

The effects of supply chain diversification during the COVID-19 crisis:

Evidence from Chinese manufacturers

Abstract

Resilience amidst a crisis is vital to survival in the turbulent contemporary business environment. Diversifying the supply chain has been proposed as an important means to build this capability. However, there is insufficient empirical evidence demonstrating the merits of supply chain diversification during a crisis. Sampling 1,434 Chinese manufacturing firms amidst the COVID-19 crisis, our two-stage least squares (2SLS) regression analyses show that firms with a diversified supply base are associated with a larger supply stream (increased abnormal inventory) and increased profitability during the COVID-19 crisis, including both the disruption and recovery periods. In addition, firms with a diversified customer base are associated with a larger demand stream (reduced abnormal inventory) during the COVID-19 crisis (both disruption and recovery periods) but show increased profitability only during the recovery period. Our study contributes to the literature on supply chain risk, disruption, diversification, and inventory management. We also discuss the practical implications of supply chain structure design in building resilience.

Keywords: Supply-base diversification, customer-base diversification, supply chain disruption, COVID-19, secondary data, regression

1. Introduction

Currently, lengthy supply chains have made firms vulnerable to turbulent business environments. “Black Swans” present tremendous difficulty for firms in managing their supply chain. The difficulties are reflected by the ever-fluctuating supply and demand caused by supply chain disruptions. The emergence of the COVID-19 crisis in 2020 has been a most critical disruptor of the global supply chain (Choi, 2020; Ivanov, 2020a), which has attracted attention to the topic of supply chain disruption not only in the business world but also in academia. Consequently, resilience, defined in the literature as a firm’s ability to withstand a disruption and recover its performance after a disruption, has become a vital operational priority in addition to traditional cost, quality, flexibility, and delivery considerations. (Ivanov and Dolgui, 2020). According to Ho et al.’s (2015) typology of supply chain risks, the COVID-19 pandemic is a macro-level (external) supply chain risk. Therefore, resilience actually reflects a firm’s risk management capability.

Previous literature has suggested the merits of diversification in coping with supply chain disruption risks (e.g., Hendricks et al., 2009; Whitney et al., 2014). The suggestion follows the conventional wisdom of “don’t put all your eggs in one basket”. Diversification strategies have prevailed in the industry to hedge against uncertainty. For example, according to a Nikkei survey conducted in March-April 2021, more than 80% of Japanese manufacturers had begun diversifying their supply chains, as the COVID-19 pandemic highlights the risks posed by highly streamlined production processes (Nikkei, 2021). Similarly, in Hong Kong, approximately 59% of corporate decision-makers diversified their businesses in the period from 2018 to 2020 to build a more resilient future (HSBC, 2020). Diversification increases a firm’s operational flexibility, which

stabilizes supply and demand by having alternative suppliers and customers when disruptive events occur (Hendricks et al., 2009). However, the literature has also emphasized the hidden costs of having a diversified supply chain. That is, supply chain complexity makes it difficult for firms to coordinate with supply chain partners in response to disruptions (Choi and Krause, 2006). Therefore, it is inconclusive whether supply chain diversification can help firms build resilience, particularly when combating a global crisis.

China, as the world's factory, offers a valuable platform for us to explore this critical issue. As reported by *The Economist* on June 23, 2021, the recent Canton Fair demonstrated the resilience of China's manufacturing sector despite the global economic downturn brought about by the outbreak of the novel coronavirus (*The Economist*, 2021). Thus, drawing on both supply- and customer-based diversification perspectives, this study investigates whether and how a diversifying supply chain influences Chinese manufacturers' resilience during the ongoing global crisis. COVID-19 has been viewed as a supply chain disruptor causing supply-demand mismatches (Ivanov, 2020a). We thus first examine the manufacturers' inventory. In addition, we examine profitability to assess the firms' overall performance during the crisis (Lo et al., 2014).

Sampling 1,434 Chinese listed manufacturers and their top five suppliers and customers, we find that during the COVID-19 crisis (both disruption and recovery periods), firms with a diversified supply base can increase inventory availability, while firms with a diversified customer base can help reduce inventory. Moreover, firms with a diversified supply base enjoy higher profitability during the crisis, whereas firms with a diversified customer base enjoy higher profitability only during the recovery period and not during the COVID-19 disruption period. This study differs

from the extant literature in two respects. First, this study exploits firms' supply chain data to reveal the impacts of customer and supply base diversification directly and separately for the first time. Second, this study separately examines the effect of diversification during a disruption shock and recovery period, using the COVID-19 outbreak as the context. These findings can contribute to the supply chain resilience and diversification literature as well as the operations management (OM) literature. Recommendations for operational managers to build a resilient supply chain are provided in the final section.

2. Literature review

2.1 Supply chain disruption

This study is related to the field of supply chain risk management, because the COVID-19 outbreak is considered as a most salient risk event that affects the availability of the global supply chain (Araz et al., 2020). Supply chain risk is the uncertainty of the occurrence of events that can adversely influence the supply chain, which can lead to operational-, tactical- or strategic-level failures (Ho et al., 2015). Risk events, when they occur, can seriously disrupt a firm's operations. OM scholars have called for a focus on *supply chain risk management*, which refers to “the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity” (Tang, 2006). The literature has substantially discussed risk management in the supply chain following the processes of risk identification (e.g., Neiger et al., 2009), assessment (e.g., Aqlan and Lam, 2015), response and control (e.g., Faisal et al., 2006; Sreedevi and Saranga, 2017). These measures aim to reduce the probability of risk events and the negative impacts when risk events occur.

Supply chain disruption is a usual consequence when supply chain risk events occur (Tang, 2006). A manufacturer facing disruptions may have difficulties acquiring raw materials (supply glitch), maintaining the continuity of production (production disruption), shipping goods in time (transportation disruption) or acquiring customer orders (demand stream disruption). Therefore, the nature of a disruption is that the manufacturer may lose its ability to match demand and supply in a timely and accurate manner (Hendricks and Singhal, 2005a). Such an inability can lead to stockout when supply falls short or overstock when demand falls short. The mismatch can consequently undermine firm performance. The literature documents that supply chain disruption can decrease firm value by 10.28% in the short term (Hendricks and Singhal 2003) and 40% in the long term (Hendricks and Singhal, 2005a). Sales and profitability performance can be undermined by 114% and 92%, respectively, in the year leading up to the disruption (Hendricks and Singhal, 2005b).

The essential negative impact of supply chain disruption requires firms to have the capability to overcome such disruptions (Pettit et al., 2013). The literature has classified the abilities that are vital in the two periods of supply chain disruption. First, firms should be capable of withstanding adverse impacts during the disruption period when unanticipated shocks become manifest (Weick et al., 2008). Second, firms should be capable of restoring normal operations quickly and resuming normal cash flow during the recovery period (Caniato and Rice, 2003; Blackhurst et al. 2011). Ivanov et al. (2017) note that the two periods are equally important, while the latter (recovery) has received substantially less attention. Firms without proper and adaptive recovery measures find it more difficult to resume firm performance (Ivanov et al., 2017). These capabilities of firms to be

alert to, adapt to, and quickly respond to changes brought about by a supply chain disruption constitute a firm's resilience (Ambulkar et al., 2015).

2.2 Diversification and firm resilience

Recent OM studies have begun to explore the factors that can increase a firm's resilience to supply chain disruption. Flexibility has been considered a vital factor enabling firms to overcome disruption (Tang and Tomlin, 2008; Richey et al., 2009; Dubey et al., 2021). Firms may diversify their supply chain to increase flexibility in response to supply chain disruption. For example, in contrast to those with a single-sourcing strategy, firms with a multiple-sourcing strategy have backup suppliers when there are failures on the part of one of the suppliers (Kleindorfer and Saad, 2005; Namdar et al., 2018). The same logic can also apply to diversification in the customer base because supply chain partners involve not only a supply base that is defined as a portion of the tier-one suppliers that can be actively managed by the focal firm through contracts and transactions but also a customer base that is defined as a portion of the tier-one customers that can be actively managed by the focal firm through contracts and transactions (Choi and Krause, 2006; Dong et al., 2020).

However, a diversified supply chain is usually more complex, which can increase the difficulties for firms to coordinate with supply chain partners (Craighead et al., 2007). Poor coordination can reduce a firm's responsiveness to disruptions (Choi and Krause, 2006; Qi et al., 2004; Tang, 2006; Xiao et al., 2007; Giri and Sarker, 2017). Firms need to make additional efforts to coordinate with diversified suppliers and/or customers in response to disruption events (Choi and Krause, 2006). Complex supply and/or customer bases call for a higher information processing capability

(Brandon-Jones et al., 2015), as such complexity increases the number of information flows, physical flows and relations to be managed (Bozarth et al., 2009). Firms with multiple suppliers and/or customers need multiple interfaces to arrange transportation when the supply chain is in disruption (Handfield and Nichols, 1999). In short, extra resources are required for firms to increase information processing capability, especially during a pandemic when the environment is highly turbulent and uncertain. Failure in supplier/customer coordination may cause inconsistent product quality (Jayaram et al., 2011) and additional efforts to configure production capacity.

In this study, we conceptualized supply chain diversification (concentration) as whether the firm concentrates its sourcing (sales) on a few large suppliers and customers. This study contributes to the debate by examining whether firms can perform better with a concentrated or diversified supply chain during the COVID-19 crisis.

3. Hypothesis development

3.1 COVID-19 outbreak in China

The COVID-19 crisis outbreaked in Wuhan, China, in January 2020. The pandemic emerged during the Chinese New Year vacation when migrant workers paused production and returned to their hometowns. Due to the lockdown policy, workers had difficulty traveling back to work, which caused the first wave of disruption in China's manufacturing sector. The shock was continuous in the first quarter of 2020. The factories cautiously resumed production when positive signs emerged in the battle against the virus. By the end of the first quarter of 2020, 90% of large-scale enterprises had resumed production (Wang, 2020). The disruption shock to China's manufacturing sector

generated devastating impacts on the global supply chain, as China is the largest supply base in the world. A survey in February 2020 shows that 94% of the Fortune 1000 were experiencing supply chain disruptions (Sherman, 2020).

The COVID-19 crisis is a unique disruptor compared with traditional disruption events (Chowdhury et al., 2021). First, the scope of the crisis can include all supply chain members even if they are in different locations (Gunessee and Subramanian, 2020). Lockdowns in the supply or demand markets may substantially affect the supply chain flows. Manufacturers may encounter the cutoff of material supply from suppliers or orders from customers because of their pauses in business. Second, COVID-19 is an evolving crisis that is continuously disrupting the global supply chain. After China's first wave of the COVID-19 pandemic was well controlled by the end of the first quarter of 2020, additional lockdowns were imposed by local governments to contain small-scale outbreaks in cities, including Beijing, Shijiazhuang (Hebei), Urumqi (Xinjiang), Ruili (Yunnan) and Guangzhou (Guangdong). These measures further disrupted the business operations in these areas and affected their supply chain partners. These features of COVID-19 provide us with a unique context to understand how the supply chain structure (i.e., diversification) affects a firm's resilience in a turbulent environment, especially when turbulence is persistent across disruption and post-disruption recovery periods.

