HORIZONTAL SUPPLY CHAIN PROPAGATION FROM THE PRESENT SEMICONDUCTOR SHORTAGE

A DIFFERENCE IN DIFFERENCES ANALYSIS

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Horizontal Supply Chain Propagation from the Present Semiconductor Shortage: A Difference in Differences Analysis

Abstract:

This paper examines the effects from the present semiconductor shortage from a horizontal supply chain propagation perspective. Using relationships data from the FactSet Supply Chain Relationships database, I find evidence supporting that the shortage of semiconductors has propagated horizontally in the supply chains. Non-semiconductor firms supplying customers who are dependent on semiconductors suffer substantially from the crisis relative to firms with no linkages to semiconductor companies. These horizontally influenced firms have been affected negatively in terms of sales growth, profit margins, stock return and return on assets. To gain deeper insight into the driving forces behind the results, I split the main sample based on size, financial leverage and asset tangibility. This analysis indicates that the propagation effect for sales growth is mainly explained by smaller firms. For stock return, horizontally affected firms with higher leverage are more penalised. The results also suggest that firms with higher asset tangibility have suffered relatively more from the horizontal supply chain propagation. This study contributes to the literature on supply chain propagation as it examines horizontal linkages and digs deeper into how shocks propagate in the supply chains by examining more dependent variables than most other studies on the subject. The results in this study can be applied for other similar global supply chain disruptions of intermediate goods with none or few substitutes. Furthermore, as the semiconductor industry is vastly geographically undiversified, both when it comes to manufacturing and important input commodities, a new chip shortage in the future is not impossible. This evidence for horizontal supply chain propagation emphasises the importance of including corporate customers' horizontal exposures and dependencies in corporate finance analysis.

Keywords:

Horizontal Supply Chain Propagation, Semiconductor Shortage, Difference in Differences, Corporate Finance

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1. Introduction

As a result of the consequences following the COVID-19 pandemic, supply chain disruptions and how they spread through the global economy have received increased visibility and coverage in both business press and academic papers. The shortage of semiconductors has been of particular interest as its role in today's digitalised economy has grown immensely, affecting the production of a wide range of goods. Yun et al. (2022) describe how the pandemic caused a transition to the digital world where demand for semiconductor dependent products such as electronic devices and computing power surged. Voas et al. (2021) explain how the semiconductor companies were unable to satisfy the growing demand, triggering a global shortage. Attinasi et al. (2021) emphasise the implications of the global semiconductor shortage. The sales of microchips have almost doubled over the past decade and practically all sectors in the world economy are dependent on a constant supply of semiconductors.

Inoue and Todo (2020) state that several studies have empirically shown that shocks propagate through supply chains. However, Barrot and Sauvagnat (2016) emphasise that examining and measuring spill over effects within networks of firms have not received enough attention in the empirical literature. These spill over effects, also known as horizontal (or indirect) supply chain propagation, means that the initial shock spreads to affect other suppliers sharing the same customers as the disrupted companies. Based on semiconductors' importance in today's economy and the demand for more studies examining horizontal supply chain propagation, I formulated the research question of this paper which is to examine if and how the global semiconductor shortage has propagated horizontally in the supply chains.

The results from this study support that the semiconductor crisis has propagated horizontally in the supply chains, influencing companies sharing a common customer with a semiconductor firm relatively negative compared to firms with no horizontal linkages to semiconductor firms. As a result of the crisis, these horizontally influenced firms have experienced relative underperformance in terms of sales growth, profit margins, return on assets and stock return. This paper also finds support

for the driving forces behind the supply chain propagation. The relative underperformance is mainly driven by smaller firms, firms with higher financial leverage and firms with higher asset tangibility. The findings in this paper emphasise the importance of including corporate customers' horizontal exposures and dependencies in corporate finance analysis.

The paper is structured as follows. Section 2 contains a review of existing literature on the topic and a more thorough motivation of the hypothesis and research question. Section 3 presents the methodology, data collection process, economic model and variables analysed. Section 4 includes the regression results for all samples, a robustness check, a critical review and comments on the wider implications of this study. Section 5 concludes the paper and presents proposes for future research.

2. Literature Review

2.1. Supply Chain Propagation

Revilla and Saenz (2014) define a supply chain disruption as an event that disrupts the flow of services or goods in a supply chain network. When a disruption occurs for a company, geographic area or industry, its effects might spread (or propagate) in the supply chain, affecting other companies negatively. According to Boehm et al. (2019), the idea that customer-supplier relationships are the key channel where shocks propagate through the economy goes back to at least the 1930th.

Barrot and Sauvagnat (2016) study the propagation effects in supply chains from idiosyncratic shocks in the form of natural disasters. They had a firm-level perspective and found that the output losses caused by a shock on a supplier spills over to other suppliers. The authors emphasise that examining and measuring spill over effects within networks of firms have not received enough attention in the empirical literature. A shock in the supply chain could propagate horizontally to other suppliers selling to the same customer as a supplier who was affected by the crisis. Difficulty identifying shocks affecting specific firms is the main explanation for the lack of previous research on this phenomenon called horizontal supply chain propagation. The authors argue that there are frictions which could prevent firms from making the needed adjustments after a supply chain disruption. If there are switching costs related to changing suppliers, shocks could propagate from firm to firm and gradually amplify. The main metric used to study the propagation effect in their research is sales growth. They also investigate if the sales drop translates to value losses. If the decrease in sales growth is simply a delay of sales, there would be little effect on companies' market values. The propagation is traced in the supply chains by using reported relationships between customers and suppliers for listed US firms. The hypothesis is that if an input is easy to substitute, there should not be any significant propagation from the shocks. They find evidence supporting that a key driver for the propagation effect is input specificity. Shocks affecting suppliers with more specific inputs that are harder to replace leads to higher degree of propagation in supply chains. The authors show large

negative spill overs to other suppliers. Hence, the suppliers who are not directly affected by the shock also experience negative performance as a result of the common customer.

Inoue and Todo (2019) study firm-level data and the actual supply chain relationships and find that the complexity of the actual network is impacting how substantial the propagation effect is. The authors show that complex supply chain networks increase the propagation effect drastically. When a complex network with many nodes and numerous linkages experiences a shock in any of the nodes, it spreads quickly to many other nodes. For less complex supply chain networks, they find that crises barely propagate at all. Hence, the structure of supply chain networks has a significant impact on the magnitude of the propagation.

Inoue and Todo (2020) report that several studies have empirically shown that shocks propagate through supply chains. Papers by Barrot and Sauvagnat (2016), Kashiwagi et al. (2018), Boehm et al. (2019) and Carvalho et al. (2021) studying the effects from natural disasters from a firm-level perspective have shown evidence of supply chain propagation and negative effect on performance for vertically linked firms. These paper study customer-supplier networks across sectors which is a common approach in supply chain propagation research.

Carvalho et al. (2021) find evidence for significant indirect propagation effects when studying propagation from an input-output linkages perspective. The authors emphasise that the manufacturing of goods in any modern economy is organised in complex supply chains and that companies rely on a variety of different intermediate inputs. The number of transactions and transports of these inputs have increased rapidly. As a result of the key role that intermediate inputs play, the risks associated with disruptions in the supply chain have increased. Risks such as firm-level shocks, cyberattacks, terrorism and natural disasters can propagate in the network to a wide range of firms and industries with potential adverse consequences on productivity. The propagation effects are amplified if there is disruption for key bottleneck inputs where no satisfactory alternatives exist. The authors also highlight the increased risk of these concerns as a result of the COVID-19 pandemic. There is also a growing interest in

studying if supply chain propagation from a disruption can translate into influencing aggregate business cycles. Lastly, the paper highlights that despite the academic and policy maker interest in the risks associated with supply chain propagation of shocks from a customer-supplier relationships perspective, there has to be more research in this area.

2.2. Semiconductors and their Role in the Global Economy

Jorgenson and Vu (2016) describe the history and basic properties of semiconductors. The first major milestone was the invention of the transistor, a semiconductor device that works like an electrical switch, encoding information in binary form as the value zero (off) or one (on). The first transistor was constructed in 1947 and the inventors John Bardeen, Walter Brattain and William Shockley won the Nobel Prize in Physics for their invention. The invention of the integrated circuit by Texas Instruments in 1958 was the second major milestone. An integrated circuit (also referred to as a chip, or microchip) consists of several transistors that can store and manipulate data. The development continued and in 1971 Intel created the first central processing unit (CPU), revolutionising how computers were designed. The CPU works as the brain of a computer, taking instructions from a stored program. A computer's processing capability is dependent on how many transistors its CPU contains.

Aelker et al. (2013) emphasise that the semiconductor supply chain is one of the most complex supply chain networks of the world. The process of producing semiconductors could include more than 800 steps, requires scarce raw materials and is far more complex than the manufacturing process of most inputs.

Several authors emphasise the importance of semiconductors in the world economy. Aelker et al. (2013) stress that semiconductors are fundamental for a wide variety of products, from airbags, power switches for trains and intelligent lightning to smartphones and computers. As a result of the massive and ever continuously expanding spread of technology in the world, the semiconductor industry has grown substantially and plays an important role in almost all industries. Jorgenson and Vu (2016) fill in and describe how the Information and Communication Technology (ICT)

has revolutionised how people work, interact, spend time and communicate. These technologies have also changed the practice of governments and businesses. This revolution is present in all countries around the world and is projected to be economically transformative in the future as well as these technologies penetrate all sectors and dimensions of life. The authors underline that the improvement and development of semiconductors is at the centre of this technology revolution. The emergence of the internet, mobile technology and globalisation has fuelled the growth and importance of semiconductors across sectors. ICT has spread to all corners of the world and has a dramatic impact on economic development, especially in areas where access to information and innovation plays a key role. According to Attinasi et al. (2021), the sales of microchips have almost doubled over the past decade as the world economy is getting more and more dependent on the supply of chips. Semiconductors are crucial complementary inputs for virtually any technological device and the importance of chips increases as the world is becoming more digitalised.

Jorgenson and Vu (2016) highlight the importance of semiconductors in the future as well. Rapidly growing trends such as internet of things, cloud computing, smart industries, data transfer, smart cities and sharing economy are all heavily dependent on the supply of semiconductors. To enable these wide spreading technology trends, the supply of chips plays an important role and thus has a significant effect on world economic growth.

Attinasi et al. (2021) further explain that even if a semiconductor is a small share of the total production input, it is a crucial part of the upstream production with few substitutes. Therefore, a chip shortage is likely to spread to many sectors in the economy.

2.2.1. The Present Semiconductor Shortage

Sheffi (2021) explains that the current global supply chain crisis and semiconductor shortage was caused by the COVID-19 pandemic. One of the main reasons for the crisis was suppliers' inability to adjust their output to the increase in demand as a result of the drastic shifts in consumption patterns after the pandemic. Work from home and

distance education fuelled the demand for semiconductor goods such as home gadgets, communication gear, computers and related hardware. All these products are dependent on semiconductors as input and the failure to ramp up the production and distribution of chips caused a global crisis.

