affect the firms and their suppliers (Tier 1, Tier 2, Tier 3, and more) (Serrano et al., 2018). Thus, financial risk propagation can affect entire supply chains.

2.2.2. The efficient market hypothesis (EMH)

Studies use EMH to understand how contamination occurs among companies (Fama, 1970). EMH can be formulated in three versions: weak, semi-strong, and strong. Although the EMH debate is a long-standing one, research shows that the semi-strong approach is more likely to be accurate, especially when markets are efficient and estimation models value stocks correctly (Ying et al., 2019).

EMH studies reveal that external events impact the stock market. For example, terrorism events have a significant and negative impact on the day after any attack (Bano and Khan, 2021). Negative events also affect the market values of suppliers and customers. Nunes (2018) found that suppliers and customers absorb the negative outcomes of events, although the supply side faces a higher risk of loss.

This study addresses BWE and RE as additional information in the semi-strong EMH. Financial risks can be huge in a pandemic like COVID-19. The BWE and RE increase fluctuations in stock exchanges and affect supply chains both downstream and upstream. The complexity and uncertainty of environmental turbulence intensify risks within the supply chain (Christopher and Lee, 2004). Disruptions can have a significantly negative impact on a firm's finances, leading to abnormal stock returns of −40%, on average, with lasting consequences that may extend into the year following the announcement of the disruption (Hendricks and Singhal, 2005).

3. The bullwhip and ripple effects and hypotheses

The BWE refers to how order variability increases as the orders move upstream in the supply chain. This effect has been studied over the years in the operations management literature that focuses on demand and price fluctuations (Forrester, 1958; Lee et al., 1997; Sucky, 2009; Wang and Disney, 2016; Ojha et al., 2019; Goodarzi and Saen, 2020; Handfield et al., 2020). Over time, contemporary topics have been investigated, such as closed-loop systems in a circular economy (Ponte et al., 2020) and customer satisfaction versus economic benefits of batching (Ponte et al., 2022).

Zhu et al. (2020) claim that the effect may not exist for all types of products or be different for each industry. Indeed, Pastore et al. (2019) suggested that the BWE is larger for fast-moving products than for slow-moving, and frequent switches from promotional to non-promotional periods tend to increase the propagation of demand variability. Goodarzi and Saen (2020) developed a model to help decision-makers in the pharmaceutical industry analyze nodes that have an inefficient BWE performance.

The lack of information sharing (Ojha et al., 2019), the absence of a pricing strategy (Özelkan et al., 2018), and financial statements (Zhaob et al., 2019; Chen et al., 2013) also affect BWE. Zhaob et al. (2019) used firms' financial proxies to investigate the links between relational capital and the BWE. Chen et al. (2013) showed that an individual firm's liquidity crunch risk (flow-based credit risk) is transmitted throughout the supply chain. A significantly high economic growth rate reduces the internal liquidity risk of suppliers but not of customers.

In addition to the BWE, we have the RE, although this is a relatively new phenomenon (Dolgui et al., 2020). In the dynamic structure of a network, the RE spreads downstream in the supply chain, while the BWE unfolds upstream. For example, RE, in service, is studied to show how individual service failures impact other points of failure involving several dependence relationships and uncertainties (Song et al., 2013). However, a RE can positively affect the supply chain. The implementation of sustainable practices induced beneficial cross-tier ripple effects (Koh et al., 2012). Furthermore, the network structure and node risk capacity can also influence different aspects of resilience (Li and Zobel, 2020).

Although BWE is a present phenomenon in the operations management field (Ponte et al., 2020), the existing BWE theories have limitations in explaining the phenomenon in some industries (Zhu et al., 2020). Besides that, a few studies have included the BWE in supply chain disruption literature (Schmitt et al., 2017; Dolgui et al., 2020). There is an opportunity to explore this effect using real supply chain networks, which are disregarded in many studies (Sucky, 2009; Isaksson and Seifert, 2016; Goodarzi and Saen, 2020). Monetary and financial supply chain considerations, such as stock market fluctuations, also deserve more attention (Chen et al., 2013; Wang and Disney, 2016; Handfield et al., 2020). In addition, studies examining the relationships between the BWE and RE are not common (see Table 1). For Isaksson and Seifert (2016), the BWE and RE—or the two-echelon perspective—are critical for studying the uncertainties that are much greater between a buyer and a supplier than within a single firm. Dolgui et al. (2020) found that RE can be a driver of the BWE.

However, the BWE and RE may be underestimated if only the supply chain is considered. Supply chains are complex networks that generate a dynamic that is amplified along the chains (Li and Zobel, 2020). For example, a natural disaster, such as the COVID-19 pandemic, produces a unique BWE (Handfield et al., 2020) that negatively affects entire supply chains (Sucky, 2009). Although the consequences of the BWE can be hard to detect and quantify economically (Wang and Disney, 2016), the COVID-19 pandemic reveals a real and devastating economic and financial crisis. Indeed, the economic disruptions caused by the virus and the accompanying uncertainty are reflected in lower valuations and increased volatility in financial markets.

Table 1
Location of our research in the literature under the sun 'Nothing new under the sun.

Authors	Bullwhip Effect	Ripple Effect	Natural Disaster	Financial Variables	Index	Industry	Method	Journal
Sucky (2009)	**Yes**	No	No	No	No	Retailers	Mathematical Model	International Journal of Production Economics
Koh et al. (2012).	No	**Yes**	No	No	No	IT industry	Multiple Case Studies	International Journal of Production Economics
Chen et al. (2013)	**Yes**	No	No	**Yes**	No	Compustat	Panel Data Regressions	Journal of Banking & Finance
Song et al. (2013)	No	**Yes**	No	No	No	Service	Bayesian network	International Journal of Production Economics
Isaksson and Seifert (2016)	**Yes**	No	No	**Yes**	No	Compustat	OLS Regression	International Journal of Production Economics
Wang & Disney (2016)	**Yes**	No	No	No	No	–	Narrative Review	European Journal of Operational Research
Özelkan et al. (2018).	**Yes**	No	No	No	No	Retail	Newsvendor model	International Journal of Production Economics
Zhao, Mashruwala, Pandit, & Balakrishnan (2019)	**Yes**	No	No	**Yes**	No	Compustat	Multivariate Regression	International Journal of Operations & Production Management
Pastore et al. (2019)	**Yes**	No	No	**Yes**	No	European automotive	regression model	International Journal of Production Economics
Ojha et al. (2019).	**Yes**	No	No	No	No	Manufacturing	Simulation	International Journal of Production Economics
Zhu et al. (2020)	**Yes**	No	No	No	No	Oil and gas	Case Studies	International Journal of Production Economics
Goodarzi and Saen (2020)	**Yes**	No	No	No	No	Pharmaceuticals	Mathematical Model	Computers & Industrial Engineering
Handfield et al. (2020)	**Yes**	No	**Yes**	No	No	Automobiles & Equipment	Interviews	International Journal of Operations & Production Management
Dolgui et al. (2020)	**Yes**	**Yes**	No	No	**Yes**	Beverages	Simulation Model	International Journal of Production Research
Ponte et al. (2020)	**Yes**	No	No	No	No	Manufacturing - Remanufacturing	Models	International Journal of Production Economics
Li and Zobel (2020)	No	**Yes**	No	No	No	Japanese auto	Simulation and regression analysis	International Journal of Production Economics
Ponte et al. (2022).	**Yes**	No	No	No	No	Manufacturing - Remanufacturing	Simulation	International Journal of Production Economics
This work	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	Airlines	Panel Data Regressions	

The financial conditions of a firm are affected in a global financial crisis. Equity markets collapse, and debt markets become fragile. Company suppliers may also adopt more rigid credit policies, and customers may have problems paying their dividends. These problems can indicate a firm's internal liquidity risk, which may spread along the supply chain. In finance, this phenomenon is called the contagion effect (Chen et al., 2013). Our first and second hypotheses are:

H1. There is a significant change in the bullwhip effect during pandemic outbreaks.