3.2 The effects of supply base diversification amid COVID-19

A usual consequence of supply chain disruption is a supply-demand mismatch because the disruption can generate supply and/or demand stream cuts (Hendricks and Singhal, 2005a). We thus first examine whether supply chain diversification can help firms stabilize supply and demand

streams. We draw on the flexibility view of diversification to develop the hypothesis (Hendricks et al., 2009). During the first quarter of 2020, the Chinese supply chain was seriously disrupted by the early COVID-19 shock. A firm may have found that its suppliers paused production, which undermines the supply. This condition undermines firms' capability to prepare inventory to sell to customers during this period. For firms concentrating sourcing on major suppliers, any disruption can affect a large proportion of the total supply. However, firms with a diversified supply base have an advantage in overcoming this difficulty because alternative key suppliers are available when failures affect their supply base.

Flexibility logic was also applied to the recovery period. Although most Chinese factories resumed operations in the second quarter of 2020, a few lockdowns were imposed because of small-scale outbreaks in various cities. Disruptive risks in the supply base persisted into this period. Firms with diversified supply bases are thus more well prepared for future disruptions. In addition, additional resources (e.g., expertise, knowledge, social capital) are available when firms have a diversified supply base, which facilitates the return of normal supply chain operations (Hendricks et al., 2009). In summary, the flexibility provided by a diversified supply base helped firms stabilize the supply stream during the pandemic. These arguments are in line with the view that firms with decentralized capacity can mitigate the negative impacts of disruption (Chopra and Sodhi, 2004). This advantage helps firms acquire necessary inputs to increase inventory available to their markets. Therefore, we hypothesize the following:

H1: Amid the COVID-19 pandemic, Chinese manufacturers with a higher supply-base diversification had a higher inventory level than those with a lower diversification.

As discussed in Section 2, however, a diversified supply chain is usually more complex, which may result in higher coordination costs (Choi and Krause, 2006). On the one hand, firms have to make additional efforts to coordinate among multiple suppliers to function smoothly. On the other hand, poor coordination may reduce firms' responsiveness to market change and result in inconsistent product quality (Jayaram et al., 2011). That being said, as analyzed above, firms with diversified supply bases have a more stable supply stream, thus avoiding idle capacity because of insufficient production inputs amid the pandemic. Thus, their capacity utilization can be increased. In addition, firms with a stable supply stream can keep inventory available for production, which enables firms to maintain a stable income stream. Furthermore, maintaining a diversified supply base allows firms to avoid backlogging and penalties, which occur when customer orders are not fulfilled. Such factors have been particularly important during the global pandemic due to the lockdowns implemented worldwide. Focusing on profitability, which measures how cost effective a firm is in delivering products to the market, firms without a diversified supply base may not even be able to generate/maintain revenue during the pandemic. Therefore, we hypothesize the following:

H2: Amid the COVID-19 pandemic, Chinese manufacturers with a higher supply-base diversification had higher profitability than those with a lower diversification.

3.3 The effects of customer base diversification amid COVID-19

Turning to the impact of customer base diversification, as suggested in Section 2, firms with a diversified customer base can also enjoy flexibility. These firms are thus advantaged in coping with supply chain disruptions on the demand side. In the event of a large-scale lockdown, firms concentrated in large customers could be seriously affected because a large proportion of orders

could be cancelled. However, firms with a diversified customer base are still able to use their inventory to produce goods for their other customers that are less affected by the pandemic. In addition, when seriously affected by one customer, the end consumer demand will be shifted to the customer's competitors, which is known as a competitive effect (Hendricks et al., 2020; Ding et al., 2021). Thus, the firm's customers may place additional orders, which compensates for the cancelled orders. Therefore, a diversified customer base can help firms avoid idle inventory because they enjoy a stabilized demand stream. This is in line with the view that supply chain density can affect the severity of the impacts of disruption (Craighead et al., 2007). A stable demand stream was reflected by a decrease in inventory during the COVID-19 pandemic. Therefore, we hypothesize the following:

H3: Amid the COVID-19 pandemic, Chinese manufacturers with a higher customer-base diversification had a lower inventory level than those with a lower diversification.

As discussed above, firms with a diversified customer base have had a stable demand stream amid the pandemic. Thus, these firms can better maintain income flow. Stable demand can also help firms maintain economies of scale in production, allowing these firms to achieve higher profitability. In addition, as indicated in Dhaliwal et al. (2016), there is a positive relationship between a firm's customer concentration and its cost of capital. Thus, firms with a concentrated customer base may suffer from higher costs when acquiring external financial resources to boost sales. The increased cost of capital has also been an essential disadvantage during the COVID-19 pandemic, as many firms required bridge loans to maintain liquidity. Based on the above arguments, we hypothesize the following:

H4: Amid the COVID-19 pandemic, Chinese manufacturers with a higher customer-base

diversification had higher profitability than those with a lower diversification.

Figure 1 provides a summary of the four hypotheses developed in this section.

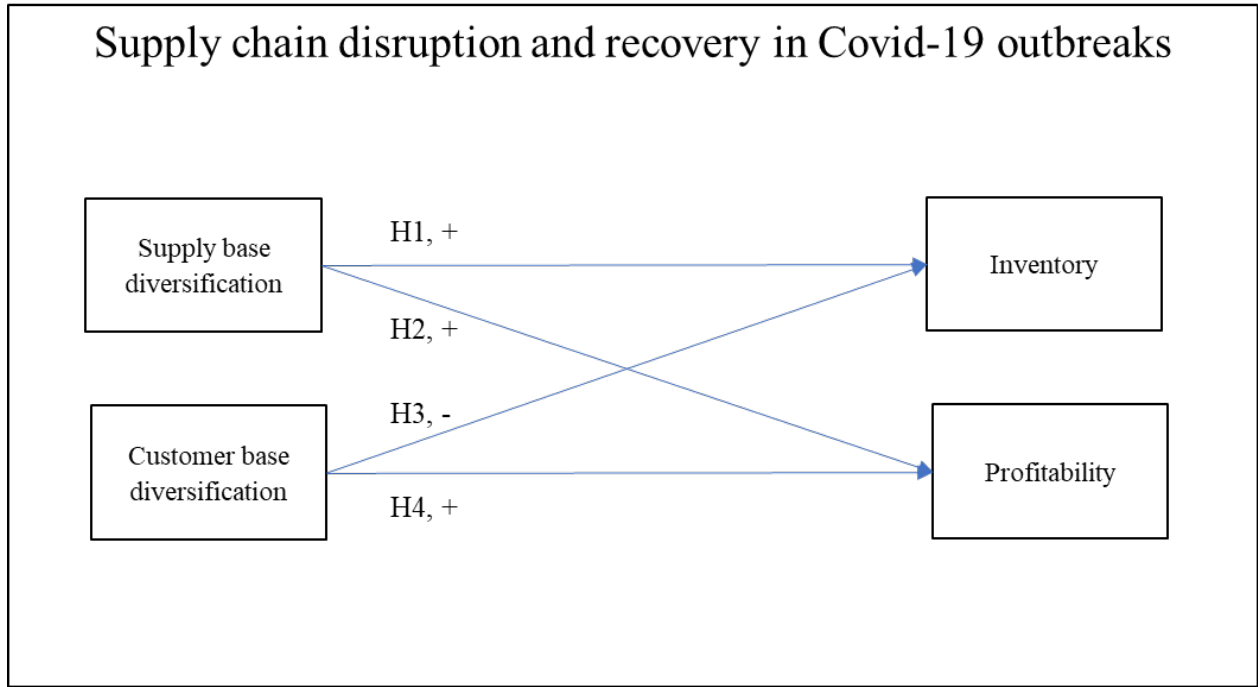


Figure 1. Hypotheses

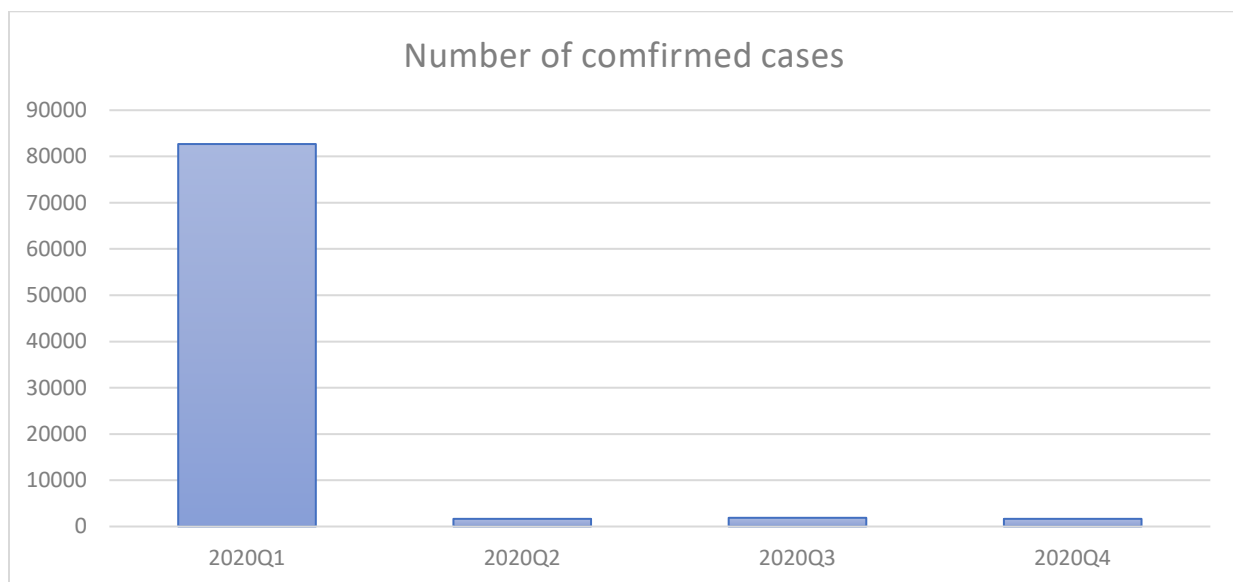
4. Data and methodology

4.1 Data

To test our hypotheses, secondary data on Chinese manufacturing firms (Category C in the industrial classification) listed on the Shanghai/Shenzhen Stock Exchange were obtained from China Security Market and Accounting Research (CSMAR). Specifically, we obtained supply chain diversification information from the supply chain research database of CSMAR, corporate

governance characteristics (as control variables) from the corporate governance database and institutional investor database of CSMAR, and financial information and other controls from the financial statements database of CSMAR. Given that supply chain diversification is our key construct, all manufacturing firms in the CSMAR database that had customer and supplier network data at year 2019 were first identified, which gave us an initial 1,648 firms. The base year of this research is 2019, when the COVID-19 crisis was not salient. Our empirical strategy for the primary models is to examine whether the different levels of supply chain diversification firms had in 2019 predicts their abnormal inventory growth and profitability in 2020. We used quarterly data as the interval of analysis.