The Supply Chain Council of European Union (2021) highlights the utilisation rate and surge in semiconductor demand as two explanations for the 2021 Global Semiconductor Crisis. The production of microchips is an expensive process where it is essential for the manufacturers to have high output for it to be profitable to keep the production running. Hence, a high utilisation rate is required for the chip manufacturers not to reduce their production capacity. There was an immediate and significant decrease in demand when the COVID-19 pandemic started. As a result of the need for high utilisation rate to be profitable, the semiconductor manufacturers reduced their production capacity. The COVID-19 pandemic then led to surge in demand for products in industries which use a lot of chips in their production. The demand for semiconductors designed for smartphones and other technical consumer products increased a lot. Combining the reduced production capacity resulting from the need for high utilisation rate, the elevated increase in the demand for semiconductors and the fact that it can take up to 24 weeks to produce a complex semiconductor, an excess demand for microchips spawned. Attinasi et al. (2021) also highlight that there were some adverse events such as droughts and fires which affected the semiconductor manufacturers and exacerbated the global chip shortage. The shipping disruptions in 2021 also amplified the semiconductor crisis, severely affecting the delivery times. The shortage is expected to persist in the short term as the process of building new plants is complex and takes time.

Jorgenson and Vu (2016) describe how the semiconductor sector has globalised substantially following the trends of efficiency and cost savings. The labour intensive parts of the manufacturing process are allocated to different low labour cost countries in Asia. As a consequence of this, the international trade of semiconductors and their wide range of intermediate inputs has soared. Hence, the semiconductor sector is particularly exposed to shipping disruptions.

Sheffi (2021) emphasises how labour shortages, plant closures, shipping delays and quarantine requirements resulting from the COVID-19 pandemic made the situation even worse. Supply chain disruptions are typically solved quickly as increased prices reduce the demand and then increased supply restores the market to equilibrium. This crisis has however continued where prices have increased substantially while the shortages have persisted. One explanation for this is that as the Western countries increased their economic activity, ports could not process the increased shipping volumes. Moreover, labour shortages magnified this effect. This resulted in long delays as ships got stuck in ports for weeks. At the same time, the demand for semiconductors soared as consumers bought more computers, TVs, game consoles and smartphones. Businesses also invested heavily in equipment with semiconductors as the demand for cloud computing (driven by data centres) and 5G grew substantially. Technology companies bought as many semiconductors as possible and a shortage started to take form. As there are few to none substitutes to semiconductors, this resulted in some major shut downs. Most automotive manufacturers were announcing plant closures and reduced production in the first half of 2021 due to shortage of semiconductors. In the first quarter of 2021, Ford was forced to significantly reduce production and expected a 50% reduction in production as a result of the global chip shortage. The Supply Chain Council of European Union (2021) estimates that in the first quarter of 2021 alone, the worldwide production of automotives is reduced by over a million units as a result of the chip shortage. The assessment is that the industry will have problems throughout all of 2021 and in to 2022.

2.3 Research Question

The temporary drop in overall demand from the COVID-19 pandemic and the need for high utilisation rate in semiconductor production caused the semiconductor manufacturers to temporarily shut down their production. As a result of the change in consumption patterns and companies' investments, the demand for semiconductors increased. As the economic activity started to pick up speed, the demand increased

even more and at the same time, shipment problems and various COVID-19 related disruptions amplified the supply problems. As a result of reducing stock of semiconductors, firms had to close down production in early 2021 and publicly announced to its stakeholders that the semiconductor crisis had spread enough to cause severe economic damage.

Combining the findings from:

1. Inoue and Todo (2019) who report that the complexity of supply chain networks impact the magnitude of supply chain propagation,
2. Aelker et al. (2013) who emphasise that the semiconductor industry has one of the world's most complex supply chain networks,
3. Attinasi et al. (2021) and Jorgenson and Vu (2016) who state that the world is heavily dependent on semiconductors,
4. and Barrot and Sauvagnat (2016) who show that shocks affecting suppliers with more specific inputs that are harder to replace leads to higher degree of propagation in supply chains,

one could expect substantial propagation in the supply chains from a disruption in the semiconductor industry. Hence, it is reasonable to believe that the 2021 Global Semiconductor Crisis could have propagated horizontally in the supply chains. Barrot and Sauvagnat (2016) also highlight that spill over effects (indirect, or horizontal supply chain propagation) within networks of firms have not received enough attention in the empirical literature. This lead to the idea of my research questions which is to examine

if and how the current global semiconductor shortage has propagated horizontally in the supply chains.

Most papers in the field studying supply chain propagation focus mainly on whether various supply chain shocks propagate and have a vertical influence on the firms' customers or customers' customers (or corresponding for suppliers). This study has an alternative approach, focusing solely on examining if the supply chain shock from the global semiconductor shortage has propagated *horizontally*, indirectly

affecting firms who supply semiconductor dependent companies. As semiconductors are complementary to other inputs and viable substitutes most often do not exist, firms might reduce production and buy less of the other inputs when the availability of semiconductors is limited. Thoroughly examining the horizontal propagation from this current supply chain disruption, including a wide range of dependent variables relevant from a corporate finance perspective, could contribute to the literature of this critical field. Furthermore, I will dig deeper and examine what characteristics that made firms more severely affected by this crisis to give suggestions on the likely outcome of similar future crises.

Lastly, as the current global semiconductor shortage recently started, not a lot of research covering this crisis has been conducted yet. If I find support for horizontal supply chain propagation from the present semiconductor shortage, the results could be useful in case of potential future semiconductor crises. And given today's geopolitical environment, a future semiconductor crisis is no impossibility. Lee et al. (2021) stress that Taiwan, which is in the frontline of the struggle between China and the United States, has become indispensable as the country accounts for 92% of the world's manufacturing capacity for the most advanced chips. Furthermore, The Supply Chain Council of European Union (2022) refers to research showing that Russia and Ukraine are important players in the semiconductor market as well. More than 90% of the neon used in U.S. semiconductor manufacturing is supplied from Ukraine and 35% of the palladium necessary for the semiconductors comes from Russia. Hence, the semiconductor industry is vastly geographically undiversified, both when it comes to manufacturing but also necessary inputs. Adding the geopolitical perspective, future disruptions in the industry are not unlikely.

2.4. Corporate Finance and Supply Chain Disruptions

As this study includes an examination of more variables than most paper in the supply chain propagation literature, previous evidence is not always available. Moreover, as this paper focuses on horizontal and not vertical supply chain propagation, the previous findings are even more scarce. For this reason, I analogically apply the effects

from supply chain disruptions in general where I do not find previous horizontal supply chain propagation studies examining a variable included in this paper. Supply chain disruptions in general might not be completely applicable and comparable to the horizontal propagation effect but it at least gives a hint on what effect that could be reasonable to expect for some of the variables. For the control variables, which also have an explanatory purpose in this paper for how the results for the dependent variables can be derived, I also apply general corporate finance theory for what to expect from the semiconductor shortage.

Sales growth is the most common variable used for studying supply chain propagation. Barrot and Sauvagnat (2016) find evidence for both vertical and horizontal supply chain propagation affecting sales growth negatively for the firms influenced. The authors also show that vertical supply chain propagation affects firm value. However, they do not present any evidence for the effect on firm value from a horizontal supply chain propagation perspective which I study in this paper. Carvalho et al. (2021) find support for vertical supply chain propagation from disruptions in terms of sales growth but find no evidence for horizontal propagation.

Parast and Subramanian (2021) show that supply disruption has a significant vertical impact on firm performance in terms of return on assets, sales and price. Moreover, Hendricks and Singhal (2003b) find evidence for supply chain disruptions affecting operating income, return on assets as well as gross and operating profit margin negatively. Hendricks and Singhal (2005) report that the equity risk increases for firms hit by a supply chain disruption. The authors also find evidence implying that disruptions in supply chains affect sales growth of smaller firms more negatively compared to bigger firms.

Hendricks and Singhal (2003a) show that smaller firms are more severely affected by supply chain disruptions compared to bigger firms. A potential explanations is that smaller firms are more likely to be highly focused and less diversified. As a result, smaller firms' profitability is more dependent on a limited set of products compared to bigger firms. It could also take longer time for smaller firms to change their behaviour to speed up the recovery from a supply chain disruption.

Guo et al. (2011) argue that lower financial leverage ratios lead to lower stock price variability. All else equal, higher financial leverage means higher risk of default. The effect financial leverage has of amplifying both positive and negative results could significantly influence companies' change and variation in market values.

According to Almeida and Campello (2007), higher tangibility of firms' assets (tangible assets account for a higher percentage of total assets) influences investments negatively in times of financial constraints. Furthermore, Iltas and Demirgunes (2020) emphasise that tangible assets, in contrast to intangible assets, could be seen as less risky investments as tangible assets can be used as collateral for debt. As a result, a firm with higher asset tangibility is likely to have lower financing costs leading to higher financial performance.

Based on the findings from these authors, I have chosen the variables suitable for the research question in this paper.

3. Methodology

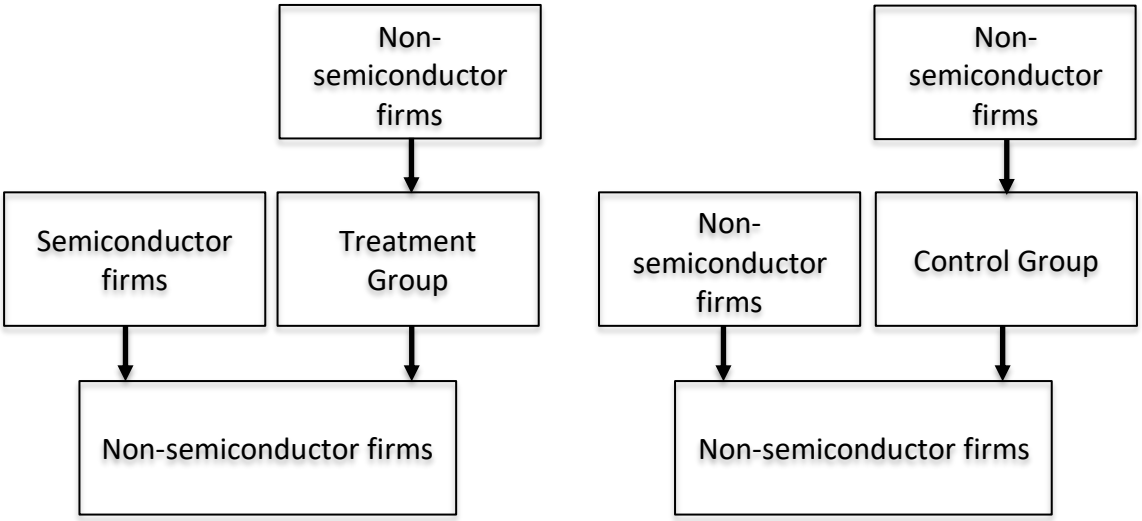
Below follows a detailed description about the methodology for this paper. First, the econometric model used is presented. Next follows a description about how the data is collected, cleaned and processed to create the supply chain network. Finally, I describe all performance metrics and control variables which are included in the regressions to examine if and how the semiconductor shortage has propagated horizontally in the supply chains.