H2. There is a significant change in the ripple effect during pandemic outbreaks.

Degree centrality is a measure of social network analysis and indicates a direct relationship with another network node. High centrality indicates there are many ties to others, demonstrating greater visibility in the network (Yan et al., 2015). A company with degree centrality shows its influence and popularity in the network (Brintrup et al., 2015). We use the degree centrality concept to indicate the number of relationships that airline companies have with their buyers and suppliers and analyze it with financial risk in the supply chain network.

Companies with many nodes' connections can influence other companies in the network. Zhaoa et al. (2019) developed a simulation model to analyze how disruptions propagate by cascading failures in the supply chain network. They used a supply chain network with 2971 firms spanning 90 industry sectors to understand reactive and proactive supply chain strategies for facing up to disruptions. The results show that when a high degree node is removed from the supply network for reactive strategies, the negative effect on the whole network is greater than when a low degree node is removed. Brintrup et al. (2015) worked with the aerospace industry, specifically with a network of the Airbus Group, which included 544 supplier companies and 1657 related relationships. The study presents a vulnerable network with a large portion of the firms connecting to hub firms. Although hub firms are connected, the cascade effect will spread quickly to the entire network if a hub firm faces disruption. Zhou et al. (2020) analyzed a bi-level BWE model using a social network analysis approach. The authors determined that high degree centrality has a greater impact on the first level BWE.

Supply chain network disruptions may be manifested as financial losses (Zhaob et al., 2019). The disruption may spread through the supply chain as a BWE or RE (Li and Zobel, 2020). Companies with more nodes in the network can have an impact on the strategic decisions of other companies that are linked to each other. Our third hypothesis is:

H3. High degree centrality is positively related to the bullwhip and ripple effects during pandemic outbreaks.

In a disruption scenario, negative financial consequences affect different nodes of the supply chain. Chen et al. (2013) observe that an individual firm's liquidity crunch risk is transmitted throughout the supply chain, which connects variations in inventory flows, cash flows, and information flows. The internal liquidity risk effects of customers on bond-yield spreads are also larger than those of the suppliers. The internal liquidity risk effect also becomes greater as it moves up the supply chain.

Filbeck et al. (2016) analyzed both suppliers and customers and found that disruption has a negative financial impact on all of them. Investors penalize the disruption more during bear-market cycles: that is, when the market falls. When a competitor announces disruptions, American automobile companies face a negative stock reaction, and contagion is significant. Ding et al. (2021) also found that the stock returns of Chinese semiconductor firms were negatively affected by the Kumamoto earthquakes, and that a negative contagion effect is transmitted through supply chain nodes.

Isaksson and Seifert (2016) introduce an approach for quantifying the BWE using financial accounting data in a multi-echelon setting. They observe that the further away from its consumers the firm is, the greater the BWE. This finding reinforces the idea that an increased number of decision points between the firm and the end consumer will distort demand and drive up the BWE. Our hypotheses, therefore, are:

H4. Finance proxies are positively related to the bullwhip and ripple effects during pandemic outbreaks.

H4a. Leverage ratios are positively related to the bullwhip and ripple effects.

H4b. Solvency ratios are positively related to the bullwhip and ripple effects.

4. Data and methods

The BWE and RE have industry-specific features, and these could contaminate data across industries and thereby impact the analysis and the results (Isaksson and Seifert, 2016). The BWE varies differently across industries (Zhaob et al., 2019). Financial markets may also vary due to differences in the capital intensity of production. When the capital intensity of production is significantly different, book-to-market and operating leverage are unrelated to returns. Therefore, studies find strong results *within* an industry, but weak results *across* industries (Novy-Marx, 2011).

The airline supply chain can be considered an ideal candidate for studying the BWE and RE. The COVID-19 pandemic has caused a significant financial loss to the aviation industry (IATA - International Air Transport Association, 2021). Additionally, the airline industry consists of a multiplex relationship between buyers and suppliers: that is, when a buyer or a supplier may be simultaneously a competitor, supplier, or partner in the supply chain (Slot et al., 2020). This complexity can modify the linear direction of the BWE and the RE, an effect that has

Table 2
Sample.

Region	Airlines	Buyers/Suppliers
Africa	4.12%	1.49%
Asia	48.45%	8.96%
Europe	19.59%	37.31%
Latin America	7.22%	2.99%
Oceania	5.15%	1.49%
USA & Canada	15.46%	47.76%
Total	100.00%	100.00%
Employees		
Maximum	136,944	351,600
Minimum	479	107
Mean	24,893	31,478
Standard Deviation	31,966	62,413
Median	11,247	9351
Age		
Maximum	100.97	109.28
Minimum	3.02	3.67
Mean	32.07	31.16
Standard Deviation	22.11	25.29
Median	24.84	22.99
Total Assets		
Maximum	64,532,000,000	152,186,000,000
Minimum	5,376,432	839,421
Mean	10,073,570,563	16,037,386,348
Standard Deviation	14,212,184,203	33,923,431,575
Median	4,126,624,000	3,684,629,500
Total Revenue		
Maximum	47,007,000,000	84,818,000,000
Minimum	358,949	1,410,914
Mean	6,718,193,698	9,014,782,951
Standard Deviation	10,028,006,982	19,615,666,789
Median	2,847,055,735	1,823,092,000

been studied over time (Forrester, 1958; Lee et al., 1997; Goodarzi and Saen, 2020; Handfield et al., 2020). Using data from the airline industry, we construct a novel proxy index and employ two regression models to investigate the effect of the COVID-19 crisis on the BWE and RE in the global airline supply chain.

4.1. Sample and data sources

Our sample data are composed of 165 companies—98 airlines and 67 buyers and suppliers—representing 65.7% of the total population of 252 companies in the global airline supply chain. This sample data set also includes companies from 50 countries in six regions. Table 2 summarizes the company demographics of our data set.

The data collection process involved two steps. First, we identified 135 public airline companies from the Thomson-Reuters database (Refinitiv EIKON system). Some companies from the list were excluded, as their work was not directly related to the airline industry (e.g., helicopters such as Era Group Inc.), or data were missing (e.g., companies with no data in 2019 and 2020, such as Syphax Airlines S.A.). We subsequently collected data from 98 airline companies. Second, we recognized the buyers/suppliers of the selected airline companies based on the database's confidence score, indicating the strength of the buyer-supplier relationship. We selected 67 out of 117 buyers and suppliers based on the following criteria: 1) if a company is a buyer or supplier for more than one airline (e.g., Boeing), then it was considered only once; 2) if a company provides services that are not directly related to the customer (e.g., banks), then it was excluded; and 3) if an airline company is a buyer or supplier of another airline company, then it was excluded because they are in the first sample, of airlines companies.

