THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Procuring electronics and semiconductors in a changing environment

A study of automakers' procurement strategies to secure supply, cost and innovation

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CHALMERS UNIVERSITY OF TECHNOLOGY

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ABSTRACT

The automotive industry is undergoing a transformation that is fueled by automation, connectivity, and electrification. Automotive original equipment manufacturers (OEMs) have and continue to become increasingly dependent on electronic and semiconductor components (SEC), in a changing environment characterized by increasing legal regulations, rapid technological development, and susceptibility to natural disasters. These factors present challenges for OEMs and their procurement to secure the needed supply, cost, and innovation of SEC. An example of these challenges is the semiconductor shortage crisis (2021–2023), which caused production stops and increased component costs for several OEMs. Looking ahead, concerns about supply and cost are accompanied by an increasing need to access innovations that enable new, advanced vehicle functions.

This thesis takes the perspective of automotive OEMs and investigates how, through their procurement, they can improve their position in the supply network to secure supply, cost, and innovation of SEC. To achieve this aim, this thesis adopts a case study of an automotive OEM's SEC supply network. Adopting a case study method allowed the exploration of the context of the automotive SEC supply network, including the relationships, the dependences between actors, and the influence of internal and external factors.

This thesis combines the findings of three papers and shows the growth of the SEC supply network as a Tier 1-centric network, marked by local power imbalances and disconnection between upstream and downstream actors, which weaken the power position of OEMs. On the other hand, procurement approaches to secure innovation and supply through interactions across the supply network, including direct connections with semiconductor suppliers, improve the OEMs' power position. The findings contribute to our understanding of the automotive SEC supply network and of the role of procurement in improving buying firms' position to secure multiple procurement objectives in decision-making environments marked by rapid change.

Keywords: procurement; semiconductors; automotive; supply network; Social Network Analysis

LIST OF APPENDED PAPERS

Paper I
Arvidsson, A.; Garcia, J.A.C.; Govik, L. Power dynamics in global supply networks at times of supply crisis.

An earlier version of the paper was presented at the 31st International IPSERA conference.

Contribution: Part of the data collection and analysis; part of interpretation of the results, contributed to the writing of the method and findings section.

Paper II
Garcia, J.A.C.; Arvidsson, A; Jonsson, P. An analysis of automakers navigating an evolving semiconductor landscape.

An earlier version of the paper was presented at the 35th NOFOMA CONFERENCE June 14-16, 2023 | Helsinki – Espoo

Contribution: main author; main responsible for conceptualization, data collection and analysis. Main part of the interpretation, writing of the paper, and responding to the review process.

Paper III
Garcia, J.A.C.; Arvidsson, A; Jonsson, P. (2023) Ensuring supply of semiconductors for automotive manufacturers: A social network perspective, In conference; 32nd International IPSERA conference on purchasing and supply chain management in Barcelona, Spain, 3-5 April 2023. IPSERA

Presented at the 32nd International IPSERA conference. An expanded version of the paper is being developed for journal submission.

Contribution: main author; main responsible for conceptualization, data collection and analysis, interpretation of the results, and writing of the paper.

ACKNOWLEDGEMENTS

When I look back almost three years, I revisit the days when I contemplated the opportunity to start my doctoral studies. The desire to understand things beyond what is visible on the surface has always moved me and right there the perfect opportunity presented itself, but with a catch: it involved five years of dedication, deadlines, peer reviews, and potentially frustration, stress and the feeling of being lost at times. I embraced that opportunity. Today, as I look back at those days, I feel grateful for my decision and for everything I have learned so far in this journey. I also recognize that I could not have come this far without the support and guidance from some truly amazing people. I would like to take this opportunity to thank them.

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Besides being grateful, I feel honored by the trust and the opportunity I have to do research as an Industrial PhD student at Scania. I want to express my gratitude to Scania for this opportunity and give a big thank you to my industrial supervision committee at Scania. The committee has been always open to discuss the ideas, the challenges and the findings of my research. Perceiving this interest and support has kept me motivated and excited to do research and generate knowledge for procurement. A special thanks to the two people with the biggest advising role in my industrial PhD journey: thank you to Stefan for being an understanding, supportive manager, with whom I feel that I can discuss any topics openly; also thank you to Felix for being an inspiring figure in my journey, someone with a vivid interest in new ways of thinking, new paradigms and an amazing capacity to understand and inspire people. Thanks to both of you and to all my colleagues who have being patient with my limited schedule, the deadline periods, for listening to my stories about my research and for creating the supportive environment I so much needed to endure this journey. A special thank you to Sheryl and Gustav for their time and dedication in reading my paper drafts, providing feedback and discussing how to make text and figures clear to procurement practitioners.

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Now, as I look ahead to the final half of my PhD project, I feel excited, inspired and determined to continuing this journey, with all the challenges and ups and downs that it involves. Afterall, I know that having these amazing people around me will make it an exciting journey.

José Augusto Campos Garcia
Gothenburg, May 2024

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1. INTRODUCTION

A global supply chain crisis began in late 2020 and attracted the attention of companies around the globe to devices that suddenly became short in supply: semiconductors (King et al., 2021). The shortage was notably severe for automotive OEMs (Brinley, 2023), who recognized the weaknesses in their power position in their supply network for semiconductor and electronic components (SEC) (Arvidsson, Garcia, et al., 2022), mainly because of low volumes, lack of relationships with semiconductor producers, and a lack of understanding of the semiconductor industry.

Semiconductor devices have been around since the invention of the first transistors in the 1940s (High-Tech, 2024; Łukasiak & Jakubowski, 2010) and are part of many devices of our everyday life. They have high technological complexity and require long, complex, and capital-intensive production processes (Geng & Jiang, 2010; Mönch et al., 2018). However, automotive OEMs seem to have missed enough attention given to these important components, at least enough to avoid or recognize a global shortage crisis in a timely manner.

The semiconductor shortage crisis is the most evident episode of the continuous change in the internal and external environment of automotive OEMs: an environment that has been changing in recent decades with the increase in electronic functions in vehicles and that is expected to continue changing with the trends of automation, connectivity, and electrification of vehicles. In the future, a weak position in the SEC supply network can present challenges to secure supply, cost and innovation of semiconductors and electronics needed for the automotive OEMs' products.

The present thesis addresses this changing environment of the automotive SEC and takes the perspective of OEMs' procurement on how to improve their power position in this network.

1.1. BACKGROUND

1.1.1. EMPIRICAL PROBLEM: A CHANGING ENVIRONMENT FOR AUTOMOTIVE ELECTRONICS

The environmental changes in the automotive SEC supply network are not a new reality and refer to changes in the overall market and within the supply network. In the overall market, legal requirements for enhanced safety, fuel efficiency and reduced emissions have prompted actors in the SEC supply network to pursue new technological solutions to meet those requirements. In the supply network, an increasing number of suppliers of mechanical and pneumatic automotive components have moved into electronic components, as new technologies from semiconductor suppliers have enabled electronic controls.

Changes in the external environment of OEMs have also caused changes in their internal environment, but the way in which OEMs dealt with the SEC supply network has remained mostly unchanged. For OEMs, the adoption of more electronics is needed to provide new functions to meet new legal requirements and customer demands. Since the adoption of the first electronics and semiconductors in electronic injection systems in the 1960s, this adoption has

increased ever since. However, despite OEMs becoming increasingly dependent on SEC, the sourcing model adopted by OEMs' procurement has remained dependent on the direct electronic component suppliers (Tier 1 suppliers).

Once the supply of semiconductors became constrained at the end of 2020, the consequences of this dependence were revealed. Lacking semiconductors, Tier 1 suppliers could not produce and deliver electronic components, and without electronic components, automakers could not produce and deliver vehicles. With the task to secure supply of SEC, OEMs' procurement has been limited by a lack of relationship with semiconductor suppliers, a lack of knowledge of the semiconductors thar are used in the electronic components they outsourced, and difficulties in obtaining the attention of semiconductor suppliers.

At the same time, the mismatch in the automotive industry's demand and the semiconductor industry's supply availability challenged the role of Tier 1 suppliers in coordinating supply and demand in the network. This mismatch also revealed the main differences in the operating models of the automotive and semiconductor industries: lead times, production flexibility, and planning horizons between the automotive and semiconductor industries (Zapp et al., 2012). These and other differences are illustrated in Figure *1*.

Table 1: Differences between the automotive and semiconductor industries.

Characteristics	**Automotive Industry**	**Semiconductor Industry**
Network position	OEM	Tier 2 or Tier 3
Product's life cycle	Long	Short
Lot sizes	Small	Large
Lead times	Short	Long
Flexibility in production	Flexible	Inflexible
Vertical Integration	Moderate	Low
Planning Horizons	Short	Long
Demand	Stable demand	Seasonal demand

Source: adapted from Zapp et al. (2012).

Similar to how the OEMs' environment has changed in the past, it is likely that these changes will continue to challenge OEMs' procurement. In the overall market, trends in automation, connectivity, and electrification are common to several industries. By recognizing the role of semiconductors in these trends and in the global economy, policymakers have directed their efforts to strengthen the local technology development and the supply of semiconductors (European Chips Act, 2022; US Chips Act, 2022). In the SEC supply network, semiconductor suppliers offer more complex and complete solutions, taking part in the value previously created by Tier 1 suppliers and directly connecting with OEMs. For OEMs, securing supply, the right cost and innovation of semiconductors becomes necessary to remain competitive in this changing environment.

To navigate this changing environment, through their procurement, OEMs must increase their understanding of this environment to address the weaknesses and limitations revealed by the semiconductor shortages.

1.1.2. THEORETICAL BACKGROUND: PROCUREMENT'S CONTRIBUTION TO ORGANIZATIONAL STABILITY AND THE SUPPLY NETWORK

For companies dealing with changing environments, procurement can play an important role in navigating changes and moving towards greater stability. In a company's interaction with the external environment, procurement is the "bridge builder" that connects the company with its external supply markets (Ellram et al., 2020, p. 3). To secure the company's needs in terms of supply, cost, and innovation (van Weele & Rozemeijer, 2022), procurement actively selects and manages a number from which it sources its needs (Choi & Krause, 2006) and the more uncertainty the external environment presents, the greater the need for a high level of strategic procurement (Ateş & Memiş, 2021; Patrucco et al., 2023).

To understand a company's interaction with its external environment, it is important to understand its position in its supply network. This thesis makes use of two theoretical lenses to increase this understanding. First, the buying firm's power position considers, among other factors, buyer-supplier dependences (Caniëls & Gelderman, 2005), its position and role in its supply network and relationships with suppliers (Kähkönen & Virolainen, 2011). The second theoretical perspective, Social Network Analysis, allows an analysis of the structure of the supply network through metrics such as network size, centralization and density, and the analysis of a firm's role in the network through its centrality (e.g., degree, closeness and betweenness centrality) (Borgatti & Li, 2009; Kim et al., 2011).

Both the firm's power position and the supply network structure have implications for the firm's procurement. A weak power position, because of for example suppliers' market power and expertise and high supplier switching costs might require strengthening supplier relationships (Caniëls & Gelderman, 2005). In addition, the firm's position in the supply network can influence its exposure to supply chain risks (Borgatti & Li, 2009) and to cost increases (Kim et al., 2011), and its ability to access supplier innovation (Kim et al., 2020).

Traditionally, the sourcing model of automotive OEMs has been built around their reliance on Tier 1 component suppliers with distant supplier relationships, a focus on cost savings, and limited usage of the innovation created by the suppliers (Lamming, 1993). The dependence on large Tier 1 suppliers makes the automotive supply network vulnerable to disruptions at these suppliers (Brintrup et al., 2015) but it allows for a cost-efficient way to manage the supply base (Doran, 2004).

Improving a buying firm's power position in such a changing environment is not an obvious task, especially in a context of increasing relevance of indirect suppliers. Existing literature addresses how firms can improve their power position in the network (Caniëls & Gelderman, 2007) and, more specifically, achieve the procurement objectives of supply assurance (Jaenichen et al., 2021; Kırılmaz & Erol, 2017), cost, (Hesping & Schiele, 2016) and innovation (Picaud-Bello et al., 2022), but most of this knowledge refers to relationships with direct suppliers.

Therefore, the existing literature lacks a supply network perspective on how procurement can influence the power position of an OEM by interacting with its supply network beyond Tier 1 suppliers. The present thesis addresses this gap and considers the supply network

beyond Tier 1 suppliers. This follows the argument that a supply network perspective is needed (Carter et al., 2007; Lee, 2010) and that firms need to go beyond traditional dyadic buyer-supplier relationships (Choi & Wu, 2009).

1.2. AIM AND RESEARCH QUESTIONS

Considering the empirical problem and the gap identified in the literature, the aim of this thesis is to investigate how automotive OEMs can improve their network position through their procurement to ensure supply, cost, and access to innovation for SEC. To achieve this aim, the following research questions are addressed in this thesis.

The first research question addresses the understanding of the SEC decision-making environment and the OEMs' power position in this environment. To improve OEMs' power position, first it is necessary to understand the supply network and factors in the network and in the external environment that influence the OEMs' power position. The need for this understanding is addressed through research question RQ1:

> RQ1: How can the SEC supply network and the OEMs' position in this network be characterized?