3.1. Econometric Model

To examine if and how the semiconductor shortage has propagated horizontally in the supply chains, a Difference in Differences analysis is conducted. This econometric model is also used in the supply chain propagation study by Carvalho et al. (2021). Difference in Differences is a statistical technique used for studying the differential effect of a 'treatment' on a treatment group versus a control group. It quantifies the effect a treatment has on an outcome by comparing the average change for the control group to the average change for the treatment group before and after the treatment event. Quantitatively, the *treatment* variable is a dummy variable having the value 1 for all periods if the company is included in the treatment group and 0 for all periods if the company is in the control group. There is also a *time* variable, which is also a dummy variable. This variable indicates whether the observed period is prior to the treatment or not, having the value 1 after and 0 before. Lastly, there is a *interaction term* which is a dummy variable having the value 1 if the observed data is for a firm in the treatment group and the observation is after the treatment and 0 otherwise.

In the context of this paper, the treatment and control group are defined based on if a company is sharing a common customer with a semiconductor firm or not and the treatment is the semiconductor shortage. A firm will be included in the treatment group if the firm is a non-semiconductor company supplying a customer who is also buying semiconductors from another supplier. The control group consists of non-

semiconductor companies who are not 'treated', meaning companies that have no linkages to semiconductor companies through their clients. These firms in the control group do not sell to any customers who are also buying semiconductors. To solely focus on the difference between firms who share a common customer with a semiconductor company and comparable firms who do not, firms with direct relationships with semiconductors are not to be included in the sample. This would otherwise distort the results of this study focusing solely on horizontal supply chain propagation as these companies are directly affected by the semiconductor shortage. Hence, semiconductor companies, companies who buy semiconductors and companies who supply semiconductor companies are not included in neither the treatment nor the control group.



Note: Arrows represent flow of goods or services in the relationships. Firms in the treatment group have a horizontal, indirect, relationship with a semiconductor company. Firms in the control group do not have this relationship. Semiconductor firms or firms with a vertical, direct, relationship with a semiconductor firm are not included in the treatment nor the control group.

Figure 1. Illustration of the definition of the treatment and control group.

The objective of this paper is to see if and how the semiconductor shortage has propagated horizontally in the supply chains. If it has, one could expect to see a relative underperformance of the treatment versus control group when comparing their performance before and after the semiconductor shortage. In other words, if I

find evidence of propagation, non-semiconductor firms sharing a common customer with a semiconductor firm should be relatively more negatively affected by the crisis compared to firms with no linkages to semiconductor firms. The definitions of the treatment group and control group are illustrated in Figure 1.

3.1.1. Fixed Effects

The regressions in this study control for both time and firm fixed effects. Time fixed effects enable controlling for variables which are constant across firms but vary over time. Firm fixed effects enable controlling for variables which are constant across time but vary between firms. It is meaningful to include both time and firm fixed effects as this paper examines the difference in differences (over a longer period) between the control and treatment group which include firms with large variations in characteristics. This application of using a time and firm fixed effects model is also used in previous studies on supply chain propagation, as in the papers by Barrot and Sauvagnat (2016) and Carvalho et al. (2021).

3.1.2. Time Periods

As discussed in the second section of this paper, most previous literature and articles about the current global semiconductor shortage mention the beginning of 2021 as the start of the crisis. To further examine this issue, I use Google Trender as a proxy. Google Trender is a service by the search engine Google that analyses the popularity of top searches on Google across various languages and regions over time. Google Search has a 92%[1] market share of the global search engine market. Hence, it should be representative for the world's interests in various subjects.

As listed companies need to publicly release information relevant for their shareholders and finance media often publishes articles about these releases that people want to read more about, Google Trender is a useful proxy for investors' (and other people's) interest in the semiconductor shortage. Figure 2 illustrates the Google Trender results (normalised as the number of searches relative to the maximum

[1] https://gs.statcounter.com/search-engine-market-share

number of searches during the period) for the phrases ‘Semiconductor shortage’ and ‘Semiconductor’. The vast increase in interest in the chip shortage coincides with the previous literature and articles as the searches for ‘semiconductor shortage’ starts in January 2021.

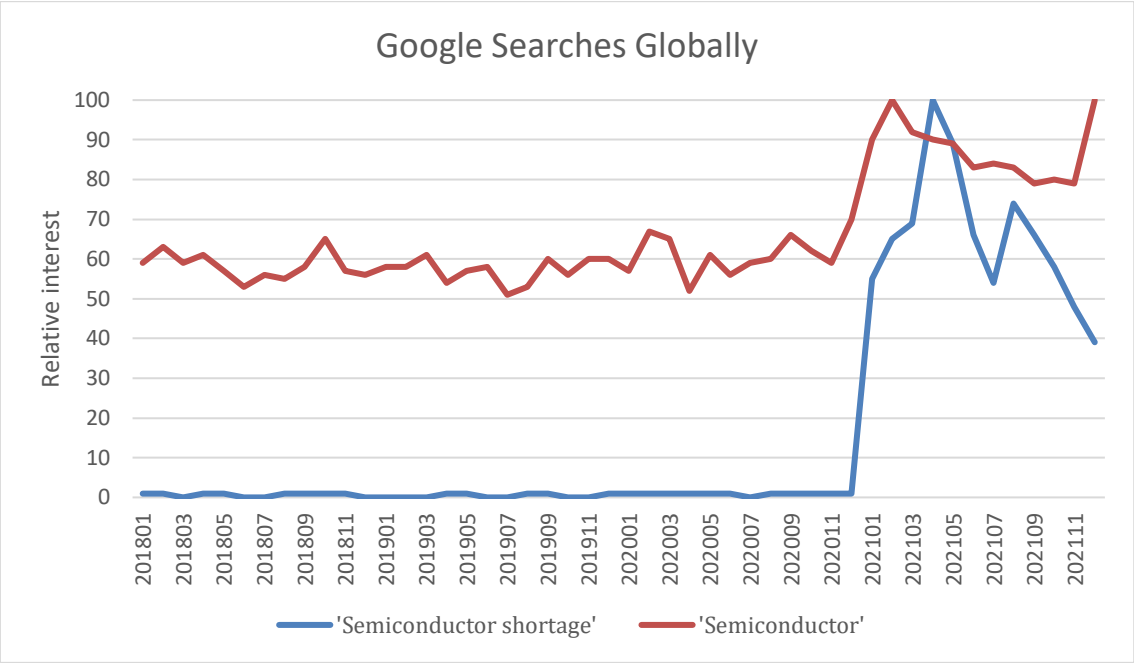


Figure 2. Relative search interest for ‘Semiconductor shortage’ and ’Semiconductor’ globally on Google between 2018-01-01 and 2021-12-31.

As a result of this, I feel confident at defining the start of the semiconductor shortage at the first quarter of 2021. And as the semiconductor shortage is still a current problem when this study is conducted in early 2022, the *time* dummy variable will have the value 1 for all periods in 2021 and 0 otherwise.

The data in this study used in all regressions goes from the first quarter of 2018 until the last quarter of 2021[2] which was the last available period when I completed the study. I include data from 2018 to get a longer period of comparison between the performance of the treatment group versus control group prior to the crisis. Simply comparing the one year period of semiconductor shortage with one year before the crisis could lead to results heavily influenced by the COVID-19 pandemic which had a significant effect on a lot of companies. Going back even further in time than 2018

[2] As I use growth metrics, the first quarter of 2018 is omitted.

could have its benefits but as will be discussed below, the longer the comparison periods, the more observations are lost due to missing values in the data.

3.2. Relationships Data

The first step of the quantitative research was defining the treatment and control group for the regressions based on the relationship data from FactSet Research Systems Supply Chain Relationships. To get a comprehensive data set with as many reported relationships as possible, I used the same method as Carvalho et al. (2021), augmenting the network by including both firms reported as customers (suppliers) by the firm itself with the reports of other companies as their supplier (customer). This enabled me to construct a data set with as many relationships as possible given the available data from FactSet. Given the scope of this paper, it is only customer and supplier relationship data which is of interest. In the initial stage, relationships for all companies available in the database are included which means more than 95.000 vertical relations.

3.2.1 Relationship Definition

The data from FactSet Research Systems Supply Chain Relationships is sourced from primary sources such as annual reports, regulatory disclosures and press releases[3]. The U.S. Securities and Exchange Commission (SEC) rule SFAS 131 requires companies to disclose customers if their revenue to one single customer is 10% or more of the firm's total revenue but some companies disclose more customers and suppliers on a more arbitrary basis. Moreover, whether a supplier or customer is disclosed in a press release or some other primary source is also arbitrary and differs from company to company. Hence, the FactSet relationships data is not complete nor entirely consistent. A relationship could be classified as terminated if the transactions between two firms goes from above to below 10% of total revenue (from 11% to 9% for example). Moreover, if a firm mentions a particular supplier or customer in a press release or some other public media but has other customers or suppliers of similar size

[3] FactSet Supply Chain Relationships | FactSet

not mentioned, only the relationship with the company mentioned in the press release will be registered in the database and the other once will be left out.

The significance of a relationship also varies and one would ideally be able to use the exposure between firms as a variable or basis for inclusion in the data sample. While companies sometimes report exact numbers such as percentage of sales or cost of goods sold and the FactSet database sometimes captures them, this information is unfortunately far from complete. This issue of simply having a binary measure of supplier-customer relationships and not a measure of significance of the relationship is also emphasised by Carvalho et al. (2021). Nevertheless, the FactSet relationship data has been used extensively in related literature for defining relationships between firms.

There are different ways of defining a relationship from the FactSet relationships data due to the potential sources of errors explained above. Wu (2015) takes a snapshot in the beginning of each year and assumes that the relationship will hold over the coming year. On the other side of the spectrum, one could narrow the definition of a semiconductor dependent company to simply including relationships over the complete period (2018-2021 in this paper). It is reasonable to believe that if a company has a relationship with a semiconductor company, the company is dependent on this specialised input even if the relationship is 'terminated' according to FactSet for any of the above mentioned reasons/sources of errors. The same reasoning holds for the possibility that FactSet obtains information about a relationship which could have started years earlier. As semiconductors are very specialised inputs, it is not very likely that a firm is dependent on semiconductors one year and independent the next year. At the same time, I also want to be conservative. For that reason, I define the treatment and control group based on relationship data starting prior to 2020 and which is not terminated before 2022 (one year prior to and after the crisis started). The relationship data will not be complete nor 100% correct no matter how this is defined, so I choose a middle way in my relationship definition.