In the post hoc analyses, we separated the samples into two. The first sub-sample used data from quarter 1 (Q1), and the second one used data from Q2 to Q4. We divided the data in this way because the pandemic situations in China in quarter 1 (Q1) and Q2-Q4 of 2020 were significantly different. Figure 2 shows China's COVID-19 confirmed cases in the four quarters of 2020.



Source: the COVID-19 & Economic Research module of CSMAR database

Figure 2. Confirmed COVID-19 cases in China

Specifically, we defined Q1 as the disruption shock period caused by COVID-19. This is because manufacturers paused production during the Chinese New Year vacation, while the pandemic outbreak extended the pause, thus causing serious disruptions. Given that 90% of large-scale enterprises resumed production by the end of Q1 (Wang, 2020) and that the pandemic was well contained from Q2 to Q4, we defined Q2 to Q4 of 2020 as the post-disruption recovery period. Figure 3 shows that the Chinese economy in Q2 and Q4 was trying to recover the losses experienced in Q1. Appendix A summarizes the data set development process. After combining the supply chain data with the corporate governance and financial data, we discarded 54 firms with abnormal statuses of special treatment (ST) and 111 firms with missing values for abnormal inventory growth, as well as 49 firms with missing values for control variables in 2019 or 2020. Thus, the final data set consists of 1,434 firms. The full sample (2020Q1 to 2020Q4) consists of 4,460 firm-quarter observations. The disruption period (2020Q1) consists of 1407 firm-quarter observations, while the recovery period (2020Q2 to 2020Q4) consists of 3,053 observations.



Source: National Bureau of Statistics of China

Figure 3. Year-to-year changes in GDP of China in 2020

4.2 Methodology

4.2.1 Dependent variable: inventory level and profitability

To measure the magnitude of the inventory shock caused by COVID-19, we used abnormal inventory growth (AIG). Specifically, following Kesavan et al. (2010), the expectation model of growth in inventory per firm was used to measure firm AIG. We used a specification to model inventory per firm in a given quarter in 2020 as depending on a firm fixed effect (J_i), inventory in the previous year ($IS_{i,t-4}$), contemporaneous and lagged cost-of-goods-sold ($CS_{i,t}$, $CS_{i,t-4}$), gross margin ($GM_{i,t}$), lagged accounts payable to inventory ratio ($PI_{i,t-4}$), fixed assets growth ($G_{i,t}$),¹ and

¹ The AIG algorithm proposed by Kesavan et al. (2010) is based on the inventory level of the US retail industry. American retail companies usually disclose information about the number of stores (for example, Kesavan et al., 2010 and Kesavan and Mani., 2013), and the growth rate of the number of stores is usually a good measure of the growth of retail companies. However, this indicator is not suitable for Chinese manufacturing companies. First, Chinese manufacturing companies do not disclose information about the number of stores. Second, compared to retail companies using the growth of the number of stores as a measure of corporate growth, for the manufacturing industry, the growth of fixed assets is a more effective measure of the growth of manufacturing companies.

lagged capital investment ($CAPS_{i,t-4}$). These factors were adopted from Keasavan et al. (2010) and Keasavan and Mani (2013). The inventory for firm i in quarter t was given as

$$IS_{i,t} = J_i + \beta_2 X'_{i,t} + \eta_{i,t} \quad (1)$$

where $X'_{i,t}$ is a column vector of all right-hand-side explanatory variables; $X'_{i,t} = (1, CS_{i,t}, GM_{i,t}, CS_{i,t-4}, IS_{i,t-4}, PI_{i,t-4}, G_{i,t}, CAPS_{i,t-4})'$; and β_2 is the row vector of the corresponding coefficients, $\beta_2 = (\beta_{20}, \beta_{21}, \beta_{22}, \beta_{23}, \beta_{24}, \beta_{25}, \beta_{26}, \beta_{27})'$.

This underlying level model was then first differenced to obtain the following growth model:

$$\Delta IS_{i,t} = \Delta X'_{i,t} \beta_2 + \Delta \eta_{i,t} \quad (2)$$

where Δ denotes the change in the variable in quarter t from quarter $t-4$.²

One may treat all coefficients β_2 in the above regression as firm specific, i.e., allowing the sensitivity of inventory to different factors such as COGS, gross margin, accounts payable to inventory ratio, fixed asset growth, and capital investment, to vary from firm to firm. However, to estimate such a model, we would need a long time-series of observations for each firm. Because our analysis used quarterly data from 2020, we lacked sufficient data for each firm to estimate such a model. To overcome the paucity of data, Kesavan and Mani (2013) assume that all firms in a given segment are homogeneous. Due to data limitations, we also assumed that all firms in each 2-digit industry code are homogeneous. Thus, the estimation model is:

$$\Delta IS_{i,t} = \Delta X'_{i,t} \beta_{2,ind(i)} + \Delta \eta_{i,t} \quad (3)$$

where $ind(i)$ denotes the corresponding industry-specific coefficients for firm i .

² We appreciate the reviewer's comments. Given that the analysis interval is one quarter, we mitigate the seasonal effect by using the year-to-year changes in the quarterly data from 2019 to 2020.

We can now obtain the expected inventory growth from the above equation, $E(\Delta IS_{i,t})$, and then compute AIG in the following way. Let $\{IS_{i,t}/IS_{i,t-4} - 1\}$ denote the actual inventory growth and $AIG_{i,t} = (\{IS_{i,t}/IS_{i,t-4} - 1\} - (E(\Delta IS_{i,t}) - 1))$ denote the abnormal inventory growth. $AIG_{i,t} > 0$ implies that firm i has abnormally high inventory growth, whereas $AIG_{i,t} < 0$ implies that firm i has abnormally low inventory growth compared to the norm of the industry to which the firm belongs after controlling for firm-level differences. The differencing technique also mitigates the seasonality in the quarterly inventory data.

Profitability was measured by the change in return on sales (ΔROS) in quarter t from quarter $t-4$. Following Corbett et al. (2005), ROS was calculated as net income divided by total sales, indicating the percentage of the sales price that is turned into profit. It is an indicator of a company's pricing strategies and how well it controls costs. A greater ROS represents higher profitability. Given that the analysis interval is one quarter, we mitigate the seasonality of ROS by using the year-to-year changes in the quarterly data from 2019 to 2020.

4.2.2 Independent variables

Previous studies (e.g., Patatoukas, 2012; Dhaliwal et al., 2016) have used the Herfindahl-Hirschman Index (HHI) to capture customer concentration. To measure supplier and customer diversification, we employed the reverse HHI. Specifically, it was calculated by squaring the market share of the five largest suppliers (customers) and then summing the resulting numbers as follows:

$$\text{Supplier (customer) diversification} = -\sum_{j=1}^5 \left(\frac{\text{Sales}_{i,j,t}}{\text{Sales}_{i,t}} \right)^2 \quad (4)$$

where $\text{Sales}_{i,j,t}$ refers to firm i 's purchases from major supplier or sales to major customer j in year t and $\text{Sales}_{i,t}$ refers to firm i 's total purchases or sales in year t . Supplier (customer) diversification ranges between -1 and 0, with higher values representing greater supplier (customer) diversification. We standardized supplier (customer) diversification at the 2-digit industry code to mitigate the confounding effects of industry-level variations. We used the market share of the top five largest suppliers/customers to compute the reverse HHI because listed firms in China only disclose sales/purchases for their five largest suppliers/customers. In addition, given that supply chain data are available yearly and the firm's top five suppliers (customers) are relatively stable, we used 2019 data for these two variables.

4.2.3 Control variables

In addition to the independent variables, we included a set of control variables to account for relevant factors that might impact the dependent and independent variables. Firm size was measured by the natural logarithm of total assets (Francis et al., 2016). Debt pressure was measured by the ratio of the book value of debt to the market value of equity, indicating firm limitations concerning financial slack (Schmidt et al., 2020). Firm age was measured by the number of years the firm has operated, representing operational experience (Fan et al., 2020). Firms that are larger, have less debt pressure, and have more operational experience have more abundant resources and established processes (Romanelli and Tushman, 1994; Saint-Germain, 2005), which would enhance firm resilience. R&D intensity was calculated by the ratio of R&D expenses to total sales (Dong et al., 2020). Innovative firms are more inclined to develop novel ideas and solutions to cope with external shocks and unforeseen changes in the environment (Teece, 2007) that can

enhance the firm's resilience to supply chain disruptions (Golgeci and Ponomarov, 2013). Production efficiency and marketing efficiency were measured by the ratio of sales to fixed assets and the ratio of sales to the sum of selling, general and administrative expenses, standardized according to the industry mean and standard deviation (two-digit industry code), respectively (Lu and Shang, 2017). Low efficiency in utilizing various firm production and marketing resources harms firm performance (Lu and Shang, 2017) thereby reducing firm resilience.

Following Hendricks and Singhal (2009), market share was calculated by a percentage measure of market share at the two-digit industry code level. A firm's market share reflects whether it is a large or small player in the industry (bargaining power), which may influence firm resilience. We further control for corporate governance characteristics since corporate governance involves the deployment of firm resources and the alignment of the diverse interests of all stakeholders (Daily et al., 2003). Corporate governance relates to high-level strategic decisions and may affect firm resilience. Following Francis et al. (2016), we employed three measures of corporate governance characteristics. Board size is calculated as the natural logarithm of the number of board members. Board independence is measured by the ratio of the number of independent directors to the total number of directors. Institutional ownership is the percentage of shares owned by institutional investors. To capture overseas sales, the reverse HHI by using the geographic location of a firm's sales in foreign and domestic markets is used to control for geographical diversification (Sun et al., 2019). Higher values represent greater international diversification. Table 1 summarizes the description of all variables.

