The effect of vertical integration on supply chain resilience during the covid-19 pandemic.

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Abstract

The purpose of this research paper is to determine the effect of vertical integration on supply chain resilience. In this study I use production functions to calculate a measurement for supply chain resilience based on key firm data during the covid-19 pandemic. This data is compared with the Fresard-Hoberg-Philips database on vertical relatedness. I find that vertically integrated firms have significantly more supply chain resilience. This result is important because it helps understand the determinants of supply chain resilience and the effects of vertical integration.

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1 Introduction

On December 31, 2019, the Wuhan Municipal Health Commission reported a small cluster of pneumonia cases in Wuhan, China. This novel disease was eventually identified as a coronavirus and rapidly started changing the world. The global trade system has been exposed to unprecedented shocks since the advent of this coronavirus, later named covid-19. As a result of these shocks, significant weaknesses were rapidly exposed in the current supply chain system, which was based on lean management, outsourcing, and a heavy reliance on China as the global manufacturing center. Now that the dust from the pandemic has settled, firms are trying to prepare their supply chains for the next crisis by increasing their supply chain resilience (SCRES). Companies are attempting to achieve this goal through various strategies, including diversification and vertical integration (VI) strategies (Zhu et al., 2020). In this thesis I will investigate if firms that are vertically integrated showed increased SCRES during the pandemic by comparing the 5000 biggest listed firms in the United States.

The core of this research is about SCRES, so what exactly is it? According to the literature review on SCRES by Tukamuhabwa et al. (2015) the best definition is as follows: “the adaptive capability of a firm’s supply chain to prepare for unexpected events, respond to disruptions, and recover from them in a timely manner by maintaining continuity of operations at the desired level of connectedness and control over structure and function” (Ponomarov, 2012, p.7). This definition clearly distinguishes the two distinct components that researchers often divide SCRES into. The first component is the resistance capacity which refers to the firm’s capacity to undergo supply chain shocks and minimize losses as the disruption occurs. This first component is called static SCRES (sometimes also referred to as structural or inherent SCRES). The second component is the recovery capacity which refers to the ability of the firm to restore operations during the post-disruption stage (Ge et al., 2022). This is usually called dynamic SCRES. In this research, the supply chain disruption being considered is the covid-19 pandemic, with the first quarter of 2020 as the designated disruption period. In the last two decades, researchers have been calling for more empirical, event-based SCRES research (Remko, 2020). The covid-19 pandemic presents a unique opportunity to conduct such empirical research on SCRES. As mentioned previously, SCRES is about the adaptive capability of a supply chain to respond to and recover from disruptions. The pandemic was a global disruption, and firms with adequate SCRES were better able to respond to and recover from the supply chain shocks caused by the pandemic than companies with inadequate SCRES. As a result of this, supply chain performance and recovery during the pandemic can be used as a measure for resilience through utilization of production functions for firms affected by supply chain disruptions during covid-19 (Jiang et al., 2023). Using production functions to measure SCRES is a recent development in SCRES research. According to Dormady et al., (2019) previously researchers measured resilience with methods which often lacked solid theoretical foundation. Due to this need for formalized resilience metrics, Dormady et al. adapted functions from traditional production theory to develop a model that facilitates analysis of SCRES by evaluating how effectively firms transform inputs into outputs. The production function provides the most accurate measurement for SCRES and allows researchers to encapsulate both the static and the dynamic components of SCRES. How much SCRES a firm possesses depends on a multitude of factors, in this thesis the impact of VI on SCRES is investigated.

Vertical integration is the degree to which a firm performs multiple stages of production by themselves. It involves the integration of activities such as sourcing, production distribution and retailing. VI can take different forms, depending on the type of ownership and control exerted by the integrating firm. If a firm expands to a production stage closer to the finished product e.g., through the acquisition of distributors or retailers, it is called forward(downstream) VI. The opposite, the integration of upstream activities like suppliers or sources of raw material, is called backward VI. VI can have many different effects on a firm’s supply chain. It can help secure distribution channels, control efficiency gains and cost reductions, improve quality control, and increase supply chain visibility (Guan & Rehme, 2012). The question whether or not to vertically integrate is usually looked at through the perspective of transaction cost economics (Riordan & Williamson, 1985). In this theory, the “make or buy” decision is made based on the risks of market exchange compared to the costs of VI (Cacciatori & Jacobides, 2005). To determine how vertically integrated a firm is, a method by Fresard et al.

(2020) is used. They created a text-based vertical relatedness measurement with Bureau of Economic Analysis vocabularies. With this measurement they made a VI database which is capitalized on in this research.

In this thesis the effect of VI on SCRES is investigated. VI is the ultimate form of supply chain integration. Usually, no supply chain is as integrated, collaborative, and as trusted as the supply chain within the own firm, the vertically integrated supply chain (Piprani et al., 2020). VI can improve control over the supply chain, increase supply chain visibility, and reduce supply chain dependence all of which may contribute to increased resilience. However, VI can also reduce flexibility and requires a potentially financially burdensome amount of capital (Um & Han, 2020). This thesis investigates how substantial this possible effect of VI on SCRES is and will help managers and researchers determine if they should expect a positive effect on their SCRES if they decide to vertically integrate. This investigation has, as far as I could find, never been done before.

This thesis also examines the contrast between service and manufacturing firms. The majority of GDP in developed western nations like the U.S. is derived from service firms but the vast majority of supply chain research is still focused on manufacturing firms (Sengupta et al., 2006). This lopsided focus on manufacturing firms also exists within SCRES research and should be addressed. The disparity is important because service supply chains are much more focused on human involvement, information flows and service performance (Sengupta et al., 2006). These elements are significantly different from those in manufacturing supply chains and thus require a different approach from both the theoretical and managerial perspective. This thesis tries to contribute to this research gap by investigating how the difference between service and manufacturing supply chains affects the relationship between VI and SCRES.

In conclusion, the recent covid pandemic has once again shown the importance of resilient supply chains. It also brings a major opportunity. Due to the global disruption affecting almost every firm in a short period of time, this is the perfect moment for empirical and event-based SCRES research. This paper aims to use that opportunity to investigate the effect of VI on SCRES, and study how that relationship can be moderated. This thesis aims to contribute to the literature base on the components of SCRES, the effects of VI and the difference between service and manufacturing firms. It aims to help managers estimate the effects of vertically integrating their firm. The thesis utilizes production functions as a measurement for resilience, and compares this measurement with the vertical relatedness database by Fresard-Hoberg-Philips. The rest of the thesis has the following structure: Chapter 2 highlights the relevant theoretical background and develops the hypothesis. In Chapter 3 the methodology is explained and justified. Chapter 4 presents the findings and analyzes the robustness, These results are discussed in Chapter 5. Finally, in Chapter 6, the conclusion and limitations of this research are presented along with recommendations for future research avenues.