3.2.2. Control and Treatment Group

To define the control group and treatment group, the first step is to see each firm's relationship, or absence of relationship, with semiconductor companies. Combining the relationship data from FactSet with CapitalIQ's industry definition *Semiconductors and Semiconductor Equipment*, I can find all firms who have a registered relationship with a semiconductor company. The other non-semiconductor suppliers to these companies buying semiconductors will be categorised as companies in the treatment group unless they have a direct relationship with a semiconductor firm themselves. All firms without reported direct relationships with semiconductor companies and without customers who buy semiconductors are categorised as firms in the control group. Actual semiconductor firms and firms with direct, vertical, relationships with semiconductor firms themselves are not allowed to be in the treatment nor the control group in this paper examining horizontal propagation.

3.3. Variables

This paper includes both backward looking accounting data on historical figures as well as forward looking stock market data. Since the semiconductor shortage is still a present crisis today in 2022, stock market uncertainty about the future could show up in the forward looking measures even if the crisis has not propagated enough to affect the performance until the end of 2021. For this reason, both accounting and stock market data is included in this paper.

The data for the variables is collected from CRSP/Compustat Merged Database - Fundamentals Quarterly. I use quarterly data to keep more observations and to reduce the influence of the COVID-19 pandemic. As the treatment period is the whole year of 2021, using year-on-year growth figures would lead to heavy influence of the COVID-19 pandemic shut down in the comparison periods. Moreover, as the treatment period consists of four quarters, potential seasonality effects are captured after the crisis with quarterly growth as well. As I include metrics such as change in stock price and stock price variability, all companies in the final sample are listed. CRSP/Compustat Merged Database includes descriptive information and market data

for firms listed in the US.

When creating the final sample, I only include firms with complete metrics without any missing values for any of my dependent or control variables in any period. The reason for this is to enable better comparison between the different regressions as they all include the same companies when doing the sampling this way. As the data from the CRSP/Compustat Merged Database has some missing values and I include a lot of dependent and control variables in my analysis to thoroughly examine the supply chain propagation from a corporate finance perspective, a lot of firms are excluded. Unfortunately, this makes the initial sample of firms in the treatment and control group significantly smaller.

As in the study by Barrot and Sauvagnat (2016), I winsorize all variables. As the data from CRSP/Compustat Merged Database – Fundamental Quarterly has quite a lot extreme outliers in itself but also from the variables I calculate from the available data, I winsorize all continuous variables by period at the 5^{th} and 95^{th} percentiles of their distributions.

3.3.1. Dependent Variables

To thoroughly study the propagation effect and analyse the supply chain propagation from the semiconductor shortage from a corporate finance perspective, I include more dependent variables in this study than most papers examining propagation effects. Based on previous literature covering supply chain propagation and supply chain disruptions in general, relevant performance metrics with available data that could be influenced by the potential supply chain propagation from the chip shortage are included in the regressions.

The first dependent variable analysed is quarterly Sales Growth, calculated as the percentage change in net turnover. This is the most common variable used in papers examining supply chain propagation, such as Barrot and Sauvagnat (2016), Carvalho et al. (2021) and Inoue and Todo (2020). Moreover, Bachas and Soto (2021) find that sales is harder to manipulate than profit. Therefore, sales is likely to respond quicker to disruptions in the market as it is less dependent on accounting decisions or

estimates compared to other accounting metrics. For these reasons, to support that the semiconductor crisis has propagated horizontally in the supply chain, it is important to show a difference in differences between the control and treatment group in terms of sales growth.

The second dependent variable analysed is Gross Profit Margin. A lot of firms in the CRSP/Compustat Merged Database have missing values for gross profit but have figures for net turnover and cost of goods sold (COGS). To keep as many observations as possible, I compute the gross profit margin manually myself with net turnover and COGS[4]. The idea here is to examine if and how the horizontal supply chain propagation from the semiconductor crisis affects the input and output prices. Gross profit margin is a suitable metric for this objective. It could be the case that firms with higher bargaining power use their stronger position and demand lower prices from their suppliers if the semiconductor shortage propagates and puts a cap on production. Hampton and Stratopoulos (2015) emphasise that gross profit margin is a good proxy for bargaining power as it simply reflects input and output prices and is not influenced by other factors such as SG&A and R&D expenses. Gross profit margin can reflect that a company with high bargaining power can demand lower prices from its suppliers and sell for higher prices to its customers. However, Boehm et al. (2019) find that prices did not change in their study about supply chain shocks. A potential explanation for this could be the stickiness of prices as a result of signed agreements that are not updated constantly.

The third dependent variable analysed is Operating Profit Margin. The same problem of missing values as for gross profit is also present for operating profit. Therefore, I calculate operating profit margin manually as well based on net turnover and operating expenses[5]. Operating profit is interesting to examine to see if and how the firms in the treatment group who might be indirectly affected by the

[4] Some firms report COGS as a negative figure in the CRSP/Compustat Merged Database some periods, leading to gross profit margin above 1 which should not be possible. My cleaning of the data has taken this into consideration and adjusted the cost of goods sold sign.

[5] Some firms report operating cost as a negative figure in the CRSP/Compustat Merged Database some periods, leading to operating profit margin above 1 which should be impossible. My cleaning of the data has taken this into consideration and adjusted the operating cost sign.

semiconductor shortage manage to lower their operating costs if sales growth and/or gross profit margin are negatively affected. Operating profit margin is a suitable metric to examine this as operating expenses are less variable (dependent on output quantity) than COGS.

The fourth dependent variable analysed is quarterly Change in Property, Plant and Equipment (PPE). Change in PPE is interesting to include as it is possible that firms horizontally affected by the crisis could reduce their investments in PPE or amortise PPE to a greater extent than firms unaffected by the crisis. This could also give a hint regarding the firms' expectation about the durability of the chip shortage.

The fifth dependent variable analysed is Return on Assets (ROA), calculated as operating profit (net turnover minus operating expenses) divided by the opening balance of total assets. ROA captures how efficiently a company is in its operation utilising its resources to generate profit. ROA is interesting to include in the analysis as even if firms' gross/operating profit margin or sales growth do not indicate a significant difference in differences between the treatment and control group, firms' profitability in relation to its assets could be affected by the crisis.

The sixth dependent variable analysed is the quarterly Change in Stock Price. Given that the financial market is efficient, stock prices will immediately reflect changed expectations about firms' future profitability. Hence, this variable is interesting to include since the stock market is forward looking. Even if I do not find proof of horizontal propagation effects on firms' historical performance until the end of 2021, investors could expect negative effects in the future which then should be reflected in the firms' stock prices. Barrot and Sauvagnat (2016) also examine firm value in their paper about supply chain propagation.

The seventh dependent variable analysed is quarterly Stock Price Variability which is based on the data available in CRSP/Compustat Merged Database. It is calculated as the difference between the highest and lowest share price during the period divided by the average of the two. This variable is interesting to include as it could capture differences in risk (from an investor perspective) between the treatment group and control group. It could also reflect uncertainty regarding the investors'

expectations about how the potential horizontal supply chain propagation will affect firms differently in the future. As this metric depends on share price, it is also influenced by the forward looking investors on the stock market and could capture other effects than the historical measures.

3.3.2. Control Variables

When analysing performance metrics from a wide range of companies in various sectors, including relevant control variables and reducing their influence increase the validity of the study. Given the dependent variables examined in this paper, three control variables which are reasonable to believe could influence the outcome are included in each regression. To capture these varying characteristics and demonstrate that they do not influence the results, I account for the companies' size, financial leverage and asset tangibility as statistical controls in all models. Furthermore, based on previous literature covering supply chain propagation/disruption and corporate finance, these variables or firm characteristics could also have explanatory power for the potential supply chain propagation from the chip shortage.

All control variables are lagged by one quarter. The control variables for each period will be the closing (opening) balance for the previous (current) period. The reason for lagging the control variables is because the variables otherwise could be influenced by the outcome of the dependent variables, which is not the objective. For example, a profitable quarter could increase the firms total assets, affecting the closing balance for size as well as financial leverage and asset tangibility.

The metric used to control for the firms' variation in size is each firm's total assets. This control variable could influence a lot of dependent variables examined in this paper. As emphasised by Wilson and Morris (2000), big firms have a tendency to generate lower sales growth than small firms. As touched upon before, bigger firms could have stronger bargaining power than smaller firms and use this position to get better terms with suppliers and customers which influences the gross profit margin. The profit margin measures could in turn influence return on assets. Fama and French (1992) found evidence for a size risk factor/premium where smaller firms tend to

outperform bigger firms. This difference is interpreted as compensation for the higher risk of small versus big firms. Hence, it is reasonable to expect that size could influence the dependent variables Change in Stock Price and Stock Price Variability as well. As size could affect a lot of the dependent variables included in this paper, it is important to control for it.

The metric used to control for the firms' variation in financial leverage is total liabilities divided by equity. Leverage is included as a control variable mainly to control for its influence on Change in Stock Price and Stock Price Variability, but it could influence other variables as well. All else equal, higher financial leverage means higher risk of default which should be reflected in the firms' stock prices. At the same time, higher financial leverage could be beneficial when a firm is performing well as it then increases the return on investment. The effect financial leverage has of amplifying both positive and negative results could significantly influence companies' change and variation in market values. Hence, controlling for variations in leverage between companies is important to control for so it does not influence the outcome.

The metric used to control for the firms' variation in asset tangibility is property, plant and equipment (PPE) as percentage of total assets. PPE is an accounting metric for non-current tangible assets. Examining the quotient between these figures could give an indication about the companies' means of production and as mentioned above, asset tangibility could also influence how firms are influenced by crisis situations. For these reasons, asset tangibility is controlled for in all regressions in this paper.

See Equation 1 for the general form of the formula used for all regressions in this paper.

$$Dependent\ variable_{i,j,t} = \beta_0 + \beta_1 * treatment_j + \beta_2 * time_t + \beta_3 * \left[treatment_j * time_t\right] + \beta_4 * size_{j,t-1} + \beta_5 * leverage_{j,t-1+} + \beta_6 * asset\ tangibility_{j,t-1} + \varepsilon_i \quad (1)$$

Note: where *i* represents the different dependent variables, *j* firms and *t* time periods.

3.4. Industries

As this paper examines *horizontal* supply chain propagation, some industries are not likely to be materially affected by the semiconductor crisis and are therefore disregarded in the main sample and analysed in the robustness check instead, testing the validity of this study. The objective of this paper is to examine how non-semiconductor companies selling to a customer which use semiconductors as input in its production are affected by the chip shortage relative to firms without this type of linkage (Figure 1 illustrates this).