4.2. Models

We developed two models. The first is an event study to analyze the BWE and RE between each buyer and supplier and the global airline companies and verify whether these effects changed because of COVID-19. The second model measures the attributes related to the BWE and RE between each buyer and supplier and the global airline companies.

4.2.1. Model 1: Index to measure the BWE and RE

This model is designed in two phases to confirm the BWE and RE in the global airline supply chain. In the first phase, and according to authors such as Brusset and Bertrand (2018) and Hsiao et al. (2021), we developed a Global Airline Stock Index (GASI) to estimate the relationship between each buyer and supplier. The GASI was created because there is no other index that includes airline companies from different countries. Our model is based on the Capital Asset Pricing Model (CAPM) of Sharpe (1964) and Lintner (1965). The CAPM is indicated for estimating the stock market's reaction to events (Hendricks and Singhal, 2003). The Sharpe-Lintner versions of the CAPM explain the differences in expected returns across assets (stocks or portfolios); other variables are unlikely to add anything to the explanation of expected returns (Friend and Blume, 1970; Fama and French, 1992).

The GASI was developed using the following steps: (1) based on a time series of 210 days (105 days before and after the pandemic was declared in the United States), we collected the stock price at the end of the day (in USD) multiplied by the number of outstanding shares of each airline company—the result is a proxy for the market value of that company on that day; (2) we checked to see whether any company had issued new shares in that period—no company had, and so no adjustment was necessary; (3) we combined the market values, and found the daily market capitalization (Market Cap) for the airline industry; and (4) we calculated the daily return of the index, based on the formula:

$$Ret_t = \frac{Market\ Cap_t - Market\ Cap_{t-1}}{Market\ Cap_{t-1}}$$

where:

Ret_t: stock return on day t.
$Market\ Cap_t$: Market Capitalization on day t.
$Market\ Cap_{t-1}$: Market Capitalization on the previous day (t-1).

In the second phase, we ran the event study. We calculated each buyer's and supplier's return based on the same formula as in Phase 1, Step 4 of the GASI. The stock price at the end of the day (the closing price) in USD was collected from 10/18/2019 to 8/10/2020. We did not consider the weekends and holidays when the stock market is closed. In total, we collected 14,137 pieces of data.

Our event day was 3/16/2020, the day on which the World Health Organization (WHO) declared a world pandemic due to COVID-19. The information on 3/16/2020 was collected only to calculate the return because the event was before and after that day. Overall, we calculated 105 returns before and 105 returns after the event.

We switched the daily market return to the daily return of the GASI. Considering this change, we worked with the following variables:

Dependent variable: The daily return of the GASI.
Independent value: The daily return of each buyer and supplier.

The final equation is:

$$AIR_t = \alpha + \beta X_{i,t} + \varepsilon$$

where.

AIR_t: Daily return of the GASI.
β: Estimated Beta coefficient.
$X_{i,t}$: The daily return of each buyer and supplier.
ε: Error term.

After performing the regressions, we found 134 β coefficients in the two groups, 67 β coefficients before the pandemic, and 67 after. Beta is a measure of the volatility—that is, the systematic risk of a buyer or supplier compared to the GASI. The β coefficient is how we measure the BWE and RE.

There are three possible scenarios for the β coefficient. If β is equal to 1.0, it indicates that airline companies and their buyers or suppliers have the same risk in the stock market. No unsystematic risk is observed. For β with a value lower than 1.0, buyers or suppliers are less volatile than the airline companies. Finally, if the β is higher than 1.0, buyers or suppliers are more volatile than the airline companies. For example, if a supplier's β is 1.5, it is assumed to be 50% more volatile than the airline companies.

4.2.2. Model 2: the BWE and RE outcomes

In this model, we run linear regression equations to confirm which variables can explain the BWE and RE between the buyer-supplier and airline companies. According to the development of the CAPM model, leverage, earnings price, debt-equity, and book-to-market ratios are explanations of expected stock returns provided by the market beta (Myers, 1977; Bhandari, 1988; Fama and French, 1992, 2006; Novy-Marx, 2011; Sarkar, 2018). Our chosen variables are:

Dependent variable:

1. β: Estimated Beta coefficient from Model 1.

Independent variables:

1. Degree centrality: the number of airline companies to which the buyer-supplier is linked.
2. Finance proxies that explain the internal financial risk:

a) Leverage ratios: Degree of Operational Leverage (DOL) and Degree of Financial Leverage (DFL).
b) Solvency ratios: price to book value, debt-to-assets ratio, and rating.

We seek to control the model with the following variables:

1. Size: The ln of total revenue.
2. Region: Region of the company headquarters. We divided companies into the United States, Canada, Latin America, Europe, Africa, Asia, and Oceania.
3. Relationship: Two dummy variables to check if the companies are buyer, supplier, or buyer-and-supplier.

The final equation was:

$$\beta_{i,t} = \alpha_0 + a_1 Strenght_{i,t} + a_2 DOL_{i,t} + a_3 DFL_{i,t} + a_4 Price - to - Book\ Value_{i,t} + a_5 Debt - to - Assets\ Ratio_{i,t} + a_6 Rating_{i,t} + a_7 Size_{i,t} + a_8 Latin\ America_{i,t} + a_9 Asia_{i,t} + a_{10} Oceania_{i,t} + a_{11} Africa_{i,t} + a_{12} Europe_{i,t} + a_{13} Buyer\ Only_{i,t} + a_{14} Buyer\ and\ Supplier_{i,t} + \varepsilon_{i,t}$$

where.

β: Estimated Beta coefficient from Model 1.
$Strength_{i,t}$: the number of ties by which the company is linked to the global airline industry.
$DOL_{i,t}$: Degree of Operating Leverage: percent change in the Earnings before Interest/percent change in total revenue.
$DFL_{i,t}$: Degree of Financial Leverage: percentage change in the Earnings per Share/percentage change in the Earnings before Interest.
$Price - to - Book\ Value_{i,t}$: Market Cap/Shareholders' Equity.
$Debt - to - Assets\ Ratio_{i,t}$: Total Debt/Total Assets.
$Rating_{i,t}$: Credit Rating measured by Refinitiv/Thompson.
$Size_{i,t}$: Ln of Total Revenue.
$Latin\ America_{i,t}\ Asia_{i,t}\ Oceania_{i,t}\ Africa_{i,t}\ Europe_{i,t}$: Control variables for the region.
$Buyer\ Only_{i,t}\ Buyer\ and\ Supplier_{i,t}$: Control variables for relationship.
ε: Error term.

5. Analysis

The first question we need to address before starting to analyze our models is: Is the GASI relevant enough to be used as a proxy for global airline companies?