In characterizing the decision-making environment, this thesis considers the SEC supply network in terms of its size, density, centralization, existing relationships between actors, and the power position of the OEM in this network. The OEMs' position in this environment is characterized by means of centrality in the network (measured through SNA metrics) as well as customer attractiveness, supplier dependence and supplier relationships.

Once an understanding of the SEC supply network and the OEMs' position in it is established, the thesis addresses the role of procurement in improving this position to ensure supply, cost, and access to innovation for SEC. This role is investigated in two phases: by investigating how the interaction between procurement and the supply network influenced the OEMs' current position in their SEC environment and how the OEMs counteracted the weaknesses of this position to secure supply during the semiconductor shortages. Thus, this role is investigated through research question RQ2, which is broken down into questions 2a and 2b:

> RQ2: How can procurement improve OEMs' position in their SEC supply network?

This research question is operationalized in two parts. First, this thesis investigates how the interaction between procurement focus and supply network structure influences the OEMs' position in the network. The second part involves the investigation of how OEMs, through procurement, counteract the weaknesses in their power position to secure supply of SEC in times of shortage. Section, 1.3 describes how these research questions were investigated in the papers appended to this thesis.

1.3. PAPERS

The research questions were investigated in three different papers. The overlaps in the literature streams, adopted concepts, and contributions from each paper to answering the research questions are represented in Figure 1.

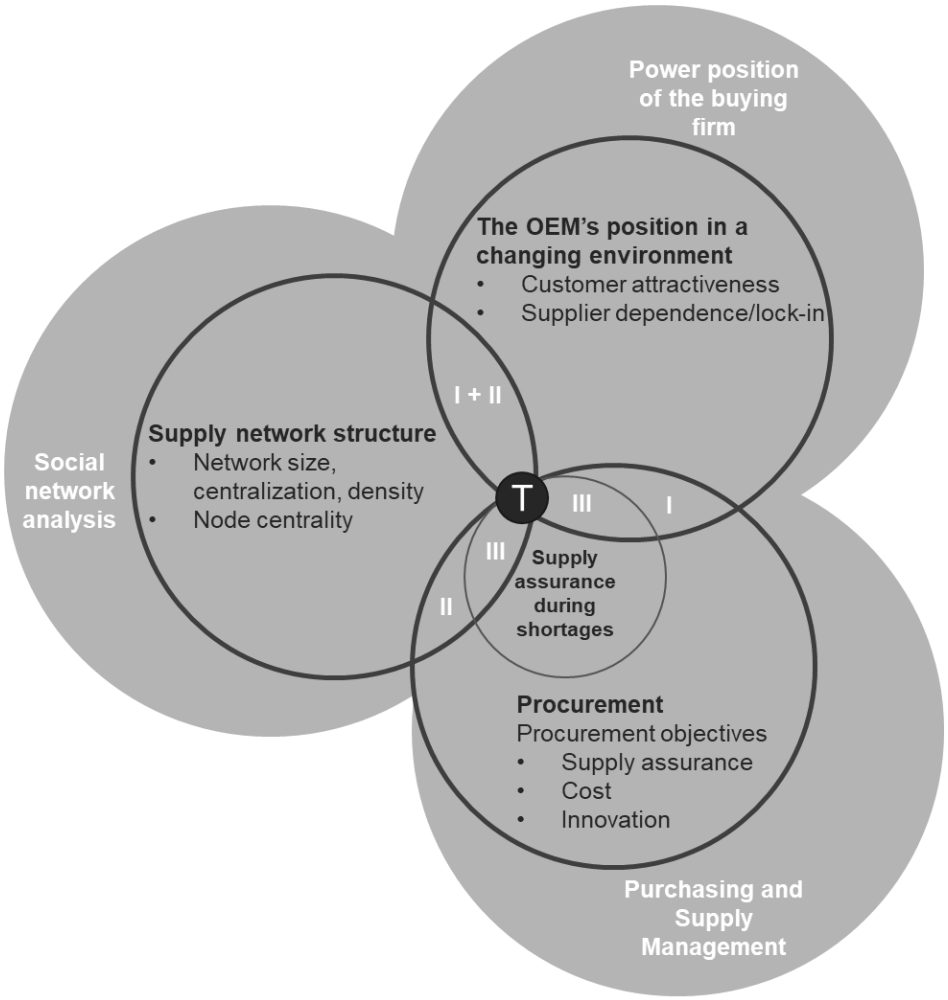


Figure 1: Overview of the overlaps of literature streams, concepts, and contributions of each paper to this thesis

To address the power position of the buying firm, Paper I addresses the OEMs' power position in a changing environment and how procurement leverages this position. Through an initial description of the supply network and the relationships and supplier dependence imbalances in the network, Paper I contributes to RQ1.

Motivated by the findings of Paper I, Paper II addresses the interaction between procurement and supply network structure to understand how this interaction influences the OEM's centrality in the network, which contributes to RQ2. Together, Papers 1 and 2 provide

insights about how the supply network structure affects the OEMs' power position in the network, which contributes to RQ1.

Paper III addresses OEMs' procurement approaches to counteract a weak power position in the network and secure SEC supply in times of shortage, contributing to RQ2.

Finally, this thesis brings together the findings and insights from these three papers and extends our knowledge of how OEMs can improve their power position through procurement's interaction with the supply network.

1.4. THESIS OUTLINE

The thesis is structured as follows: section 2 presents the frame of reference adopted in this thesis. Section 3 presents the research design and methods adopted in the different studies. Section 4 contains a summary of the findings of the appended papers. Section 5 discusses the findings related to the aim and research questions. Section 6 presents the conclusions and limitations.

2. THEORETICAL FRAMEWORK

This section presents the different theoretical perspectives that compose the theoretical framework adopted in this thesis. The first part of the theoretical framework is composed of literature in the field of Purchasing and Supply Management (PSM), such as definitions and roles of the procurement, procurement objectives, and approaches to secure component supply. The second part of the framework includes the power position of the buying firm and Social Network Analysis (SNA), in support of the network perspective adopted in this thesis.

2.1. PURCHASING AND SUPPLY MANAGEMENT

PSM is a multidisciplinary research field (Wynstra et al., 2019): it applies theories from different disciplines to investigate topics that span from a strategic character (e.g., supplier relationship management, category sourcing), through tactical (e.g., product specification, supplier selection and contracting) to operational processes (e.g., ordering, receiving, payment).

The PSM field has a close link to practice, which has experienced a shift from an operational to a strategic focus, resulting in diverging descriptions of the roles and responsibilities within PSM (Ellram et al., 2020). Acknowledging the distinct descriptions of the roles in PSM research and practice, this section presents the definition and role of procurement adopted in the present thesis.

2.1.1. DEFINITION AND ROLE OF PROCUREMENT

The literature in the PSM research field presents several terms that are often used interchangeably but that hold distinctions in their meaning, such as procurement, purchasing, buying, and sourcing. According to (van Weele & Rozemeijer, 2022), the concept of buying entails the steps of requesting bids and negotiating contracts with suppliers. Beyond the scope of buying, purchasing also includes interplay with internal actors to discuss and challenge specifications. Procurement, in turn, encompasses an even broader scope and relates to managing the company's external resources to secure the supply goods, services, capabilities and knowledge needed for the company's operations.

In the present thesis, I adopt the concept of procurement as in van Weele and Rozemeijer (2022) as I consider buying firms' (automotive OEMs') management of external resources (the SEC supply network) and collaboration with internal actors (such as Research & Development, logistics). The scope of procurement, considered in this thesis in comparison to other terms in the PSM literature, is presented in Figure *2*.

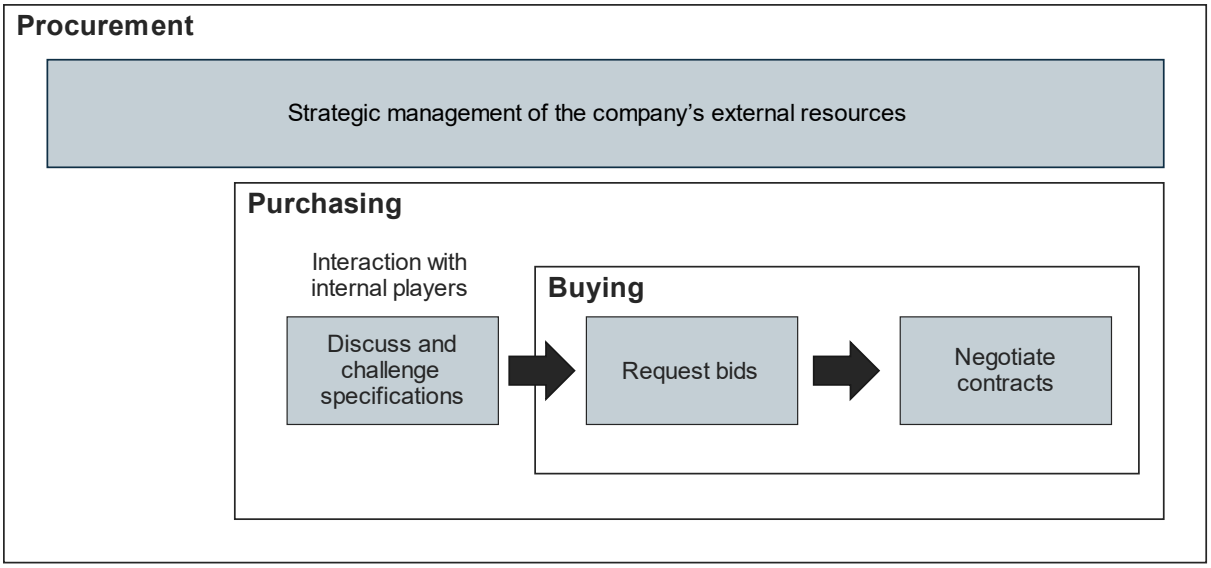


Figure 2: The scope of procurement in comparison to other terms in the PSM literature

2.1.2. PROCUREMENT STRATEGY AND ITS OBJECTIVES

The PSM strategy encompasses policies to guide the firm's supply and sourcing needs (Hesping & Schiele, 2015). It includes purchasing objectives and practices and seeks to strike a balance between the objectives of cost savings, supply assurance, and value enhancement through innovation (van Weele & Rozemeijer, 2022).

Among procurement objectives, cost is the most predominant in PSM research (Wynstra et al., 2019) and has been a traditional part of procurement's identity (Murfield et al., 2021). This can be accomplished through sourcing strategies such as demand pooling, product optimization, pricing evaluation, and supplier relationship enhancement (Schiele, 2007). Cost savings gain relevance because of the cost high share of procured products for OEM firms (Schiele, 2019) and achieving cost savings requires procurement professionals with a set of skills including commercial, technical, and supply market knowledge (Schütz et al., 2020).

Procurement can also help to drive innovation by involving suppliers in New Product Development (NPD) and cultivating relationships that are aligned with technology roadmaps (Arvidsson, Melander, et al., 2022; Schiele, 2010). For example, even though some companies might intervene in sub-supplier selection for critical components, in many cases this responsibility is given to direct suppliers because of a lack of resources to manage sub suppliers (Johnsen, 2011).

Procurement's contribution to innovation is linked to several factors, including closer integration with other organizational functions and a comprehensive skill set of technical and market knowledge (Blome et al., 2013; Legenvre & Gualandris, 2018; Luzzini & Ronchi, 2011). Research on procurement involvement in NPD has focused primarily on the involvement of dyadic relationships with direct suppliers, and the role of procurement in involving suppliers that are further in the supply network remains unexplored (Johnsen et al., 2022).

Ensuring the availability of goods and services is part of the procurement function and is essential to meet the demands of internal customers and support the company's operations

(Monczka et al., 2020). As the costs caused by the lack of supplies are far higher than the costs of the components themselves, ensuring supply becomes one of procurement's main priorities (Schiele, 2019).

Regarding approaches to secure supply in the face of disruptions, Dabhilkar et al. (2016) find that disruption response involves proactive and reactive measures, addressed both to internal and external stakeholders, but the study does not examine in detail the actions adopted by the companies facing disruptions. Previous studies have shown the benefits of enhanced information sharing (Finkenstadt & Handfield, 2021; van Hoek, 2021) and of sharing information with upstream suppliers (Spieske et al., 2022). Among mid- and long-term supply assurance measures, the literature indicates that strengthening existing supplier relationships and creating new connections to upstream suppliers can support supply assurance (Küffner et al., 2022; Spieske et al., 2022; van Hoek, 2021).

2.2. DECISION MAKING ENVIRONMENT

In the present thesis, the exploration of the decision-making environment of the buying firm is operationalized through an investigation of the SEC supply network. This is done through the analysis of the supply network structure using SNA metrics and through the analysis of the power dynamics in the supply network. This section presents the theoretical foundation of both perspectives adopted in this thesis.