2 Literature review and hypothesis development
2.1 Theoretical background

2.1.1 What is resilience

The conceptual roots of the term resilience lie in the fields of individual psychology and child behavior science where it referred to the ability of people to tolerate stress and recover from traumatic situations, later the term evolved to become a characteristic of a system instead (Van der Vegt et al., 2015). This is also how the term has been used in the last decades of operations research. In operations research SCRES is “the adaptive capability of a firm’s supply chain to prepare for unexpected events, respond to disruptions, and recover from them in a timely manner by maintaining continuity of operations at the desired level of connectedness and control over structure and function” (Ponomarov, 2012). There are two distinct components which determine SCRES (Essuman et al., 2020; Jiang et al., 2023). 1) The significance of the drop in operational performance immediately following the disruptive event. This is called static resilience (Occasionally also called inherent or structural resilience). 2) the ability of the supply chain to return to normal operating performance once recovery action starts. This is called dynamic resilience. The normal shock-resilience path of a firm is shown in figure 1 below:

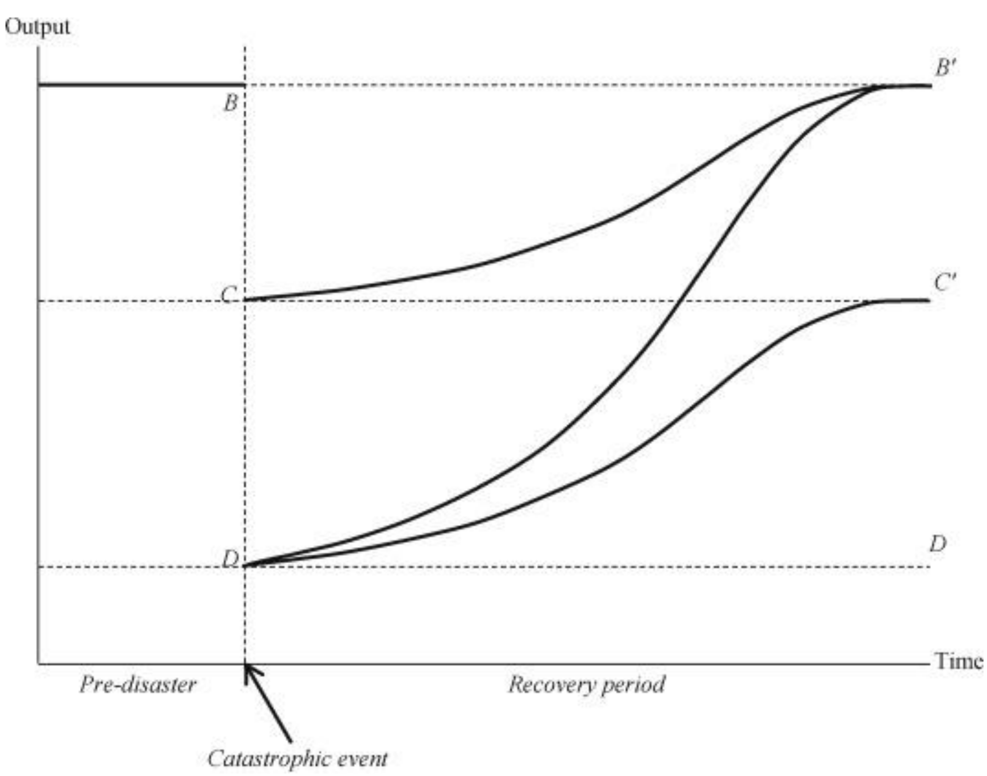

Figure 1 (Dormady et al., 2019)

In this figure the company output is represented on the y-axis with time on the x-axis. Point B displays the normal output while C and D represent some possible output levels immediately after the catastrophic event. This graph clearly shows the two distinct components of resilience. Static resilience determines how far the output drops at the time of the catastrophic event and dynamic resilience affects the speed at which the firm recovers towards pre-disaster output levels.

According to Tukamuhabwa et al. (2015), the majority of SCRES research is conceptual/theoretical and the few empirical studies that exist are often case studies or surveys with very limited responses. They stated that due to this lack of empirical research it is difficult for researchers to grasp how SCRES can be achieved or lost in the real world. According to them, another issue with SCRES research is that almost all research is also cross sectional while resilience is adaptive over time and thus, currently the coevolution, risk migration and adaptation of SCRES cannot be fully understood. One of the few longitudinal, empirical studies on SCRES is by Jüttner and Maklan (2011). They did an explanatory multiple case study on the relationship between resilience, supply chain risk management and supply chain vulnerability for firms before, during and after the 2008 financial crisis and found significant positive correlations between SCRM and SCRES.

2.1.2 The key factors of a resilient supply chain.

A resilient supply chain is a supply chain that has the ability to effectively withstand disruptions while maintaining as much operational continuity as possible and has the ability to quickly recover from any significant disruptions. In the past, multiple researchers have tried to determine what factors increase SCRES. Soni et al. (2014) asked 287 experts working in the field of supply chain management what factors they considered important contributors to SCRES and then later asked them to rate the importance of all potential contributors on a five-point Likert scale. With this survey that they combined with the literature they found ten factors that are important to increase resilience. According to their expert respondents the three most important factors are:

Supply chain agility, supply chain collaboration, and information sharing. Jüttner and Maklan (2011) agree that supply chain collaboration is an important factor, and also found evidence showing an important role for supply chain flexibility and supply chain visibility for dynamic SCRES. They also state that making a supply chain resilient is an ongoing journey and that firms must create a culture of continuous improvement with a learning mindset to foster resilience. Finally, in a literature review by Tukamuhabwa et al. (2015), the most common drivers of SCRES according to researchers were found to be Flexibility, creating redundancy, collaboration, and agility. Some of these factors can be quite ambiguous and hard to measure, to solve this researchers have created other methods which will be discussed in the next section.

2.1.3 How to measure supply chain resilience

Because SCRES cannot be directly observed or measured researchers use other, indirect, methods in an attempt to measure it. Soni et al. (2014) were the first to seriously try to quantify SCRES. In their research they used graph theory because they argued this is the best way to quantify the degree of inheritance of variables and the number of interactions present between these variables. They then proposed 10 enablers for SCRES based on the literature and a survey with 103 experts. With these enablers they created a SCRES index through which a system can be compared to a perfect system. This resilience measurement is great for individual managers that want to improve their firm's SCRES but requires deep knowledge about a firm and is not feasible for use on a large sample. Since 2014 a few more researchers have tried to measure resilience. This has been done through surveys, stock price changes, profitability, operating revenue, inventory and more, but a lot of these studies lack formal theoretical underpinnings (Dormady et al., 2019; Jiang et al., 2023). More recently, a growing body of work has started to assess resilience from the viewpoint of production functions. According to Dormady et al. (2019), these functions can illustrate how efficiently and effectively enterprises arrange the combination of inputs to meet production objectives or maximize profits. In their paper Dormady et al. (2019) adapted the production function and mapped it onto SCRES tactics. This adapted production function is the best way to measure resilience for this research because it is accurate, feasible and can simultaneously assess thousands of firms. It is also recently being more commonly adopted as the academic standard for measuring resilience (Jiang et al., 2023) The methodology section will further expand on using this production function as a measure of resilience.

2.1.4 Background on vertical integration research

Vertical integration is the degree to which a firm has consolidated multiple stages of the supply chain under single ownership or control (Maddigan, 1981). VI research was pioneered and refined by Harrigan (1984; 1985; 2003). In her research she wrote that the VI decision is based on transaction cost economics. Transaction cost economics is an economic theory that suggests that firms choose to vertically integrate when the cost of transactions in the market exceeds the cost of performing those activities internally. According to this theory, firms will internalize activities that are too complex or risky to contract out, as well as activities that are key to their competitive advantage. Harrigan suggests that companies need to consider a range of factors when deciding whether to pursue VI. These factors include the complexity and riskiness of the activities involved, the potential cost savings and other benefits of VI and the potential drawbacks of reduced flexibility and innovation.

Transaction cost economics is an older theory but in the literature it is still seen as the most important factor in the VI decision. Perry (1989) argues for two more determinants of VI besides transaction costs. The first of these is technological economies. Technological economies are benefits that help organizations produce things faster, better or cheaper for example with economies of scale or in the steel production process, energy can be saved if the steel only needs to be heated once. The second extra determinant Perry proposes is about market imperfections. In this argument he states that factors like imperfect competition, externalities and asymmetric information can motivate firms to vertically integrate.

