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An analysis of automakers navigating an evolving semiconductor landscape

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Abstract

Purpose – In this paper, we investigate the coevolution of the supply network and procurement strategies in the context of semiconductors and electronics for the automotive industry over 3 decades. We aim to explain how procurement strategy interrelates with changes in supply network structure and what the implications of a hub-centric structure network structure are for procurement in supply.

Design/methodology/approach – We collected in-depth primary and secondary data that stretched back to 1996 from a leading automotive European original equipment manufacturer (OEM) and its network. Using social network analysis (SNA), we identified OEMs' procurement focus and mapped the evolution of the supply network, the links in the network, and the environmental forces impacting the strategies and the network.

Findings – Our findings describe the supply network for semiconductor and electronic components to the automotive industry. The findings suggest that a focus on cost can lead to a Tier 1-centric network structure with many tiers that can fail to assure supply or capture innovation when the external environment is marked by high uncertainty. In such situations, increasing complexity by creating more links in the network can improve transparency and contribute to supply assurance and innovation.

Practical implications – The findings indicate that managers should consider the role of the supply network in selecting their strategy to attain objectives of cost, innovation, and supply assurance.

Originality/value – This paper presents empirical-based insights into the automotive semiconductor and electronic component supply chain (SC), the unexpected implications of hub-centric supply networks, and the use of SNA in the SC in context.

Keywords Procurement, Social network analysis, Supply management, Automotive, Semiconductors

Paper type Case study

1. Introduction

Automotive OEMs experienced quite stable supplies of semiconductors and electronic components (SECs) during the first 2 decades of the twenty-first century, strongly relying on their Tier 1 component suppliers. However, with an increasing demand for and reliance on these components, OEMs found themselves in a vulnerable position, unable to secure an adequate supply of SECs during the semiconductor shortages of 2020–2023. The shortages revealed the OEMs' lack of knowledge about semiconductors and a lack of relationships between OEMs and semiconductor producers (King *et al.*, 2021). This creates concerns for the future of OEMs given the increasing costs and technological relevance of SECs for autonomous, connected, and electrified vehicles (MIT Technology Review Insights, 2022; Boston *et al.*, 2021). External trends and events in the years preceding 2023 (e.g. geopolitics, climate change, technological advancements) increased OEMs' uncertainties about and

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reliance on their supply networks and raised questions concerning the position of the OEMs and the Tier 1 suppliers in the network.

The European automotive supply chains are characterized by and rely on a modular design, build-to-order, and synchronous supply of components from OEMs and Tier 1 suppliers (Bennett and Klug, 2012), which often involves co-located supplier clusters (Reichhart and Holweg, 2008). This has developed strong ties between OEMs and Tier 1 suppliers, where Tier 1 suppliers develop, produce, and deliver modules or systems. The Tier 1s collaborate with a range of Tier 2 and Tier 3 suppliers, while the OEMs focus on their Tier 1 collaborations. Previous studies have long argued for long-term strategic partnerships, similar to the relationships developed between the OEMs and the component suppliers, for seamless supply (dos Santos *et al.*, 2020; Lamming, 1993). The occurrence of the global shortage crisis of semiconductors (2020–2023), due to disruptions at indirect suppliers, has raised the question as to how OEMs ended up in such a vulnerable position in their networks. With the automotive's SEC network expanding geographically as well as in the number of its actors, many have argued whether or not Tier 1 established relationships have made good on their promises.