2.2.1. SOCIAL NETWORK ANALYSIS

The theoretical perspective behind SNA is called Network Theory (Borgatti & Halgin, 2011), which considers that a network is a set of actors (also called nodes) that are connected by a set of connections (also called ties). The arrangement of the connections between nodes constitutes the network structure. Network Theory concerns the interaction between the network structure and given processes to generate outcomes for nodes and the whole network (Borgatti & Halgin, 2011). Network Theory is applied to the social sciences through SNA as a strategy for investigating social structures (Otte & Rousseau, 2002).

SNA has diverse applications and has been applied in fields such as physics and biology (Borgatti & Halgin, 2011). SNA has also been applied in Supply Chain Management (SCM), as researchers recognized the value of adopting a network perspective to analyze supply chains (Borgatti & Li, 2009; Carter et al., 2007). The next sections expand on the application of SNA in the SCM field and the intersections between this application and the PSM concepts studied in the present thesis.

2.2.2. SOCIAL NETWORK ANALYSIS IN SUPPLY CHAIN MANAGEMENT

SNA's relevance in Operations and Supply Chain Management (OSCM) extends to aspects such as supply chain relationships, innovation (Wichmann & Kaufmann, 2016), resilience (Kim et al., 2015; Li et al., 2020), robustness (Brintrup et al., 2015) and risk propagation (Basole & Bellamy, 2014; Garvey et al., 2015). Such an analysis offers an exploration of the roles of the nodes depending on their position in the network and how the

network structure influences the performance of individual firms and of the whole network (Kim et al., 2011).

SNA can analyze both the hard (e.g., financial and material flows) and soft (e.g., information sharing) ties between firms in a supply network, making it a suitable approach for SCM studies. Aided by a qualitative analysis of ties, SNA can provide strong insights into supply network collaboration and performance (Borgatti & Li, 2009; Han et al., 2020).

Based on Kim et al. (2011), and as summarized in Table *2* I, SNA metrics of network complexity, network centralization, and node centrality can be used to characterize the supply network and implications at the node and network levels and for both the flow of material and the transactional relationship. The present thesis focuses only on transactional relationship metrics.

Table 2: SNA metrics for characterizing the supply network structure (Kim et al., 2011, p. 197, 199)

Supply network characteristic	**Metric**	**Implications of a high score for the procurement context**
Node centrality	Degree centrality in transactional relationships	Coordinator role: To reconcile differences of network members and align their opinions with the greater supply network goals
	Closeness centrality in transactional relationships	Navigator role: To explore, access, and collect various information with greater autonomy in the supply network
	Betweenness centrality in transactional relationships	Broker role: To mediate dealings between network members and turn them into an advantage
Network centralization	Centralization in transactional relationships	Lack of interactions between central and peripheral firms in a supply network. Decoupled relationships between firms at different tiers
Network complexity	Complexity in transactional relationships	More firms involved in transferring information Active interactions at a local level Slow relaying of communications from downstream to the final assembler

Node centrality refers to a node's position and relative importance in the network (Borgatti & Li, 2009; Kim et al., 2011). In supply networks, a high degree of centrality (the node's number of connections) represents a firm's rich access to resources and information, which gives it a role in the integration and allocation of material flows and the ability to influence other firms' operations and decisions. In addition, its position on the shortest path between other firms in the network (high betweenness centrality) gives a firm the responsibility of controlling the flows of materials and information between suppliers and customers as well as the ability to control interactions between firms. Firms with a high betweenness centrality become critical for the network, as a failure of these firms can slow down the whole network and impact cost, quality, and lead times (Borgatti & Li, 2009; Kim et al., 2011). Finally, high

closeness centrality (associated with the node's average distance from all other nodes in the network) suggests a firm's independence through its ability to reach other firms quickly, and a firm with low closeness centrality might face information distortion, disruption risk, and cost increases (Borgatti & Li, 2009; Kim et al., 2011).

As a complement to node-level metrics, network-level metrics concern the structure and operation of the entire network. For instance, network complexity is described based on network size (i.e., number of nodes in the network) and density (degree of interdependency between nodes): a larger network size can indicate longer paths and more time needed to reach other firms and complete a task (Borgatti & Li, 2009; Kim et al., 2011) and additional operational effort to manage suppliers (Choi & Krause, 2006). Supplier interrelatedness can indicate dependencies between suppliers (Kim et al., 2011), but existing relations between suppliers can facilitate cooperation between them (Ateş & Memiş, 2021; Choi & Krause, 2006). Network centralization, in turn, represents the extent to which power is concentrated in a few central nodes, which can cause low responsiveness and low effectiveness in decision-making and issue-solving (Kim et al., 2011).

In addition to metrics, other relevant SNA concepts include structural holes (Burt, 1992), which proposes that nonredundant contacts in the network can increase the flow of novel information. However, in a supply chain context, redundant connections between companies might enhance information and personnel flows (Borgatti & Li, 2009). Another important concept is the strength of ties (Granovetter, 1973), which is defined as a combination of the amount of time, emotional intensity, intimacy and reciprocal services in a tie.

2.2.3. POWER DYNAMICS IN THE SUPPLY NETWORK AND THE POWER POSITION OF THE BUYING FIRM

Power dynamics in a supply network can occur at three levels: the micro (intrafirm), macro (interfirm and supply network), and meso (external environment) levels. According to resource dependence theory (RDT), a firm's dependence on external resources controlled by others significantly influences its power within a network of organizations (Caniëls & Gelderman, 2007; Pazirandeh & Norrman, 2014; Pfeffer & Salancik, 2015).

At the micro (intrafirm) level, a buying company's power position is influenced by factors such as resources, specialized capabilities, demand share, and reputation (Kähkönen & Virolainen, 2011; Pazirandeh & Norrman, 2014; Pfeffer & Salancik, 2015).

At the meso (supply network) level, power is influenced by dyadic interfirm relationships. In each relationship, power imbalances can arise due to control over critical information, negotiation skills, and supplier substitutability (Pazirandeh & Norrman, 2014; Pfeffer, 1981). As buying firms depend on suppliers and their complex supply networks (Xiao et al., 2019), the power position of the buying firm can also be influenced by local power imbalances in the supply network and the overall supply network structure.

Finally, changes in the macro (external environment) level can affect the power balances and a buying firm's power position. These changes can refer to broader economic trends and global market shifts (Cox et al., 2001) as well as geopolitical and global disruptions and regulations (McNamara & Newman, 2020; Pazirandeh & Norrman, 2014).

Similar to the levels of power dynamics, improving a buying firm's power position in the network can require approaches at these three levels. At the micro level, such actions include increasing customer attractiveness, gaining supplier attention (Pulles et al., 2019; Schiele & Vos, 2015) and replacing assets in the supply network with others of higher value (Cox et al., 2001). Approaches at the meso level of the supply network can include strengthening supplier relationships (Eisenhardt & Schoonhoven, 1996) and increasing customer attractiveness to gain a supplier's preferred customer status (Goldberg & Schiele, 2020; Pellegrino et al., 2020). At the macro level, the buying firm's actions involve adapting to the changes in external forces (Pfeffer & Salancik, 1977).

2.3. INTERRELATIONSHIP BETWEEN PROCREMENT AND THE SUPPLY NETWORK

Practices to reduce costs include rationalizing the supply base and the pooling of demands, both of which imply a reduction in the number of supplier connections (Patrucco et al., 2023; Schiele, 2007). In fact, companies focusing on cost could select fewer suppliers to explore economies of scale (Kim & Narasimhan, 2019) and a single Tier 1 supplier to coordinate the rest of a component's supply chain in the pursuit of higher efficiency and lower procurement and supply resource (e.g., manufacturing tools) needs (Choi & Linton, 2011).

In contrast to cost, an innovation focus benefits from connections to direct and indirect suppliers. A firm's innovation performance depends on its ability to access knowledge and information through its position in the network (Bellamy et al., 2014), through connections with direct and indirect suppliers (Kim et al., 2020). Because it might be difficult to leverage indirect suppliers' knowledge through direct suppliers, a firm needs to go beyond Tier 1 suppliers to explore innovation opportunities (Kim et al., 2020; Legenvre & Gualandris, 2018). Connections with direct and indirect suppliers can create higher network complexity through higher density, which has been found to support innovation performance (Ateş & Memiş, 2021). However, increased complexity can require high coordination efforts and limit the benefits of indirect connections (Kim et al., 2020), In addition, connections with indirect suppliers can be hindered by a lack of familiarity with technical aspects and a lack of internal resources (Johnsen, 2011; Mena et al., 2013). This is because capturing innovation within the supplier base requires a more comprehensive skill set in terms of the procurement function and closer integration with other organizational functions (Legenvre & Gualandris, 2018; Luzzini & Ronchi, 2011).

Supply assurance, which is critical in times such as the COVID-19 pandemic, relies on practices such as internal information sharing, supplier redundancy, product flexibility, and robust supplier selection criteria (Küffner et al., 2022; Pereira et al., 2020). Supplier redundancy and product flexibility can require a larger number of suppliers; therefore, higher centrality can contribute to supply assurance (Li et al., 2020). This is because a firm's low centrality can imply greater reliance on its Tier 1 suppliers, thereby increasing the supply load and criticality of Tier 1 suppliers (Kim et al., 2020). On the other hand, Bode and Wagner (2015) have shown that a greater number of suppliers and supplier tiers increases the chance of supply disruptions. They suggested that procurement practitioners seeking to reduce supply assurance risks must reduce supply chain complexity, even though the ways to do so might vary for different practitioners.

Overall, each procurement objective can lead to different supply network characteristics, which have implications for the buying firm's position. Furthermore, the focus of procurement on each objective adapts to external factors such as market conditions, product complexity, culture, leadership, attitudes, and financial, technological, and organizational aspects (Ghobadian et al., 2007; González-Benito et al., 2010). For instance, environmental stability allows for a focus on cost, but uncertainties in demand, supply, product characteristics, and technologies necessitate relationship-based practices and deeper knowledge (Patrucco et al., 2023). Therefore, we can expect that external environmental conditions influence the interaction between procurement focus and supply network structure.

2.4. SUMMARY OF THEORETICAL FRAMEWORK

A summary of the theoretical framework and the concepts adopted in each paper in this thesis is presented in Table *3*.

<table>
<tr><th></th><th></th><th>Paper I</th><th>Paper II</th><th>Paper III</th></tr>
<tr><th>Part of the thesis</th><th>Literature streams</th><th colspan="3">Concepts adopted in each paper</th></tr>
<tr><td rowspan="4">Purchasing and Supply Management (PSM)</td><td rowspan="4">Procurement</td><td colspan="3">Procurement definition and role</td></tr>
<tr><td colspan="3">Procurement approaches</td></tr>
<tr><td></td><td>Procurement objectives</td><td></td></tr>
<tr><td colspan="3">Supply disruption response</td></tr>
<tr><td rowspan="4">Decision making environment</td><td>Power position of the buying firm</td><td>Supplier dependence/lock-ins
Attractiveness: Demand share, reputation</td><td></td><td></td></tr>
<tr><td>Power dynamics in the supply network</td><td>Supplier dependence/lock-ins
Power unbalances</td><td></td><td></td></tr>
<tr><td rowspan="2">Social Network Analysis: Supply network characteristics and node roles</td><td></td><td><u>Network level:</u> size, density, centralization
<u>Node level:</u> degree, closeness and betweenness centrality</td><td><u>Node level:</u> degree and closeness centrality</td></tr>
<tr><td></td><td>Hub-centric networks
Broker, coordinator roles</td><td>Structural holes
Tie strength</td></tr>
</table>

Table 3: Summary of the theoretical framework adopted in this thesis.

Due to the focus on the role of OEM procurement, the procurement literature, and its concepts, such as the definition and role of procurement, approaches, and supply disruption response, are adopted in all the papers. One exception is the adoption of procurement objectives, per van Weele and Rozemeijer (2022), which are used only in Paper II.

The concepts adopted to investigate the decision-making environment are more varied throughout the thesis. Concepts related to the power position of the buying firm and power dynamics in the supply network are adopted only in Paper I, which is in line with its aim to characterize the SEC supply network and the OEMs' power position within it. On the other hand, SNA concepts are used in Papers 2 and 3 to support the network perspective adopted in this thesis. Paper II adopted both network-level and node-level metrics and other SNA concepts such as the definition of hub-centric networks and node roles in the network. In turn, Paper III adopts the network-level metrics of degree and closeness centrality as well as other concepts such as structural holes and tie strength.

3. METHODS

This section describes the research design adopted in this thesis, starting with ontological and epistemological considerations, the research approach and method, the case, and data collection and analysis methods. Some considerations and reflections on the choice of methods are presented at the end of this section.

3.1. ONTOLOGY AND EPISTEMOLOGY

In business research, ontology and epistemology are crucial philosophical assumptions that reflect the views of researchers in their consideration of reality and how knowledge about reality can be gained (Bell et al., 2022). As Burell and Morgan (1979) argue, all researchers possess such views on the nature of the social world and how it ought to be investigated, that is, ontological and epistemological positions.