Vertical integration offers several potential benefits to organizations. As discussed earlier, VI can reduce transaction costs, provide technical economies, and take advantage of market imperfections. Besides those factors VI can also help secure distribution channels, improve quality control, and increase supply chain visibility (Guan & Rehme, 2012). Besides these potential benefits VI can also present some challenges and risks that firms need to consider. Some examples are: increased complexity, loss of flexibility and the requirement of large investments which can be financially burdensome. Successful implementation requires effective management, coordination, and continuous monitoring of the newly integrated supply chain (Bresnahan & Levin, 2012).

2.1.5 The service supply chain.

Supply chains are key components of modern firms. The goal of a supply chain is to seamlessly let goods, services, and information flow from their upstream origin to the end consumer while creating value. Service and manufacturing supply chains share common goals but there are distinct differences between them. The fundamental disparity between them is that manufacturing supply chains usually deal with tangible products with a lead time between creation and consumption while service pure supply chains deal with intangible products that are often produced and consumed at the same time. The service supply chain consists of seven key service processes (Ellram et al., 2004):

1. Information flow
2. Capacity and skills management
3. Customer relationship management
4. Supplier relationship management
5. Service delivery management
6. Cash flow
7. Demand management

Research into service supply chains is limited, especially compared to manufacturing supply chains (Sengupta et al., 2006). This is curious since services make up the vast majority of GDP in modern, western economies. Akkermans and Vos (2009) investigated the discrepancies between service and manufacturing supply chains. In their research on amplification effects in service supply chains they found that service supply chain managers commonly follow manufacturing supply chain principles but that not everything that works for physical products can be copied for service supply chains. They wrote that the primary reason for this diversity is that services are made-to-order while manufacturing is often made-to-stock. One result of this difference is that extra demand cannot be dealt with through extra inventory, but instantly results in backlog and increased workload (Akkermans & Vos, 2009).

In a pivotal service supply chain management study by Maull et al. (2012) the perspective was flipped around from the perspective of the company to the customer. Maull et al. found this perspective important because customers are commonly engaged in the design, creation, and delivery of services. By taking the customer perspective they found that in service operations the customer can take over the role of project manager and create the customized service they desire. If organizations support these customers while respecting their hierarchies and boundaries they can help create value at a significant premium in a system-integrating role. This study is one of many that supports the idea that service supply chains should be approached significantly differently than manufacturing supply chains. Understanding these differences is crucial for businesses to design and manage effective supply chains tailored to their specific industries and customer requirements (Baltacioglu et al., 2007).

2.2 Hypothesis development

2.2.1 The relationship between vertical integration and supply chain resilience

The research base on the effect of VI on SCRES is very limited and the research that does exist is based on single case studies or of conceptual nature. Ishida (2020) states that Nitori, a home furnishing store in Japan, has a high degree of VI since it produces 90% of its products through local subsidiaries it wholly owns. They suggest that this high degree of VI could be a reason why they achieved an extremely fast recovery during the covid crisis and that this tactic could potentially also be used by other firms as a way to more quickly recover from supply chain shocks.

Perhaps the most relevant approach to analyze VI's effect on SCRES is by dissecting SCRES into its different components. Soni et al. (2014) identified the ten most important enablers for SCRES through an extensive literature review combined with expert surveys. These ten components could be affected by VI in a variety of ways. The first and, according to these researchers, the most important component of SCRES is supply chain agility. Supply chain agility is about creating value for the customer by being flexible, responsive, and customizable (Wang et al., 2015). Some approaches to achieve this supply chain agility is through information integration, virtual integration, network integration, process integration (Swafford et al., 2008; Wang et al., 2015). These different integration strategies could be more easily achieved with full VI than with outside supply chain partners and thus VI could potentially lead to increased supply chain agility and SCRES. The second important SCRES enabler according to Soni et al. (2014) is supply chain collaboration (SCC). SCC is the capacity to effectively cooperate with other organizations for mutual benefit. This mutual benefit can be conceived in areas like shared forecasting, postponement and risk sharing. In times of crisis collaboration is the glue that can hold supply chains together (Richey & Autry, 2009). Incentive alignment and decision synchronization are the two key elements of SCC. Both incentive alignment and decision synchronization are essential for effective responses to supply chain disruptions (Simatupang & Sridharan, 2008). According to Christopher and Peck (2004) SCC could involve information exchange which facilitates knowledge sharing around supply chain risks and uncertainties. Furthermore, SCC allows supply chain partners to better provide assistance during supply chain shocks which enhances resilience (Scholten et al., 2014). Collaboration also helps regulate risks more effectively, reduces uncertainty and increases event readiness (Soni et al., 2014). These positive effects of SCC on SCRES could be a factor in the potential positive effect of VI on SCRES because VI improves SCC (Pishchulov et al., 2022). SCC is much easier within a fully vertically integrated firm but, even with partial VI significant supply-chain collaboration improvements can be achieved (Pishchulov et al., 2022). There are also other enablers of SCRES in the study by Soni et al. that could be affected by VI: risk and revenue sharing, trust among players, supply chain visibility, adaptive capability, and supply chain structure. Each of these components is affected differently by VI and could potentially have its own distinct effect on the relationship between VI and SCRES.

Another way to analyze VI's effect on SCRES is through supply chain integration (SCI). SCI is "the extent of coordination between manufacturers and their suppliers in making decisions related to capacity planning, demand forecasting, inventory management, and replenishment as well as the flow of materials." (Piprani et al., 2020, p. 59). If a firm has a high degree of VI, it could be seen as the ultimate form of SCI since the supply chain is completely integrated within the firm and thus VI's effect on resilience could be comparable with the effect that a great amount of SCI has. Piprani et al. (2020) studied how SCR mediates the relationship between SCI and company performance in manufacturing firms in Pakistan through a questionnaire. In this study they found that better SCI allowed these manufacturing firms to reduce variability and better respond to any disruptions and volatilities which caused increased SCRES and performance. Zhuo et al. (2021) did a case study on 4 companies in the Chinese pig sector and found that SCI has a positive effect on supply chain agility and supply chain robustness, from which they concluded it also enhances SCRES.

Finally, in an analysis by Tukamuhabwa et al. (2015) it was suggested that supply chain visibility can increase SCRES. Supply chain visibility implies firms have significant information about the status of assets in their supply chain. This helps effective disaster responses but also prevents unnecessary overreactions in high stress environments. The increased visibility that integration provides could allow a firm to benefit from better performance during supply chain disruptions. Saenz and Revilla (2014) provide an example of this effect during the 2011 earthquake and tsunami in Japan. Even though this disaster was a huge disruption to global supply chains, causing more than $215 billion dollar in damages, the technology company Cisco's revenue was almost unaffected. They managed this feat through their great supply chain visibility. Within the first 24 hours after the disaster the company had mapped out its entire affected supply base and traced its customers. This allowed Cisco to compose a supply chain resiliency program and address the vulnerabilities with great success. This example shows the importance of visibility for SCRES. This holds significance because "Vertical integration could improve supply chain visibility by eliminating the boundaries between two supply chain members, thereby giving companies access to detailed information about the successive parts of the pipeline" (Guan & Rehme, 2012, p. 198). This once again shows a potential indirect effect of VI on SCRES. This study, together with the previously mentioned studies into VI and SCI's effect on SCRES lead to the following hypotheses:

Hypothesis 1A: A higher degree of vertical integration leads to increased static supply chain resilience.

Hypothesis 1B: A higher degree of vertical integration leads to increased dynamic supply chain resilience.