The automotive SEC supply network typically involves a multi-tier web of suppliers, contractors, and other partners, each with their own unique capabilities and expertise (Mönch *et al.*, 2017). Procurement, especially in the aftermath of crises, has the potential to directly shape/reshape the supply market and, thus, impact the position of buying firms (Pedersen and Ritter, 2022), but in practice, it is questionable whether the automotive OEMs have adjusted to the structure and characteristics of the supply network. The procurement function of a firm seeks to strike a balance between cost saving, supply assurance, and value enhancement through innovation by interacting with the supply network and selecting what suppliers to manage directly and from which to source the company's needs (Choi and Krause, 2006). While strategic sourcing and supplier selection can actively influence the supply structure network (Kim and Narasimhan, 2019), much of the supply network structure is said to "emerge" without the control of a buying firm (Choi *et al.*, 2001). Regardless of a supply network's emergence, the performance of both direct and indirect suppliers can impact how a firm achieves its procurement objectives (Choi and Linton, 2011), and therefore it is important to consider direct and indirect suppliers in a firm's supply network. The occurrence of supply disruptions at indirect suppliers beyond OEMs' connections with Tier 1 suppliers adds to the question of how procurement strategies influence, and are influenced by, the shape of the supply network, especially beyond the Tier 1 suppliers. Consequently, the automotive SEC supply network represents a relevant research subject to explore procurement strategy and supply network structure interactions.

To study multi-tier supply networks, an investigation of the network structure can be valuable. Social network analysis (SNA) is a theoretical lens developed to explain how network structures relate to processes and decisions to yield outcomes for the nodes and the network as a whole (Borgatti and Halgin, 2011). SNA has been used in SC contexts, where the value addition process is both linear and does not contain reciprocal connections between suppliers (Han *et al.*, 2020). SNA also posits that in many real-world supply networks, the material flows are coordinated by central, highly connected hubs such as the automotive industry's Tier 1 suppliers, or in the so-called hub-centric supply network structures (Hearnshaw and Wilson, 2013). The relevance of these hubs is especially noticeable in the automotive supply network context of our study (Doran, 2004; Brintrup *et al.*, 2015). Previous studies revealed an overall inclination of automotive OEMs to outsource to and rely on Tier 1 suppliers as part of their pursuit of cost efficiency (Choi and Linton, 2011), with the exception of OEMs' direct relationships with lower tier suppliers of key subcomponents (Kim *et al.*, 2011; Choi and Hong, 2002). Thus, the exploration of the supply network in the SEC context can also help us assess the hub-centric role of Tier 1s in supply chains. Using the SNA lens, this study aims to answer the following research questions:

RQ1. How does the OEMs' procurement strategy and supply network structure interrelate over time?

RQ2. What implications does the hub-centric supply network structure have for the OEMs' procurement of the SECs?

To answer these questions, we investigated the procurement strategies adopted by automotive OEMs in the period 1996–2023 (to date). Adopting SNA in this study allowed us to analyze the complex web of connections in the automotive SEC network and to analyze the network's structure and dynamics in terms of centrality, information flows, and exposure to SC risks. This perspective helped us examine not only the direct connections between automakers and their suppliers but also the indirect relationships, collaborations, and forces that influence how information, resources, and innovation flow through the network.

Our findings contribute to the automotive SC literature on the relevance, constraints, and contributions of a Tier 1-centric supply network structure (Choi and Linton, 2011). They provide valuable insight into the recent discussions on the resilience, relevance, and complexities of semiconductor SCs (Congress.gov, 2022; European Commission, 2023), as they show the changes and network structure linked to the automotive industry. Our study also contributes to our understanding of SNA metrics and concepts for studying supply chains (Kim *et al.*, 2011; Borgatti and Li, 2009) and to the future of procurement strategizing of the increasingly critical empirical field of SEC supply and of the supply of other critical categories such as electric vehicle batteries.

The remainder of this paper is organized as follows: Section 2 presents the frame of reference, Section 3 presents the adopted case and method, Section 4 presents the results, Section 5 presents a discussion of the findings, and Section 6 provides concluding remarks.

2. Frame of reference

2.1 Social network analysis

SNA is a powerful paradigm, a structural analysis, used to describe and analyze the connections between nodes (actors) in a network (Carter *et al.*, 2007). SNA allows both mapping of relationships and visualization of network structures resulting from these relationships (Han *et al.*, 2020). 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 that 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 supply chain management (SCM) studies (Borgatti and Li, 2009; Han *et al.*, 2020). A set of metrics can help analyze structures and relationships in mathematical terms and combined with more in-depth and qualitative analysis of the ties, can provide strong insights into supply network collaborations and performances (Borgatti and Li, 2009; Han *et al.*, 2020).