Horizontal supply chain propagation means how a company is affected by its *corporate* customers' other suppliers. As this study focuses solely on this horizontal relationship, consumer product centred companies are excluded from the main sample. Firms in the Consumer Staples sector (GICS[6] code 30) are not to be included in the main sample. These are firms in the industry of producing essential products used by consumers such as food, beverage and household products. It is not reasonable to assume a material horizontal supply chain propagation from the chip shortage for this sector. A company selling a consumer staple product such as toilet paper to a corporate customer is not likely to be very affected by if this corporate customer use semiconductors as input in its production or not.

Firms in the Consumer Discretionary sector (GICS code 25) are excluded for the same reason. These are firms selling consumer products such as apparel, home furnishing and jewellery. It should be mentioned that a lot of the firms in the consumer discretionary sector most likely have been affected by the semiconductor crisis *vertically,* meaning that the firms could have experienced problems getting supplied with enough semiconductors to supply their customers' demand. Voas et al. (2021) explain that companies manufacturing consumer discretionary products such as microwaves, refrigerators and washing machines have been affected by the chip

[6] The Global Industry Classification Standard (GICS) is an industry taxonomy developed for the global financial community by Standard & Poor's and MSCI where all major public companies are assigned a classification code. The GICS codes are used to create financial market indexes.

shortage. However, as this paper solely examines *horizontal* supply chain propagation from the chip shortage, companies in the consumer discretionary sector are excluded for similar reasons as for consumer staples companies. The amount of washing machines or jewellery sold is not likely to be materially affected by if the firm supplies these products to a firm using semiconductors as input in their production or not. Companies in the Healthcare sector (GICS code 35) such as healthcare providers are excluded for the same reason. Lastly, following the methodology of Barrot and Sauvagnat (2016), firms in the Financial sector (GICS code 40) are also excluded.

The Materials sector (GICS code 15) is one of the sectors included in the main sample. This industry classification includes firms within verticals such as chemicals, metals and mining. These firms could be horizontally influenced by the semiconductor shortage. For instance, if a metal company is supplying a company using semiconductors as input in its production, the chip shortage could lead to this customer buying less metals as it lacks the complementary chips needed in the production. The idea of horizontal supply chain propagation examined in this paper is that a similar peer metal company solely supplying firms which do not use semiconductors in their production then would do relatively better during the crisis as its customers do not have this problem with scarcity of complementary input chips. This logic of differences between firms within sectors due to horizontal supply chain propagation is applicable for the firms in all sectors included in the main sample. In additional to firms in the Materials sector, firms in the Industrial, Energy, Information Technology, Real Estate, Communication Services and Utilities sectors are also included in the main sample. Table 1 shows descriptive statistics for the main sample.

Table 1. Descriptive Statistics for the Main Sample

Panel A: Dependent var.	Obs.	Mean	Std. dev.	p5	p95
Sales Growth	6135	0.029	0.147	-0.659	0.665
Gross Profit Margin	6135	0.392	0.208	-0.300	0.837
Operating Profit Margin	6135	0.180	0.168	-0.783	0.539
Change in PPE	6135	0.032	0.174	-0.223	1.980
Return on Assets	6135	0.028	0.021	-0.038	0.091
Change in Stock Price	6135	0.042	0.218	-0.727	0.976
Stock Price Variability	6135	0.325	0.211	0.092	1.470
Panel B: Control var.	**Obs.**	**Mean**	**Std. dev.**	**p5**	**p95**
Size	6135	12,432	17,337	146	71,162
Financial Leverage	6135	2.396	2.377	0.301	12.544
Asset Tangibility	6135	0.314	0.263	0.024	0.847

Panel C: Groups	Obs.
Treatment Group	3720
Control Group	2415

Note: This table presents the summary statistics for the main sample. Panel A presents the winsorized dependent variables which consist of 6135 firm-quarters between the second quarter of 2018 and the fourth quarter of 2021. There are 409 companies in this sample, 248 in the treatment group and 161 in the control group. Sales Growth is the quarterly change in Sales. Gross Profit Margin is the difference between Sales and Cost of Goods Sold divided by Sales for the quarter. Operating Profit Margin is the difference between Sales and Operating Expenses divided by Sales for the quarter. Change in PPE is the quarterly change in Property, Plant and Equipment. Change in Stock Price is the quarterly change in Stock Price. Stock Price Variability is the difference between the highest stock price and the lowest stock price registered during the quarter divided by the average of the two. Return on Assets in the difference between Sales and Operating Expenses for the quarter divided by the Assets (opening balance of the quarter). Panel B presents the winsorized control variables included in all regressions. Size is the Total Assets (mUSD), Financial Leverage is Liabilities divided by Equity and Asset Tangibility is Property, Plant and Equipment divided by Total Assets. All accounting data is from CRSP/Compustat Merged Database. Panel C presents the number of observations in the treatment versus the control group. 248 companies are included in the treatment group, which are companies that share a common customer with a semiconductor company. 161 companies are included in the control group, which are companies that do not share a common customer with a semiconductor firm. Neither the treatment nor the control group have a recorded relationship with a semiconductor company or are semiconductor companies themselves. Relationships data comes from FactSet Research Systems Supply Chain Relationships.

4. Results

Below follows a presentation of the results in this study. First, the regression results for the main sample with all observations included. Second, the results from the regressions where the main sample is split at the median based on the companies' Size, Financial Leverage and Asset Tangibility. Third, the regression results for a robustness check of the model including companies in sectors which are unlikely to be materially affected by horizontal supply chain propagation from the semiconductor crisis. Forth, I present a critical review of the limitation of the data and results in this paper. Lastly, I discuss the wider implications of the results in this paper.

4.1. Main Sample

Table 2 presents the results for the Difference in Differences regressions for all dependent variables for the main sample with all observations included. The interaction term coefficient shows the treatment group's average difference in performance after and prior to the semiconductor shortage compared to the corresponding difference for the control group. Hence, a negative interaction term coefficient means that the companies in the treatment group on average have experienced a bigger drop (or lower increase) in performance when comparing after and prior to the crisis compared to the companies in the control group.

The most commonly used variable when studying supply chain propagation is sales growth. The interaction term coefficient for Sales Growth is significantly negative, implying that the semiconductor crisis has propagated horizontally in the supply chain, causing a negative effect on sales growth for the companies supplying semiconductor dependent firms compared to companies who do not. The difference in differences is 1.8 percentage points. This means that on average, the companies in the treatment group have experienced 1.8 percentage points less sales growth increase relative to its performance prior to the crisis compared to the companies in the control group.

The interaction term coefficient for Gross Profit Margin is also significantly negative. The difference in differences is a 1.1 percentage point in relative

underperformance in gross profit margin for firms in the treatment group.

For Operating Profit Margin, the interaction term coefficient is negative and significant at the 10% level. The difference in differences between the treatment and control group is 1.1 percentage points, which is the same as for Gross Profit Margin. Operating expenses are generally of less variable nature compared to COGS. Combining the operating profit margin result with the results from the sales growth and gross profit margin regressions, this implies that the firms horizontally affected by the semiconductor crisis who have experienced relative underperformance in sales growth and gross profit margin have managed to reduce the negative margin effect by lowering operating expenses. This is not necessarily positive as reducing operating expenses as a response to lower sales growth and gross profit margin could affect future profitability negatively.

The interaction term coefficient for Change in PPE is negative but insignificant. Hence, this study does not find any evidence for the semiconductor crisis propagating horizontally to influence the companies' investments in PPE differently at this point. This could have several possible explanation. It could suggest that firms expect the effects from the semiconductor shortage to be temporary and that it therefore does not influence net investments significantly. It could also be that it takes time to adjust book value of these fixed tangible assets.

For Return on Assets (ROA), the interaction term coefficient is significantly negative by 0.3 percentage points. This finding is not surprising given the previous results in this study. Relative underperformance in sales growth, gross profit margin and operating profit margin and no significant change in PPE would translate to lower return on assets as long as the companies in the treatment group do not manage to reduce their other asset classes relative to the companies in the control group[7]. Hence, the companies horizontally affected by the semiconductor shortage which share a common customer with a semiconductor firm have been relatively less efficient in its operations utilising its resources to generate profit after the crisis started.

[7] Return on Assets is calculated with total assets and not only PPE as denominator.

Table 2. Regression Results: Main Sample with all Observations

Number of obs: 6135 Number of firms: 409					
	Interaction Term	Size	Financial Leverage	Asset Tangibility	R2
Sales Growth:	-0.018**	-4.97e-7	0.008***	0.062	0.156
	(0.008)	(6.51e-7)	(0.002)	(0.053)	
Gross Profit Margin:	-0.011***	1.46e-7	0.001	0.003	0.002
	(0.004)	(3.52e-7)	(0.001)	(0.029)	
Operating Profit Margin:	-0.011*	4.07e-7	-0.001	0.069*	0.136
	(0.005)	(4.46e-7)	(0.001)	(0.036)	
Change in PPE:	-0.012	-3.40e-6***	-1.04e-4	-0.851***	0.058
	(0.009)	(7.35e-7)	(0.002)	(0.060)	
Return on Assets	-0.003***	-3.21e-7***	-4.65e-4***	0.018***	0.013
	(0.001)	(5.98e-8)	(1.56e-4)	(0.005)	
Change in Stock Price:	-0.023**	-3.54e-6***	0.007***	0.085	0.381
	(0.010)	(7.97e-7)	(0.002)	(0.065)	
Stock Price Variability:	0.001	-2.93e-7	0.007***	0.085	0.440
	(0.007)	(5.53e-7)	(0.001)	(0.065)	

Note: This table presents the regression results from the Difference in Differences analyses for the main sample. The formula for the regressions is $Dependent\ variable_{i,j,t} = \beta_0 + \beta_1 * treatment_j + \beta_2 * time_t + \beta_3 * [treatment_j * time_t] + \beta_4 * size_{j,t-1} + \beta_5 * leverage_{j,t-1+} + \beta_6 * asset\ tangibility_{j,t-1} + \varepsilon_i$ where each dependent variable is presented separately. The Interaction Term indicates how the difference for the treatment group before and after the semiconductor crisis varies from the corresponding difference for the control group. Size, Financial Leverage and Asset Tangibility are control variables. R2 is the overall R2. The treatment group includes firms who share a common customer with a semiconductor firm and the control group includes firms who do not. All regressions include firm fixed effects which absorb the treatment coefficient. As all regressions also include time fixed effects, the time coefficient is not relevant either and therefore not presented in the table above. Significance at the 10%, 5% and 1% levels are demonstrate with *, ** and *** respectively.