To answer this question, we checked whether any company was large enough to become a proxy for the market. We compared three different scenarios. We selected the top five weighted-average companies in the GASI on the first day and last day, and the average analysis (see Table 3).

Table 3
GASI composition.

Group 1		Group 2		Group 3	
Company	10/18/2019	Company	8/11/2020	Company	Average
Delta Air Lines Inc	10.09%	Southwest Airlines Co	9.00%	Delta Air Lines Inc	9.23%
Southwest Airlines Co	8.33%	Delta Air Lines Inc	8.17%	Southwest Airlines Co	8.62%
United Airlines Holdings Inc	6.60%	Ryanair Holdings PLC	6.96%	Ryanair Holdings PLC	5.54%
Air China Ltd	4.51%	Air China Ltd	5.67%	Air China Ltd	5.46%
Ryanair Holdings PLC	4.23%	China Southern Airlines Co Ltd	4.71%	United Airlines Holdings Inc	5.09%
Total	33.76%	Total	34.52%	Total	33.93%

Table 3 shows that on 10/18/2019, the largest company represented around 10% of the total. When we move to 8/11/2020, the largest company represents less than 10% of the total. Finally, when we take the average for the period, the top company again represents less than 10%. When we combine the top five companies, they represent about one-third of the total GASI. Therefore, we cannot assume that any company can be used as a proxy for the entire global airline company market.

Likewise, the top five companies are from different countries, so comparing the GASI with a specific country's index is inappropriate. We also compare the GASI and the S&P500, one of the most popular stock market indexes. Because the data are not normal, we performed the Mann–Whitney test and obtained a p-value of 0.03, which means we cannot accept the hypothesis that there is no difference between the GASI and S&P 500.

5.1. Model 1 – An index to measure the BWE and RE

Once we had a reliable market index for the GASI, we performed the analysis by way of 134 simple linear regressions to find the β for each buyer and supplier before and after the pandemic. The results, which are summarized in Table 4, reveal a significant β for all companies (p-value below 0.05).

The systematic risk for buyers and suppliers is different. Before the pandemic, 50% of the buyers had more risk than the global airline industry. This percentage increased after the pandemic to 62.5%. On the other hand, the suppliers (BWE) have less risk than the global airline industry because around 30% of the companies have a β lower than they had before and after the pandemic. Table 5 presents the descriptive statistics of the buyers' and suppliers' β.

The descriptive statistics show that buyers had more risk than suppliers before and after the pandemic. The dispersion is similar, as is the maximum β. Fig. 1 demonstrates the difference in β before and after the pandemic on suppliers and buyers.

The relationship between β before and after the pandemic is not the same for suppliers and buyers. Therefore, to check whether there is a significant change in β after the pandemic started, we performed two different tests, analyzing the BWE for suppliers, and investigating the RE on buyers.

First, we tested whether the supplier's data are normally distributed, for which we used the Kolmogorov Smirnov test. It revealed that the data before the pandemic are normal, but the data after the pandemic are not. Then, considering the existence of abnormal data, we performed the Wilcoxon nonparametric test. The Wilcoxon p-value is 0.146, so we accept the statistical hypothesis that there is no difference in the BWE before and after the COVID-19 pandemic.

For buyers, we performed the Shapiro–Wilk test. The data before and after the pandemic have a normal distribution, so we performed the parametric t-test, when we paired two samples for means. The p-value is 0.035, so we rejected the statistical hypothesis that there is no difference

Table 4
Bullwhip and ripple effect.

Buyer/Supplier	Effect	Period	Lower than 1	Greater than 1
Buyers	Ripple effect	Before the pandemic	50.0%	50.0%
		After the pandemic	37.5%	62.5%
Suppliers	Bullwhip effect	Before the pandemic	66.7%	33.3%
		After the pandemic	69.8%	30.2%

Table 5
β descriptive statistics.

	Buyers		Suppliers	
	Before the Pandemic	After the Pandemic	Before the Pandemic	After the Pandemic
Mean	.9584	1.1799	.8715	.8071
Median	1.0170	1.2545	.8330	.6910
Variance	.146	.234	.157	.275
Standard Deviation	.38269	.48338	.39614	.52407
Minimum	.27	.38	.06	.01
Maximum	1.69	1.96	1.93	2.33

before and after the pandemic. The means are 0.96 before and 1.18 after the pandemic. For buyers, the RE is greater after the pandemic. The results do not support H_1, but do support H_2. The difference between the β will be investigated in Model 2.

5.2. Model 2 - BWE and RE outcomes

After the BWE and RE were analyzed, we ran a linear regression to examine why there were different β for companies in the same supply chain. We measured financial and non-financial variables. For financial variables, we examined the financial risk of each company. The financial risk variables were leverage and solvency ratios. For non-financial variables, the following factors were examined: (1) the degree centrality of each company in the supply chain; (2) where they are located; and (3) the relationship between the company and the airline industry. The descriptive statistics are presented in Table 6.

There are no negative Betas in the descriptive statistics, and the mean is below but close to one. On average, for every 1% change in the stock price of the airline companies, the stock price of buyers and suppliers changed by 0.88%. Degree centrality shows that, on average, each buyer and supplier is related to approximately four companies. The large range in the leverage ratios (DOL and DFL) is related to our sample; we have profitable and nonprofitable companies. When there is a negative number, the company experiences a net loss instead of net income. With regard to solvency ratios (price-to-book-value and debt-to-assets), a negative price-to-book-value ratio means the market cap is lower than the book value (equity), which indicates that the company is not profitable for its investors. Thus, the greater the price-to-book-value ratio, the greater the market cap than the book value (equity).

For the debt-to-asset ratio, the best ratio possible is zero, so the company has no debt. On the other hand, a ratio greater than one means that debts are greater than the sum of all its assets. Therefore, the greater the debt-to-asset ratio, the greater the risk of becoming insolvent in the long run. The linear regression model, comparing the dependent variable β to the independent and control variables, is shown in Table 7.

The regression model provided an adjusted R^2 0.577, a significant ANOVA, and goodness of fit in linear regression. We found eight operationally and financially significant variables and control variables. The operational variable, 'degree centrality,' is positive and significant (0.011 **). The more airline companies the buyer or supplier is linked to, the greater the BWE and RE. For instance, if a company is a buyer or supplier for 30 airline companies, the BWE and RE will be greater than for a company that is a buyer or supplier for 15 companies. H_3 is supported.

We found three significant financial variables: one for leverage and two for solvency. The significant leverage variable is the Degree of Operating Leverage (DOL) (0.004 ***). When a company has a high DOL, it is more affected by the BWE and RE (β). These results are consistent with the CAPM theory, which suggests a positive relationship between DOL and financial risk (Myers, 1977; Bhandari, 1988; Novy-Marx, 2011). The BWE and RE are proxies for financial risk. They impact more than one company, and the supply chain network may suffer significant damage to its capital structure.

There are two significant financial and accounting variables. The first variable is the Price to Book Value, which is negative and significant

Table 6
Descriptive statistics – model 2.