Ontology refers to the nature of reality, and ontological positions can be either objectivist or constructionist (Bell et al., 2022). An objectivist ontological position considers reality to be objective and independent of human interaction or observation, while a constructionist ontological position assumes that reality is socially constructed and made real through human actions and the meanings attributed to them. The question that surrounds an ontological position is thus whether reality is external to the individual or a product of human consciousness (Burell & Morgan, 1979).

The other philosophical assumption, epistemology, refers to the view of how knowledge about reality can be gained and is therefore directly guided by one's ontological position (Bell et al., 2022). A positivistic position is guided by an objectivist ontology and assumes the existence of an objective reality that can be understood through observation and measurement, while an interpretivist position is guided by a constructionist ontology and advocates the importance of *understanding* why and how social action constructs the social world (Bell et al., 2022).

Critical realism is the philosophical approach proposed by Bhaskar (1975) that recognizes the existence of an objective reality, while our subjective observation of reality is limited to fully capturing this reality. Recognizing that objective reality is inexorable, Bhaskar proposes the existence of three domains: the domain of *Real*, in which the mechanisms exist, independent of human observation; the domain of *Actual*, in which events take place, be them experienced by human actors or not; and the domain of *Empirical*, in which experiences about the event can be observed and collected (Bhaskar & Hartwig, 2016).

The critical realist philosophical approach is appropriate for this thesis because to achieve the aim of the thesis and answer its research question, all three domains are relevant. It assumes that there are real, objective mechanisms that influence the power position of buying firms in their supply network. These mechanisms manifest through events that may or may not be recognized by the social actors that are part of the supply network. Among these events, the experiences of the involved social actors can be empirically observed. In particular, regarding the understanding of the mechanisms that influence buying firms' power position, this thesis sets out to identify the relevant observations and experiences that could further our

understanding of the events and thereby enable the explanation of the mechanisms behind the phenomenon studied. This is reflected in the choice of methods, in which observations and experiences gathered from involved social actors were always triangulated with other sources to provide accounts of the events and mechanisms that could be as close to reality as possible.

3.2. RESEARCH APPROACH

The present thesis adopted a predominantly qualitative exploratory research approach. An exploratory research approach is motivated by the aim of generating knowledge and enhancing our understanding of a topic about which there is little scientific knowledge but there is a reason to explore it (Stebbins, 2001). A qualitative research approach is appropriate for generating new knowledge, especially when placed in the natural settings of organizations (Bluhm et al., 2011).

As defined by Ketokivi and Choi (2014), qualitative research addresses the meaning and interpretation of concepts in their specific context of inquiry, which makes it appropriate for the present thesis's aim, which is strongly focused on its empirical context. To aid in the analysis of the qualitative data, in Papers 2 and 3, the qualitative data was complemented by quantitative data through the application of SNA, as explained in the next sections.

Apart from an exploratory research approach and the overall aim to generate new knowledge, this thesis addressed both theory generation and theory elaboration; therefore the interaction between theory and the empirical context varied in the different papers (Ketokivi & Choi, 2014), based on each paper's intended contribution to theory. Figure *3* presents an overview of how the theory and the empirical context interact in each paper and the contribution to theory intended in each paper, in which the thickness of the arrows represents the relative balance between theory and empirical data.

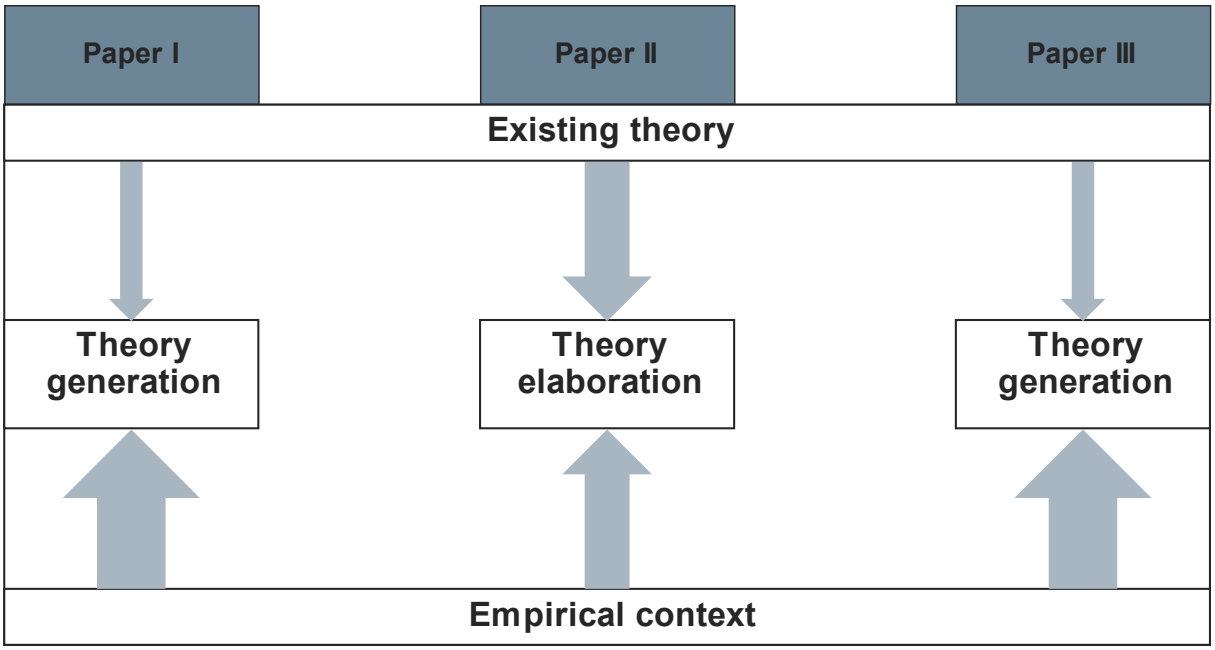


Figure 3: Interaction between theory and empirical context in each paper in this thesis. Adapted from Ketokivi and Choi (2014)

As represented in Figure *3*, Paper I had the goal of generating theory about the studied empirical context and therefore focused on the empirical context. On the other hand, Paper II made use of existing theory in the procurement and SNA literature and, to elaborate these theories, maintained a balance between existing theory and the empirical context. Finally, Paper III again focused on the empirical context to generate theory in an unexplored field (procurement approaches for supply assurance). Given the overall aim to increase knowledge regarding the empirical context, the case study method was chosen as the research method, as it will be explained in section 3.3.

3.3. CASE STUDY AS A RESEARCH METHOD

In the present thesis, the case study method was adopted in all three papers to gain contextual richness (Piekkari & Welch, 2018) and explore the contemporary phenomena in this context (Halinen & Törnroos, 2005) as well as historical phenomena (Wieland et al., 2024). This section describes how the case study method was employed in each of the papers regarding data sampling, collection, and data analysis.

The choice of case study as the research method for this thesis is motivated by the "how" type of research question and the embeddedness of the phenomena in its empirical context (Yin, 2018). Furthermore, as Easton (2010) argues, the case study method offers the flexibility of iteration and combination of multiple data sources in the researcher's interaction with the empirical context to disentangle and explore complex sets of relationships.

The choice of the case study method fits the exploratory character of the research questions and the investigated phenomena. The multitude of factors influencing the power position of OEMs in the SEC supply network benefits from the explanatory power of the case study method and the possibility that it offers to approach data analysis holistically and understand the relationships between factors (Piekkari & Welch, 2018).

The specificity of the empirical context further motivated the choice of the case study approach. Understanding the characteristics and relationships in the studied supply network is crucial for delineating the phenomena that occur. In this context, the case study method is valuable for refining the existing theory and defining the limits of the generalizability of the findings (Stake, 1994).

3.3.1. CASE SELECTION AND DESCRIPTION

The research in this thesis adopted the case of the SEC supply network of OEM-A, a leading European commercial vehicle manufacturer. In addition to OEM-A, this supply network includes Tier-1 suppliers, electronics manufacturing service (EMS) companies, semiconductor suppliers, authorized distributors, and other OEMs in OEM-A's holding group. The selection of OEM-A and its supply network is supported by traditional case selection criteria, such as a representative case and the potential to be a revelatory case (Yin, 2018).

According to both criteria, the selection of OEM-A's supply network as the case is also supported by the research questions and adopted theoretical concepts. As Dubois and Gibbert (2010) argue, a fit between theory, the case method and the phenomena must be achieved. The theoretical framework suggests that a high level of strategic procurement can influence the

supply network through supplier selection. Thus, the strategic position of procurement, which is common among the OEMs in the network and representative of other automotive OEMs, makes it appropriate to investigate the role of procurement in influencing the firm's power position, allowing for an extension of our understanding of the studied phenomena (Piekkari & Welch, 2018).

In addition, the revelatory potential of the unique access to data and to experienced informants within the OEMs and their suppliers is crucial to generate an in-depth understanding of how procurement interacts with the supply network to influence the OEMs' power position. Access to the data allows iterations within the research context to ensure the collection of observable evidence that allows for an understanding of the events and mechanisms that influence the power position of OEMs (Easton, 2010).

In the studied network, the OEMs develop, manufacture, and provide services for commercial and passenger vehicles. OEMs outsource the development and production of most components used in their products, including electronic components, which are electronic control units (ECUs) and sensors. ECUs are electronic devices programmed to control a certain function of a vehicle based on the data received from the sensors, such as lights, engine, or stability control. For electronics, development and manufacturing are outsourced to direct Tier 1 suppliers. Each electronic component can contain up to 1000 subcomponents, including semiconductors, passive (resistors, transistors, and others) and electromechanical (printed circuit board, screws, connectors, cables, among others) parts. Typically, every electronic component has only one Tier 1 supplier, because high development costs make the selection of multiple suppliers (i.e., multisource) financially unfeasible. The Tier 1 supplier is then responsible for selecting and procuring all subcomponents needed to produce an electronic component.

The present thesis adopted the case of the SEC supply network from the perspective of OEM-A. The same network is considered in all three papers that are part of the thesis, but the network actors considered in each paper differed depending on the paper's aims and scope. In paper I, data collection involved OEM-A and two other OEMs in its holding group as well as Tier 1 suppliers. In paper II, OEM-A and two other OEMs in its holding group (not the same two OEMs as in paper I) and actors from the semiconductor industry were included in the data collection to aid the understanding of the interaction between procurement focus and supply network; the paper focused on ECUs (because of the greater technical complexity of the ECUs compared with sensors) and on the microcontroller unit (MCUs) in each ECU (because the MCU is the most important and most complex semiconductor in an ECU). Finally, paper III focused on the ECUs with the most severe shortage cases for OEM-A and the MCUs used in these ECUs; to allow an in-depth investigation of the procurement approaches adopted to secure supply of components in shortage, the scope of data collection was limited to OEM-A.

3.3.2. RESEARCH PROCESS

To address the need to explore the SEC supply network and the position of the OEMs, Paper I was executed through data collection during the first months of the semiconductor crisis (January–May 2021). The findings of Paper I were used in the conceptualization and scope

definition of Paper II, in which data collection and analysis took place between September 2022 and March 2024. Finally, data collection and analysis for Paper III took place between November 2022 and March 2023. The timeline of the research process is represented in Figure *4*.

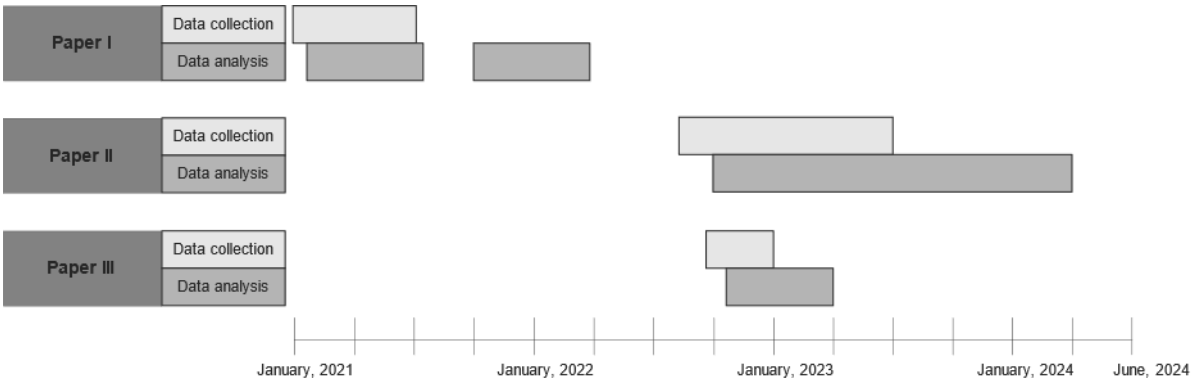


Figure 4: Timeline of the research process

In Paper I, the author contributed to part of the data collection and analysis; part of the interpretation of the results, and part of the writing of the methods and findings sections. The findings of this paper revealed the main weaknesses of automotive OEMs' procurement during the semiconductor shortages and emphasized the need for knowledge in this research context. Following these early findings, the following studies continued with a qualitative approach through case studies to explore the context of OEM-A's SEC supply network.