Table 1. Variable definition

Variable	Description	Source	Reference
ΔROS	The change in return on sales between quarter t and t-4.	CSMAR-Financial statements	Corbett et al. (2005)
AIG	Quarterly abnormal inventory growth	CSMAR-Financial statements	Kesavan et al. (2010)
Supplier diversification	Reverse supplier HHI based on top 5 suppliers, standardized at the 2-digit industry level	CSMAR- Supply chain research	Patatoukas (2012)
Customer diversification	Reverse customer HHI based on top 5 customers, standardized at the 2-digit industry level	CSMAR-Supply chain research	Dhaliwal et al. (2016)
Firm Size	The natural logarithm of total assets	CSMAR-Financial statements	Francis et al. (2016)
Debt pressure	Total debt divided by the market value of equity	CSMAR-Financial statements	Schmidt et al. (2020)
Firm age	The natural logarithm of the number of years a firm has operated	CSMAR-Chinese listed firm's basic information	Fan et al. (2020)
R&D	The ratio of R&D expenses to total sales	CSMAR-Financial statements	Dong et al. (2020)
Production efficiency	Sales divided by fixed assets, standardized at the 2-digit industry level	CSMAR-Financial statements	Lu and Shang (2017)
Marketing efficiency	Sales divided by the sum of selling, general and administrative expenses, standardized at the 2-digit industry level	CSMAR-Financial statements	Lu and Shang (2017)
Market share	Sales divided by total sales across firms within the same 2-digit industry code	CSMAR-Financial statements	Hendricks and Singhal (2009)
Board size	The natural logarithm of the number of board members	CSMAR-Corporate governance	Francis et al. (2016)
Ind. directors	The ratio of the number of independent directors to the total number of directors	CSMAR-Corporate governance	Francis et al. (2016)
Institutional ownership	The percentage of institutional ownership	CSMAR-Institutional Investor	Francis et al. (2016)
Geographical diversification	Reverse sales HHI based on foreign and domestic markets	CSMAR- Footnotes to Financial statements	Sun et al. (2019)

4.2.4 Endogeneity and estimation method

Despite the multiple control variables that are included in the analysis, there may still be endogeneity issues. Endogeneity concerns may arise due to reverse causality. In our model, the independent variables have a time lag with respect to the dependent variables. Therefore, the odds of reverse causality are reduced. However, endogeneity may also arise from the confounding effects of unobserved variable(s); the associations in the regression models may occur because both the independent and dependent variables are related to an unobserved variable (Wooldridge, 2015). For example, firms with managers with better management skills may have the capability to manage diversified supply chains and achieve better profitability. Therefore, we use the two-stage least squares (2SLS) estimation first developed by Theil (1953) and Basmann (1957) to address endogeneity problems.

Following Campa and Kedia (2002) and Tong (2011), in the first stage, we included an industry's average customer (supplier) diversification and firm-specific characteristics as explanatory variables to estimate the diversification level. Lang and Stulz (1994) and Maksimovic and Phillips (2002) suggest that industry characteristics influence the decision to diversify. Following Tong (2011), the average industry customer (supplier) diversification was measured by the average reverse customer (supplier) HHI based on the top 5 customers in the firm's two-digit industry classification code (developed by the China Securities Regulatory Committee). Firm-specific characteristics might also influence the decision to diversify. Following Campa and Kedia (2002) and Tong (2011), firm-specific characteristics included firm size, profitability, investment and their lagged values. We controlled for firm size as the logarithm of sales and firm profitability as the ratio of earnings before interest and taxes (EBIT) to assets. Larger, more profitable firms were

more likely to have more resources to diversify their supply chain and then improve firm resilience. Capital expenditures were used to capture firm investment, measured by the ratio of capital expenditures to assets. Firms with a high level of investment might diversify their supply chain more actively since it would help them to enhance firm resilience. Appendix B presents the results of the first-stage regression analysis. In the second stage, we used the fitted value from the first stage as an instrument for diversification to evaluate the effect of supplier (customer) diversification on firms' inventory level and profitability. Our model takes the following general form:

The first-stage regression:

$$\begin{aligned} & \text{Supplier (Customer) diversification} \\ &= f(\text{Industry supplier (customer) diversification, controls'}) \end{aligned} \quad (5)$$

where supplier (customer) diversification was supply chain diversification, industry supplier (customer) diversification was the industry's average customer (supplier) diversification, and the control variables included firm size, profitability, investment and their lagged values.

The second-stage regression is as follows:

$$\begin{aligned} & \text{Firm's inventory level} \\ &= f(\text{Predicted supplier (customer) diversification, controls}) \end{aligned} \quad (6)$$

$$\begin{aligned} & \text{Firm's profitability} \\ &= f(\text{Predicted supplier (customer) diversification, controls}) \end{aligned} \quad (7)$$

where a firm's inventory level was measured by AIG, profitability was measured by ROS, predicted supplier (customer) diversification was the predicted value of supplier (customer) diversification from the first-stage regression, and the control variables included firm size, debt

pressure, firm age, R&D intensity, production efficiency, marketing efficiency, market share, board size, board independence, institutional ownership and geographical diversification.

5. Empirical results

Table 2 presents the descriptive statistics and the correlations among the variables subjected to regression analysis. Concerns about multicollinearity are not critical since most of the correlation coefficients among the key variables are lower than 0.50 and no variance inflation factor (VIF) is larger than 4.

5.1 Full period (Q1 to Q4)

We performed the analysis for the entirety of 2020 to examine the overall impacts of supply chain diversification. These results were used as the primary tests of the hypotheses. Table 3 presents the results of our analysis during the whole period. Model 1 in Table 3 examined the hypothesized effect of supply-base diversification (H1) and customer-base diversification (H3) on the firm inventory level. The impact of supplier diversification on AIG is significantly positive ($\beta = 0.062$, p value = 0.000). The result confirms that Chinese manufacturers with higher supply-base diversification had a higher inventory level than those with lower diversification during the COVID-19 pandemic, supporting H1. The result shows a significantly negative impact of customer diversification on AIG ($\beta = -0.052$, p value = 0.000). This suggests that amid the COVID-19 pandemic, Chinese manufacturers with higher customer-base diversification had a lower inventory level than those with lower diversification, supporting H3.

Model 2 in Table 3 examined the hypothesized effect of supply-base diversification (H2) and customer-base diversification (H4) on profitability. The impact of supplier diversification on the change in ROS is positive and significant ($\beta = 0.039$, p value = 0.000). This result suggests that amid the COVID-19 pandemic, Chinese manufacturers with higher supply-base diversification had higher profitability than those with lower diversification, supporting hypothesis H2. The impact of customer diversification on the change in ROS is not significant ($\beta = 0.004$, p value = 0.518), suggesting that customer-base diversification had no significant effect on profitability in 2020 as a whole.

Table 2. Descriptive statistics and correlation matrix

Variable	Mean	S.D.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Panel A: Full period																
AIG	-0.051	0.292	1.000													
ΔROS	-0.019	0.276	-0.022	1.000												
Supplier diversification	-0.046	0.070	-0.025*	0.082***	1.000											
Customer diversification	-0.047	0.077	-0.000	0.043***	0.142***	1.000										
Firm Size	22.003	1.091	-0.025*	0.029**	0.064***	0.044***	1.000									
Debt pressure	0.249	0.166	-0.121***	0.035**	0.033**	0.014	0.609***	1.000								
Firm age	2.963	0.265	-0.015	-0.001	-0.042***	0.019	0.095***	0.062***	1.000							
R&D	0.047	0.042	0.025*	0.044***	0.073***	-0.069***	-0.244***	-0.302***	-0.121***	1.000						
Production efficiency	-0.023	0.964	-0.022	0.002	-0.094***	-0.014	0.016	-0.028*	0.017	-0.078***	1.000					
Marketing efficiency	0.004	0.988	0.037**	0.009	-0.133***	-0.126***	0.249***	0.206***	0.013	-0.274***	0.220***	1.000				
Market share	0.010	0.023	0.056***	0.001	0.028*	0.073***	0.466***	0.263***	0.055***	-0.211***	0.123***	0.178***	1.000			
Board size	2.081	0.189	0.023	0.013	0.057***	0.017	0.231***	0.139***	0.100***	-0.092***	-0.001	0.095***	0.076***	1.000		
Ind. directors	0.380	0.055	-0.023	-0.003	-0.019	0.011	-0.025*	0.010	-0.003	0.034**	-0.038**	-0.064***	0.028*	-0.624***	1.000	
Institutional ownership (%)	35.512	23.727	0.035**	-0.007	-0.027*	-0.023	0.348***	0.102***	0.108***	-0.139***	0.027*	0.133***	0.230***	0.164***	-0.049***	1.000
Geographical diversification	-0.965	0.107	0.019	0.048***	0.046***	0.009	0.001	-0.008	-0.019	0.084***	0.035**	-0.010	-0.042***	-0.042***	0.056***	0.010
Panel B: Disruption period																
AIG	0.007	0.297	1.000													
ΔROS	-0.063	0.290	0.000	1.000												
Supplier diversification	-0.046	0.069	-0.045*	0.080***	1.000											
Customer diversification	-0.048	0.079	0.019	0.051*	0.141***	1.000										
Firm Size	21.985	1.087	0.045*	0.035	0.062**	0.053**	1.000									
Debt pressure	0.238	0.160	-0.061**	0.014	0.017	0.019	0.612***	1.000								
Firm age	2.963	0.265	0.022	-0.014	-0.027	0.023	0.099***	0.063**	1.000							
R&D	0.046	0.043	-0.008	-0.043	0.058**	-0.077***	-0.266***	-0.296***	-0.140***	1.000						
Production efficiency	-0.092	0.903	-0.003	0.034	-0.091***	0.002	0.026	-0.045*	0.031	-0.090***	1.000					
Marketing efficiency	-0.015	0.975	0.062**	0.064**	-0.137***	-0.110***	0.239***	0.172**	0.036	-0.300***	0.243***	1.000				
Market share	0.010	0.023	0.118***	0.026	0.026	0.074***	0.462***	0.251***	0.055**	-0.207***	0.137***	0.188***	1.000			
Board size	2.081	0.190	0.037	0.022	0.060**	0.012	0.227***	0.130***	0.102***	-0.110***	0.016	0.105***	0.081***	1.000		
Ind. directors	0.380	0.055	-0.031	-0.018	-0.021	0.012	-0.024	0.013	-0.008	0.052**	-0.052*	-0.075***	0.025	-0.625***	1.000	
Institutional ownership (%)	35.421	23.771	0.060**	0.017	-0.029	-0.024	0.329***	0.098***	0.107***	-0.146***	0.046*	0.128***	0.224***	0.158***	-0.045*	1.000
Geographical diversification	-0.966	0.106	0.023	0.064**	0.048*	0.007	0.002	-0.006	-0.019	0.068**	0.044	-0.025	-0.044	-0.045*	0.058**	0.020
Panel C: Recovery period																
AIG	-0.078	0.285	1.000													
ΔROS	0.002	0.268	-0.011	1.000												
Supplier diversification	-0.046	0.070	-0.016	0.084***	1.000											
Customer diversification	-0.047	0.077	-0.008	0.039**	0.143***	1.000										
Firm Size	22.011	1.093	-0.056***	0.025	0.065***	0.040**	1.000									
Debt pressure	0.254	0.168	-0.141***	0.037**	0.040**	0.011	0.608***	1.000								
Firm age	2.963	0.265	-0.032*	0.005	-0.049***	0.018	0.094***	0.061***	1.000							
R&D	0.048	0.041	0.048***	0.085***	0.081***	-0.065***	-0.234***	-0.308***	-0.112***	1.000						
Production efficiency	0.009	0.989	-0.021	-0.020	-0.095***	-0.022	0.011	-0.025	0.011	-0.075***	1.000					
Marketing efficiency	0.012	0.993	0.029	-0.020	-0.132***	-0.134***	0.253***	0.220***	0.003	-0.263***	0.210***	1.000				
Market share	0.010	0.023	0.027	-0.012	0.028	0.073***	0.467***	0.269***	0.055***	-0.213***	0.117***	0.173***	1.000			
Board size	2.081	0.188	0.016	0.009	0.055***	0.020	0.233***	0.144***	0.098***	-0.084***	-0.009	0.091***	0.074***	1.000		
Ind. directors	0.380	0.055	-0.020	0.004	-0.018	0.011	-0.026	0.008	-0.001	0.026	-0.032*	-0.059***	0.029	-0.624***	1.000	
Institutional ownership (%)	35.554	23.711	0.024	-0.019	-0.027	-0.023	0.356***	0.103***	0.109***	-0.135***	0.019	0.135***	0.233***	0.167***	-0.050***	1.000
Geographical diversification	-0.965	0.107	0.018	0.040**	0.045**	0.010	0.001	-0.009	-0.019	0.091***	0.031*	-0.003	-0.041**	-0.040**	0.055***	0.005