Stock price development and how the market reacts to the horizontal supply chain propagation from the semiconductor crisis is an important result from a corporate finance perspective. The interaction term coefficient for Change in Stock Price is negative and significant. The difference in differences between the treatment and control group is 2.3 percentage points. As several backward looking accounting performance metrics are also negative and significant, it is not clear how much of the relative stock underperformance that is caused by confirmed, publicly available underperformance versus uncertainty about the future discounted in the stock prices. Regardless, the result implies that the horizontal supply chain propagation from the semiconductor shortage has affected stock prices. This evidence emphasises the importance of including corporate customers' horizontal exposures and dependencies in corporate finance analysis.

The interaction term coefficient for Stock Price Variability is not significant. Hence, this study finds no evidence for higher or lower quarterly variability in stock price for companies indirectly affected by the semiconductor shortage compared to companies with no registered indirect linkages to semiconductor firms at this stage[8].

4.2. Split Samples

To further examine and possibly gain deeper insights into the horizontal supply chain propagation from the semiconductor crisis, I perform an analysis where the main sample is split at the median based on the companies' Size, Financial Leverage and Asset Tangibility. This enables possibly deeper insight into which types of firms, based on the three mentioned characteristics, that are driving the results in the main regressions and that investors should be particularly cautious with from a horizontal supply chain propagation perspective.

4.2.1. Size Split

Table 3 presents the results for the regressions where the main sample is split at the median based on the average size of total assets between 2018 and 2020. The split is based on the values during the pre-shock time period to avoid influence from potential effects from the semiconductor crisis. Panel A shows the results for the bigger companies and Panel B shows the corresponding results for the smaller companies in the main sample. Comparing interaction term coefficients in Table 3 Panel A with the matching coefficient in Panel B could give insights into how size explains the results in the regressions with all companies included (Table 2), as the companies in the regressions in Table 3 Panel A and B together constitute the sample in Table 2.

The negative interaction term coefficient for Sales Growth is higher (in absolute terms) and more significant for the smaller compared to the bigger companies. For smaller companies, the difference in differences is a relative underperformance by 1.8

[8] The Stock Price Variability variable in this paper is based on stock prices on a quarterly basis. It is possible that the stock price variability with daily data would support a difference in differences between the companies in the treatment group and control group when comparing after and prior to the semiconductor crisis.

percentage points, significant at the 10% level. For bigger companies, the difference in differences is insignificant. Hence, the result for the important variable sales growth which is the most common variable studied when examining supply chain propagation seems to include a size effect. This is an interesting finding. The vital result in this paper implying that the semiconductor shortage has propagated horizontally in the supply chains from a sales growth perspective seems to be explained mainly by the smaller firms in the main sample. Similar results have been found for supply chain disruptions in general. A possible explanation presented by Hendricks and Singhal (2003a) is that smaller firms are more likely to be highly focused and dependent on a limited set of products compared to bigger firms. It could also take longer time for smaller firms than bigger firms to change their behaviour.

The interaction term coefficients for Gross Profit Margin is significant for bigger but not smaller firms[9]. For Operating Profit Margin (and Change in PPE), the coefficients are insignificant both when examining the bigger and smaller companies.

For ROA, the interaction term coefficient is larger in magnitude and more significantly negative for the smaller compared to bigger firms. Hence, there is higher difference in differences for smaller companies than for bigger companies.

The interaction term coefficient for Change in Stock Price is negative and significant at the 10% level for smaller companies but insignificant for bigger companies. Hence, the horizontal supply chain propagation effect in terms of stock price is more prevalent for smaller companies than for bigger companies. As with the results in the regressions for the main sample, I can not draw any conclusions regarding how much of the stock return underperformance that is caused by confirmed underperformance publicly available in the accounting data versus uncertainty about the future discounted in the stock prices. The reason for this is that the smaller firms have been affected by both relative underperformance in sales growth and stock price, and it is not examined in this study how much of the stock return that is explained by the sales growth effect or discounted future uncertainties.

[9] Robustness check will show that this variable might not be robust.

Table 3. Regression Results: Main Sample Split on Size

Number of firms: 204					
Panel A: Bigger firms	Interaction Term	Size	Financial Leverage	Asset Tangibility	R2
Sales Growth:	-0.017	-6.83e-7	0.016***	-0.047	0.162
	(0.013)	(6.20e-7)	(0.003)	(0.090)	
Gross Profit Margin:	-0.015**	1.51e-7	1.94e-4	0.037	0.003
	(0.007)	(3.55e-7)	(0.002)	(0.052)	
Operating Profit Margin:	-0.012	1.44e-7	-0.003	0.031	0.080
	(0.009)	(4.34e-7)	(0.063)	(0.063)	
Change in PPE:	-0.014	-2.19e-6***	-0.001	-0.511***	0.053
	(0.009)	(4.44e-7)	(0.002)	(0.064)	
Return on Assets	-0.002*	-3.04e-7***	-0.001***	0.018***	0.010
	(0.001)	(4.25e-8)	(1.89e-4)	(0.006)	
Change in Stock Price:	-0.018	-2.32e-6***	0.011***	0.095	0.404
	(0.012)	(6.06e-7)	(0.003)	(0.088)	
Stock Price Variability:	0.007	-4.14e-9	0.002	0.145**	0.482
	(0.009)	(4.44e-7)	(0.002)	(0.064)	
Number of firms: 205					
Panel B: Smaller firms	Interaction Term	Size	Financial Leverage	Asset Tangibility	R2
Sales Growth:	-0.018*	-1.45e-5**	0.003	0.109*	0.112
	(0.011)	(5.88e-6)	(0.002)	(0.065)	
Gross Profit Margin:	-0.006	-2.09e-6	1.57e-4	-0.029	0.022
	(0.005)	(2.91e-6)	(0.001)	(0.032)	
Operating Profit Margin:	-0.005	7.34e-7	0.001	0.019	0.037
	(0.007)	(4.03e-6)	(0.001)	(0.045)	
Change in PPE:	-0.005	-6.31e-5***	-3.46e-4	-1.213***	0.072
	(0.016)	(8.74e-6)	(0.003)	(0.097)	
Return on Assets	-0.003**	-1.51e-6**	7.44e-5	0.009	0.001
	(0.001)	(6.68e-7)	(2.26e-4)	(0.007)	
Change in Stock Price:	-0.029*	-4.86e-5***	0.006**	-0.007	0.345
	(0.016)	(8.88e-6)	(0.003)	(0.099)	
Stock Price Variability:	-0.006	8.94e-6	0.009***	3.06e-4	0.383
	(0.010)	(5.76e-6)	(0.002)	(0.064)	

Note: This table presents the regression results from the Difference in Differences analyses where the main sample is split at the median based on Size (Total Assets). Panel A shows the bigger companies in the main sample and Panel B the smaller companies. The formula for the regressions is $Dependent\ variable_{i,j,t} = \beta_0 + \beta_1 * treatment_j + \beta_2 * time_t + \beta_3 * [treatment_j * time_t] + \beta_4 * size_{j,t-1} + \beta_5 * leverage_{j,t-1+} + \beta_6 * asset\ tangibility_{j,t-1} + \varepsilon_i$ where each dependent variable is presented separately. The Interaction Term indicates how the difference for the treatment group before and after the semiconductor crisis varies from the corresponding difference for the control group. Size, Financial Leverage and Asset Tangibility are control variables. R2 is the overall R2. The treatment group includes firms who share a common customer with a semiconductor firm and the control group includes firms who do not. All regressions include firm fixed effects which absorb the treatment coefficient. As all regressions also include time fixed effects, the time coefficient is not relevant either and therefore not presented in the table above. Significance at the 10%, 5% and 1% levels are demonstrate with *, ** and *** respectively.

As when analysing the main sample, the interaction term coefficients for Stock Price Variability is insignificant for both the smaller and bigger firms.

The results from this analysis where the main sample is split based on size show that the horizontal propagation effect from the semiconductor crisis has affected smaller companies more than bigger companies.

4.2.2. Financial Leverage Split

Table 4 presents the results for the regressions where the main sample is split based on the average Financial Leverage (liabilities to equity ratio) between 2018 and 2020. Panel A shows the results for the companies in the main sample with higher leverage and Panel B the companies with lower leverage. Comparing interaction term coefficients in Table 4 Panel A with the matching coefficient in Panel B could give insights into how leverage could explain the results in the regressions with the main sample and how the propagation's influence varies depending on firm characteristics.

The interaction term coefficient for Sales Growth is negative and insignificant in both the regression for the higher levered firms and lower levered firms. This lack of difference between these coefficients implies that financial leverage does not explain the horizontal supply chain propagation in terms of sales growth in the main sample.

For Gross Profit Margin, the result from the regression with the main sample showing a significant negative difference in differences seems to be explained by lower rather than higher levered firms. The coefficient for lower levered firms is significantly negative and the corresponding coefficient for higher levered firms is insignificantly positive. I see no clear explanation to this result when looking at it in isolation as I have not found any previous literature finding a similar result. A possible explanation could be sector related[10]. It is possible that some sector(s) where the firms typically are less levered have been particularly influenced by horizontal supply chain propagation from the semiconductor crisis in terms of gross profit margin compared to other sectors where firms typically are more highly levered. Gross profit margin is mainly explained by the relationship between input prices relative to output prices. Therefore, this

[10] Robustness check will show that this variable might not be robust, which could be the explanation.

possible explanation could be due to varying bargaining power, competition within the sector or to what degree the products are differentiable or more commodity like substitutes between different sectors.

There are no differences in sign nor significance for the interaction term coefficients for Operating Profit Margin between the samples which suggests that the gross profit margin difference effect is offset by changes in operating expenses.

As in the regression with the main sample, the interaction term coefficients for Change in PPE are insignificant for both the higher and lower levered firms.

The interaction term coefficients for Return on Assets for higher and lower levered firms are very similar. Hence, the result for Return on Assets from the regression with the main sample does not seem to include a leverage effect.

The interaction term coefficient for Change in Stock Price is negative and significant at the 10% level for the higher levered sample and insignificant for the lower levered sample. All else equal, higher financial leverage means higher risk of default. A higher levered firm being (or expected to be) negatively affected by horizontal supply chain propagation would have higher risk of default compared to a lower levered firm, which should be reflected in the stock prices. The relative operational underperformance for the treatment group is stronger in the sample with lower levered firms compared to the sample with higher levered firms. At the same time, companies in the treatment group have experienced a significant relative underperformance in stock return in the higher levered sample and not in the lower levered sample. Hence, these results imply that horizontally affected firms with higher leverage have been relatively more penalised by investors on the stock market. The important finding in this paper that the semiconductor shortage has propagated horizontally in the supply chains and affected stock prices is likely to include a financial leverage effect.

As in the regression with the main sample, the interaction term coefficients for Change in Stock Price Variability are insignificant for both the higher levered and lower levered firms.