2.2.2 The moderating effect of the difference between service and manufacturing supply chains.

Services account for 85% of U.S. GDP yet academic research is largely focused on manufacturing supply chains. Academics widely recognize that there is a major need for more research about service supply chains (Ellram et al., 2004; Sengupta et al., 2006; Wang et al., 2015). In this research the difference between service and manufacturing supply chains introduces unique dynamics that may moderate the relationship between VI and SCRES. Because service supply chains are less dependent on physical goods and instead focused on more intangible inputs like information, technology, and skilled labor they might be less vulnerable to supply chain disruptions than manufacturing supply chains.

In manufacturing supply chains, the focal part is the standardized and centralized procedures and controls around the physical goods while in service supply chains the value is usually predominantly created by human labor (Sengupta et al., 2006). This distinction may cause different effects during a supply chain shock. During the US-China trade war for example, tariffs were commonly placed on goods that physically crossed the border, causing significant disruptions for manufactured products while services were often less affected. This phenomenon that service supply chains are affected differently during shocks suggests that the hypothesized increase in resilience for vertically integrated firms is also different for service supply chains.

The contrast between service and manufacturing supply chains can be important in multiple ways when we consider VI's effect on SCRES. One way this could be different is because in manufacturing firms long term supplier relationships and the supply network structure are vital for superior performance while in service supply chains information sharing and service customization are more important (Sengupta et al., 2006). VI affects the supplier relationship and the supply network structure very positively, as the firm becomes its own supplier. VI also has a strong positive effect on information sharing but the effect on service customization is more ambiguous (Goebel et al., 2009). This could be a cause for a stronger positive relationship between VI and SCRES for manufacturing supply chains.

According to (Shahin, 2010) another difference between service supply chains and manufacturing supply chains is that service supply chain management is more complicated than manufacturing supply chain management. This could be a reason outsourcing to specialized firms is better for resilience than full VI in service supply chains. A different paper by Huang and Jahromi (2021) also recommends service firms to outsource additional inventory locations. They also suggest subcontracting capacity to increase procurement and distribution flexibility, which could be a better way to increase resilience than VI for service firms. Finally, they also stated that supply chain visibility and information sharing could improve SCRES for service firms. Because VI positively affects supply chain visibility and information sharing this indicates that VI does have some positive effect on SCRES of service supply chains (Thompson et al., 1991).

Service supply chains face unique challenges related to service design, capacity management and resource allocation. VI may have a stronger positive impact on SCRES in manufacturing supply chains partly because the complexities of service supply chains and their reliance on external partners limit the effectiveness of VI. These factors lead to the following hypotheses for the moderating effect on the relationship between VI and SCRES:

Hypothesis 2a: Firms that operate in the manufacturing sector experience a more significant increase in static supply chain resilience through vertical integration than the average service firm.

Hypothesis 2b: Firms that operate in the manufacturing sector experience a more significant increase in dynamic supply chain resilience through vertical integration than the average service firm.

3 Methodology

3.1 Data

The focus of this research is on U.S. firms during the covid pandemic. The data was collected in a period of two years from Q4 of 2019 till Q4 of 2021. Firm level information was collected through Compustat and the Fresard-Hoberg-Philips database on vertical relatedness. Initially, the Firms included were the 4489 U.S. listed firms in the 2020 version of the Fresard-Hoberg-Philips vertical integration database. These 4489 companies are all U.S. listed firms with at least $5 million in sales and positive assets. From this list any firms that were not active during any quarter between Q4 2019 and Q4 2021 were removed which left 4363 firms. Not every firm in this list had data on total assets, revenue, employees, and cost of goods sold on Compustat for each quarter. Because these data points are required for the resilience measurement in the production function and can't reasonably be substituted without affecting the accuracy of the results these firms were removed. In this step a total of 1606 firms were removed which left 2757 firms with a total of 22056 firm-quarter observations.

3.2 Resilience

This thesis used a recent advancement in resilience research to measure resilience. Following Dormady et al. (2019) and Jiang et al., (2023), a production function was used. A production function is a measure that allows comparison of varying input-output relationships, it is used to describe and calculate the relationship between the input and output quantities of goods. The production function is the most credible way to measure resilience during the pandemic because it encompasses capital investment, labor inputs, and intermediate inputs (Jiang et al., 2023). Just like Jiang et al., (2023) the classic Cobb-Douglas production function was used:

$$ln(VA_{it}) = \alpha lnK_{it} + \beta lnL_{it} + \gamma lnM_{it} + \varepsilon_{it}$$

(*Jiang et al.,* 2023)

This function is made up of the output, three different inputs and the error, which will later be used to help calculate the measure for resilience. $\mathbf{VA_{it}}$ is the total sales revenue, also described as the output of the production function of firm **i** in quarter **t**. The main inputs of the production function are **K L** and **M** which stand for assets, number of employees and expense of inputs for firm **i** in quarter **t**. Each of the inputs is preceded with its own coefficient, shown in the function with α β and γ. These coefficients represent the output elasticity for that input. For a 1% change in the input value the output VA_{it} is changed by this coefficient in percentage. These coefficients were obtained through a linear regression on the entire sample with sales revenue as dependent variable. The final term in the production function is the ε_{it}. If we assume that each input reveals its own value in the output this ε_{it} is the unexplained leftover. This is the firm's total factor productivity (TFP). The TFP during supply chain shocks can help us measure resilience. Specifically, the change in TFP can be used as a measurement for resilience (Ambulkar et al., 2015) The measurement for resilience is created by comparing the TFP with the previous quarter for static resilience and the recovery quarter(s) for dynamic resilience.

$$Static\ resilience\ =\ TFP_{it}\ -\ TFP_{it-1}$$

$$Dynamic\ resilience\ =\ TFP_{it}\ -\ TFP_{it-5}$$

In this research, Q1 of 2020 was marked as the disruption quarter which was then compared with the previous quarter to create a measure for static resilience. The disruption quarter was also compared with the recovery quarter, Q2 of 2021. This quarter was picked because this was the first quarter since the first infections that cases were at a very low level and most accurately represents how well companies were able to recover from the initial shock before infection waves caused by new variants caused new supply chain shocks. This quarter's TFP was then compared with the disruption quarter to create a measure for dynamic resilience.

3.3 Vertical integration

To determine the degree of VI the vertical integration measurement method by Frésard et al. (2020) was used. Fresard et al. (2020) investigated the effect of innovation activities on VI and created the VI measurement for their research. They first identified and extracted firm business descriptions from the SEC Edgar database for their sample. In these descriptions firms are required by law to accurately report any significant products they offer. They then used Bureau of Economic Analysis input-output tables to create commodity-to-word correspondence tables. They also used a commonly neglected resource in the Bureau of Economic Analysis Input-Output Tables called ‘Detailed Item Output’. This table verbally describes the nature of each good or service with a description of up to 25 distinct words. The researchers then created a set of words related to each commodity and computed the intensity of vertical relatedness between combinations of commodities. To prevent accidently labeling horizontal relations as vertical they removed words that rarely co-appear within a given commodity’s vocabulary. These lists were then compared to firms’ business descriptions where firms with many vertically related word-combinations were determined to be more vertically integrated. After robustness checks they determined that this method of measuring VI provides a high correlation coefficient and has statistical significance. For a complete, in-depth explanation please refer to their article about this method. Fortunately, the researchers decided to open their data up to the public in a free to use database called the Fresard-Hoberg-Philips vertical relatedness database. The degree of VI was taken from the database for the sample and was used in this research to determine degree of VI for the U.S. listed firms. The reason this method of determining VI degree was chosen is because it was proven to be 50% more effective than previous methods based on NAICS codes when testing on Compustat segment files and Capital IQ’s “Key Developments” database. These are databases with smaller numbers of known vertical relatedness and the Fresard-Hoberg-Philips method doing well in these tests likely means it is the best method for VI research (Fresard et al., 2020).