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 3. Supply chain diversification and firm inventory and profitability during the full period (N=4460)

Dependent variable:	AIG			Δ ROS		
	Model 1			Model 2		
	Coef.	Std. errors	p-value	Coef.	Std. errors	p-value
Supplier diversification	0.062***	0.009	0.000	0.039***	0.008	0.000
Customer diversification	-0.052***	0.007	0.000	0.004	0.007	0.518
Firm Size	-0.013*	0.007	0.068	-0.022***	0.007	0.002
Debt pressure	-0.250***	0.034	0.000	0.075**	0.033	0.022
Firm age	-0.008	0.016	0.614	0.005	0.016	0.750
R&D	0.126	0.111	0.257	0.338***	0.107	0.002
Production efficiency	-0.019***	0.005	0.000	-0.004	0.004	0.342
Marketing efficiency	0.016***	0.005	0.000	-0.001	0.005	0.829
Market share	1.021***	0.215	0.000	-0.198	0.208	0.341
Board size	0.036	0.030	0.229	0.009	0.029	0.767
Ind. directors	-0.041	0.101	0.687	-0.016	0.097	0.872
Institutional ownership (%)	0.000	0.000	0.152	-0.000	0.000	0.373
Geographical diversification	0.059	0.040	0.142	0.114***	0.038	0.003
Constant	0.346*	0.177	0.051	0.470***	0.171	0.006
Quarter FE	Yes			Yes		
F statistics	18.465***		0.000	8.424***		0.000
R ²	0.062			0.029		
Adjusted R ²	0.059			0.026		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

5.2 Post hoc analyses

In addition to the primary results, we separated the full sample to examine the effects of supply chain diversification in different stages of the COVID-19 crisis in China.

5.2.1 Disruption period (Q1)

Table 4 presents the results of our analysis of the COVID-19 outbreak in Q1 of 2020. Model 1 in Table 4 examined the hypothesized effect of supply-base diversification (H1) and customer-base diversification (H3) on the firm inventory level. The impact of supplier diversification on AIG is significantly positive ($\beta = 0.093$, p value = 0.000). The result confirms that Chinese manufacturers with higher supply-base diversification had higher inventory availability than those with lower diversification during the COVID-19 pandemic, further supporting H1. The result shows a significantly negative impact of customer diversification on AIG ($\beta = -0.076$, p value = 0.000).

This suggests that amid the COVID-19 pandemic, Chinese manufacturers with higher customer-base diversification had a lower inventory level than those with lower diversification, further supporting H3.

Model 2 in Table 4 examined the hypothesized effect of supply-base diversification (H2) and customer-base diversification (H4) on profitability. The impact of supplier diversification on the change in ROS is significantly positive ($\beta = 0.081$, p value = 0.000). This result confirms that Chinese manufacturers with higher supply-base diversification had higher profitability than those with lower diversification during the COVID-19 pandemic, further supporting H2. The result shows a significantly negative impact of customer diversification on the change in ROS ($\beta = -0.024$, p value = 0.000). This suggests that amid the COVID-19 pandemic, Chinese manufacturers with higher customer-base diversification had lower profitability than those with lower diversification. The result is contrary to H4.

The surprising result refuting H4 echoes the supply chain complexity argument that additional efforts were required for firms to manage different customers. We thus interviewed two industry practitioners to understand why this drawback outweighs the merits of customer diversification amidst the COVID-19 disruption. The two practitioners are managers with over 10 years of experience in China's pharmaceutical and electronic manufacturing sectors. Both informants proposed that this is because of the difficulties of reconfiguring capacity for different customers early in the COVID-19 pandemic. Chinese manufacturing sectors are export oriented. When firms have key customers located in different countries, customizations are required to fulfill unstable and diverse requirements. In addition, logistic costs and instability dramatically increase the

delivery costs of Chinese manufacturers. Therefore, although firms can obtain orders with diversified customer bases amidst the early COVID-19 pandemic, the costs to fulfill the demand increased.

Table 4. Supply chain diversification and firm inventory and profitability during the disruption period (N=1407)

Dependent variable:	AIG			Δ ROS		
	Model 1			Model 2		
	Coef.	Std. errors	p-value	Coef.	Std. errors	p-value
Supplier diversification	0.093***	0.008	0.000	0.081***	0.015	0.000
Customer diversification	-0.076***	0.007	0.000	-0.024*	0.012	0.059
Firm Size	-0.008	0.007	0.559	-0.035***	0.013	0.007
Debt pressure	-0.216***	0.033	0.001	0.008	0.063	0.893
Firm age	0.028	0.016	0.352	-0.016	0.029	0.593
R&D	0.094	0.107	0.633	-0.216	0.195	0.268
Production efficiency	-0.023**	0.004	0.011	-0.003	0.009	0.717
Marketing efficiency	0.015*	0.005	0.079	0.009	0.009	0.300
Market share	1.445***	0.208	0.000	-0.105	0.386	0.786
Board size	0.006	0.029	0.916	0.004	0.054	0.944
Ind. directors	-0.157	0.097	0.393	-0.080	0.182	0.660
Institutional ownership (%)	0.000	0.000	0.360	-0.000	0.000	0.981
Geographical diversification	0.078	0.038	0.283	0.179**	0.072	0.013
Constant	0.235	0.171	0.463	0.949***	0.318	0.003
Quarter FE	No			No		
F statistics	7.130***		0.000	3.706***		0.000
R ²	0.062			0.033		
Adjusted R ²	0.054			0.024		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

5.2.2 Recovery period (Q2 to Q4)

Table 5 shows the results of our analysis during the recovery period (Q2-Q4 of 2020). Model 1 in Table 5 examined the hypothesized effect of supply-base diversification (H1) and customer-base diversification (H3) on the firm inventory level. The impact of supplier diversification on AIG is significantly positive ($\beta = 0.048$, p value = 0.000). The result confirms that Chinese manufacturers with higher supply-base diversification had a higher inventory level than those with lower diversification during the COVID-19 pandemic, further supporting H1. The result shows a significantly negative impact of customer diversification on AIG ($\beta = -0.041$, p value = 0.000).

This suggests that amid the COVID-19 pandemic, Chinese manufacturers with higher customer-base diversification had a lower inventory level than those with lower diversification, further supporting H3.

Model 2 in Table 5 examined the hypothesized effect of supply-base diversification (H2) and customer-base diversification (H4) on profitability. The impact of supplier diversification on the change in ROS is significantly positive ($\beta = 0.019$, p value = 0.055). This result confirms that Chinese manufacturers with higher supply-base diversification had higher profitability than those with lower diversification during the COVID-19 pandemic, further supporting H2. The result shows a significantly positive impact of customer diversification on the change in ROS ($\beta = 0.018$, p value = 0.023). This finding suggests that amid the COVID-19 pandemic, Chinese manufacturers with higher customer-base diversification had higher profitability than those with lower diversification, supporting H4.

Table 5. Supply chain diversification and firm inventory and profitability during the recovery period (N=3503)

Dependent variable:	AIG			Δ ROS		
	Model 1			Model 2		
	Coef.	Std. errors	p-value	Coef.	Std. errors	p-value
Supplier diversification	0.048***	0.010	0.000	0.019*	0.010	0.055
Customer diversification	-0.041***	0.009	0.000	0.018**	0.008	0.023
Firm Size	-0.015*	0.009	0.070	-0.016**	0.008	0.050
Debt pressure	-0.261***	0.040	0.000	0.109***	0.038	0.004
Firm age	-0.025	0.019	0.199	0.013	0.018	0.487
R&D	0.159	0.134	0.237	0.628***	0.127	0.000
Production efficiency	-0.018***	0.005	0.001	-0.004	0.005	0.396
Marketing efficiency	0.017***	0.006	0.002	-0.005	0.005	0.303
Market share	0.831***	0.258	0.001	-0.236	0.245	0.335
Board size	0.050	0.036	0.169	0.009	0.034	0.798
Ind. directors	0.011	0.121	0.925	0.015	0.114	0.892
Institutional ownership (%)	0.000	0.000	0.244	-0.000	0.000	0.283
Geographical diversification	0.049	0.048	0.308	0.081*	0.045	0.073
Constant	0.301	0.212	0.155	0.310	0.201	0.122
Quarter FE	Yes			Yes		
F statistics	9.150***		0.000	4.913***		0.000
R2	0.043			0.024		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

In summary, we find that firms with a diversified supply base can increase their inventory availability and profitability during the disruption period (Q1 of 2020), recovery period (Q2 to Q4) and the whole period (Q1 to Q4) of the crisis. In addition, firms with a diversified customer base can reduce their inventory, reflecting a more stable demand stream during the disruption period (Q1 of 2020), recovery period (Q2 to Q4) and the whole period (Q1 to Q4). However, customer-base diversification has no significant effect on profitability in 2020 as a whole. This is likely because the beneficial effects that of customer diversification on profitability in the recovery period were compensated for by its negative impacts in the disruption period. Thus, we identify the boundary condition for H4 in terms of the disruption/recovery period.