Variables	Minimum	Maximum	Mean	Standard Deviation
Beta	0.064	1.927	0.880	0.397
Degree centrality	1.000	52.000	3.900	9.053
Size				
Degree of Operational Leverage (DOL)	−72.341	179.502	3.869	27.712
Degree of Financial Leverage (DFL)	−161.525	19.029	−3.349	23.659
Price-To-Book Value	−44.542	37.257	4.899	10.693
Debt-To-Assets Ratio	0.000	1.156	0.323	0.225

Table 7
Linear regression.

Dependent variable β	**Variables**	**Coefficient**	**p-value**
	Constant	0.899	0.029**
Independent variables	Degree centrality	0.011	0.028**
	DOL	0.004	0.001**
	DFL	0.001	0.421
	Price-to-Book Value	−0.009	0.008***
	Debt-to-Assets Ratio	0.715	0.000***
	Rating	−0.017	0.901
Control variables	Size	−0.005	0.785
	Latin America	0.426	0.040**
	Asia	−0.464	0.001***
	Oceania	−0.371	0.178
	Africa	−0.688	0.013**
	Europe	−0.159	0.050**
	Buyer only	−0.137	0.355
	Buyer and Supplier	−0.133	0.240
	ANOVA	6.942	0.000**
	Adjusted R^2	0.577	
	Standard error	0.258	
	Durbin-Watson	1.929	

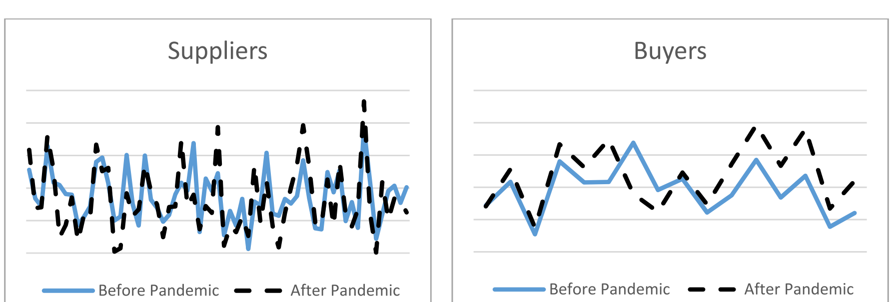

Fig. 1. Bullwhip and ripple effects.

(−0.009 ***). This result indicates that the greater the stock price compared to the equity, the lower the BWE and RE. Investors can consider this company to be low risk. The negative coefficient is found in financial research, such as that conducted by Fama and French (2006, 2015), Novy-Marx (2011), Chen and Kawaguchi (2018). The second variable is the Debt-to-Assets Ratio, which is positive and significant (0.715 ***). Companies with high debt are more affected by the BWE and RE. The CAPM theory also reveals a positive relationship between debt and risk. Bhandari (1988) was one of the first authors to find this relationship. More recent studies have confirmed the same result (Negrea and Toma, 2017). The results support hypotheses H_4, H_{4a}, and H_{4b}. Finally, our control variables demonstrate that companies in Europe, Asia, and Africa may be less affected by the BWE and RE than companies in the United States or Canada.

6. Discussion

Economic systems suffer critical risks when there is a disruption in the supply chain (Filbeck et al., 2016). Although disasters may have a low frequency of occurrence, they create widespread and long-term negative impacts (Ding et al., 2021). Exogenous disruptions in supply chain management can be disastrous. In recent years we have observed an increase in the number of studies that explore supply chain vulnerability involving disasters (Brusset and Bertrand, 2018). Disruptions, such as natural disasters that increase vulnerability, are outside the supply chain's direct control and are difficult to manage because they have different effects on the supply chain. Firms that are interconnected experience increased vulnerability to disruption (Ding et al., 2021).

The COVID-19 pandemic is a global health and financial crisis challenge. It has shown that disruption can affect several supply chains in different parts of the world. The crisis was holistic and came without notice in all countries, whether developed, emerging or poor. As a result, industries in different parts of the world have faced disruptions in their supply chains.

The pandemic severely affected the airline industry, as passenger-kilometers flown represent the main source of airline revenue. With government-imposed shutdowns, companies canceled most of their flights and saw passenger demand drop sharply, in some cases by around 95% (Rappeport and Chokshi, 2020). Even though governments released billions of dollars worldwide, the financial crisis was not only inevitable (Handfield et al., 2020), it was unprecedented in its scale and spread worldwide throughout the global airline supply chain, leading to a BWE and RE.

While the BWE and RE are facts in the aviation industry, they are not the same in intensity for all companies in the supply chain. Our Model 1 combined the airline companies into one single node by way of the GASI. We compared the GASI to each buyer and supplier and realized that some companies were more affected than others. We found that the RE increased after the start of the COVID-19 pandemic, but not the BWE. Several factors can influence the BWE, such as the industry, raw materials, long-term contracts, and demand forecasts. The BWE of some supply chains is smooth (Zhu et al., 2020). In service companies, such as airlines in which there are long-term contracts and services and products are made to order, the BWE resulting from the COVID-19 pandemic crisis comes later. Our results agree with some of the semi-strong EMH studies (Ying et al., 2019) that state that historical price is not enough for determining future price or other information, because the BWE and RE must be considered.

Our Model 2 demonstrated that the number of relationships is positively related to the BWE and RE. Studies show that the global supply chain may be more susceptible to risks because of the numerous links interconnecting the network (Olson and Wu, 2010). Some companies with a high degree of centrality play an important role in disseminating information (Brintrup et al., 2015).

Our regression analysis reveals that companies with a higher degree of operating level (DOL), higher debt, and a lower share price are the most vulnerable to the BWE and RE. These results indicate that companies with "underlying conditions"—that is, those with the worst financial indicators—are the most exposed to risk in their industries. Novy-Marx (2011) found that DOL, debt, and share price can explain stock return *in* the industry, but not a sector. Despite the COVID-19 pandemic affecting all companies, those in the global airline supply chain with financial capabilities suffered less from the BWE and RE.

Financial capability is an important source of resilience for surviving a crisis. Gittell et al. (2006) found that, for the aviation industry, a pre-crisis business model that meets the needs of the existing competitive environment can help company resilience. Strategies involving relational and financial capabilities can be used to minimize the impact of the crisis. Financial capability, low unit costs, and low debt levels are factors for avoiding layoffs and dealing with unforeseen events. Low debt levels give companies flexibility in a downturn due to lower fixed costs. Financial capability is expected to be particularly important in the face of a sustained crisis.

6.1. Theoretical contributions

This study contributes to supply chain literature in different ways. First, supply chain management literature has focused on traditional BWE problems, such as supplier selection, inventory, and forecasting, and has overlooked important topics, such as pandemics or financial problems (Besiou and Van Wassenhove, 2020). The coronavirus pandemic introduced us to different problems requiring new methods and/or algorithms. Quantitative models should be explored further (Besiou and Van Wassenhove, 2020). Our study advances in this context bringing a quantitative perspective to the field in the COVID-19 context.