3.4 Service and manufacturing firms.

To determine whether firms are manufacturing or service-based firms, the Global Industry Classification Standard (GICS) was used. GICS is a widely recognized framework that categorizes companies into different industry sectors and subsectors based on their primary business activities. The GICS divides firms into 25 industry groups which can be further subdivided into 74 industries and 163 sub-industries. In this paper the firms with no or very little physical goods and products like those in the finance, education and communication industries were classified as service firms. Companies in industries that are more focused on the creation and movement of physical products like consumer staples, industrials and materials were considered as manufacturing firms. The classification that each of the 163 sub-industries was placed in is available in appendix A. This classification of service and manufacturing firms was then used to create an interaction variable to test the effects of service firms on the relationship between VI and SCRES.

3.5 Control variables

To account for confounding effects, some variables that might impact resilience are introduced as control variables. First of all, smaller firms might have less resources to battle the covid-19 shock or they could be more nimble and able to adjust more easily, thus firm size is used as a control variable. Total firm assets, according to the Compustat database, is used as measure for firm size. Second, younger firms might have higher risk tolerances than older firms which could affect resilience. Firm age is taken as a control variable. The firm age is determined by the difference between the firm's initial public offering date and April first, 2022. Of course, IPO date is not the same as firm age. Unfortunately there was no data on firm age available for the sample and thus IPO date was the most accurate, available replacement. Some firms did not have data on their IPO date in Compustat. About half the firms in the sample also did not have any IPO date available, for these firms the average age of firms in their industry was used instead. Third, high-tech firms could potentially innovate faster and thus more easily adapt to covid shocks. R&D capability is taken as a control variable which is estimated through the ratio of R&D expenses to total expenses. Not all firms had R&D expense data available, firms without any R&D expense data instead got the average R&D expense for firms in their industry imputed. Finally, whether a firm is focused more on physical products or services might also have a direct effect on SCRES besides its potential moderating effect. Because of this potential direct effect, manufacturing firm is used as a control variable. The determinants of a manufacturing firm can be found in the previous paragraph or appendix A.

3.6 Data analysis.

To test the main effect and the moderator the data was first downloaded from Compustat and the Fresard-Hoberg-Philips dataset and transferred into data analysis program SPSS. In the data cleanup process, duplicate observations were removed and outliers were checked. If data was missing in any of the variables that were required for the TFP and resilience measurement the entire observation was removed to preserve validity. For missing data in the control variables, the data was imputed as described in the previous paragraph. For each quarter the production function was performed according to the previously described method which resulted in a TFP for each quarter. The TFP numbers were then combined into a single dataset together with the control variables on firm size, service vs manufacturing, R&D capability, and firm age. The TFP's were subtracted to create measurements for static and dynamic resilience. To identify the effect of VI on static SCRES, an OLS linear regression was performed with as dependent variable static SCRES and with the control variables and VI as independent variables. For the effect of dynamic resilience the process was repeated with dynamic resilience as the dependent variable and the same independent variables. To test the moderator, an interaction variable was created by multiplying the dummy variable for service firms with the degree of vertical integration. The regression analysis was then repeated. The results of the analyses are presented in chapter four.

4 Findings

To analyze the relationship between the variables, an OLS regression was performed. Table 1, which can be seen below presents the coefficients for the dependent variable static resilience. The results of the regression show that the coefficient between static resilience and vertical integration is significantly positive. This indicates that firms that are more vertically integrated have significantly more static SCRES than firms that are less vertically integrated. This result is significant at the $p < 0.05$ level. This result supports hypothesis 1A: A higher degree of vertical integration leads to increased static supply chain resilience. The results show no significant correlation with any of the control variables.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-.014	.022		-.652	.515
	Vertical Integration	5.527	.850	.130	6.500	<.001
	Manufacturing Firms	-.024	.018	-.027	-1.339	.181
	Firm Size	2.156E-7	.000	.024	1.234	.217
	R&D Expense	-2.789E-5	.000	-.016	-.857	.391
	Firm Age	.001	.001	.021	1.112	.266

a. Dependent Variable: Static Resilience

Table 1

In table 2, the results of the linear regression with dependent variable dynamic resilience and independent variables vertical integration, service firm, firm age, total assets, and R&D expense are shown. The results showed a significantly positive relationship between vertical integration and dynamic resilience at the $p < 0.05$ level. This result indicates that firms that vertically integrate had a significantly higher degree of dynamic SCRES during the covid pandemic. The hypothesis 1B: “A higher degree of vertical integration leads to increased dynamic supply chain resilience” is supported by the results. The results also show that one of the control variables, manufacturing firms, had a lower degree of SCRES at the $p < 0.05$ level. The other control variables show no significant effect.

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.202	.033		6.196	<.001
	Vertical Integration	6.707	1.293	.104	5.188	<.001
	Manufacturing Firms	-.092	.027	-.069	-3.436	<.001
	Total Assets	3.171E-7	.000	.023	1.192	.233
	R&D Expense	-9.195E-6	.000	-.004	-.186	.853
	Firm Age	.001	.002	.010	.516	.606

a. Dependent Variable: Dynamic Resilience

Table 2

Along with the relationship between VI and SCRES the difference between service and manufacturing firms was also tested through the interaction variable manufacturing*vertical integration. In table 3, the effect of vertical integration on static resilience for manufacturing firms is shown. The interaction variable shows no significant effect on static SCRES. In table 4 the effect of the interaction variable on dynamic resilience is shown. Once again, the interaction variable shows no significant effect. Because the linear regression shows no significant effect of the moderator on either static or dynamic resilience hypothesis 2a: “Firms that operate in the manufacturing sector experience a more significant increase in static supply chain resilience through vertical integration than the average service firm” and hypothesis 2b: “Firms that operate in the manufacturing sector experience a more significant increase in dynamic supply chain resilience through vertical integration than the average service firm” are both rejected. The results provide no significant evidence that the difference between manufacturing and service firms moderates the relationship between VI and SCRES.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-.017	.024		-.732	.464
	Vertical Integration	6.106	1.931	.144	3.162	.002
	Manufacturing Firms	-.019	.023	-.021	-.811	.418
	Total Assets	2.163E-7	.000	.024	1.238	.216
	R&D Expense	-2.770E-5	.000	-.016	-.851	.395
	Firm Age	.001	.001	.021	1.110	.267
	Manufacturing*Vertical_Integration	-.716	2.141	-.017	-.334	.738

a. Dependent Variable: Static Resilience

Table 3

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.189	.036		5.261	<.001
	Vertical Integration	9.019	2.943	.140	3.065	.002
	Manufacturing Firms	-.073	.035	-.054	-2.074	.038
	Total Assets	3.196E-7	.000	.023	1.201	.230
	R&D Expense	-8.439E-6	.000	-.003	-.170	.865
	Firm Age	.001	.002	.010	.511	.609
	Manufacturing*Vertical_Integration	-2.853	3.262	-.046	-.875	.382

a. Dependent Variable: Dynamic Resilience

Table 4

4.2 Robustness analysis

In this thesis I made some choices regarding the timing of the recovery quarter, what firms qualify as service firms and some of the control variables. These choices are all well motivated and/or based on other reliable literature. However, it is still important to consider the impact on the results if other choices were made. In this part of the findings chapter some of these other options will be investigated and discussed.