5.2.3. Comparing pandemic vs. pre-pandemic periods

The COVID-19 crisis has provided an ideal context in which to examine the merits of supply chain diversification because the supply chain during the crisis is highly uncertain and unstable. The Chinese supply chain is also seriously disrupted by the crisis. Our results also lead to a question: are the findings specific to the COVID-19 context? To further investigate this question, we conducted a post hoc analysis to compare the effects of supply chain diversification on firms between the pandemic (year 2020) and pre-pandemic (year 2019) time. Specifically, we first expanded the research scope from the four quarters of 2020 to the eight quarters from 2019 to 2020. We then introduced the variable of *DCOVID-19* to indicate the quarters in year 2020. Specifically, the dummy variable was coded “1” for observations at the quarters in the year of 2020 and “0” otherwise. We then used this dummy variable to interact with the supply chain diversification variables to reveal the different impacts between year 2020 and 2019. The results, reported in

Table 6, suggest that compared to the pre-COVID-19 period, Chinese manufacturers with higher supply-base diversification can further increase their inventory availability (coefficient = -0.050, $p < 0.01$), and firms with higher customer-base diversification have a higher profitability (coefficient = 0.055, $p < 0.01$) during the COVID-19 period. These results reveal the different merits of supplier and customer diversification amidst the COVID-19 crisis.

Table 6. Supply chain diversification and firm inventory and profitability (pre-COVID-19 and COVID-19 period) (N=6883)

Dependent variable:	AIG			Δ ROS		
	Model 1			Model 2		
	Coef.	Std. errors	p-value	Coef.	Std. errors	p-value
Supplier diversification	-0.004	0.008	0.615	0.070***	0.009	0.000
Customer diversification	-0.050***	0.008	0.000	-0.053***	0.009	0.000
Supplier diversification \times DCOVID-19	0.041***	0.011	0.000	-0.017	0.012	0.168
Customer diversification \times DCOVID-19	-0.000	0.011	0.966	0.055***	0.012	0.000
DCOVID-19	-0.114***	0.011	0.000	-0.006	0.012	0.618
Firm Size	0.013**	0.006	0.021	-0.042***	0.007	0.000
Debt pressure	-0.205***	0.028	0.000	0.141***	0.031	0.000
Firm age	-0.004	0.013	0.755	0.026*	0.015	0.085
R&D	-0.142	0.092	0.124	0.770***	0.105	0.000
Production efficiency	-0.002	0.004	0.567	-0.009**	0.004	0.029
Marketing efficiency	0.013***	0.005	0.005	-0.001	0.005	0.914
Market share	0.834***	0.178	0.000	0.179	0.202	0.377
Board size	0.048*	0.025	0.053	-0.007	0.028	0.793
Ind. directors	-0.001	0.083	0.993	0.015	0.095	0.878
Institutional ownership (%)	0.000	0.000	0.614	0.000	0.000	0.974
Geographical diversification	0.065*	0.035	0.065	0.024	0.040	0.554
Constant	-0.155	0.146	0.287	0.746***	0.165	0.000
Quarter FE	Yes			Yes		
F statistics	22.009***		0.000	11.725***		0.000
R ²	0.057			0.031		
Adjusted R ²	0.055			0.029		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

5.3 Robustness checks

We conducted a battery of additional tests to check the robustness of our main findings. First, some may argue that the inventory and profitability of firms are conditional on the firm's industry. To address the industry effects on our dependent variables, we standardized AIG and change in ROS according to the 2-digit industry classification code. We then reran the 2SLS regression analysis and presented the analysis in Table 7. The findings are largely similar to those we obtained from

the primary models (Tables 3, 4 and 5). Thus, the industry effects do not contradict our conclusions.

Second, firms with overseas key suppliers or customers face a more complex situation compared with the firms with domestic suppliers and customers. For example, the situations of COVID-19 may not be the same in different countries. We thus conducted tests to examine whether these international connections confound our results. Specifically, we first revisited the supply chain data and removed the firms with overseas suppliers or customers and reran the analyses. Table 8 presents the results. We find that the results are largely identical to the results of primary models. In addition, we reviewed each firm's annual report and identified whether the firm had any overseas sales. We then developed a dummy variable coded “1” for the firms with overseas sales and “0” otherwise. We then used the overseas sales dummy to replace geographical diversification and reran the 2SLS regression analysis; the results are presented in Table 9. We obtained similar conclusions to those from the primary models (Tables 3, 4 and 5). Thus, the overseas supply chain connection of firms does not have a significant effect on our results.

In addition, our data of dependent variables span two years (2019 and 2020), while our supply chain diversification data were taken in 2019 (pre-pandemic time). Some may argue that firms may have changed their key suppliers or customers in these two years and confound the results. To mitigate this concern, we revisited the supply chain data and removed firms with supplier or customer changes from 2019 to 2020. We then reran the analyses, and the results are presented in Table 10. The results are largely identical to those in Tables 3, 4 and 5. In general, the various tests discussed above demonstrate that the main findings are robust and provide additional support for all the hypotheses.

**Table 7. Supply chain diversification and firm inventory and profitability
(Robustness check 1: industry-adjusted DV)**

Dependent variable:	AIG (Industry adjusted)			Δ ROS (Industry adjusted)		
	Model 1			Model 2		
	Coef.	Std. errors	p-value	Coef.	Std. errors	p-value
Panel A: Full period (N=4460)						
Supplier diversification	0.227***	0.029	0.000	0.127***	0.025	0.000
Customer diversification	-0.180***	0.024	0.000	-0.006	0.021	0.759
Firm Size	-0.051**	0.024	0.031	-0.082***	0.021	0.000
Debt pressure	-0.755***	0.113	0.000	0.166*	0.098	0.091
Firm age	-0.037	0.055	0.495	0.018	0.047	0.710
R&D	0.025	0.373	0.946	0.660**	0.323	0.041
Production efficiency	-0.062***	0.016	0.000	-0.013	0.013	0.321
Marketing efficiency	0.048***	0.016	0.002	-0.002	0.014	0.911
Market share	1.680**	0.724	0.020	0.987	0.626	0.115
Board size	0.162	0.101	0.111	0.024	0.088	0.787
Ind. directors	-0.143	0.339	0.673	-0.111	0.293	0.705
Institutional ownership (%)	0.000	0.001	0.692	-0.001	0.001	0.288
Geographical diversification	0.160	0.134	0.234	0.271**	0.116	0.020
Constant	1.467**	0.595	0.014	1.769***	0.515	0.001
Quarter FE	Yes			Yes		
F statistics	17.093***		0.000	8.283***		0.000
R ²	0.058			0.029		
Adjusted R ²	0.055			0.025		
Panel B: Disruption period (N=1407)						
Supplier diversification	0.331***	0.051	0.000	0.282***	0.044	0.000
Customer diversification	-0.255***	0.042	0.000	-0.100***	0.037	0.006
Firm Size	-0.043	0.043	0.320	-0.131***	0.038	0.001
Debt pressure	-0.656***	0.212	0.002	0.017	0.185	0.926
Firm age	0.071	0.099	0.476	-0.060	0.087	0.489
R&D	-0.296	0.661	0.654	-0.334	0.577	0.563
Production efficiency	-0.068**	0.030	0.025	-0.008	0.026	0.772
Marketing efficiency	0.044	0.029	0.133	0.036	0.026	0.159
Market share	2.783**	1.304	0.033	-0.058	1.138	0.959
Board size	0.079	0.182	0.665	0.018	0.159	0.909
Ind. directors	-0.416	0.614	0.499	-0.299	0.536	0.577
Institutional ownership (%)	0.000	0.001	0.826	-0.000	0.001	0.640
Geographical diversification	0.187	0.245	0.445	0.481**	0.214	0.024
Constant	1.247	1.076	0.247	3.456***	0.940	0.000
Quarter FE	No			No		
F statistics	6.001***		0.000	4.507***		0.000
R ²	0.053			0.040		
Adjusted R ²	0.044			0.031		
Panel C: Recovery period (N=3053)						
Supplier diversification	0.177***	0.035	0.000	0.051*	0.030	0.093
Customer diversification	-0.144***	0.029	0.000	0.041*	0.025	0.097
Firm Size	-0.055*	0.029	0.053	-0.058**	0.025	0.018
Debt pressure	-0.784***	0.134	0.000	0.241**	0.115	0.037
Firm age	-0.089	0.065	0.176	0.049	0.056	0.386
R&D	0.236	0.451	0.601	1.194***	0.388	0.002
Production efficiency	-0.060***	0.018	0.001	-0.014	0.016	0.360
Marketing efficiency	0.051***	0.019	0.007	-0.017	0.016	0.286
Market share	1.193	0.869	0.170	1.480**	0.747	0.048
Board size	0.198	0.122	0.105	0.022	0.105	0.834
Ind. directors	-0.019	0.405	0.963	-0.021	0.348	0.952
Institutional ownership (%)	0.000	0.001	0.704	-0.001	0.001	0.327
Geographical diversification	0.143	0.160	0.373	0.170	0.138	0.218
Constant	1.244*	0.713	0.081	1.161*	0.612	0.058
Quarter FE	Yes			Yes		
F statistics	7.912***		0.000	3.063***		0.000
R ²	0.038			0.015		
Adjusted R ²	0.033			0.010		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

**Table 8. Supply chain diversification and firm inventory and profitability
(Robustness check 2: removing firms with overseas customers/suppliers)**