Second, our study advances this discussion by proposing an econometric model that reveals the internal financial risk associated with the BWE and RE. Although several studies have focused on the BWE (Forrester, 1958; Lee et al., 1997; Goodarzi and Saen, 2020; Handfield et al., 2020), few have examined both the BWE and the RE (Dolgui et al., 2020). Our study also emphasizes the BWE and RE on the intended buyer-supply relationships of supply networks. Analyzing networks can be helpful for capturing the impacts of disruptions better (Zhaoa et al., 2019). Third, we use the semi-strong EMH to explain the BWE and RE. The EMH is widely studied in finance, but is rarely explored in the context of supply chain management (Nunes, 2018). The EMH can explain how the BWE and RE occur and indicate strategies for managing their effects. Fourth, our study considers node risk. We identify the most vulnerable companies to the BWE and RE through of higher degree of operating level (DOL) and debts, and a lower share price. Li and Zobel (2020) augments the importance of considering the node risk capacity, which is the firm's ability to face a possible disruption.

Finally, our study adds to the few existing studies of financial risk in the supply chain (Handfield et al., 2020; Zhu et al., 2020). Some of the studies in operational management have presented financial performance in terms of respondents' perceptions. We worked with actual numbers for stock prices and market caps that were taken from stock exchanges, and we used actual financial statements for the leverage and debt-to-asset ratios. As far as we are aware, no studies have presented a general index for financial risks in the supply chain. We pushed the boundaries and developed a new index called the GASI, which represents companies in the airline industry. The GASI is a combination of the 100 global public airlines in a single parameter. This index can be used to measure the BWE and RE in the global airline supply chain. An index is an effective way for companies to measure an event's impact on business (Brusset and Bertrand, 2018) and help them increase information transparency. Indeed, Ponte et al. (2020) show that the information transparency may increase or decrease the BWE ratio in closed-loop supply chains. We also analyzed the relationship between the internal risk proxies and the BWE and RE.

6.2. Managerial implications

From the managerial perspective, we believe that the results of our research can contribute to the measurement of BWE and RE throughout the supply chain. There are several ways of measuring financial health in the stock market, such as the S&P 500, Dow Jones Industrial Average, and the Nasdaq Composite. But these indexes represent companies in several industries together. So, the GASI was created for the airline industry and represented companies from different countries around the globe. The GASI is a valuable tool for the global airline supply chain and can be used as a barometer to evaluate the extent of the BWE and RE. Buyer and supplier managers will be able to develop financial analyses that compare their own companies with the global results of global airline companies. The GASI is based on public records and can be updated in real-time.

We found key financial proxies that managers can use in advance to strengthen their business against an outbreak in the supply chain. So, although we refer to the BWE and REs in the supply chain, preventive financial measures and changes in policies can be implemented by individual companies to mitigate supply chain risks.

New economic shocks and supply chain disruptions will occur in the future, and companies could combine the GASI and financial information to formulate their mitigation strategies. Therefore, it is important to be prepared well in advance by working on the DOL and debt to avoid potential losses. The GASI is also a base CAPM, a model that has been tested and validated, which helps companies reduce the costs involved in modeling and designing new information systems.

6.3. Limitations and research directions

This research has its limitations. First, we worked with the airline industry. This industry choice allowed us to use a homogeneous network with different nodes, but limited the extent to which the results can be generalized and applied to other industries. Financial variables and the BWE and RE could be explored for other industries. Second, the data are not exhaustive because they were collected from a database that contained only publicly-listed firms, a sample comprising companies that had shares quoted on the stock market. Although our sample used companies that were representative of the aviation industry, those companies whose financial data had not been published were not used. Any conclusions that are drawn, therefore, should consider the lack of private firms in the sample. Future research might apply the GASI to decide whether the results of this research could be used in different industries or in those that are similar to the aerospace industry. Third, the COVID-19 pandemic is a recent event, so the data collection period was limited. Supply networks are dynamic, and any future research could extend the collection period and compare the results on a timeline.

7. Conclusion

This paper studied the impacts that the COVID-19 crisis had on the bullwhip and ripple effects in the global airline industry. The global supply chain is constantly changing, and disasters and pandemics are part of this new world, but, as the saying goes, “there is nothing new under the sun.” For the past two decades, the airline industry has had to face up to the 9/11 terrorist attacks, the SARS, H5N1, H1N1, and Ebola outbreaks. Neither were any flights possible in European airspace as a result of the eruption of Iceland’s Eyjafjallajökull volcano in 2010. These events led to a reduction in capacity, job losses, and financial insecurity in the industry (Sehl, 2020).

Natural disasters will happen, but we do not know where or when. Since they are of low probability and high impact, it is difficult for managers in any industry to spend physical and financial resources to create preventive plans. But if decision-makers are able to estimate their expected losses, they can respond and create mitigation strategies to minimize them.

This study calls for more attention to be paid to financial information. Indexes are important tools for understanding the financial disruption that can spread through a supply chain network. Global supply chains are vulnerable to disruption transmission. The GASI was created to help managers and researchers estimate and measure the impact of a pandemic on a financial structure. If companies know what financial and non-financial variables impact their BWE and RE, they can manage them more effectively and so handle the bullwhip and ripple effects better.

CRediT authorship contribution statement

Marcia Regina Santiago Scarpin: Conceptualization, Investigation, Writing – original draft. **Jorge Eduardo Scarpin:** Conceptualization, Writing – review & editing. **Nayane Thais Krespi Musial:** Methodology, Formal analysis, Visualization, and Review. **Wilson Toshiro Nakamura:** Validation, Supervision, and Writing- Reviewing Final paper.

References

Bano, G., Khan, N.U., 2021. Terrorism and Pakistan stock exchange: evidence from 'war on terror. Pakistan Journal of Criminology 12 (2), 19–33.

Besiou, M., Van Wassenhove, L.N., 2020. Humanitarian operations: a world of opportunity for relevant and impactful research. Manuf. Serv. Oper. Manag. 22 (1), 135–145.

Bhandari, L.C., 1988. Debt/equity ratio and expected common stock returns: empirical evidence. J. Finance 43 (2), 507–528. https://doi.org/10.1111/j.1540-6261.1988.tb03952.x.

Boissay, F., Gropp, R., 2013. Payment defaults and interfirm liquidity provision. Rev. Finance 17 (6), 1853–1894. https://doi.org/10.1093/rof/rfs045.

Brintrup, A., Wang, Y., Tiwari, A., 2015. Supply networks as complex systems: a network-science-based characterization. IEEE Syst. J. 11 (4), 2170–2181. https://doi.org/10.1109/JSYST.2015.2425137.

Brusset, X., Bertrand, J.L., 2018. Hedging weather risk and coordinating supply chains. J. Oper. Manag. 64, 41–52. https://doi.org/10.1016/j.jom.2018.10.002.

Caniato, F., Gelsomino, L.M., Perego, A., Ronchi, S., 2016. Does finance solve the supply chain financing problem? Supply Chain Manag.: Int. J. 21 (5), 534–549. https://doi.org/10.1108/SCM-11-2015-0436.

Chen, J., Kawaguchi, Y., 2018. Multi-factor asset-pricing models under markov regime switches: evidence from the Chinese stock market. Int. J. Financ. Stud. 6 (2), 54. https://doi.org/10.3390/ijfs6020054.