First of all, the recovery quarter that was used to determine dynamic SCRES in this research was determined to be the second quarter of 2021. This quarter was different than similar research for a couple of reasons. Jiang et al., (2023) picked the quarter right after the disruption, to determine resilience for Chinese firms. This quarter could not be used for the sample from the United States in this research due to the differences in the way the pandemic developed between China and the United States. In China, for much of this quarter new cases were down to less than 100 infections a day, less than 0.3% of the first peak (World Health Organization, 2021). In the United States, the first wave rolled right into the second and with 150000+ confirmed cases a day in that period despite limited testing capacity, the pandemic was still very much developing (World Health Organization, 2021). Because of this dynamic the recovery quarter was determined to be Q2 of 2021. During this time cases and deaths were a lot lower and the economy was in a period of recovery before the new variants created new lockdowns and new supply chain shocks. Others might argue that 2021 Q1 is a better pick as recovery quarter because deaths numbers started declining after January 11. To ensure robustness I repeated my research with data from this period. These findings can be found in Appendix B1. The results from this data show similar results with a positive correlation between VI and SCRES with a significance level < 0.05. This result demonstrates that the findings on dynamic SCRES hold when adjusting to a similar recovery quarter. Arguments could also be made to use the third quarter of 2021 as a recovery quarter because at this time firms had a longer opportunity after the first covid waves to adjust. Similar robustness analysis was performed on this period with similar results. The results of this analysis can be found in Appendix B2.

The second robustness check is regarding the determinants of a service or a manufacturing firm. In this research GICS codes were used. This was done by going through all 163 of the sub-industries in the official industry taxonomy and determining based on the name of the sub-industry and the context from the industry groups in whether a firm should be marked as a service or manufacturing firm. Because this method is partly subjective and relies on judgement calls it is important to test if the results hold in case a different system is used. To test the robustness of this method, I recreated the service and manufacturing classification with a different method. Fan et al. (2022) used the Standard Industrial Classification (SIC) to classify firms in service industries with little to no physical product. They marked firms in Finance, insurance, real estate, public administration and non-classifiable industry as service focused firms (SIC codes 4000-4999, 6000-6799, 7000-8999, 9100-9999). With data from Compustat, I recreated this method, applied it to my sample, and created a new variable to determine the interaction effect between SIC manufacturing firms and VI. The results of this analysis with static resilience are in appendix C1, the results for dynamic resilience can be found in C2. The results for the regression with static resilience are very similar as in the main findings with a significant correlation between VI and SCRES, but nothing else. The results for dynamic resilience in C2 are quite interesting. The robustness analysis suggests a significantly negative correlation between the interaction variable SIC Manufacturing firms and SCRES. This suggests that manufacturing firms benefit less from the increased SCRES gained by VI than service firms. This is the opposite of hypothesis 2b, in which it was hypothesized that manufacturing firms would benefit more significantly from the relationship. The reason why this correlation exists and why it only does so when using SIC codes to determine manufacturing firms is unknown. This could be an interesting avenue for future research. Besides this, VI is once again significantly correlated to SCRES at the 0.05 significance level.

For the final robustness analysis the focus is on the control variables R&D expense and firm age. Both of these variables were taken from the Compustat database, which is one of the most reliable and complete databases in existence for this type of data but unfortunately there was no data on firm age and R&D for a large part of the sample. For R&D expense data was available for 2972 firms. To make sure that analysis could also be completed on the firms without R&D expense data, the rest of the observations were imputed. The average R&D expense for the industry a firm operates in was used for this imputation. This decision was made because firms in similar industries often have similar R&D expenses. However, sometimes this data can vary wildly and thus other methods were also tested. First, in appendix D1 the results are shown with just the 2972 firms that had R&D data available in Compustat. For the second robustness test in D2, the data on R&D expense was imputed with the assumption that for all firms without data the expense was zero. Finally in D3 it is assumed that firm R&D expense has nothing to do with the firm's sector's R&D expense and thus the data was imputed with the average R&D expense of the entire sample. The results in appendix D1, D2 and D3 show no significant changes from the main findings. The other control variable with a significant amount of missing data was firm age. Because firm age is not kept track of in any database I could find, the years since IPO was used as a measure for age. Not every firm had IPO data in the database, a total of 1949 firms did have this data. For the data in the findings section, firms with missing observations had their data imputed with the average age for firms in their industry. For robustness, in appendix D4, D5 and D6 the findings are presented with respectively: just the 1949 firms with known data, the assumption that all firms with missing data went public 1 year ago, and the average age for the entire sample. It is also possible that firms that went public a longer time ago are less likely to have data available. To cover this, in D7 firms with missing data were given double the average age for their industry. These regressions all gave results that show these different ways of data imputation had no significant effect on the strength and significance of the main effect. To make sure no confounding effects exist, some different combinations using different recovery quarters, manufacturing classifiers, and control variable imputations were also checked. None of these combinations showed any meaningful significant effects.

5 Discussion

In this thesis I investigated the effect of VI on SCRES during the covid pandemic and the effect of firm type on this relationship. I tested the hypotheses with data from 2757 firms' performance before, during and after the covid pandemic. In the analysis, which used production functions combined with linear regressions it was shown that vertically integrated firms have significantly more SCRES than the average firm. These results have significant theoretical and practical implications.

5.1 Theoretical contributions

First, a significant contribution of this study is that it provides evidence that vertically integrating steps of the production process within a firm can increase SCRES. It adds to literature that has already shown that supply chain integration and collaboration between different firms can increase resilience (Piprani et al., 2020; Zhuo et al., 2021; Lotfi & Larmour, 2021) but this is, as far as I could find, the first time that the relationship between VI and SCRES is explored. This contribution is additionally important because it helps answer a call from the literature. As mentioned in the introduction, in the last 15 years researchers have been writing about the need for more empirical and event-based SCRES literature (Kahn & burnes, 2007; Sohdi et al., 2012; Remko, 2020). This call for research was strengthened because research was often conceptual in nature with limited or weak empirical evidence (Scholten et al., 2020; Remko, 2020). This thesis helps fill that literature gap by using the covid-19 pandemic as supply shock event and analyzing empirical data based on thousands of firms. To fulfil this analysis, this research creates a measurement for SCRES through production functions. According to Dormady et al. (2019) most metrics, tactics, definitions, and indices in the current literature that try to describe resilience do so without or with barely any theoretical underpinning. This thesis attempts to help build the theory by using the thorough framework based on production theory for examining economic resilience that was created by Dormady et al. specifically for research like this, in which measuring resilience across firms is important. This relatively novel way of using production functions has not yet commonly been utilized by researchers and doing more research with this is an important addition to the literature.

Second, this thesis separately investigates the two distinct stages of a supply chain disruption. This separation of the static resistance in the disruption stage and dynamic resilience in the recovery stage is widely recognized by researchers (Ge et al., 2022) but very limited amount of researchers have investigated these two components separately such that the differences and similarities can be compared. This research provides evidence that the two resilience components behave similarly when it comes to the effect of VI on SCRES. This research also shows a difference between dynamic and static resilience even though it was not the goal of this research to find it here. The results suggest that manufacturing firms have, on average, less dynamic resilience than service focused operations. This result does not hold for static resilience and provides the literature with a disparity that could help answer questions about the different behaviors of static and dynamic resilience.

Third, part of the goal of this research was to examine the moderating effect of the difference between service and manufacturing firms on the relationship between VI and SCRES. The results did not provide any evidence for the presence of this moderating effect, neither for strengthening or weakening the effect. Even though the effect was not as originally hypothesized, it is crucial for the scholarly literature to acknowledge non-significant results to prevent biases and enhance the overall understanding of SCRES. In a previous study, Sengupta et al., 2006 highlighted the importance of investigating the differences between manufacturing and service firms. This research's results suggest that the disparity might not be found as a moderating effect on the relationship between VI and SCRES. However, the effect might be found in the future as a direct effect of firm type on SCRES.