Dependent variable:	AIG			Δ ROS		
	Model 1			Model 2		
	Coef.	Std. errors	p-value	Coef.	Std. errors	p-value
Panel A: Full period (N=4300)						
Supplier diversification	0.063***	0.009	0.000	0.047***	0.008	0.000
Customer diversification	-0.049***	0.007	0.000	0.004	0.007	0.506
Firm Size	-0.015**	0.007	0.036	-0.023***	0.007	0.001
Debt pressure	-0.244***	0.035	0.000	0.036	0.032	0.262
Firm age	-0.014	0.017	0.395	0.006	0.016	0.694
R&D	0.104	0.113	0.355	0.404***	0.105	0.000
Production efficiency	-0.021***	0.005	0.000	-0.005	0.004	0.278
Marketing efficiency	0.015***	0.005	0.003	0.002	0.005	0.650
Market share	0.985***	0.221	0.000	-0.186	0.207	0.367
Board size	0.049	0.031	0.113	0.009	0.029	0.762
Ind. directors	-0.009	0.103	0.932	0.022	0.096	0.822
Institutional ownership (%)	0.000	0.000	0.175	-0.000	0.000	0.227
Geographical diversification	0.067	0.041	0.101	0.060	0.038	0.117
Constant	0.386**	0.182	0.034	0.440***	0.170	0.010
Quarter FE	Yes			Yes		
F statistics	17.326***		0.000	9.355***		0.000
R ²	0.061			0.034		
Adjusted R ²	0.057			0.030		
Panel B: Disruption period (N=1356)						
Supplier diversification	0.093***	0.015	0.000	0.089***	0.015	0.000
Customer diversification	-0.073***	0.013	0.000	-0.021*	0.013	0.089
Firm Size	-0.011	0.013	0.422	-0.037***	0.013	0.004
Debt pressure	-0.196***	0.065	0.003	-0.024	0.063	0.710
Firm age	0.022	0.030	0.462	-0.014	0.029	0.630
R&D	0.067	0.199	0.738	-0.170	0.195	0.384
Production efficiency	-0.026***	0.009	0.005	-0.006	0.009	0.537
Marketing efficiency	0.013	0.009	0.142	0.011	0.009	0.190
Market share	1.454***	0.397	0.000	-0.095	0.389	0.808
Board size	0.020	0.056	0.725	0.000	0.054	0.995
Ind. directors	-0.144	0.186	0.441	-0.082	0.182	0.655
Institutional ownership (%)	0.000	0.000	0.484	-0.000	0.000	0.737
Geographical diversification	0.087	0.074	0.241	0.138*	0.073	0.059
Constant	0.294	0.329	0.371	0.983***	0.321	0.002
Quarter FE	No			No		
F statistics	6.569***		0.000	4.242***		0.000
R ²	0.060			0.039		
Adjusted R ²	0.051			0.030		
Panel C: Recovery period (N=2944)						
Supplier diversification	0.049***	0.011	0.000	0.027***	0.011	0.006
Customer diversification	-0.038***	0.009	0.000	0.018**	0.009	0.027
Firm Size	-0.018**	0.009	0.045	-0.017**	0.009	0.036
Debt pressure	-0.261***	0.041	0.000	0.069*	0.041	0.066
Firm age	-0.031	0.020	0.118	0.014	0.020	0.443
R&D	0.141	0.137	0.302	0.707***	0.137	0.000
Production efficiency	-0.019***	0.006	0.001	-0.004	0.006	0.395
Marketing efficiency	0.016***	0.006	0.007	-0.002	0.006	0.682
Market share	0.776***	0.265	0.004	-0.221	0.265	0.360
Board size	0.062*	0.037	0.097	0.011	0.037	0.751
Ind. directors	0.052	0.123	0.676	0.070	0.123	0.530
Institutional ownership (%)	0.000	0.000	0.219	-0.000	0.000	0.217
Geographical diversification	0.057	0.049	0.244	0.021	0.049	0.635
Constant	0.335	0.218	0.124	0.252	0.218	0.203
Quarter FE	Yes			Yes		
F statistics	8.767***		0.000	5.574***		0.000
R ²	0.043			0.028		
Adjusted R ²	0.038			0.023		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 9. Supply chain diversification and firm inventory and profitability
(Robustness check 3: alternative measure to control for the effect of firms with overseas sales)

Dependent variable:	AIG			Δ ROS		
	Model 1			Model 2		
	Coef.	Std. errors	p-value	Coef.	Std. errors	p-value
Panel A: Full period (N=4460)						
Supplier diversification	0.062***	0.009	0.000	0.039***	0.008	0.000
Customer diversification	-0.052***	0.007	0.000	0.004	0.007	0.514
Firm Size	-0.013*	0.007	0.071	-0.021***	0.007	0.002
Debt pressure	-0.251***	0.034	0.000	0.073**	0.033	0.024
Firm age	-0.008	0.016	0.623	0.005	0.016	0.736
R&D	0.128	0.111	0.247	0.346***	0.107	0.001
Production efficiency	-0.020***	0.005	0.000	-0.005	0.004	0.308
Marketing efficiency	0.017***	0.005	0.000	-0.001	0.005	0.861
Market share	1.016***	0.215	0.000	-0.210	0.208	0.312
Board size	0.035	0.030	0.247	0.006	0.029	0.828
Ind. directors	-0.043	0.101	0.672	-0.017	0.097	0.859
Institutional ownership (%)	0.000	0.000	0.144	-0.000	0.000	0.405
Oversea sales (dummy)	0.018	0.012	0.144	0.029**	0.012	0.012
Constant	0.287*	0.172	0.095	0.354**	0.166	0.033
Quarter FE	Yes			Yes		
F statistics	18.464***		0.000	8.266***		0.000
R ²	0.062			0.029		
Adjusted R ²	0.059			0.025		
Panel B: Disruption period (N=1407)						
Supplier diversification	0.093***	0.015	0.000	0.081***	0.015	0.000
Customer diversification	-0.076***	0.013	0.000	-0.023*	0.012	0.060
Firm Size	-0.007	0.013	0.567	-0.034***	0.013	0.008
Debt pressure	-0.217***	0.063	0.001	0.005	0.063	0.938
Firm age	0.028	0.030	0.348	-0.015	0.029	0.613
R&D	0.096	0.197	0.625	-0.216	0.195	0.268
Production efficiency	-0.023**	0.009	0.011	-0.004	0.009	0.649
Marketing efficiency	0.015*	0.009	0.076	0.009	0.009	0.276
Market share	1.436***	0.388	0.000	-0.117	0.385	0.762
Board size	0.004	0.054	0.937	0.000	0.054	0.997
Ind. directors	-0.157	0.183	0.391	-0.085	0.182	0.640
Institutional ownership (%)	0.000	0.000	0.346	0.000	0.000	0.975
Oversea sales (dummy)	0.020	0.022	0.361	0.055**	0.022	0.011
Constant	0.156	0.311	0.617	0.768**	0.309	0.013
Quarter FE	No			No		
F statistics	7.104***		0.000	3.732***		0.000
R ²	0.062			0.034		
Adjusted R ²	0.053			0.025		
Panel C: Recovery period (N=3053)						
Supplier diversification	0.048***	0.010	0.000	0.019*	0.010	0.054
Customer diversification	-0.040***	0.009	0.000	0.018**	0.008	0.023
Firm Size	-0.015*	0.008	0.072	-0.016*	0.008	0.053
Debt pressure	-0.262***	0.040	0.000	0.109***	0.038	0.004
Firm age	-0.025	0.019	0.203	0.013	0.018	0.484
R&D	0.161	0.134	0.230	0.637***	0.127	0.000
Production efficiency	-0.018***	0.005	0.001	-0.004	0.005	0.383
Marketing efficiency	0.017***	0.006	0.002	-0.005	0.005	0.314
Market share	0.828***	0.258	0.001	-0.247	0.245	0.313
Board size	0.049	0.036	0.181	0.007	0.034	0.831
Ind. directors	0.008	0.121	0.944	0.016	0.114	0.891
Institutional ownership (%)	0.000	0.000	0.237	-0.000	0.000	0.298
Oversea sales (dummy)	0.016	0.014	0.256	0.017	0.014	0.211
Constant	0.253	0.206	0.219	0.228	0.195	0.243
Quarter FE	Yes			Yes		
F statistics	9.167***		0.000	4.800***		0.000
R ²	0.043			0.023		
Adjusted R ²	0.039			0.018		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

**Table 10. Supply chain diversification and firm inventory and profitability
(Robustness check 4: removing firms with supplier or customer changes)**

Dependent variable:	AIG			Δ ROS		
	Model 1			Model 2		
	Coef.	Std. errors	p-value	Coef.	Std. errors	p-value
Panel A: Full period (N=3831)						
Supplier diversification	0.072***	0.009	0.000	0.040***	0.009	0.000
Customer diversification	-0.048***	0.008	0.000	-0.002	0.007	0.766
Firm Size	-0.022***	0.008	0.003	-0.023***	0.007	0.001
Debt pressure	-0.262***	0.036	0.000	0.109***	0.035	0.002
Firm age	-0.028	0.017	0.112	-0.006	0.017	0.708
R&D	0.163	0.117	0.164	0.263**	0.112	0.019
Production efficiency	-0.023***	0.005	0.000	-0.006	0.005	0.241
Marketing efficiency	0.017***	0.005	0.001	-0.005	0.005	0.338
Market share	0.841***	0.233	0.000	-0.165	0.224	0.462
Board size	0.052	0.032	0.106	-0.002	0.031	0.947
Ind. directors	0.014	0.107	0.898	-0.050	0.103	0.628
Institutional ownership (%)	0.000	0.000	0.151	-0.000	0.000	0.361
Geographical diversification	0.065	0.041	0.112	0.112***	0.039	0.004
Constant	0.554***	0.188	0.003	0.572***	0.180	0.002
Quarter FE	Yes			Yes		
F statistics	16.660***		0.000	6.441***		0.000
R ²	0.065			0.026		
Adjusted R ²	0.061			0.022		
Panel B: Disruption period (N=1208)						
Supplier diversification	0.102***	0.016	0.000	0.085***	0.016	0.000
Customer diversification	-0.072***	0.013	0.000	-0.042***	0.013	0.001
Firm Size	-0.018	0.014	0.184	-0.041***	0.013	0.002
Debt pressure	-0.237***	0.067	0.000	0.108*	0.065	0.094
Firm age	0.004	0.031	0.894	-0.028	0.030	0.355
R&D	0.176	0.203	0.385	-0.344*	0.196	0.079
Production efficiency	-0.025***	0.009	0.009	-0.006	0.009	0.508
Marketing efficiency	0.010	0.009	0.254	0.004	0.009	0.664
Market share	1.183***	0.417	0.005	-0.026	0.401	0.949
Board size	0.047	0.057	0.410	-0.026	0.055	0.639
Ind. directors	-0.045	0.192	0.814	-0.186	0.185	0.314
Institutional ownership (%)	0.000	0.000	0.658	0.000	0.000	0.672
Geographical diversification	0.108	0.073	0.141	0.151**	0.071	0.033
Constant	0.437	0.335	0.192	1.171***	0.323	0.000
Quarter FE	No			No		
F statistics	6.245***		0.000	3.454***		0.000
R ²	0.064			0.036		
Adjusted R ²	0.053			0.026		
Panel C: Recovery period (N=2623)						
Supplier diversification	0.057***	0.011	0.000	0.018*	0.011	0.092
Customer diversification	-0.036***	0.009	0.000	0.018**	0.009	0.042
Firm Size	-0.024***	0.009	0.009	-0.015*	0.009	0.075
Debt pressure	-0.270***	0.043	0.000	0.116***	0.041	0.005
Firm age	-0.042**	0.021	0.045	0.001	0.020	0.942
R&D	0.168	0.143	0.241	0.580***	0.137	0.000
Production efficiency	-0.022***	0.006	0.000	-0.005	0.005	0.372
Marketing efficiency	0.020***	0.006	0.001	-0.009	0.006	0.141
Market share	0.693**	0.281	0.014	-0.226	0.268	0.398
Board size	0.053	0.039	0.170	0.006	0.037	0.876
Ind. directors	0.039	0.130	0.766	0.013	0.123	0.917
Institutional ownership (%)	0.000	0.000	0.142	-0.000	0.000	0.170
Geographical diversification	0.045	0.049	0.364	0.091*	0.047	0.052
Constant	0.514**	0.227	0.024	0.358*	0.216	0.098
Quarter FE	Yes			Yes		
F statistics	9.033***		0.000	4.281***		0.000
R ²	0.049			0.024		
Adjusted R ²	0.044			0.018		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

6. Conclusion and discussion

Sampling Chinese manufacturing sectors, this study examined the effects of supply chain diversification on inventory level and profitability amid the COVID-19 pandemic in China. Applying 2SLS regression estimation, we find that firms with a diversified supply base can increase their inventory availability and profitability. This finding is valid in both the disruption period (Q1 of 2020) and recovery period (Q2 to Q4) of the crisis. In addition, firms with a diversified customer base can reduce their inventory, which signals a stable demand stream. This finding is also consistent during both the disruption and recovery periods. However, firms with a diversified customer base are found to have higher profitability only in the recovery period but not in the disruption period.