Paper II was an exploratory investigation of the evolution of OEMs' procurement strategy and the SEC supply network structure in the period 1996–2023. The paper aimed to increase the understanding of how Procurement strategies adopted by the OEMs during this period were interrelated with the evolution of the SEC supply network structure. To achieve this aim, the study was designed as an exploratory qualitative study and the qualitative analysis was complemented by SNA metrics to analyze the characteristics of the supply network structure and the position of companies in the supply network.

From the period studied in Paper II, Paper III focused on the semiconductor shortage crisis and was an in-depth investigation of the Procurement practices adopted by OEM-A in the period 2021-2023. In contrast to the data collection in Paper II that involved 3 OEMs, Paper III prioritized the focus on one OEM to allow an in-depth investigation of its procurement practices. This paper aimed to identify the practices adopted by OEM-A's procurement to secure supply of components in shortage and how these practices influenced changes in the supply network structure. Once again, a qualitative research design was adopted through the case study method, and SNA metrics were used to analyze changes in the supply network during the crisis.

3.3.3. DATA SAMPLING AND COLLECTION

Although the SEC supply network of OEM-A has been adopted as the case throughout the present thesis, the network actors considered in each paper and included in the data collection varied depending on the paper's aim. In total, 22 interviews were conducted with

OEM-A for all three papers, of which nine were for paper I, 11 were for Paper II and two were for Paper III. In addition, three Tier 1 suppliers, one semiconductor supplier, two independent distributors, and three market experts were interviewed. As secondary data, 15 news articles, supplier lists and process documents were also used to increase understanding of the concepts and reduce potential interview biases (e.g., in Paper II). Table *4* presents an overview of the data sources of each paper.

Table 4: Overview of data sources

Paper	**Firm groups**	**Firms**	**Sources**
Paper I	OEMs	OEM-A, OEM-B, OEM-C	10 interviews – procurement 1 interview – R&D
	Tier 1 suppliers	Tier 1 A, Tier B, Tier C	3 interviews – sales and business development
	Semiconductor industry	Distributors External market expert	2 interviews - independent distributors 1 interview - market expert
Paper II	OEMs	OEM-A, OEM-C, OEM-D	13 interviews - Procurement 4 interviews - R&D 1 interview - logistics
	Semiconductor industry		2 interview – semiconductor industry experts 1 interview – semiconductor supplier
	OEMs	OEM-A	E/E architecture schematics Supplier lists 15 news articles
Paper III	OEMs	OEM-A	Secondary data Procurement taskforce process documents
	OEMs	OEM-A	2 validation interviews - procurement
	OEMs	OEM-A	Participatory observation

In Paper I, the data collection aimed at gathering perspectives that contributed to the understanding of automotive OEMs' power position in the SEC supply network. To ensure these perspectives, data were collected through interviews with informants from three automotive OEMs and Tier 1 suppliers to those OEMs, which assured a supplier perspective in this paper. The lack of semiconductor suppliers in the data sampling reflects the lack of access to semiconductor suppliers at the time of data collection (January–May 2021).

Paper II adopted a mix of data sources to ensure the validity of its retrospective perspective (Lefebvre et al., 2022). Furthermore, two other OEMs in the same holding group as OEM-A were added to the data sampling to increase the validity of our understanding of the phenomena that took place in the considered time span. Interviews with individuals from the three OEMs were intended to identify their procurement focus during the studied period, while secondary data such as news articles, network maps, and supplier lists were used to validate and complete the historical view. In addition, interviews with one semiconductor supplier and two experts in the SEC supply network were aimed at considering the external perspective in the study.

Finally, Paper III primarily adopted process documents from OEM-A with lists of practices adopted by OEM-A's procurement to secure component supply of SEC in times of shortages. This paper used the findings of Paper I to identify early measures adopted by OEM-A in the early phase of the crisis (March–May 2021). This data was reviewed and updated according to the process documents from October 2022. The process data was complemented by information obtained by the first author through their participatory observation in OEM-A's crisis taskforce for 10 months (March–December 2021). Finally, the data was validated through interviews with the two main employees involved in the practices adopted by OEM-A: the taskforce leader and the purchaser responsible for semiconductor procurement at the time of the interviews.

3.3.4. DATA ANALYSIS

Different qualitative data coding techniques were adopted, and the supply network data were analyzed through SNA in Papers 2 and 3. This section elaborates on the techniques adopted in each paper.

In Paper I, pattern coding (Eisenhardt, 2021) was used to identify procurement strategies, the OEM's procurement power, sources of power (based on a combination of sources of power and as perceived by the respondents), and the impact of each procurement strategy on the OEM's power position. The analyses were then sent to the case representatives for feedback and input and to increase the validity of the findings.

In Paper II, the data analysis was divided into three phases, allowing iterations between the theoretical background and empirical observations to elaborate upon the adopted theory (Dubois & Gibbert, 2010). This included two phases of pattern coding (Eisenhardt, 2021) of interviews and secondary data, the representation of supply network maps and the calculation of supply network metrics using the software Pajek (De Nooy et al., 2018), and the analysis of node centrality as well as network centralization and complexity (Kim et al., 2011). Although there are different definitions of complexity in the literature, the analysis measured complexity through the network metrics of size and density (Kim et al., 2011). After the codes from the first analysis phases were matched with the relevant concepts from the literature, observations were once again coded to identify the interaction between procurement focus, supply network structure, and external and internal environmental factors. Similar instances of interaction were grouped into categories (Schreier, 2014).

In Paper III, the analysis involved the analysis of process documents and the categorization of procurement approaches according to the network actors involved in them (Schreier, 2014). Changes in the network were analyzed through network maps and OEM-A's degree and node centrality (Kim et al., 2011). Data from the first round of analysis was used for the design of the validation interviews (Pawson, 1996). Data from the validation interviews was analyzed through pattern coding (Eisenhardt, 2021) in the second analysis round to identify relationships between procurement approaches, changes in the supply network structure, and supply assurance. Additional procurement approaches named by the informants during and after the validation interviews were included in the list of approaches.

In summary, Figure *5* presents the adopted data analysis framework.

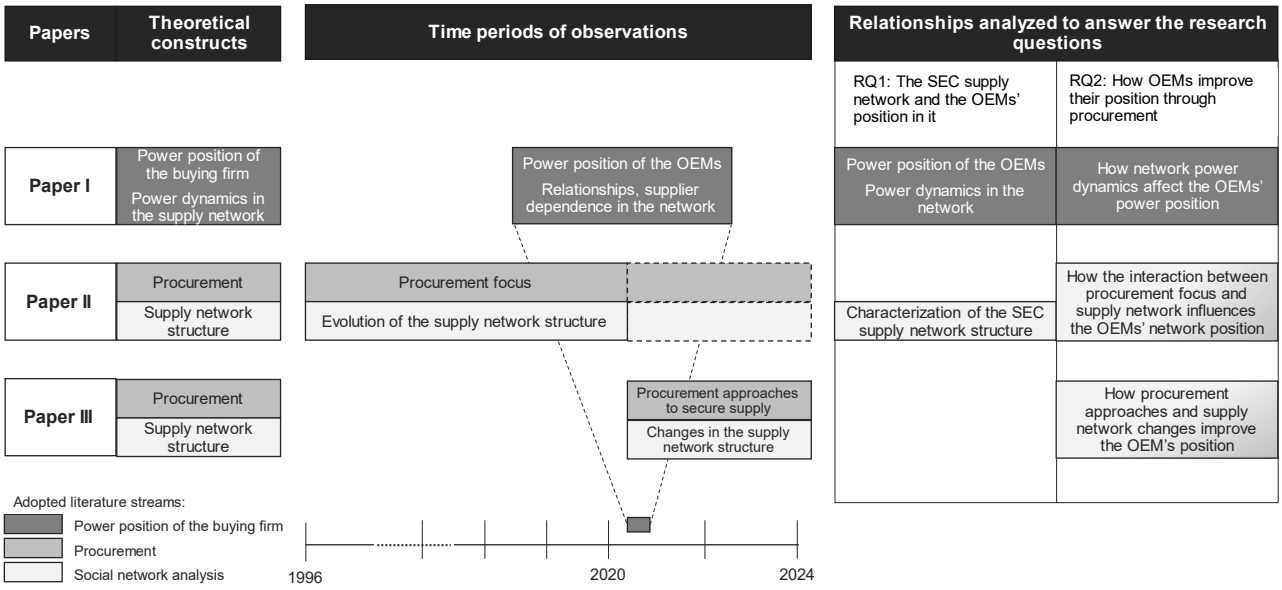


Figure 5: Data analysis framework

3.4. REFLECTION ON METHODOLOGICAL QUALITY AND ETHICAL CONSIDERATIONS

In qualitative research, the assessment of research quality involved the definition of trustworthiness based on the works of (Guba, 1981) and (Lincoln & Guba, 1985): they defined four criteria for the assessment of research quality: credibility, transferability, dependability, and confirmability.

Credibility is the extent to which the findings reliably and accurately account the experiences of informants and the investigated phenomenon. In the present thesis, this was addressed through the adoption of several different actors in the network, including multiple OEMs, Tier 1, and semiconductor suppliers. In addition, to address the limitations in informants' accounts of events in the distant past, different data sources such as archival documents and news articles were used, together with triangulation between sources and validation of findings through validation interviews.

Transferability questions whether the findings can be applied to other contexts. In the present thesis, the research focused on the empirical context of the automotive SEC supply network and the in-depth character of the investigation is likely to compromise the generalizability of the findings. However, the applicability of the findings to other contexts has been discussed with practitioners of OEM-A, with positive feedback regarding transferability of the findings.

Dependability refers to the consistency of the data, especially across time. Here, dependability was ensured through the detailed description of the research methods, which was enhanced through the peer-review process in which the paper were subject to and presentations at conferences.

Finally, confirmability refers to the absence of bias and the objectivity of the researcher in conducting the data analysis. In this thesis, it is important to recognize the author's previous and current direct involvement in the procurement function of OEM-A. Therefore, since the beginning of the PhD project, special attention has been given to the risk of bias in the research, which has been addressed through collaboration between the authors of the papers and the use of triangulation between data sources.

Besides quality of research, ethical considerations are important to ensure research objectivity, as ethical transgressions can lead to erroneous or biased research (Shamoo & Resnik, 2022). In the present thesis, especially given its close connection with industry and the author's dual role as researcher and practitioner, the following main issues arise: conflict of interest, bias, continuous consent in interviews and potential to harm people. As Shamoo and Resnik (2022) argue, education and mentoring are the two main strategies to prevent ethical misconduct and this has been applied through courses in research ethics and research methods, as well as through the mentoring in the PhD research project. Further reflections on each of identified issues are presented in the next paragraphs.

Regarding bias and conflict of interest, many questions and findings in the present thesis are connected to the author's previous positions at OEM-A. As the research findings could have interpretations of whether past strategies and decisions were "right", this can create conflicts of interest and affect scientific objectivity (Shamoo & Resnik, 2022) and bias based on the author's previous experience. The first step in addressing this issue has been the awareness to recognize it and reflect on it. My motivation to develop research is a general interest in developing knowledge and learn from past experiences, no matter if that reveals past wrong decisions. Moreover, objectivity of the research questions, methods and findings has been guaranteed through open discussions with the academic supervisors and in an industrial supervision committee with five members of the OEM-A's procurement. This follows the rule from the Swedish Research Council (2017, p. 10) to "openly account for my interests and other associations".

Similarly, the use of interviews as the main data collection technique requires consent of interviewees for the use of information they provide (Allmark et al., 2009). An important step taken in every interview was to inform at the beginning of interviews about how the data will be used and ask for consent for recording and transcribing. However, Allmark et al. (2009) highlight that as interviewees start reporting on historical events, they might reveal more details than they had intended at the beginning of the interview. To deal with this issue, interviewees were asked during and after the interviews whether there was any sensitive information that would require confidential treatment and for content identified as sensitive, interviewees were asked to review the data before publication in papers.

Finally, the research of past events and decisions comes with the risk of harm to the reputation of people involved in those events. In line with the rule from the Swedish Research Council (2017, p. 10) to "strive to conduct my research without doing harm to people, animals or the environment", this concern has been actively dealt with through a clear the intent of the research: to develop knowledge and understanding for the future, and not to revisit questions such as what should have been done in the past. Interview questions and presentations have

been framed following this intent to prevent harm to people who have been involved in the investigated phenomena.

4. FINDINGS

Taken together, the three papers present findings that enhance our understanding of the automotive SEC supply chain's context, especially the interaction of OEMs' procurement strategy with the supply network. This section summarizes the findings from the appended papers, which is followed by a presentation of the findings to address the research questions of this thesis.

4.1. SUMMARY OF FINDINGS FROM THE APPENDED PAPERS

The findings of Paper I indicated the vulnerable position of automotive OEMs in the SEC supply network and raised the question of how such a position was created. Understanding the past can reveal insights into the relationships at play in this context, which can be valuable for understanding current and future trends (Wieland et al., 2024). Therefore, Paper II aimed to investigate the coevolution of procurement strategies and the SEC supply network. This aim was achieved by investigating the evolution of the procurement strategies of three OEMs and the SEC supply network structure of one of the OEMs in the period of 1996–2023.