Finally, this study contributes to the existing VI literature. Vertical integration is still a very common practice, both by internal expansions and by mergers and acquisitions. Much of the VI literature dates from the 70's and 80's and even though that literature is still relevant and valid, it is important to keep adding to this base with modern insights and techniques to reflect on the modern VI environment. The literature is trying to accurately describe the proper motivations behind the vertical integration decision, in this decision more opaque factors like SCRES should also be carefully considered. This thesis provides some empirical evidence indicating that VI can potentially increase SCRES. By incorporating this finding into the broader research base, it contributes to a comprehensive and modern understanding of the key factors influencing successful VI.

5.2 Managerial contributions

Supply chain disruptions in recent years like those caused by the covid-19 pandemic, trade wars, and the Suez Canal blockade have once again made it clear that supply chain shocks are inevitable. In today’s environment where supply chains are increasingly stretching across the globe and becoming more and more complex, supply chain managers must reconsider how prepared their operations really are and look at all available options to build SCRES.

The main managerial implication of this study can be split in two parts, the first part is for managers looking to vertically integrate their supply chain. Managers that are looking to vertically integrate need to know what effects VI will have on their firm. They can use this study to help assess the effect of VI on the resilience of their supply chain. The results of this study show that, on average, firms experience increased SCRES if they are more vertically integrated. Because of this increase, firms that are going to vertically integrate could on average expect more SCRES when the integration is complete. Naturally, this increase is just an average and could be different for each individual firm. The second part of the main managerial contribution is for firms that are trying to build SCRES. In the current situation with highly complex supply chains going through many unexpected shocks, it is quite understandable that firms want to increase their SCRES. How to increase SCRES is currently quite a difficult question. The building blocks of SCRES are still quite ambiguous and the literature does not have a great understanding of increasing resilience. The evidence in this thesis suggests that VI could be a way to build SCRES. Using VI as a resilience building mechanic would of course be quite drastic but if a company experiences a lot of supply chain problems in times of crisis due to external suppliers and customers, they could decide to incorporate those production steps within the firm to reduce these problems in the future and potentially increase resilience.

A second, smaller implication lies in the unexpected difference between static and dynamic resilience. The linear regression showed that service firms have a positive correlation with static SCRES, but this relationship was not proven for dynamic SCRES. This suggests that firms that mainly provide services can expect to face less difficulty during the initial shock of a supply chain crisis but expect no difference during the recovery stages. For manufacturing firms, it might be even more important to improve their dynamic SCRES due to this discrepancy.

6 Conclusions, limitations, and recommendations

6.1 Conclusion

The aim of this research was to identify the effect of vertical integration on supply chain resilience, and the effect that the distinction between service and manufacturing firms has on this relationship. Based on a quantitative analysis of data on 2757 of the biggest US firms during the covid pandemic it can be concluded that, on average vertical integration increased both static and dynamic supply chain resilience for these firms during covid-19. This result indicates that vertical integration increases supply chain resilience.

6.2 Limitations

To provide an accurate view of what conclusions we can and cannot draw from this study it is important to look at the limitations. First of all, the entirety of the data is based on the 5000 biggest US firms that are listed on the stock market. This means the data might not be representative for firms from other countries, smaller firms, or private firms. The second limitation is due to the timing of this research. The study specifically looked at data during the covid-19 pandemic and generalizes based on that data. It could be possible that different crises could yield different results for any of the parameters.

Another possible limitation could exist due to the removal of firms from the initial data sample. The sample started with 5000 firms but about 2300 had to be removed due to missing data in one of the key components. Even though no biases were found it is possible that the removal of these companies influenced the results. The data from VI is another limitation. The data was obtained from the Fresard-Hoberg-Philips database. This database uses word associations to determine degree of VI. The data quite accurately matches the degree of VI when checked to reality. However, it does not tell us exactly how many steps of the production process are integrated and can’t tell us anything about whether the firm has recently completed a VI project. This data might possibly provide different results but would have to be collected through deep research into each individual firm which is almost impossible with this many firms in the sample.

6.3 Recommendations for future research

Some of the limitations of this research could be taken on in future research. First, in the future similar studies could be done with different samples. A study could investigate if similar relationships exist for the relationship between VI and SCRES with a sample of small firms, a sample of unlisted firms, or a samples of firms from different countries. Furthermore, this research was done with data during a pandemic. Even though I hope there will never be another supply chain shock, this is unrealistic and these future supply chain shocks could be great to test the generalizability of this study.

Future research directions also lie in the supply chain risk management (SCRM) field. This study showed that firms with more VI have higher SCRES, but similar research could also be done through a SCRM approach by asking the research question: can we increase SCRES by vertically integrating. Finally, in the findings section of this thesis it was shown that service firms have more static resilience on average, while having the same dynamic resilience. This is a really interesting difference which is currently hard to explain. A future study could take a deeper dive on this difference and its potential managerial and theoretical implications.

Finally, the robustness analysis suggested a significantly negative correlation between the interaction variable SIC Manufacturing firms and SCRES. Because the reason for this suggested relationship is completely unknown, it could be an excellent future research direction.

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Appendix:

Appendix A:

	GICS codes	Sub-industries
Service firms	10101020, 20201049-20202030, 20302009-20305030 25301009-25302020, 35102009-45201020 50101009-60201040	Oil & Gas Equipment & Services, Environmental & Facilities Services, Office Services & Supplies, Diversified Support Services, Security & Alarm Services, Human Resource & Employment Services, Research & Consulting Services, Data Processing & Outsourced Services, Passenger Airlines, Marine Transportation, Rail Transportation, Passenger Ground Transportation, Airport Services, Highways & Railtracks, Marine Ports & Services, Casinos & Gaming, Hotels, Resorts & Cruise Lines, Leisure Facilities, Restaurants, Education Services, Specialized Consumer Services, Health Care Services, Health Care Facilities, Managed Health Care, Life Sciences Tools & Services, Diversified Banks, Regional Banks, Diversified Financial Services, Multi-Sector Holdings, Specialized Finance, Commercial & Residential Mortgage Finance, Transaction & Payment Processing Services, Consumer Finance, Asset Management & Custody Banks, Investment Banking & Brokerage, Diversified Capital Markets, Financial Exchanges & Data, Mortgage REITs, Insurance Brokers, Life & Health Insurance, Multi-line Insurance, Property & Casualty Insurance,

		Reinsurance, Internet Software & Services, IT Consulting & Other Services, Internet Services & Infrastructure, Application Software, Systems Software, Electronic Manufacturing Services, Alternative Carriers, Integrated Telecommunication Services, Wireless Telecommunication Services , Advertising, Broadcasting, Cable & Satellite, Publishing, Movies & Entertainment, Interactive Home Entertainment, Interactive Media & Services, Electric Utilities, Gas Utilities, Multi-Utilities, Water Utilities, Independent Power Producers & Energy Traders, Renewable Electricity, Diversified REITs, Industrial REITs, Hotel & Resort REITs, Office REITs, Health Care REITs, Multi-Family Residential REITs, Single-Family Residential REITs, Retail REITs, Other Specialized REITs, Self-Storage REITs, Telecom Tower REITs, Timber REITs, Data Center REITs, Diversified Real Estate Activities, Real Estate Operating Companies, Real Estate Development, Real Estate Services
Manufacturing firms	10101010, 10102009-20201010 20301010 25101009-25203030 25501009-	Oil & Gas Drilling, Integrated Oil & Gas, Oil & Gas Exploration & Production, Oil & Gas Refining & Marketing, Oil & Gas Storage & Transportation, Coal & Consumable Fuels, Commodity Chemicals Diversified Chemicals, Fertilizers & Agricultural, Chemicals Industrial Gases, Specialty Chemicals, Construction Materials, Metal, Glass & Plastic Containers, Paper & Plastic Packaging Products & Materials, Aluminum, Diversified Metals & Mining,