6.1 Implications for supply chain risk and disruption

COVID-19 is a macro-level (external) supply chain risk. Its disruption impacts on supply chains are caused by a combination of natural and man-made factors: The pandemic was caused by a novel coronavirus, which is natural, while the responses to the pandemic (e.g., lockdowns, production pauses) are man-made. The complex interaction between virus transmission and human responses makes the business environment very turbulent (Foss, 2020). Thus, this study first contributes to the supply chain risk management literature by examining COVID-19, which has a unique feature: turbulence and uncertainty are salient in both the disruption and recovery periods. This requires firms to conduct risk mitigation measures not only to buffer the disruption but also the recovery (Ivanov, 2020a). We take exploit the stages of the COVID-19 pandemic in China and firms' quarterly announcements to examine risk mitigation measures during both the disruption

and recovery periods. This echoes the recent call for scholars to consider disruptions with recovery measures (Ivanov et al., 2017).

The literature has proposed risk mitigation methods for COVID-19 from different perspectives, including slack (Wieczorek-Kosmala, 2021), agility (Ivanov, 2020b), and operational diversification (Li et al., 2021). We extended the discussion from firm-specific factors to a firm's supply chain structure. Specifically, our findings indicate that a firm's resilience to supply chain disruption is related not only to the firm's internal efforts as proposed in extant studies but also to the diversification of its supply and customer bases. This finding also echoes the idea that modern competition has gone beyond "firm versus firm" to "supply chain versus supply chain" (Ketchen and Hult, 2007). Future research may further extend from the supply and customer bases to the firm's supply chain network. The supply chain network includes all interconnected parties that exist up- or downstream of the focal firms (Choi and Krause, 2006). For example, scholars may study whether diversification in a firm's second-tier suppliers affects the firm's resilience to disruption. Scholars may also explore whether the interconnection between a firm's suppliers makes the firm more fragile in a turbulent environment (Wu et al., 2010)

6.2 Implications for diversification

In the OM literature, the concept of diversification has been operationalized as whether a firm's operations are geographically widespread and span across different industries. Narasimhan and Kim (2002) and Lampel and Giachetti (2013) investigated the impacts of geographical and product market diversification on firm performance. Hendricks et al. (2009) and Kovach et al. (2015) examined whether a firm's diversification helps the firm operate better in disrupted and dynamic

environments. Recent research has extended the scope of diversification from the firm to the supply base. It has generally been operationalized as “spatial complexity”, indicating whether a firm’s supply base is geographically widespread (e.g., Bode and Wagner, 2015; Lu and Shang, 2017). Our study adopts another perspective to understand supply chain diversification: whether firms concentrate their suppliers and markets in few partners or extend their transactions to more partners. This operationalization is closely related to a long-term debate regarding the merits of using single versus multiple suppliers (Stevenson, 2018) and extends the discussion to single versus multiple customers. Specifically, we examine the performance implications of supply and customer base diversification in the context of supply chain disruption. The results generally favor the advantages of having a diversified supply chain when a firm is experiencing and recovering from a disruption.

Our results are different from Hendricks et al.’s (2009) finding that geographical and product market diversification does not help a firm cope with disruption. This is likely first because the research window of Hendricks et al. (2009) is 1987 to 1998, while our sample is taken in 2020 when supply chain coordination skills have been greatly improved. Firms may use collaborative planning, forecasting and replenishment and vendor-managed inventory facilitated by advanced enterprise systems. Closer supply chain integration has mitigated the complexity impacts of having a diversified supply base (Narasimhan and Kim, 2002). Our results are also consistent with scholars’ suggestions to diversify the supply chain in the post-COVID-19 era (Sharma et al., 2020). Future research can explore the boundary conditions of our findings. For example, are the merits of supply chain diversification contingent on management skills or market conditions?

6.3 Implications for inventory management

Inventory management has been a central focus of the OM literature (Stevenson, 2018). Scholars suggest that firms should maintain an optimal inventory level that can balance the customer service level and inventory holding costs (Ballou, 2004). Kesavan and Mani (2013) find that AIG has an inverted U-shaped impact on a firm's future earnings per share. Supply chain disruption can be caused by the supply or demand side (Hendricks et al., 2009). A disruption in the supply stream may cause stockout, while a disruption in the demand stream may cause overstock. Both scenarios can cause supply-demand mismatch and consequently affect firm performance (Fan and Zhou, 2018). This study advances inventory management by demonstrating that the supply chain structure can be used to manage inventory, especially during periods of supply chain disruption. Specifically, we find that a diversifying supply base facilitates a firm's replenishment, while a diversifying customer base facilitates a firm's destocking. Our findings are different from Korcan Ak and Patatoukas's (2016) finding that customer base concentration can help firms maintain a lower inventory level. This is likely because Korcan Ak and Patatoukas's (2016) sample used a long research window (1977-2006) but did not specifically focus on the supply chain disruption period. Therefore, our results provide a plausible boundary condition to Korcan Ak and Patatoukas's (2016) conclusion. This difference indicates that inventory management techniques should be contingent on the supply chain and environmental changes.

6.4 Implications for operational managers and policy makers

This research used the COVID-19 context and offered operational managers implications to build resilience. Scholars (e.g., Sharma et al. 2020) and consultants (e.g., Deloitte, 2020) have suggested

that firms diversify the supply chain to mitigate supply chain risk and disruption. This research provided evidence and showed that firms with a diversified supply chain have an advantage in coping with and recovering from disruption. With the prospect of dynamism in the future business environment, managers should revisit their supply and revenue structure. Although transacting with few suppliers and customers can save firms very substantial coordination costs, these firms can be fragile when any failures happen to their supply chain partners. Despite the suggestion to diversify supply and customer bases geographically, we recommend that operational managers consider diversifying in terms of dependence on supply chain partners, avoiding overreliance on few suppliers or customers.

The resilience of manufacturing sectors has become a vital aspect of competitiveness. Our results suggest that governments should encourage firms to have backup suppliers and markets. For example, the government can build platforms for firms to search for suitable suppliers and customers, which facilitates supply-demand matches in periods of disruption. In addition, bridge loans are essential for firms that suffered serious disruptions during COVID-19. We suggest that the government should examine supply chain diversification in the manufacturing sector to evaluate systematic supply chain risks. These evaluation results can be important references when determining the loan size for firms.

6.5 Limitations

This study has taken measures to increase the validity of its analysis. However, this study suffered from limitations to be addressed in future research. First, we sampled Chinese firms and used the COVID-19 pandemic context in China. However, China contained the crisis rapidly and has a comprehensive industrial infrastructure. These factors help firms cope with and recover from

disruption. Future research may use contexts with longer disruption periods to examine the merits of supply chain diversification. Second, this study used the top five suppliers and customers to examine firms' supply chain diversification because of data availability. Future research may use more comprehensive supply chain data (e.g., full supplier and customer lists) to examine the sensitivity of our conclusions. Third, the COVID-19 pandemic is a disruption event that evolved rapidly over a long period of time. The results may be different in "shape" disruption events such as hurricanes and earthquakes because disruption risk is less salient in the recovery period. This research focuses on the impacts of supply chain diversification on the inventory level and profitability. Future research may extend the scope to other organizational factors, such as production capacity, labor productivity and corporate social responsibility performance. In addition, this study focused on the impacts of the firm's supply and customer base defined as the first-tier suppliers and customers (Dong et al., 2020). Future research may extend the analysis to the second-tier suppliers and customers to reveal the supply chain network effect on the firm's resilience. Last, this study used total inventory to calculate the inventory indicators. However, the effects of supply chain diversification may have different impacts on the sub-categories of the firm inventory (e.g., raw material, semi-finished goods and finished goods). Future research may use these alternative inventory measures to replicate the analyses.

Appendix A: Data set development

Steps	Description	Discard	Firms	Observations
1	Select firms with reported suppliers and customers		1648	6332
2	ST firms	54	1594	6106
3	Missing value for abnormal inventory growth	111	1483	4699
4	Missing value for control variables	49	1434	4460

Appendix B: First-stage regression (N=4460)

Dependent variable:	Supplier diversification			Customer diversification		
	Model 1			Model 2		
	Coef.	Std. errors	p-value	Coef.	Std. errors	p-value
Industry supplier diversification _t	1.045***	0.041	0.000			
Industry customer diversification _t				0.849***	0.044	0.000
Sale _t	0.001	0.004	0.778	-0.010**	0.004	0.012
Sale _{t-1}	-0.007	0.005	0.173	0.001	0.006	0.826
Sale _{t-2}	0.013***	0.004	0.001	0.012***	0.004	0.004
EBIT _t	-0.004	0.012	0.737	0.011	0.014	0.449
EBIT _{t-1}	0.013	0.013	0.332	0.061***	0.015	0.000
EBIT _{t-2}	-0.010	0.020	0.641	-0.011	0.023	0.630
Capital expenditures _t	0.692***	0.230	0.003	1.063***	0.262	0.000
Capital expenditures _{t-1}	-0.729***	0.223	0.001	-0.798***	0.255	0.002
Capital expenditures _{t-2}	-0.162	0.161	0.314	0.003	0.184	0.988
Constants	-0.131***	0.018	0.000	-0.082***	0.020	0.000
F statistics	69.438***		0.000	46.847***		0.000
R ²	0.135			0.095		
Adjusted R ²	0.133			0.093		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

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