According to Kim *et al.* (2011), as summarized in Table 1 SNA metrics of network complexity, network centralization, and node centrality can be used to characterize supply networks and analyze impacts and implications at both the node and the network levels and for both the flow of material and the transactional relationship. For the purpose of this paper, we focus only on transactional relationship metrics.

Node centrality refers to a node's network position, degree centrality measures the node's number of connections, betweenness centrality measures how often the node lies in the

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

Source(s): Based on Kim *et al.* (2011, pp. 197, 199)

Table 1. SNA metrics for characterizing the supply network structure

shortest path between two other nodes in the network, and closeness centrality reflects the node's average distance from all other nodes in the network (Kim *et al.*, 2011).

By measuring a node's position in the network, node-level metrics also represent the node's relative importance (Borgatti and Li, 2009; Kim *et al.*, 2011). In supply networks, a high number of connections (degree centrality) 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 to control the flows of materials and information between suppliers and customers as well as the ability to control the interaction 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 and Li, 2009; Kim *et al.*, 2011). Lastly, high closeness centrality suggests a firm's independence through its ability to quickly reach other firms, and a firm with low closeness centrality might face information distortion, disruption risk, and cost increases (Borgatti and Li, 2009; Kim *et al.*, 2011).

Network centralization 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). Network complexity is described by Kim *et al.* (2011) as being based on the network size (i.e. number of nodes in the network) and network density (i.e. the degree of interdependency between nodes).

Each aspect of supply network complexity has various implications for the supply network. A larger network size can indicate longer paths and more time needed to reach other firms and complete a task (Borgatti and Li, 2009; Kim *et al.*, 2011) and additional operational effort to manage suppliers (Choi and Krause, 2006). Supplier interrelatedness can indicate dependencies between suppliers (Kim *et al.*, 2011), but existing relations between suppliers can facilitate cooperation between them (Choi and Krause, 2006; Ateş and Memiş, 2021).

2.2 Interrelationship between procurement and the supply network

To secure a firm's current and future needs, the procurement function seeks to strike a balance between the objectives of cost savings, supply assurance, and innovation (Van Weele, 2018). Among procurement objectives, cost is the most predominant according to research (Wynstra *et al.*, 2019) and has been a traditional part of procurement's identity (Murfield *et al.*, 2021). Practices to reduce cost build on procurement's commercial, technical, and supply market knowledge (Schütz *et al.*, 2020) and include rationalizing the supply base and the pooling of demands, both of which imply a reduction in the number of supplier connections (Schiele, 2007; Patrucco *et al.*, 2023). In fact, companies focusing on cost could select fewer suppliers to explore economies of scale (Kim and Narasimhan, 2019) and a single Tier 1 supplier to coordinate the rest of a component's SC in the pursuit of higher efficiency and lower procurement and supply resource (e.g. manufacturing tools) needs (Choi and Linton, 2011). Therefore, we can expect that over time, a focus on cost through exploring economies of scale and increasing the efficiency of internal resources may impact procurement by limiting the number of supplier connections.

In contrast to cost, a focus on innovation benefits from connections to direct and indirect suppliers. Such a focus should include involving suppliers in new product development (NPD) and cultivating supplier relationships that are aligned with technology roadmaps (Arvidsson *et al.*, 2022; Schiele, 2010). According to the SNA literature, a firm's innovation performance depends on its ability to access knowledge and information through its position in the network (Bellamy *et al.*, 2014). Connections with direct and indirect suppliers are crucial for innovation (Kim *et al.*, 2020), since it might be difficult to leverage indirect suppliers' knowledge through direct suppliers. Hence, a firm needs to go beyond Tier 1 suppliers to explore innovation opportunities (Legenvre and Gualandris, 2018; Kim *et al.*, 2020). This is clearly the case when the buying firm drives innovation. It may, to some extent, also be the case for supplier-driven innovations, for example, those that are conducted by Tier 1 suppliers acting as system and module suppliers (Brandes *et al.*, 2013). However, the potential of indirect connections can be constrained by the coordination of a large number of direct ties (Kim *et al.*, 2020) and by a lack of familiarity with technical aspects and a lack of internal resources (Mena *et al.*, 2013; Johnsen, 2011). This is because capturing innovation within the supplier base requires a more comprehensive skill set at the procurement function and closer integration with other organizational functions (Legenvre and Gualandris, 2018; Luzzini and Ronchi, 2011). Thus, we can expect that an innovation focus prompts connections with both direct and indirect suppliers, but this can be limited by internal factors such as technical knowledge, cross-functional cooperation, and resource availability.