The findings in Paper II provide an overview of the coevolution of OEMs' procurement strategies and supply network structure. It also provides a list of the external and internal environmental factors that influenced this coevolution. These findings contribute to the answers to research questions RQ1 and RQ2.

After understanding the power position of OEMs in the face of shortages and how this position was created over time, the next question to be investigated was how an OEM could respond to the identified limitations, to secure supply of SEC during the shortages. Papers I and II addressed the semiconductor shortages, but none of them involved a detailed investigation of how automotive OEMs acted to secure supply of SEC. Paper I revealed some of the actions adopted by OEMs (e.g., escalation within the holding group, increasing information visibility), but focused on the power position of the OEMs and factors that hindered their ability to secure supply at the beginning of the shortages (January–May, 2021). Paper II focused on the overall change in OEMs' procurement focus and in the supply network in the period 2021–2023 in comparison to the period 1996–2020, but specific actions adopted by the OEMs are not within the scope of Paper II.

Nevertheless, Papers I and II unveiled important questions concerning OEMs' reactions to disruptions caused by the semiconductor shortages. First, as Paper I revealed OEMs' vulnerable position in the SEC supply network, it becomes relevant to investigate how OEMs counter this position and secure component supply. Second, the findings in Paper II indicated that the semiconductor shortages interrupted almost three decades of OEMs' cost focus and led to deviations from the traditional Tier 1-centric supply network structure. Further understanding of how this impacted OEMs' practices and the roles played by network actors is needed.

To contribute to this understanding, Paper III aimed to investigate how the supply assurance approaches adopted by OEMs' procurement changed the SEC supply network, and how these measures and network changes affected OEMs' ability to secure supply. This aim

was achieved through a case study of OEM-A's approaches in response to the semiconductor shortages in the 2021–2023 period.

The findings of Paper III provide a list of approaches adopted by OEM-A to secure supply of SEC during the shortages and to address challenges and limitations created in previous periods. The list of approaches and the understanding of how OEMs address their limitations contribute to answering research question RQ2.

4.2. EMPIRICAL DESCRIPTION OF THE SEC SUPPLY NETWORK AND THE POSITION OF THE OEMS

The core of the automotive SEC supply network is composed of semiconductor suppliers, Tier 1 suppliers, and automotive OEMs. These companies are present in the supply of all electronic components purchased by the OEMs. Other actors that are part of the network are authorized distributors and EMS companies, which perform services that are outsourced by Tier 1 suppliers. Finally, independent distributors are companies that act in the spot market, buying and selling material to and from Tier 1 suppliers, especially in times of supply shortage, but they do not have direct contact with semiconductor suppliers. A simplified representation of the network is presented in Figure 6.

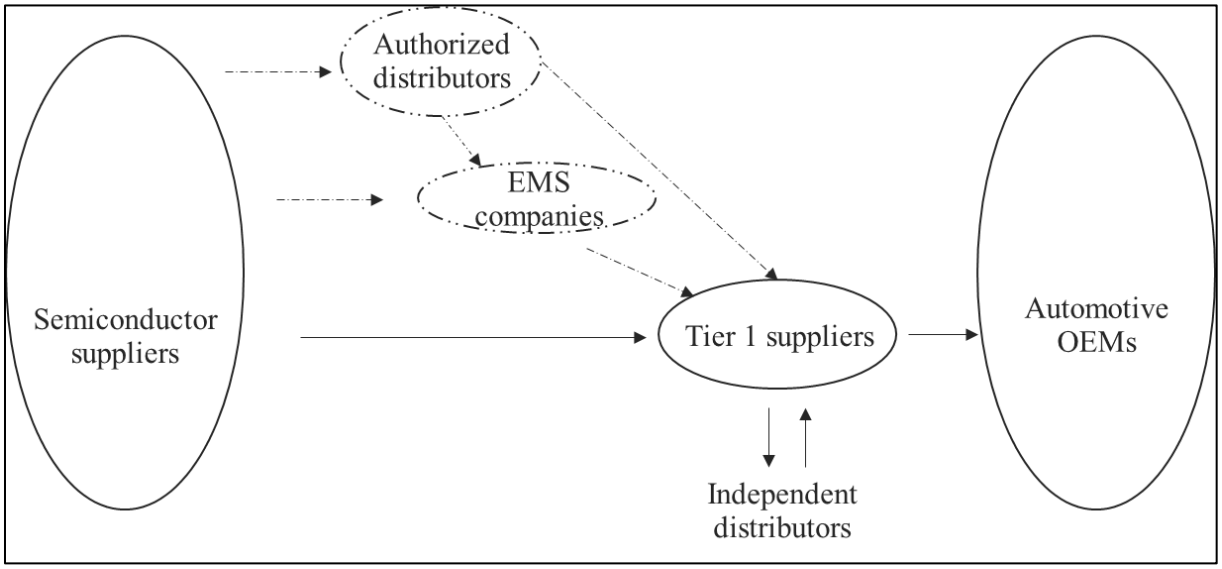


Figure 6: Simplified representation of the SEC supply network

Because Tier 1 suppliers source all the subcomponents needed for their production, every ECU or sensor has its own supply chain: subcomponents, including semiconductors, flow from subcomponent suppliers to Tier 1 suppliers; Tier 1 suppliers, in turn, assemble subcomponents to produce an electronic component and deliver it to the OEM. In some cases, the Tier 1 supplier might outsource activities to other types of companies, such as the manufacturing of electronics to EMS companies and the ordering and logistics management of semiconductors to authorized distributors.

In this supply network, OEMs are perceived as attractive customers because of their technical sophistication and drive of innovation. In particular, OEMs perceived as premium brands attract Tier 1 suppliers' interest to work with them. In general, automotive volumes are

considered small in comparison to volumes in the semiconductor industry but passenger vehicle OEMs are attractive to Tier 1 suppliers because of their higher volumes while commercial vehicle makers are attractive to Tier 1 suppliers because of their long-lasting volumes.

The selection of Tier 1 suppliers for electronic components occurs through Early Supplier Involvement (ESI), due to the high share of supplier-developed technology in the development of electronics. The early involvement and selection of suppliers, the use of single source, and the long development times for electronic components create a lock-in position for OEMs as they become dependent on a specific Tier 1 supplier as only possible supplier for an electronic component.

As the main business partners to OEMs in the SEC supply network, Tier 1 suppliers are divided into two groups: one group contains traditional electronics Tier 1 suppliers while the other group contains suppliers with experience in mechanical and hydraulic components, to which electronic functionality was added over time. The outsourcing of electronics manufacturing to EMS companies is more common in the second group of suppliers, because these suppliers' expertise is in the development of complete electromechanical systems rather than the production of electronic components.

Tier 1 suppliers' relationships with semiconductor suppliers are largely affected by their size and purchased volume of semiconductors: Tier 1 suppliers with larger volumes maintain direct relationships with semiconductor suppliers; in contrast, if Tier 1 suppliers' volumes are not large enough to procure them directly from semiconductor suppliers, authorized distributors provide services for ordering and logistics management between Tier 1 suppliers and semiconductor suppliers.

Finally, semiconductor suppliers are becoming increasingly attracted to the increasing volumes of automotive OEMs because of the shift toward electrification. The semiconductor industry's dependence on high volumes is due to the capital intensity and high investments for semiconductor production. From the semiconductor industry's perspective, automotive OEMs' demand for semiconductors is small, compared with that of other industries such, as telecommunications and consumer electronics. This hinders the attractiveness of OEMs to semiconductor suppliers.

The interactions between OEMs, Tier 1 suppliers and semiconductor suppliers are characterized by an overall broker role of Tier 1 suppliers, harmonizing the demands from OEMs and offerings from semiconductor suppliers. The existence of Tier 1 suppliers with such a role is another factor that differentiates the automotive industry from other industries that have a larger demand share in the automotive industry, such as the telecommunications industry: "It is only when I started at (an automotive OEM), that I sort of came in contact with the other part of the business where you have a Tier 1 supplier sort of designing and producing the part" (Semiconductor Expert, interview, October 2022). The OEMs' expertise is focused on specifying the function and requirements for the electronic component and its integration with other electronic components in the vehicle. Tier 1 suppliers, in turn, possess expertise in electronic component design and the selection of semiconductor components to be used.

In addition to coordinating the technological demands of OEMs and technological advancements from semiconductor suppliers, Tier 1 suppliers also hold the responsibility of matching the demand and supply between the short planning horizons and flexible demands of automotive OEMs with the long production lead times and long-term volume commitment of semiconductor suppliers.

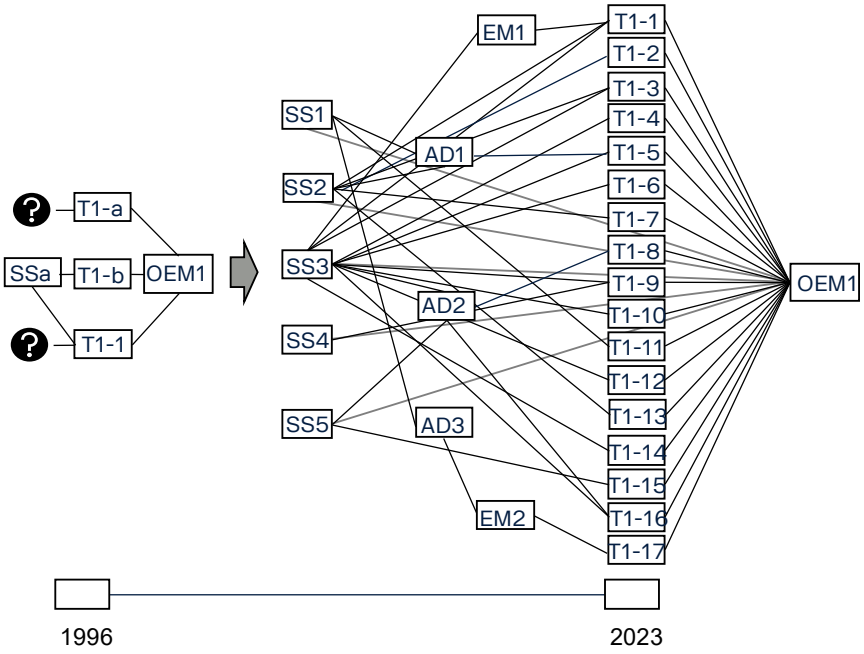
In summary, the position of OEMs in the SEC supply network is characterized by the following elements: focus and expertise on electronic component function and integration in the vehicle; lack of direct relationships with semiconductor suppliers in favor of direct relationships with Tier 1 suppliers only; lack of long-term volume commitment, especially in comparison to other industries with higher demand shares of semiconductors (e.g. telecommunications); and lack of knowledge about semiconductors. These factors characterized the weak position of the OEMs in the network, which motivated further investigation of how this position was established, as presented in section 4.3.

4.3. COEVOLUTION OF OEMS' PROCUREMENT STRATEGY AND SUPPLY NETWORK STRUCTURE (OR LACK THEREOF)

The coevolution of procurement strategy and supply network structure in the context of the automotive SEC was marked by the following main elements: OEMs' procurement focus on cost and Tier 1 supplier relationships accompanied by the evolution of a Tier 1-centric supply network in the period 1996–2020; the focus on semiconductor innovation by OEMs' R&D in this period, prompting direct but informal connections with semiconductor suppliers with no procurement involvement; and a change from a previous lack of supply assurance focus in which supply was assured through Tier 1 suppliers (1996–2020) to a strong supply assurance focus in the period 2020–2023, supported by procurement's direct connections with semiconductor suppliers, an increase in the OEMs' centrality and in the network's density.

For most of the studied period (1996–2020), OEMs' cost and Tier 1 supplier focus was matched by the evolution of a Tier 1-centric supply network. This was a result of the OEMs' decision to focus on relationships with Tier 1 suppliers, to focus on core competence, and to increase cost efficiency. Supported by the external environment of stable suppliers, the Tier 1-centric supply network supported OEMs' focus on cost savings.

The mapping of the supply network evolution between 1996 and 2023 showed that the network experienced growth in network size (especially in the number of Tier 1 suppliers) because of the addition of new electronics, increasing network centralization, and decreasing density (see Paper II for the SNA metrics). Despite OEMs' attempts to reduce complexity in their supply network, the SNA metrics show split results: a lower network density indicates lower network complexity, but a larger network size indicates greater network complexity. Figure *7* illustrates this evolution of the supply network through maps of the network in 1996 and 2023. The evolution of a hub-centric network is further supported by the decreasing closeness centrality of the OEMs (average distance from all actors in the network) despite their increasing degree centrality (number of direct connections).



(?): The supplier could not be identified
SS: Semiconductor Supplier; AD: Authorized Distributor;
EMS: Electronics Manufacturing Services; T1: Tier 1 supplier

Figure 7: Maps of the SEC supply network in 1996 and 2023

The analysis of the network maps, together with data from interviews, showed the central position that the Tier 1 supplier maintained over the years, especially until 2020, in controlling the information flows, supplies and coordinating innovation in the supply network. Relying on Tier 1 suppliers to this extent also prevented OEMs from developing further technical knowledge about semiconductors or approaches to secure semiconductor supply.