	35102010 45201019-45301020	Copper, Gold, Precious Metals & Minerals, Silver, Steel, Forest Products, Paper Products, Aerospace & Defense, Building Products, Construction & Engineering, Electrical Components & Equipment, Heavy Electrical Equipment, Industrial Conglomerates, Construction Machinery & Heavy Transportation Equipment, Agricultural & Farm Machinery, Industrial Machinery & Supplies & Components, Trading Companies & Distributors, Commercial Printing, Air Freight & Logistics, Automotive Parts & Equipment,Tires & Rubber, Automobile Manufacturers, Motorcycle Manufacturers, Consumer Electronics, Home Furnishings, Homebuilding, Household Appliances, Housewares & Specialties, Leisure Products, Apparel, Accessories & Luxury Goods, Footwear, Textiles, Broadline Retail, Apparel Retail, Computer & Electronics Retail, Home Improvement Retail, Other Specialty Retail, Automotive Retail, Home furnishing Retail, Drug Retail, Food Distributors, Food Retail, Consumer Staples Merchandise Retail, Brewers, Distillers & Vintners, Soft Drinks & Non-alcoholic Beverages, Agricultural Products & Services, Packaged Foods & Meats, Tobacco, Household Products, Personal Care Products, Health Care Equipment, Health Care Supplies, Health Care Distributor, Biotechnology, Pharmaceuticals, Communications Equipment, Technology Hardware, Storage & Peripherals, Electronic Equipment & Instruments, Electronic Components, Technology Distributors, Semiconductor

		Materials & Equipment, Semiconductors

Appendix B1:

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.483	.029		16.843	<.001
	vertinteg_2020	6.470	1.137	.114	5.689	<.001
	Manufacturing_1_for_manu	-.084	.024	-.070	-3.532	<.001
	atq_2020q1	2.764E-7	.000	.023	1.178	.239
	RD_sector_average_imputed	-4.484E-6	.000	-.002	-.103	.918
	firm_age_sector_Average_imputed	.000	.001	-.002	-.079	.937

a. Dependent Variable: resilience_2021_q1

Appendix B2:

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.335	.033		10.234	<.001
	vertinteg	6.880	1.297	.106	5.304	<.001
	Manufacturing	-.098	.027	-.072	-3.620	<.001
	atq	4.695E-7	.000	.034	1.758	.079
	RD	-8.113E-6	.000	-.003	-.163	.870
	firm_age	.001	.002	.017	.889	.374

a. Dependent Variable: resilience_2021_q3

Appendix C1:

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.026	.032		-.815	.415
	vertinteg	6.773	1.783	.159	3.798	<.001
	atq	2.276E-7	.000	.025	1.304	.192
	RD	-2.644E-5	.000	-.015	-.813	.416

	firm_age	.001	.001	.021	1.109	.267
	GICSubIndustriess	-3.422E-11	.000	-.001	-.050	.960
	SIC_Manu_Times_VI	-1.730	1.755	-.042	-.986	.324

a. Dependent Variable: Static_resilience

C2:

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.203	.049		4.163	<.001
	vertinteg	10.614	2.734	.165	3.882	<.001
	Assets	3.746E-7	.000	.027	1.407	.159
	RD	-3.051E-6	.000	-.001	-.062	.951
	firm_age_	.001	.002	.011	.567	.571
	GICSubIndustriess	-1.407E-9	.000	-.028	-1.344	.179
	SIC_manufcaturing*Vertical_Integration	-6.395	2.693	-.103	-2.374	.018

a. Dependent Variable: Dynamic_resilience

D1:

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.022	.037		-.595	.552
	vertinteg	5.307	2.024	.125	2.623	.009
	atq	6.969E-7	.000	.043	2.081	.038
	GICSubIndustriess	-1.232E-10	.000	-.003	-.149	.881
	SIC_manufcaturing*Vertical_Integration	-.594	1.960	-.014	-.303	.762
	RD_no_imputation	-2.013E-5	.000	-.012	-.597	.551
	firm_age_sector_Average_imputed	.001	.001	.024	1.143	.253

a. Dependent Variable: Static_resilience

D2:

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.026	.032		-.815	.415
	vertinteg	6.773	1.783	.159	3.798	<.001
	atq	2.277E-7	.000	.025	1.304	.192
	GICSubIndustriess	-3.424E-11	.000	-.001	-.050	.960
	SIC_manufcaturing*Vertical_Integration	-1.730	1.755	-.042	-.986	.324
	RD_0_for_missing_values	-2.644E-5	.000	-.015	-.813	.416

	firm_age_sector_Average_imputed	.001	.001	.021	1.109	.267

a. Dependent Variable: Static_resilience

D3:

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.026	.032		-.812	.417
	vertinteg	6.771	1.783	.159	3.797	<.001
	atq	2.275E-7	.000	.025	1.303	.193
	GICSubIndustriess	-3.641E-11	.000	-.001	-.053	.958
	SIC_manufcaturing*Vertical_Integration	-1.728	1.755	-.042	-.985	.325
	RD_Mean_imputed	-2.621E-5	.000	-.015	-.806	.421
	firm_age_sector_Average_imputed	.001	.001	.021	1.108	.268

a. Dependent Variable: Static_resilience

D4:

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.034	.043		-.797	.426
	vertinteg_2020	5.495	3.147	.110	1.746	.081
	atq_2020q1	6.337E-8	.000	.005	.208	.835

	GICSubIndustriess	1.138E-10	.000	.003	.119	.905
	SIC_Manu_Times_VI_2020	-.673	2.996	-.014	-.225	.822
	RD_sector_average_imputed	-4.074E-5	.000	-.013	-.537	.591
	Firm_age	.001	.001	.024	.965	.334

a. Dependent Variable: Static_resilience

D5:

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.007	.029		-.235	.814
	vertinteg_2020	6.962	1.775	.164	3.923	<.001
	atq_2020q1	2.353E-7	.000	.026	1.349	.178
	GICSubIndustriess	-1.140E-11	.000	.000	-.017	.987
	SIC_Manu_Times_VI_2020	-1.789	1.754	-.043	-1.020	.308
	RD_sector_average_imputed	-2.619E-5	.000	-.015	-.805	.421
	Age_missing_is_1	.000	.001	-.005	-.279	.780

a. Dependent Variable: Static_resilience

D6:

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.022	.033		-.679	.497
	vertinteg_2020	6.902	1.776	.162	3.885	<.001
	atq_2020q1	2.287E-7	.000	.025	1.310	.190
	GICSubIndustriess	-2.647E-11	.000	-.001	-.039	.969
	SIC_Manu_Times_VI_2020	-1.789	1.754	-.043	-1.020	.308
	RD_sector_average_imputed	-2.595E-5	.000	-.015	-.798	.425
	SMEAN(Age_copy)	.001	.001	.015	.795	.427

a. Dependent Variable: Static_resilience

D7:

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.043	.033		-1.309	.191
	vertinteg_2020	6.288	1.805	.148	3.483	<.001
	atq_2020q1	2.022E-7	.000	.022	1.155	.248
	GICSubIndustriess	3.202E-11	.000	.001	.047	.963
	SIC_Manu_Times_VI_2020	-1.501	1.759	-.036	-.854	.393

	RD_sector_average_imputed	-2.646E-5	.000	-.015	-.814	.416
	Double_sector_average	.002	.001	.040	2.022	.043

a. Dependent Variable: Static_resilience