Chen, T.K., Liao, H.H., Kuo, H.J., 2013. Internal liquidity risk, financial bullwhip effects, and corporate bond yield spreads: supply chain perspectives. J. Bank. Finance 37 (7), 2434–2456. https://doi.org/10.1016/j.jbankfin.2013.02.011.

Choi, W.G., Kim, Y., 2005. Trade credit and the effect of macro-financial shocks: evidence from U.S. panel data. J. Financ. Quant. Anal. 40 (4), 897–925.

Christopher, M., Lee, H., 2004. Mitigating supply chain risk through improved confidence. Int. J. Phys. Distrib. Logist. Manag. 34 (5), 388–396. https://doi.org/10.1108/09600030410545436.

Ding, L., Lam, H.K., Cheng, T.C.E., Zhou, H., 2021. The contagion and competitive effects across national borders: evidence from the 2016 Kumamoto earthquakes. Int. J. Prod. Econ. 235, 108115. https://doi.org/10.1016/j.ijpe.2021.108115.

Dolgui, A., Ivanov, D., Rozhkov, M., 2020. Does the ripple effect influence the bullwhip effect? An integrated analysis of structural and operational dynamics in the supply chain. Int. J. Prod. Res. 58 (5), 1285–1301. https://doi.org/10.1080/00207543.2019.1627438.

Esposito, E., Raffa, L., 2007. Global reorganisation in a high-technology industry: the aircraft industry. Int. J. Glob. Small Bus. 2 (2), 166–184.

Fama, E.F., 1970. Efficient capital markets: a review of theory and empirical work. J. Finance 25 (2), 383–417. https://doi.org/10.2307/2325486.

Fama, E.F., French, K.R., 1992. The cross-section of expected stock returns. J. Finance 47 (2), 427–465. https://doi.org/10.1111/j.1540-6261.1992.tb04398.x.

Fama, E.F., French, K.R., 2006. The value premium and the CAPM. J. Finance 61 (5), 2163–2185. https://doi.org/10.1111/j.1540-6261.2006.01054.x.

Fama, E.F., French, K.R., 2015. A five-factor asset pricing model. J. Financ. Econ. 116 (1), 1–22. https://doi.org/10.1016/j.jfineco.2014.10.010.

Filbeck, G., Kumar, S., Liu, J., Zhao, X., Ellinger, A., 2016. Supply chain finance and financial contagion from disruptions-evidence from the automobile industry. Int. J. Phys. Distrib. Logist. Manag. 46 (4) https://doi.org/10.1108/IJPDLM-04-2014-0082.

Forrester, J., 1958. Industrial dynamics. A major breakthrough for decision makers. Harv. Bus. Rev. 36 (4), 37–66.

Friend, I., Blume, M., 1970. Measurement of portfolio performance under uncertainty. The. The American economic review 60 (4), 561–575.

Gittell, J.H., Cameron, K., Lim, S., Rivas, V., 2006. Relationships, layoffs, and organizational resilience: airline industry responses to September 11. J. Appl. Behav. Sci. 42 (3), 300–329. https://doi.org/10.1177/0021886306286466.

Goodarzi, M., Saen, R.F., 2020. How to measure bullwhip effect by network data envelopment analysis? Comput. Ind. Eng. 139, 105431. https://doi.org/10.1016/j.cie.2018.09.046.

Gupta, A., Mau, R.R., Marion, J.W., 2015. Supply chain risk management in aviation and aerospace manufacturing industry-an empirical study. Int. J. Supply Chain Operat. Resil. 1 (3), 300–317.

Handfield, R.B., Graham, G., Burns, L., 2020. Coronavirus, tariffs, trade wars and supply chain evolutionary design. Int. J. Oper. Prod. Manag. 40 (10), 1649–1660. https://doi.org/10.1108/IJOPM-03-2020-0171.

Hendricks, K.B., Singhal, V.R., 2003. The effect of supply chain glitches on shareholder wealth. J. Oper. Manag. 21 (5), 501–522. https://doi.org/10.1016/j.jom.2003.02.003.

Hendricks, K.B., Singhal, V.R., 2005. An empirical analysis of the effect of supply chain disruptions on long-run stock price performance and equity risk of the firm. Prod. Oper. Manag. 14 (1), 35–52. https://doi.org/10.1111/j.1937-5956.2005.tb00008.x.

Hsiao, C.Y.L., Ai, D., Wei, X., Sheng, N., 2021. The contagious effect of China's energy policy on stock markets: the case of the solar photovoltaic industry. Renew. Energy 164, 74–86. https://doi.org/10.1016/j.renene.2020.08.161.

IATA - International Air Transport Association, 2021. Economic Performance of the Airline Industry. Available from: https://www.iata.org/en/iata-repository/publications/economic-reports/airline-industry-economic-performance—october-2021—report/.

Isaksson, O.H., Seifert, R.W., 2016. Quantifying the bullwhip effect using two-echelon data: a cross-industry empirical investigation. Int. J. Prod. Econ. 171, 311–320. https://doi.org/10.1016/j.ijpe.2015.08.027.

Ivanov, D., Dolgui, A., 2021. OR-methods for coping with the ripple effect in supply chains during COVID-19 pandemic: managerial insights and research implications. Int. J. Prod. Econ. 232, 107921. https://doi.org/10.1016/j.ijpe.2020.107921.

Koh, S.C., Gunasekaran, A., Tseng, C.S., 2012. Cross-tier ripple and indirect effects of directives WEEE and RoHS on greening a supply chain. Int. J. Prod. Econ. 140 (1), 305–317. https://doi.org/10.1016/j.ijpe.2011.05.008.

Lee, H.L., Padmanabhan, V., Whang, S., 1997. Information distortion in a supply chain: the bullwhip effect. Manag. Sci. 43 (4), 546–558. https://doi.org/10.1287/mnsc.43.4.546.

Li, Y., Zobel, C.W., 2020. Exploring supply chain network resilience in the presence of the ripple effect. Int. J. Prod. Econ. 228, 107693. https://doi.org/10.1016/j.ijpe.2020.107693.

Lintner, J., 1965. The valuation of risk assets and the selection of risky investments in stock portfolios and capital budgets. Rev. Econ. Stat. 47 (1), 13–37. https://doi.org/10.2307/1924119.

Myers, S.C., 1977. Determinants of corporate borrowing. J. Financ. Econ. 5 (2), 147–175. https://doi.org/10.1016/0304-405X(77)90015-0.

Negrea, B., Toma, M., 2017. Dynamic CAPM under ambiguity—an experimental approach. J. Behav. Exper. Finan. 16, 22–32. https://doi.org/10.1016/j.jbef.2017.09.001.

Novy-Marx, R., 2011. Operating leverage. Rev. Finance 15 (1), 103–134. https://doi.org/10.1093/rof/rfq019.

Nunes, M.F., 2018. Supply chain contamination: an exploratory approach on the collateral effects of negative corporate events. Eur. Manag. J. 36 (4), 573–587. https://doi.org/10.1016/j.emj.2017.09.003.

Ojha, D., Sahin, F., Shockley, J., Sridharan, S.V., 2019. Is there a performance tradeoff in managing order fulfillment and the bullwhip effect in supply chains? The role of information sharing and information type. Int. J. Prod. Econ. 208, 529–543. https://doi.org/10.1016/j.ijpe.2018.12.021.