The long-lasting match between the OEMs' cost focus and a cost-efficient Tier 1-centric supply network was opposed by a mismatch with the other two procurement objectives. First, when innovation could not be obtained in a timely manner from Tier 1 suppliers, and OEMs decided to increase their control over the software used in their vehicles, OEMs' Research and Development departments established informal but direct contacts with semiconductor suppliers in the late 1990s and early 2000s.

These direct contacts increased OEMs' understanding of the latest semiconductor technologies available on the market, which were needed to meet increasing legal requirements and reduce time-to-market for new vehicle features. Despite R&D's recognition of the increased relevance of semiconductors to secure needed innovation, direct connections with semiconductor suppliers did not involve the OEMs' procurement. The lack of involvement from procurement in these connections can be explained by resource limitations at procurement, lack of knowledge about semiconductors, and a strong position of R&D in making decisions on semiconductors.

The second instance of mismatch refers to the lack of semiconductor supply assurance practices by the OEMs' procurement, despite the increasing number of semiconductors in vehicles and the increasing dependence of OEMs on semiconductors throughout the period

1996–2020. Despite the increasing value of semiconductors and the occurrence of disruptions that affected other OEMs (e.g., semiconductor supply disruptions caused by an earthquake and tsunami in Fukushima, Japan in 2011, which), the studied OEMs did not change their sourcing model relying on Tier 1 suppliers until 2020. As explained by an OEM's purchaser: "At that time, we did not know much about semiconductor industry and for us, it was more the focus on the price (…) and not how we can really secure our supply because from our perspective, the Tier 1 is handling it and he has to secure our supplies" (OEM Semiconductor Purchaser, interview, November 2022). It was only when a major crisis impacted the automotive OEMs that their procurement functions in the period 2020–2023 sought to establish direct connections with semiconductor suppliers and other measures to secure component supply.

Finally, the findings revealed the implications of a Tier 1-centric supply network for OEMs' procurement. The delegation of semiconductor-related responsibilities to Tier 1 suppliers and the reliance on them prevented OEMs from developing familiarity with semiconductors, although semiconductors became increasingly critical over the years. The resulting lack of knowledge and detachment from the semiconductor industry contributed to the OEMs' unawareness of the complexity of the production process in the semiconductor industry and the development of semiconductor supply and demand mismatches in 2020, which ultimately caused the shortages of 2021–2023. From a Tier 1 supplier's perspective, the excessive delegation of responsibilities can overload on the suppliers' ability to coordinate supply and demand in the supply network, which can cause a generalized disruption in the whole network.

4.4. APPROACHES ADOPTED BY OEM FIRMS TO SECURE SEC SUPPLY

The approaches adopted by OEM-A to respond to semiconductor shortages and secure SEC supply differed regarding what actors they involved: internal approaches, approaches focused on Tier 1 suppliers, and approaches that addressed the rest of the supply network. Figure 8 presents an overview of these approaches.

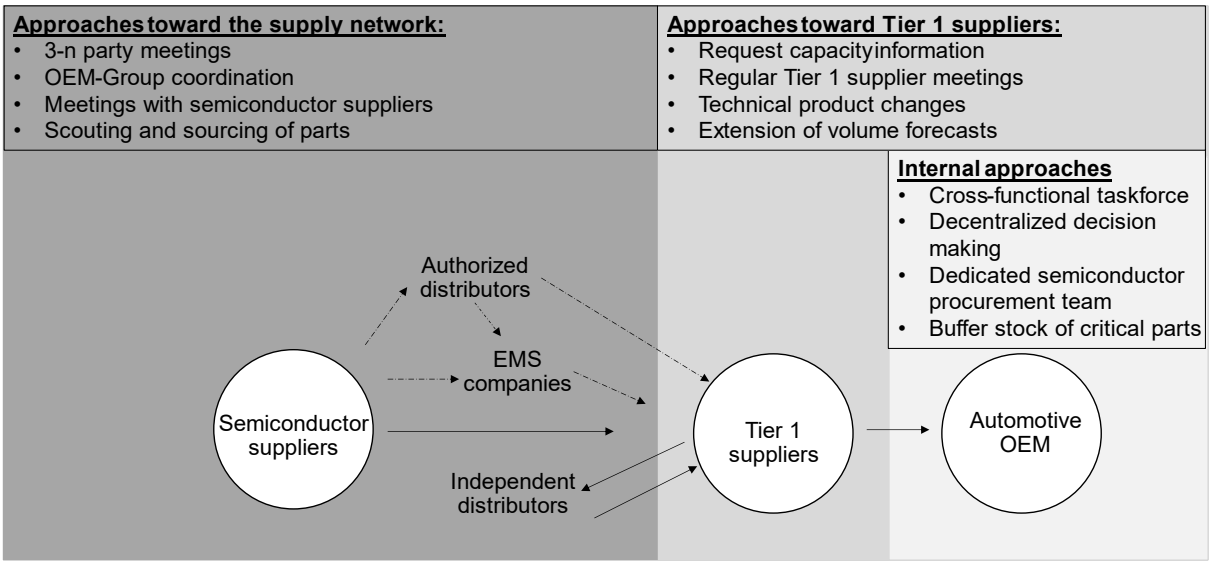


Figure 8: Overview of approaches adopted by OEM-A to secure SEC supply in times of shortage

Internal approaches concerned coordination routines between functions and decision-making processes within the OEM, with a dominant short-term focus. This includes a cross-functional taskforce team, and decentralized decision making. These approaches were adopted to increase information sharing across the company, enable more accurate assessments of the shortages and accelerate decision making towards the supply network.

Approaches that involved Tier 1 suppliers also strongly focused on the short-term assurance of supply, which included requesting capacity information from Tier 1 suppliers, technical product changes, and regular meetings to follow up on component availability. These approaches were aimed at obtaining timely information from them, increasing knowledge of semiconductors used in electronics, strengthening the relationship, and obtaining priority from these suppliers.

Finally, approaches that went beyond Tier 1 suppliers in the network included meetings with the other actors in the supply chain for a component, sourcing of semiconductors from independent distributors and meetings with semiconductors suppliers. Most of these actions had a short-term orientation to solve the supply issues at hand by reducing the OEM's dependence on Tier 1 suppliers to obtain information, to obtain information that was not available to Tier 1 suppliers, and to enhance the priority given to the OEM by semiconductor suppliers. However, contact with semiconductor suppliers has developed a long-term orientation to sustain relationships with these suppliers.

By adopting these approaches, OEM-A altered the supply network by establishing new connections and strengthening its existing connections with Tier 1 suppliers. This was reflected in the SNA metrics through higher degree and closeness centrality. Closer relationships with Tier 1 suppliers enhanced trust and collaboration (e.g., when technical changes were needed on short notice to remove components in shortage) and increased the amount of information available to OEM-A. On the other hand, connections to new actors in the supply network enhanced information transparency, both of information from semiconductor suppliers and of the OEM's demands.

These approaches also addressed some of the previously identified weaknesses in the power position of OEMs in the SEC supply network. The lack of relationships with semiconductor suppliers was addressed through regular meetings with semiconductor suppliers, including top management meetings and communication through OEM-A's holding group. Internal factors such as the lack of knowledge on semiconductors and resource limitations were addressed especially through the creation of a "Dedicated semiconductor team." OEMs also addressed the weaknesses of their suppliers' position by increasing the transparency and commitment of volumes.

5. DISCUSSION

The present thesis aimed to enhance our understanding of the automotive SEC supply and the automotive OEMs' position in it (research question RQ1) and of how OEMs can improve their position through procurement's interaction with the supply network (research question RQ2). Through an in-depth case study of an OEM's supply network, this thesis has provided answers to these research questions, as it is summarized in Figure 9.

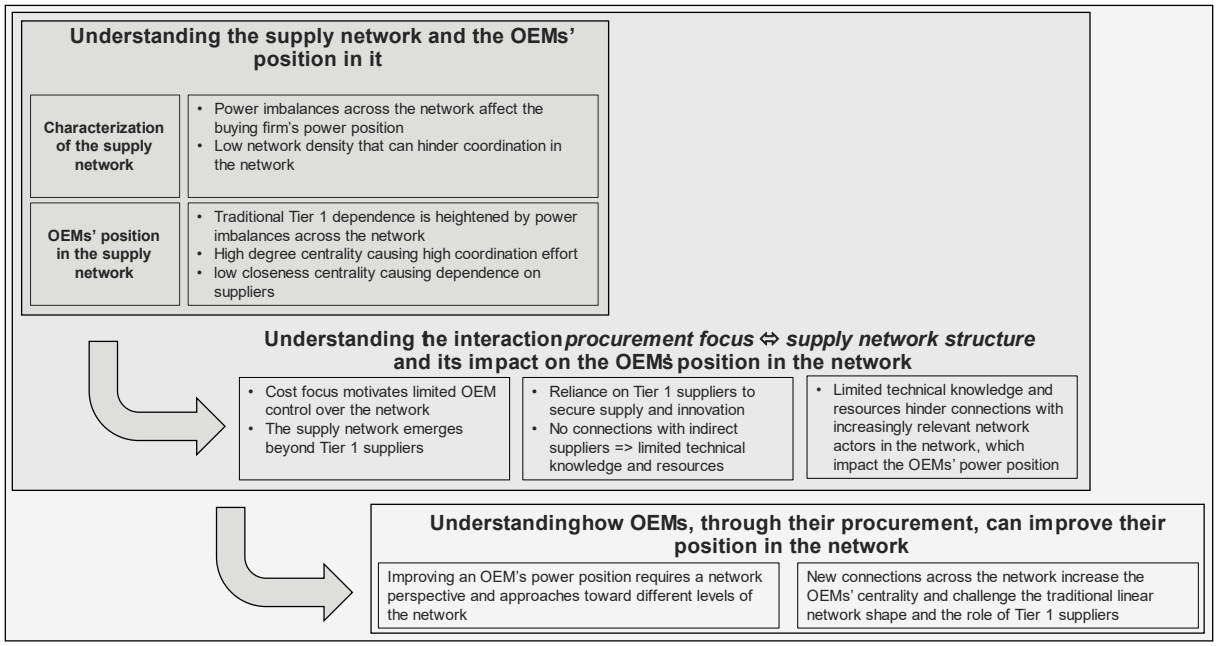


Figure 9: Summary of findings in response to the research questions in this thesis.

In Figure 9, the arrows depict how the understanding of each group of concepts supports the aim of the present thesis: to create an understanding of how OEMs can improve their position in the network through procurement. In doing this, the findings contributed to the procurement literature and to the application of SNA in an SCM context, as will be explored in this section.

5.1. RQ1: THE SEC SUPPLY NETWORK AND THE POSITION OF OEMS IN IT

To achieve this thesis's aim, the investigation of the research question RQ1 aimed to enhance the understanding of the OEMs' decision-making environment for SEC, through a description of the SEC supply network and of the OEMs' position in this network. In this section, the findings regarding this research question are analyzed with consideration of two literature streams: the power position of the buying firm (attractiveness of the buying firm, supplier dependence, and availability of second source) and SNA (node-level and network-level metrics).

Regarding power and relationships in the network, issues of customer attractiveness and power imbalances are present at different levels of the supply network. According to existing theory, power imbalances can arise based on dependences in interfirm relationships in the network (Caniëls & Gelderman, 2007; Pfeffer & Salancik, 2015), and based on intrafirm factors, such as demand share, reputation, and substitutability (Pazirandeh & Norrman, 2014).

In the context of the SEC decision-making environment, OEMs are highly dependent on Tier 1 suppliers due to supplier lock-ins and a lack of relationship with semiconductor suppliers. However, Tier 1 suppliers are also dependent on semiconductor suppliers due to supplier lock-ins and low volumes compared with semiconductor volumes purchased by other industries. Thus, OEMs also become dependent on Tier 1 suppliers' power positions toward semiconductor suppliers, which demonstrates how local power imbalances further in the supply network affect the OEMs' power position (Xiao et al., 2019).

The application of SNA in the SCM context offers a further way to understand supply networks (Borgatti & Li, 2009; Kim et al., 2011) and proposes the existence of a central, highly connected node, called a "hub" that connects and coordinates the network (Hearnshaw & Wilson, 2013). The structural holes between OEMs and semiconductor suppliers empower the broker role of Tier 1 suppliers as hubs in the network (Burt, 1992; Kim et al., 2011). However, as connections across the network begin to reshape the traditional network structure and deviate from the linear structure predicted by SNA theory (Han et al., 2020), this challenges the position of the hub nodes in the network.

The analysis of the SNA metrics of network complexity and centralization shows interesting insights. First, increasing centralization of connections around OEMs implies a central position of OEMs in information flows in the network (Kim et al., 2011). However, contextual data reveal that OEMs remain dependent on Tier 1 suppliers due to the unique information paths for each ECU. This findings emphasizes the importance of contextual data to complement the analysis of network metrics (Kim et al., 2011). Similarly, despite claims for practitioners to reduce the complexity of their supply networks (Bode & Wagner, 2015), low complexity (represented by low network density) due to lack of connections across the network hindered the coordination of supply and innovation in the SEC supply network. This finding corroborates the positive effects of supply network complexity (Ateş & Memiş, 2021).