Supply assurance, critical in times like the COVID-19 pandemic, relies on practices such as internal information sharing, supplier redundancy, product flexibility, and robust supplier selection criteria (Pereira *et al.*, 2020; Küffner *et al.*, 2022). In particular, supplier redundancy and product flexibility can require a larger number of suppliers, and therefore, higher centrality can contribute to supply assurance (Kim *et al.*, 2011; 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.*, 2011). On the other hand, Bode and Wagner (2015) found that a higher 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 SC complexity, even though the ways to do so might vary for different practitioners. Thus, our understanding of the existing literature suggests that high node centrality contributes to supply assurance, but the buying firm might face increased supply network complexity and the consequent operational burden to manage the supply network.

Overall, each procurement objective can lead to different supply network characteristics, and striving for all three objectives simultaneously might be challenging (Ramírez *et al.*, 2020). Furthermore, procurement's focus 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.

3. Method

3.1 Case study method

We adopted a case study approach (Ellram, 1996) to gain contextual richness (Piekkari and Welch, 2018) and conducted an in-depth investigation of a focal OEM's supply network for the period of 1996–2023. Case studies are also suitable for studying contemporary phenomena without separating them from their contexts (Halinen and Törnroos, 2005). This was central to our aim of understanding the reasons why procurement would not adapt to the characteristics of the supply network.

3.2 Case description

The case is the supply network for the SECs of an automotive OEM (OEM1), which includes its Tier 1 suppliers, electronics manufacturing service (EMS) companies, semiconductor suppliers, authorized distributors (ADs), and other OEMs (two additional OEMs were considered in this study). The case study OEM is a leading North European firm that develops, manufactures, and provides services mainly for commercial and passenger vehicles. In the last 2 decades, it has experienced a notable increase in the number of electronic components in its vehicles and, at the time of the study, was implementing changes in its procurement of electronics and semiconductors, which caused it to have a distinct interest in and openness to the study. The OEMs in this network outsource the development and production of most components used in its products, including electronic parts – electronic control units (ECUs) and sensors. ECUs are electronic devices programed to control a certain function of the vehicle based on the data received from the sensors, such as brakes, lights, or powertrain components. For electronics, development and manufacturing are outsourced to selected direct Tier 1 suppliers, who source all the subcomponents needed for their production: semiconductors and passive (resistors, transistors, and others) and electro-mechanical (printed circuit board, screws, connectors, cables, among others) parts. This study focused on semiconductors and ECUs.

In this network, Tier 1 suppliers might outsource electronics manufacturing to EMS companies as well as semiconductor ordering and logistics management to authorized distributors. The design, production, and sale of semiconductors are done by integrated device manufacturers (IDMs). Although the steps of semiconductor production might be outsourced, in this study we consider IDMs as semiconductor suppliers, since they have relationships with Tier 1 suppliers.

3.3 Data collection

This study employed a set of alternate rounds of data collection and analysis, using 19 interviews, two years of participatory observations, and archival data to get in-depth insight into the context. To cover the broad time period considered in the study, we adopted a mix of data sources to insure the validity of our retrospective perspective (Lefebvre *et al.*, 2022). The study took the perspective of OEM1 and its supply network. The two other OEMs in the same holding group were added to increase the validity of our understanding of the phenomena in the time span.

Interviewees were selected based on their participation in decision-making for SEC in their respective firms, their years of experience, and their positions in the years studied (see Table 2 for more details).