Olson, D.L., Wu, D.D., 2010. A review of enterprise risk management in supply chain. Kybernetes 39 (5), 694–706. https://doi.org/10.1108/03684921011043198.

Özelkan, E.C., Lim, C., Adnan, Z.H., 2018. Conditions of reverse bullwhip effect in pricing under joint decision of replenishment and pricing. Int. J. Prod. Econ. 200, 207–223. https://doi.org/10.1016/j.ijpe.2018.03.018.

Pastore, E., Alfieri, A., Zotteri, G., 2019. An empirical investigation on the antecedents of the bullwhip effect: evidence from the spare parts industry. Int. J. Prod. Econ. 209, 121–133. https://doi.org/10.1016/j.ijpe.2017.08.029.

Pellegrino, R., Costantino, N., Tauro, D., 2019. Supply Chain Finance: a supply chain-oriented perspective to mitigate commodity risk and pricing volatility. J. Purch. Supply Manag. 25 (2), 118–133. https://doi.org/10.1016/j.pursup.2018.03.004.

Prasad, E., Wu, E., 2020. April 2020 update to TIGER: the coronavirus collapse is upon us. Available from: https://www.brookings.edu/research/april-2020-update-to-tiger-the-coronavirus-collapse-is-upon-us/.

Ponte, B., Dominguez, R., Cannella, S., Framinan, J.M., 2022. The implications of batching in the bullwhip effect and customer service of closed-loop supply chains. Int. J. Prod. Econ. 244, 108379. https://doi.org/10.1016/j.ijpe.2021.108379.

Ponte, B., Framinan, J.M., Cannella, S., Dominguez, R., 2020. Quantifying the Bullwhip Effect in closed-loop supply chains: the interplay of information transparencies, return rates, and lead times. Int. J. Prod. Econ. 230, 107798. https://doi.org/10.1016/j.ijpe.2020.107798.

Quarshie, A.M., Leuschner, R., 2020. Interorganizational interaction in disaster response networks: a government perspective. J. Supply Chain Manag. 56 (3), 3–25. https://doi.org/10.1111/jscm.12225.

Rappeport, A., Chokshi, N., 2020. Crippled Airline Industry to Get $25 Billion Bailout, Part of it as Loans. Available from: https://www.nytimes.com/2020/04/14/business/coronavirus-airlines-bailout-treasury-department.html.

Sarkar, S., 2018. Optimal DOL (degree of operating leverage) with investment and production flexibility. Int. J. Prod. Econ. 202, 172–181. https://doi.org/10.1016/j.ijpe.2018.05.022.

Schmitt, T.G., Kumar, S., Stecke, K.E., Glover, F.W., Ehlen, M.A., 2017. Mitigating disruptions in a multi-echelon supply chain using adaptive ordering. Omega 68, 185–198. https://doi.org/10.1016/j.omega.2016.07.004.

Sehl, K., 2020. How the Airline Industry Survived SARS, 9/11 the Global Recession and More. Available from: https://apex.aero/articles/aftershocks-coronavirus-impact/.

Serrano, A., Oliva, R., Kraiselburd, S., 2018. Risk propagation through payment distortion in supply chains. J. Oper. Manag. 58–59, 1–14. https://doi.org/10.1016/j.jom.2018.01.003.

Sharpe, W.F., 1964. Capital asset prices: a theory of market equilibrium under conditions of risk. J. Finance 19 (3), 425–442. https://doi.org/10.1111/j.1540-6261.1964.tb02865.x.

Singamneni, S., Yifan, L.V., Hewitt, A., Chalk, R., Thomas, W., Jordison, D., 2019. Additive manufacturing for the aircraft industry: a review. J. Aeronaut. Aero. Eng. 8 (214) https://doi.org/10.4172/2329-6542.1000214.

Song, B., Lee, C., Park, Y., 2013. Assessing the risks of service failures based on ripple effects: a Bayesian network approach. Int. J. Prod. Econ. 141 (2), 493–504. https://doi.org/10.1016/j.ijpe.2011.12.010.

Slot, J.H., Wuyts, S., Geyskens, I., 2020. Buyer participation in outsourced new product development projects: the role of relationship multiplexity. J. Oper. Manag. 66 (5), 578–612. https://doi.org/10.1002/joom.1085.

Sucky, E., 2009. The bullwhip effect in supply chains—an overestimated problem? Int. J. Prod. Econ. 118 (1), 311–322. https://doi.org/10.1016/j.ijpe.2008.08.035.

Tang, C.S., Zimmerman, J.D., Nelson, J.I., 2015. Managing new product development and supply chain risks: the Boeing 787 case. Supply Chain Forum Int. J. 10 (2), 74–86. https://doi.org/10.1080/16258312.2009.11517219.

Wang, X., Disney, S.M., 2016. The bullwhip effect: progress, trends and directions. Eur. J. Oper. Res. 250 (3), 691–701. https://doi.org/10.1016/j.ejor.2015.07.022.

Wuttke, D.A., Blome, C., Henke, M., 2013. Focusing the financial flow of supply chains: an empirical investigation of financial supply chain management. Int. J. Prod. Econ. 145 (2), 773–789. https://doi.org/10.1016/j.ijpe.2013.05.031.

Yan, T., Choi, T.Y., Kim, Y., Yang, Y., 2015. A theory of the nexus supplier: a critical supplier from a network perspective. J. Supply Chain Manag. 51 (1), 52–66. https://doi.org/10.1111/jscm.12070.

Ying, Q., Yousaf, T., Akhtar, Y., Rasheed, M.S., 2019. Stock investment and excess returns: a critical review in the light of the efficient market hypothesis. J. Risk Financ. Manag. 12 (2), 97. https://doi.org/10.3390/jrfm12020097.

Zaremba, A., Kizys, R., Aharon, D.Y., Demir, E., 2020. Infected markets: novel coronavirus, government interventions, and stock return volatility around the globe. Finance Res. Lett. 35, 101597. https://doi.org/10.1016/j.frl.2020.101597.

Zhao, K., Zuo, Z., Blackhurst, J.V., 2019. Modelling supply chain adaptation for disruptions: an empirically grounded complex adaptive systems approach. J. Oper. Manag. 65 (2), 190–212. https://doi.org/10.1002/joom.1009.

Zhaob, R., Mashruwala, R., Pandit, S., Balakrishnan, J., 2019. Supply chain relational capital and the bullwhip effect: an empirical analysis using financial disclosures. Int. J. Oper. Prod. Manag. 39 (5), 658–689. https://doi.org/10.1108/IJOPM-03-2018-0186.

Zhou, H., Yip, W.S., Ren, J., To, S., 2020. An interaction investigation of the contributing factors of the bullwhip effect using a Bi-level social network analysis approach. IEEE Access 8, 208737–208752. https://doi.org/10.1109/ACCESS.2020.3038680.

Zhu, T., Balakrishnan, J., da Silveira, G.J., 2020. Bullwhip effect in the oil and gas supply chain: a multiple-case study. Int. J. Prod. Econ. 224, 107548. https://doi.org/10.1016/j.ijpe.2019.107548.