Table 4. Regression Results: Main Sample Split on Financial Leverage

Number of firms: 204					
Panel A: Higher Leverage	Interaction Term	Size	Financial Leverage	Asset Tangibility	R2
Sales Growth:	-0.017	8.48e-7	0.002**	-0.037	0.152
	(0.012)	(1.03e-6)	(0.001)	(0.073)	
Gross Profit Margin:	2.08e-4	-8.52e-7	0.002***	-0.096	0.035
	(0.011)	(9.01e-7)	(0.001)	(0.064)	
Operating Profit Margin:	-0.004	-4.56e-7	-0.001	0.016	0.026
	(0.013)	(1.12e-6)	(0.001)	(0.079)	
Change in PPE:	-0.017	-1.33e-6	6.06e-5	-0.679***	0.063
	(0.012)	(1.01e-6)	(0.001)	(0.071)	
Return on Assets	-0.002*	-3.07e-7***	-1.75e-4**	0.020***	0.005
	(0.001)	(9.11e-8)	(8.33e-5)	(0.006)	
Change in Stock Price:	-0.026*	-3.69e-6***	0.001	0.090	0.345
	(0.014)	(1.20e-6)	(0.001)	(0.084)	
Stock Price Variability:	-0.005	6.88e-7	0.003***	0.110*	0.370
	(0.010)	(8.53e-7)	(0.001)	(0.060)	
Number of firms: 205					
Panel B: Lower Leverage	Interaction Term	Size	Financial Leverage	Asset Tangibility	R2
Sales Growth:	-0.015	-1.58e-6	0.037***	0.157**	0.129
	(0.011)	(1.12e-6)	(0.012)	(0.078)	
Gross Profit Margin:	-0.012**	-9.75e-7*	0.010*	-0.042	2.0e-4
	(0.005)	(5.54e-7)	(0.006)	(0.039)	
Operating Profit Margin:	-0.011	-7.28e-8	0.010	-0.048	0.011
	(0.006)	(6.75e-7)	(0.007)	(0.047)	
Change in PPE:	-0.011	-4.88e-6***	-1.08e-4	-1.019***	0.061
	(0.013)	(1.40e-6)	(0.015)	(0.098)	
Return on Assets	-0.002**	-4.59e-7***	0.001	0.011	0.017
	(0.001)	(1.06e-7)	(0.001)	(0.007)	
Change in Stock Price:	-0.018	-2.98e-6**	0.035**	0.129	0.404
	(0.014)	(1.48e-6)	(0.015)	(0.103)	
Stock Price Variability:	0.008	1.17e-7	0.049***	-0.047	0.406
	(0.001)	(9.68e-7)	(0.010)	(0.067)	

Note: This table presents the regression results from the Difference in Differences analyses where the main sample is split at the median based on Financial Leverage (Liabilities divided by Equity). Panel A shows the higher levered companies in the main sample and Panel B the lower levered. The formula for the regressions is $Dependent\ variable_{i,j,t} = \beta_0 + \beta_1 * treatment_j + \beta_2 * time_t + \beta_3 * [treatment_j * time_t] + \beta_4 * size_{j,t-1} + \beta_5 * leverage_{j,t-1+} + \beta_6 * asset\ tangibility_{j,t-1} + \varepsilon_i$ where each dependent variable is presented separately. The Interaction Term indicates how the difference for the treatment group before and after the semiconductor crisis varies from the corresponding difference for the control group. Size, Financial Leverage and Asset Tangibility are control variables. R2 is the overall R2. The treatment group includes firms who share a common customer with a semiconductor firm and the control group includes firms who do not. All regressions include firm fixed effects which absorb the treatment coefficient. As all regressions also include time fixed effects, the time coefficient is not relevant either and therefore not presented in the table above. Significance at the 10%, 5% and 1% levels are demonstrate with *, ** and *** respectively.

The main takeaway from this analysis where the main sample is split based on Financial Leverage is that higher levered firms have been more negatively affected by the horizontal propagation effect from a stock price perspective compared to less levered companies. Based on the coefficients, this could be a result of investors' uncertainty or expectation that the chip shortage will remain, causing a selling pressure on stocks of highly levered firms horizontally affected by the crisis due to increased risk of financial distress.

4.2.3. Asset Tangibility Split

Table 5 presents the results for the regressions where the main sample is split based on the average Asset Tangibility (PPE as percent of total assets) between 2018 and 2020. Panel A shows the results for the companies with higher asset tangibility and Panel B the results for the companies in the main sample with lower asset tangibility. As with the previous sample split analyses, comparing matching interaction term coefficients between the samples could give insights into drivers explaining the results in the regressions with the main sample.

The interaction term coefficients for Sales Growth are negative and insignificant both for the higher and lower asset tangible samples. As this study finds no evidence for significant difference between these coefficients, asset tangibility does not seem to explain the evidence of horizontal supply chain propagation in terms of sales growth in the main sample.

For Gross Profit Margin, the interaction term coefficient for the firms with higher asset tangibility is insignificantly negative and for the firms with lower asset tangibility the corresponding coefficient is positive and insignificant. For Operating Profit Margin, the interaction term coefficient for the lower asset tangible firms is positive and significant at the 10% level. The corresponding coefficient for higher asset tangible firms is negative but insignificant. In the regressions with the main sample, both these coefficients are significantly negative. Hence, given that these two samples together accounts for the companies in the main sample, these results suggest that

asset tangibility might have an explanatory effect for the findings in the main sample for margins.

For Change in PPE, both interaction term coefficients are negative and insignificant. However, the coefficients indicate an asset tangibility effect driving the results in the main sample for Return on Assets. The interaction term coefficient is significant and negative for the higher asset tangible firms but positive and significant at the 10% level for the lower asset tangible firms. As these coefficients have different signs and both are significant, this implies that the negative difference in differences in the main sample is explained by the higher asset tangible companies. Hence, the ROA result in the main regression includes an asset tangibility effect where the semiconductor shortage has propagated horizontally affecting high asset tangible firms. These firms with a lot fixed tangible assets have been relatively negative affected by the crisis in terms of how efficiently they are utilising its resources to generate profit.

For Change in Stock Price, the interaction term coefficients are negative but insignificant for both the higher and lower asset tangible firms. In Table 5 Panel B, the Stock Price Variability interaction term coefficient is significant. This is the only regression in this paper where this coefficient is significant. The positive significant coefficient means that for firms with lower asset tangibility, the quarterly stock price variability has increased after the semiconductor crisis relatively more for firms in the treatment group versus firms in the control group. This result could be a result of variability in financial performance or the companies' future guidance but it could also be that investors on the stock market have had a hard time figuring out how the semiconductor crisis will horizontally affect these lower asset tangible firms, causing an increase in stock price variability.

This analysis suggests that firms with higher asset tangibility have been more negatively affected by the horizontal supply chain propagation from the semiconductor crisis than firms with lower asset tangibility.

Table 5. Regression Results: Main Sample Split on Asset Tangibility

Number of firms: 204					
Panel A: Higher Tangibility	Interaction Term	Size	Financial Leverage	Asset Tangibility	R2
Sales Growth:	-0.002	-7.91e-7	0.015***	0.086	0.185
	(0.014)	(1.09e-6)	(0.003)	(0.079)	
Gross Profit Margin:	-0.016	-9.91e-7	0.006**	-0.037	0.007
	(0.013)	(1.00e-6)	(0.003)	(0.073)	
Operating Profit Margin:	-0.019	-5.59e-7	0.006*	0.004	0.027
	(0.014)	(1.11e-6)	(0.003)	(0.080)	
Change in PPE:	-0.004	-1.64e-6***	-0.002***	-0.166***	0.019
	(0.003)	(2.56e-7)	(0.001)	(0.018)	
Return on Assets	-0.005***	-3.67e-7***	-0.001	0.014**	0.046
	(0.001)	(9.28e-8)	(2.87e-4)	(0.007)	
Change in Stock Price:	-0.021	-2.82e-6**	0.016***	0.093	0.395
	(0.015)	(1.13e-6)	(0.004)	(0.082)	
Stock Price Variability:	-0.012	4.74e-7	0.011***	0.141**	0.407
	(0.010)	(8.03e-7)	(0.002)	(0.058)	
Number of firms: 205					
Panel B: Lower Tangibility	Interaction Term	Size	Financial Leverage	Asset Tangibility	R2
Sales Growth:	-0.006	-1.11e-6	0.001	0.151*	0.159
	(0.009)	(8.16e-7)	(0.001)	(0.087)	
Gross Profit Margin:	0.003	-2.67e-8	0.001	0.031	4.0e-4
	(0.004)	(3.27e-7)	(0.001)	(0.035)	
Operating Profit Margin:	0.008*	1.00e-6**	-0.002***	0.083*	0.064
	(0.004)	(4.15e-7)	(0.001)	(0.044)	
Change in PPE:	-0.013	-7.17e-6***	0.002	-2.853***	0.214
	(0.018)	(1.69e-6)	(0.003)	(0.179)	
Return on Assets	0.001*	-2.77e-7***	-4.41e-4***	0.034***	3.0e-4
	(0.001)	(8.06e-8)	(1.36e-4)	(0.009)	
Change in Stock Price:	-0.002	-3.27e-6***	-3.97e-4	0.304**	0.406
	(0.014)	(1.28e-6)	(0.002)	(0.135)	
Stock Price Variability:	0.020**	-1.11e-6	0.003**	0.004	**0.464**
	(0.009)	(8.37e-7)	(0.001)	(0.089)	

Note: This table presents the regression results from the Difference in Differences analyses where the main sample is split at the median based on Asset Tangibility (PPE divided by Total Assets). Panel A shows the higher asset tangibility companies in the main sample and Panel B the lower. The formula for the regressions is $Dependent\ variable_{i,j,t} = \beta_0 + \beta_1 * treatment_j + \beta_2 * time_t + \beta_3 * [treatment_j * time_t] + \beta_4 * size_{j,t-1} + \beta_5 * leverage_{j,t-1+} + \beta_6 * asset\ tangibility_{j,t-1} + \varepsilon_i$ where each dependent variable is presented separately. The Interaction Term indicates how the difference for the treatment group before and after the semiconductor crisis varies from the corresponding difference for the control group. Size, Financial Leverage and Asset Tangibility are control variables. R2 is the overall R2. The treatment group includes firms who share a common customer with a semiconductor firm and the control group includes firms who do not. All regressions include firm fixed effects which absorb the treatment coefficient. As all regressions also include time fixed effects, the time coefficient is not relevant either and therefore not presented in the table above. Significance at the 10%, 5% and 1% levels are demonstrate with *, ** and *** respectively.

4.3. Robustness Check

To test the robustness of the model used in this paper, I conduct the same analysis with a sample of firms in industries who are unlikely to be materially affected by the semiconductor shortage from a *horizontal* supply chain propagation perspective. These are the firms in the industries excluded from the main sample, namely firms in the consumer staples, consumer discretionary, financial and healthcare sectors. To strengthen the validity of my model, I would now hope to see insignificant difference in differences between the treatment and control group in the regressions with companies in these sectors. The results are presented in Table 6.