The position of the OEMs in the network is characterized by high degree centrality and low closeness centrality. Both measures reveal insights that corroborate what is predicted by the SNA metrics: the high coordination effort created by high degree centrality and the low independence due to low closeness centrality (Kim et al., 2011).

In summary, the decision-making environment for automotive SEC is characterized by a growing supply network, traditionally based on Tier 1 suppliers' acting as hubs, and consequent low density due to the lack of connections across the network. The OEMs' power position in this environment is characterized by dependence on Tier 1 suppliers, supplier lock-ins, and different levels of attractiveness depending on the OEMs' products and technological orientation. This is in line with previous literature pointing to the historical dependence on Tier 1 suppliers in the automotive industry (Doran, 2004; Hearnshaw & Wilson, 2013; Lamming, 1993). However, the findings of this thesis also reveal the power imbalances across the network and low attractiveness compared to other industries further hinder the OEMs' position in the network (Cox et al., 2001; Xiao et al., 2019).

5.2. RQ2: WAYS FOR OEM FIRMS TO IMPROVE THEIR POSITION IN THE SEC SUPPLY NETWORK THROUGH PROCUREMENT

Building on the understanding of the OEMs' SEC decision making environment and their position, this section analyses ways for OEMs to improve their position in the supply network through procurement. This analysis is performed in two parts, with the first part focusing on how the procurement focus and supply network structure interacted in the past to shape the OEMs' position, while the second part focuses on how procurement addressed weaknesses in the OEMs' position to secure SEC supply during the semiconductor shortages.

The literature suggests that buying firms can directly influence and control the structure of their supply network through the selection and management of suppliers (Choi & Krause, 2006; Kim & Narasimhan, 2019), but much of the supply network structure emerges beyond the control of the buying firm (Choi et al., 2001). In the SEC supply network, supporting a cost focus prompted limited OEM control and prevailing emergence of the supply network beyond Tier 1 suppliers, which increased OEMs' dependence on direct suppliers. These findings add a perspective of procurement focus to our understanding of the formation of supply networks suppliers (Choi & Krause, 2006; Kim & Narasimhan, 2019) and corroborates the risk of excessive emergence (Choi & Linton, 2011; Choi et al., 2001) through a power position perspective (Caniëls & Gelderman, 2005; Cox et al., 2001).

A focus on supply assurance and innovation requires more connections, including connections with indirect suppliers (Chae et al., 2019; Choi & Linton, 2011; Kim & Narasimhan, 2019). In the case of the SEC supply network, as OEMs relied on direct suppliers to achieve these objectives, this prevented them from connecting with indirect suppliers, allocating resources to work with indirect suppliers and developing knowledge about their products. This, in turn, further prevented connections with indirect suppliers. These findings support the role of internal organizational factors to facilitate connections with indirect suppliers to support supply assurance and innovation (Chae et al., 2019; Kim et al., 2020; Luzzini & Ronchi, 2011). Further, as the increasing relevance of indirect suppliers affects the power balances in the network, these internal factors also impact an OEM's power position in the network (Casciaro & Piskorski, 2005; Pfeffer & Salancik, 1977).

Finally, the findings also reveal how OEMs can address weaknesses in their power position to access innovation and supply of semiconductors. The literature suggests that this might require additional connections (Kim et al., 2020; Kim et al., 2011; Li et al., 2020) and that improving a firm's power position involves increasing customer attractiveness, strengthening relationships and adapting to the changes in external forces (Eisenhardt & Schoonhoven, 1996; Goldberg & Schiele, 2020; Schiele & Vos, 2015). The investigation of the SEC supply network shows that OEMs' approaches to improve their power position involve internal organizational factors, strengthening relationships with Tier 1 suppliers, and establishing new connections in the supply network. These findings corroborate the importance of a supply network perspective in addressing the buying firm's power position (Kim et al., 2011; Xiao et al., 2019). The list of approaches to secure supply of components in shortage contributes to a limited literature on supply disruption response, especially from a PSM perspective (Dabhilkar et al., 2016; Küffner et al., 2022).

In summary, the findings provide a twofold contribution to the understanding of how OEMs can improve their position in the SEC supply network through procurement. First, the insights from the period 1996–2020 provide examples of factors that hindered the OEMs' position and should be considered carefully in the future, such as the overdependence on Tier 1 suppliers to secure supply and innovation, and the lack of understanding of the rest of the supply network and the power dynamics in it. Second, the approaches adopted in 2021–2023 to secure supply during the semiconductor shortages can be added to procurement's box of tools to improve the OEMs' power position, such as increasing OEMs' centrality, establishing direct relationships with powerful suppliers, and improving customer attractiveness. These findings demonstrate the power of SNA metrics to explain firms' position in the supply network (Kim et al., 2011) and how OEMs can interact with the supply network to improve the OEMs' position in their decision-making environment.

6. CONCLUDING REMARKS

Motivated by early signs of a weak power position of automotive OEMs in their SEC supply network, this thesis has aimed to enhance our understanding of how OEMs, through their procurement, can improve their position in the SEC supply network. To achieve this aim, two research questions were investigated: to understand the SEC supply network and the position of OEMs in it, and to determine how procurement interacts with the supply network to improve this position.

Through a case study of the SEC supply network, including more than 30 interviews, process documents, archival documents and participatory observations, the answers to these two questions provide valuable insights for procurement theory and practice as well as for understanding rapidly changing supply networks such as the SEC supply network.

6.1. THEORETICAL CONTRIBUTIONS

The first contribution of this thesis is the understanding of the SEC supply network, its Tier 1-centric structure and its dependencies, supplier lock-ins and power imbalances in it. This understanding extends our understanding of power dynamics in supply networks by showing how sources of power at the micro, meso and macro levels affect a buying firm's power position (Caniëls & Gelderman, 2007; Pazirandeh & Norrman, 2014; Pfeffer & Salancik, 2015).

Following the understanding of the SEC supply network, this thesis delineates the power position of the OEMs in this network through power dynamics and SNA metrics. The combination of these two literature streams adds to the potential applications of SNA, especially when combined with contextual data on relationships in the network (Kim et al., 2011), and it provides the procurement literature with ways to analyze the power position of buying firms in the whole supply network (Cox et al., 2001; Xiao et al., 2019).

The third contribution of this thesis regards the interaction between procurement focus and the supply network structure over time. It contributes to the PSM literature by showing the limitations and implications of OEMs' continued focus on cost and Tier 1- supplier relationships (Murfield et al., 2021; van Weele & Rozemeijer, 2022). This adds to the existing debate about the control and emergence of the supply network structure (Choi & Linton, 2011; Choi et al., 2001; Kim & Narasimhan, 2019): especially in supply networks with high technological relevance and supply uncertainty of indirect suppliers, OEM firms must not overly delegate responsibilities to direct suppliers and must maintain the ability to sense changes in the external environment and adapt to their external environment.

The findings also contribute to the SNA literature by adding a longitudinal view of network evolution. The use of node and network level metrics, combined with contextual interview data, highlighted the consequences of network characteristics over time and of perceived overload on central Tier 1 suppliers. This finding corroborates the value of adopting SNA combined with contextual data in the SCM context (Kim et al., 2011).

This thesis contributes to the PSM literature by providing an overview of the approaches adopted by an OEM to secure supply of components in times of shortage, which contributes to the existing but scarce knowledge about how companies react to supply disruptions and

shortages to secure supply (Finkenstadt & Handfield, 2021; Küffner et al., 2022). It also furthers our understanding of how an OEM firm adopts approaches involving different actors in the supply network and alters the supply network structure to secure supply of components in shortage. To the knowledge of the benefit of higher degree and closeness centrality for supply assurance (Li et al., 2020), these findings add insights into how enhanced centrality affects OEM firms. This is especially relevant in the case of the automotive industry and its complex supply network (Brintrup et al., 2015), and in the SEC context of OEMs' high dependence on Tier 1 suppliers.

Finally, the findings provide ways in which OEMs can improve their power position in the SEC supply network through procurement, especially through approaches adopted to secure supply during semiconductor shortages. Such approaches address the weaknesses of the OEMs' position in the network as well as new opportunities brought about by new environmental conditions, such as semiconductor suppliers' increased interest in the automotive industry due to electrification. This has led to changes in the OEMs' procurement and highlights the increased need for knowledge and collaboration with R&D.

6.2. PRACTICAL IMPLICATIONS

The present thesis addresses the empirical problem of the changing environment of the SEC supply network. This changing environment poses challenges to automotive OEMs and their procurement's role to secure supply, cost and innovation of SEC in the future. The findings have several practical implications for procurement practitioners, especially in the automotive SEC supply network and for other firms in similar contexts of rapid environmental change and rapid technological development. These implications relate to the importance of adopting a supply network perspective, the importance of considering the supply network structure in devising procurement strategies and, ultimately, finally the importance of external and internal factors for the power position of buying firms.

Regarding the first implication, the findings show the importance of adopting a supply network perspective. In contrast to automotive OEMs' traditional focus on relationships with Tier 1 suppliers, the power position of OEMs in the network is also influenced by the overall structure of the network, and local power unbalances such as those between Tier 1 suppliers and semiconductor suppliers. This means that even if the OEM has a favorable power position toward a Tier 1 supplier, it may still face challenges in achieving its procurement objectives if that Tier 1 supplier has a weak power position toward the rest of the network. To practitioners, this thesis proposes that mapping the supply network, analyzing SNA metrics and identifying power imbalances can aid in obtaining a holistic view of an OEM's position in the network.

By adopting a supply network perspective, practitioners may want to consider the current and desired supply network structure when devising procurement strategies to improve their firms' power position. Although a cost-efficient supply network centered around Tier 1 suppliers may support the achievement of cost savings, this may bring about challenges in the form of supply dependence and a lack of crucial relationships to secure supply and innovation. The findings show that practitioners can directly influence the structure of the supply network to improve their firms' power position and support the achievement of their procurement objectives.

Finally, practitioners benefit from this thesis as it highlights how internal and external factors form a firm's power position. Among the internal factors, the level of technical knowledge of the purchased components, resource availability and collaboration with internal functions are crucial for procurement's interaction with the supply network. Regarding external factors, the findings of this thesis reveal the importance of monitoring for changes in demand patterns and rapid technological development in other industries as well as the influence of legal regulation on product characteristics.

6.3. LIMITATIONS

As with any research work, the present thesis has limitations, arising from scope limitations, the adopted OEM perspective, and data access. Scope limitations include the adoption of a single case study and a specific supply network. This supply network was selected as a representative and revelatory case, because of the rapid environmental changes affecting the network and consequent limitations regard the generalizability of the findings. The adopted OEM perspective is justified by the thesis's aim that is focused on the power position of the OEMs, but the author recognizes the potential value of investigating the power position of other actors in the supply network and how different perspectives would contribute to the formation of knowledge about this supply network. Finally, although data access was greatly supported by the direct access to OEM-A, it was limited by limited data availability on semiconductor components used in the ECUs and the availability of data on decisions made in the early period of the studied period (see Paper II for more details on this limitation and how it was addressed).

6.4. FUTURE RESEARCH AVENUES

As the research presented in the present thesis advances our knowledge of the automotive SEC supply network, many further possibilities for future research exist, including further investigations of the SEC supply network as well as the application of the findings from the SEC supply network to the rest of the OEMs' procurement organization. This section expands on these possibilities.

The present thesis reveals how external factors have influenced the SEC supply network and the OEMs' procurement in the past three decades, and further research can investigate how this influence is expected to prevail in the coming years. As revealed by this thesis's findings, a relevant topic in this matter is the procurement capabilities needed at OEMs to leverage external factors.

Another research possibility revealed by this thesis is the exploration of the role of OEMs' procurement in securing innovation in a changing environment of rapid technological change. The periods studied have been characterized by a strong focus on cost and supply assurance, but even in those periods, it is possible to recognize the importance of procurement in ensuring innovation in the SEC supply network. Further studies could focus on procurement capabilities and collaboration with R&D that enable the role of procurement in supporting innovation.

Finally, another possibility for future research is the extension to the rest of procurement of the knowledge generated based on the SEC supply network, which would investigate whether

the findings on the SEC supply network can be applied to the procurement of other types of components and to what extent the knowledge created in the research thus far can be extended to the rest of the OEMs' procurement organizations.

These research opportunities also relate to the continuation of my PhD project. In addition, the expansion of Paper III, the investigation of trends and procurement capabilities in the future of the SEC supply network seems to be a natural step in my project. The initial conceptualization of a Delphi study involving actors from different tiers of the supply network was presented at the IPSERA Conference 2024 as a working paper. After the Delphi study, I would be interesting in either of the two possibilities: focusing on the OEM's procurement role in securing innovation or the extension of the current findings to the rest of the OEMs' procurement organization.

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