The only significant interaction term coefficient is the one for Gross Profit Margin. This could have two possible explanations. It could be that the firms in these industries actually are horizontally affected by the semiconductor shortage from a gross profit margin perspective. A possible explanation could be that the semiconductor dependent firms negotiate and demand lower prices from their suppliers in these sectors as a response to the crisis. It could also be the case that the Gross Profit Margin regression is not robust. This variable is calculated manually from the data available in CRSP/Compustat Merged Database and as discussed above, the data was not always convincing.

The interaction term coefficients for Sales Growth, Gross Profit Margin, Operating Profit Margin[11], Change in Stock Price and Return on Assets were all both negative and significant in the regressions for the main sample presented in Table 2. Considering also the insignificant interaction term coefficients in the main regressions, the signs of these coefficients also point towards the expected direction based on the hypothesis underpinning the model (firms in the treatment group more negatively affected by the semiconductor shortage relative to firms in the control group). The interaction term coefficients from the robustness check in Table 6 do not only lack significance (except Gross Profit Margin) but also have signs that vary from what is

[11] Operating Profit Margin was significant at the 10% level, all other variables mentioned were significant at least at the 5% level.

expected from the hypothesis of horizontal supply chain propagation that built the foundation of the model.

Hence, except from possible Gross Profit Margin, this robustness check concludes that the observed results in the main analysis are likely to be attributed to the semiconductor crisis and not other confounding events[12] as I find a stronger economic impact on the subset of firms that are arguably more horizontally exposed to the semiconductor industry given their product complementarity.

Table 6. Regression Results: Robustness Test with Industries Unlikely to be Influenced

Number of obs: 5385 Number of firms: 359	Interaction Term	Size	Financial Leverage	Asset Tangibility	R2
Sales Growth:	0.010	-1.19e-6***	0.002	0.124**	0.109
	(0.010)	(4.31e-7)	(0.002)	(0.062)	
Gross Profit Margin:	-0.018***	9.33e-7***	0.002***	-0.002	0.025
	(0.004)	(1.70e-7)	(0.001)	(0.024)	
Operating Profit Margin:	-0.004	6.95e-7***	0.002**	-0.072*	0.143
	(0.006)	(2.60e-7)	(0.001)	(0.037)	
Change in PPE:	0.017	-1.70e-7	-0.002	-0.749***	0.165
	(0.011)	(4.64e-7)	(0.002)	(0.067)	
Return on Assets	0.001	-1.92e-7***	-8.66e-5	-0.033***	2.0e-4
	(0.001)	(3.97e-8)	(1.39e-4)	(0.006)	
Change in Stock Price:	0.008	1.67e-7	0.006***	-0.020	0.370
	(0.010)	(4.46e-7)	(0.002)	(0.064)	
Stock Price Variability:	-0.004	3.42e-7	0.002**	0.084**	0.382
	(0.007)	(2.91e-7)	(0.001)	(0.042)	

Note: This table presents the regression results from the Difference in Differences analyses for the industries excluded from the main sample which include the companies in industries which are unlikely to be materially affected by horizontal supply chain propagation from the semiconductor shortage. The formula for the regressions is $Dependent\ variable_{i,j,t} = \beta_0 + \beta_1 * treatment_j + \beta_2 * time_t + \beta_3 * [treatment_j * time_t] + \beta_4 * size_{j,t-1} + \beta_5 * leverage_{j,t-1+} + \beta_6 * asset\ tangibility_{j,t-1} + \varepsilon_i$ where each dependent variable is presented separately. The Interaction Term indicates how the difference for the treatment group before and after the semiconductor crisis varies from the corresponding difference for the control group. Size, Financial Leverage and Asset Tangibility are control variables. R2 is the overall R2. The treatment group includes firms who share a common customer with a semiconductor firm and the control group includes firms who do not. All regressions include firm fixed effects which absorb the treatment coefficient. As all regressions also include time fixed effects, the time coefficient is not relevant either and therefore not presented in the table above. Significance at the 10%, 5% and 1% levels are demonstrate with *, ** and *** respectively.

[12] As an additional check, I do regressions for change in earnings per share for the main and robustness check samples where I find that the interaction term is significantly negative in the main sample and insignificant in the robustness check sample. Given the other variables analysed and previous results, this should be expected.

4.4. Limitations of Data Sample

There are several limitations with the data used in this study. The data from CRSP/Compustat Merged Database has a lot of missing values. As one of the objectives of this study was to get a deeper insight into the details of how horizontal supply chain propagation could affect companies, I study more dependent variables than most previous literature. Moreover, as I want to make the analysis of the various variables and samples comparable between each other, I only include companies with complete data for all variables in all periods. An alternative approach would be to include all observations with complete data for each variable. For example, Sales Growth would include all companies with available sales data for each period and Change in Stock Price would include all companies with available stock prices each period. However, this approach would make comparison hard. It could then be the case that sales growth and profitability decreased for the treatment group relative to the control group when comparing after and before the crisis started but the difference in differences for stock price return is insignificant. Then, one could not make the conclusion that the stock market interprets the shock as temporary and that the treatment group would catch up on the control group in coming periods. The reason for this is that the results would not be comparable as the analyses for sales growth or profitability include other companies than the regression for stock price. As a result of my approach, a lot of observations (companies) had to be excluded as one missing value out of 160 in total (10 variables, 16 quarters) was enough to have the company excluded from the sample. It is unfortunate to have to drop these observations but I value the comparability between results over the sample size as the objective of this paper is to get deeper insights. Despite this limitation, I still find significant results in line with the hypotheses in this paper with this smaller sample size.

Another limitation with the data used in this study is the relationships data from FactSet Research Systems Supply Chain Relationships. On the one hand, it is good that the database collects and registers relationships from several sources as it increases the amount of registered relationships available and thus the sample size. On the other hand, the data for the significance of the relationship is often missing and it

is therefore not possible to decide which data to include and exclude based on significance of the relationships. This results in a data sample used in this paper which has not considered the exposure that firms in a relationship have to each other and all relationships are treated equal. Moreover, whether a supplier or customer is disclosed in a press release and therefore registered by FactSet includes an arbitrary element as the disclosures differ from company to company. Hence, the relationship data used in this study is not entirely consistent.

It should also be mentioned that the examination of the firms' performance on the stock market does not take common risk factors used for calculating abnormal return into consideration. This paper only includes return and stock price variability. Hence, these results should be interpreted from a mean-variance rather than an abnormal return perspective.

The results also highlights some possible limitations with this study. It should be noted that the R2s for Gross Profit Margin, Operating Profit Margin and Return on Assets are significantly lower than the R2s for the other dependent variables. The main variables of interest in this paper, Sales Growth and Change in Stock Price, have significantly higher R2s. Moreover, the results from the robustness check regressions imply that one should treat the results for Gross Profit Margin with caution as that interaction term coefficient was significant in the robustness check as well.

Lastly, I want to emphasise that the results from this study might not always be applicable on a general level for all types of supply chain disruptions as this paper studies only one crisis. The semiconductor shortage studied in this paper might have special characteristics compared to other supply chain disruptions that make the conclusions from this paper not necessarily applicable for all types of supply chain disruptions. This paper study a global shortage of an important intermediate input in the world economy which is specialised and hard to substitute. Hence, the results from this paper are most applicable on crises where there is a global shortage of a complementary input with similar characteristics.

4.5. Wider Implications

This study finds evidence supporting that the shortage of semiconductors has propagated horizontally in the supply chains, influencing firms' sales growth, profit margins, stock return and return on assets. This paper gives detailed insights into how similar crises could propagate horizontally and affect firms with varying characteristics differently. However, and as recently noted, the results from this paper should preferably be applied on similar supply chain disruptions where there is a global shortage of an intermediate input which is specialised and hard to substitute.

With that said, it is not impossible that similar crises occur in the future. According to The Supply Chain Council of European Union (2022), Russia and Ukraine are important players in the commodity market as 90% of the neon used in the U.S. semiconductor manufacturing is supplied from Ukraine and 35% of the palladium necessary for the semiconductors comes from Russia. And as emphasised by Lee et al. (2021), Taiwan, which is in the middle of struggle between China and the United States, accounts for 92% of the world's manufacturing capacity for the most advanced chips. Hence, the semiconductor industry is vastly geographically undiversified, both when it comes to manufacturing but also necessary inputs. This lack of diversification could lead to new semiconductor crisis in the future.

5. Conclusion

The research question in this paper was to examine if and how the present semiconductor shortage has propagated horizontally in the supply chains, affecting non-semiconductor companies sharing a common customer with a semiconductor firm relatively negative compared to firms with no linkages to semiconductor firms. I have studied a wide range of variables and the results imply that the semiconductor shortage has propagated horizontally, affecting these firms' sales growth, margins, stock return and return on assets relatively negative. The most commonly used variable when studying supply chain propagation, sales growth, is robust and significantly negative. So is the change in stock price which is an important outcome in corporate finance. This paper fails to find any significant results suggesting any difference in differences between the treatment and control group for investments in PPE as well as stock price variability when studying the main sample.

Splitting the main sample based on the companies' size, financial leverage and asset tangibility gave deeper insights into how firms' characteristics influence the effects from the propagation and what types of firms that are driving the results in the main regressions. The findings imply that when it comes to the relative underperformance in the sales growth, it is mainly explained by smaller firms. The results also suggest that horizontally affected firms with higher leverage are more penalised than lower levered firms. Hence, in case of a similar future global supply chain disruption, the results in this study imply that investors should be cautious with highly levered and smaller firms with horizontal relationships to the disrupted industry. Moreover, my results also suggest that higher asset tangible firms have been more negatively influenced by the chip shortage. The evidence for horizontal supply chain propagation in this paper emphasises the importance of including corporate customers' horizontal exposures and dependencies in corporate finance analysis.

Several important issues remain open to future research. First, as the semiconductor shortage is a current crisis when this study is completed, it would be interesting to see how it develops and study the effects after the crisis is over. This

would enable an analysis of the groups' relative performance after the crisis. It would be interesting to examine if the relative underperformance in terms of sales growth is 'lost' or if the firms in the treatment group catch up after the crisis and overperform the firms in the control group.

Second, the binary firm-level linkages used in this paper enable estimates for if and how the semiconductor shortage has propagated horizontally but using a relationship data set with value of firm-to-firm transactions would enable a more detailed analysis. Moreover, data for variables capturing the diversification of companies' product and customer portfolios or proxies for the degree of differentiation or bargaining power would enable even deeper insights into if and how different types of firms are influenced by horizontal supply chain propagation.

Lastly, further research could study similar supply chain disruptions of specialised intermediate inputs to see if the results are in line with my findings.

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