As our initial data showed that the microcontroller unit (MCU) is the most important semiconductor among up to 1,000 parts in an ECU, we focused on identifying the MCU supplier

Data types	Data sources	Contribution to the data
4x Interviews with senior engineers (interviewee code "T" for technical department) with 10–20 years of experience in automotive electronics and who participated in the OEMs' selection of MCUs	R&D • OEM1-T1 • OEM1-T2 • OEM2-T1 • OEM3-T1	R&D's perspective of the sourcing work towards the supply network Reasons for selection of MCUs Names of suppliers of ECUs and MCUs Changes in the supply network Validation of network maps
5x Interviews with senior procurement (interview code "P") and supplier quality management (interview code "SQM") professionals with more than 15 years of experience in the procurement of electronics	Procurement • OEM1-P1 (2x), OEM1-P2, OEM1-P3, OEM1-P4 • OEM1-SQM1 (2x), OEM1-SQM2 • OEM2-P1. OEM2-P2 • OEM3-P1	Procurement focus and its motivation Validation of network maps Changes in the supply network
1 Interview with logistics coordinator (interview code "L")	Logistics • OEM1-L1	Responsibilities of procurement and logistics to secure component supply
3x Interviews with professionals with 10+ years in the semiconductor industry	Semiconductor industry • SEC expert SE-1 • SEC expert SE-2 • Business development • semiconductor supplier SS1	The semiconductor industry's perspective on OEMs' sourcing strategy Impacts of OEMs' procurement focus for the network
Secondary data on network from OEM1	Schematics of OEM1's E/E architecture containing all ECUs used in the years 1996, 2005, 2015, 2020 and 2023	List of ECUs purchased by OEM1 in each year: each schematic drawing showed all ECUs used in OEM1's vehicles for a given year
Secondary data on network from OEM1	• Excel document with the Tier 1 and MCU suppliers per ECU • Sourcing documents	Names of Tier 1 and semiconductor suppliers: for each ECU, the list provided names of suppliers involved For years 2015, 2020, and 2023, names of suppliers were obtained from existing OEM1's supplier lists For years 1996 and 2005, names of suppliers were obtained through interviews
Secondary data on the network	15 news articles containing complementary or confirmatory information to collected data	Validation and complementation of interview data
Participatory observation	Two years of participation by one of the authors in the procurement team responsible for ECUs at one of the OEMs	Names of Tier 1 and semiconductor suppliers

Source(s): Created by the authors

Table 2.
Overview of conducted interviews and other data sources

for each ECU. The data revealed that the first decisions with potential impacts on the supply network dated back to 1996, which was set as the starting point of the study period. The relevant documents we reviewed included schematics of OEM1's electrics/electronics (EEs) architecture in the studied period (i.e. drawings showing all the ECUs used in a vehicle in different years) and lists of suppliers for each ECU, which allowed us to produce initial supply network maps.

Interviews with individuals from the three OEMs were intended to identify their procurement focus during the studied period, validate the network maps produced, and complement preceding interviews. The interviews obtained the respondents' accounts as far back as their experience allowed. Secondary sources, such as news articles (see Appendix 1 for a full list of news articles) and sourcing documents, were used to validate and complete our historical view. Participatory observations were used to triangulate the other sources; one of the authors had a central role in OEM1's department responsible for more than 70% of its ECUs from 2020 to 2023. The analysis and interpretations were conducted in between all three authors to minimize any participatory bias. The understanding of the early portion of the studied period (1996–2010) was completed by conducting interviews with procurement professionals from OEM1 with 15 or more years of experience, including a senior management member.

3.4 Analysis

Open coding was used to identify the overall procurement strategy adopted by the OEMs in the studied period, relevant changes in the supply network structure, and the importance of external events (i.e. regulatory changes and natural events). The analysis generated three main periods for analysis: 1996–2004 (to represent connections established by the OEMs with semiconductor suppliers), 2005–2020 (to maintain these connections), and 2020–2023 (a shift of procurement's focus to supply assurance).

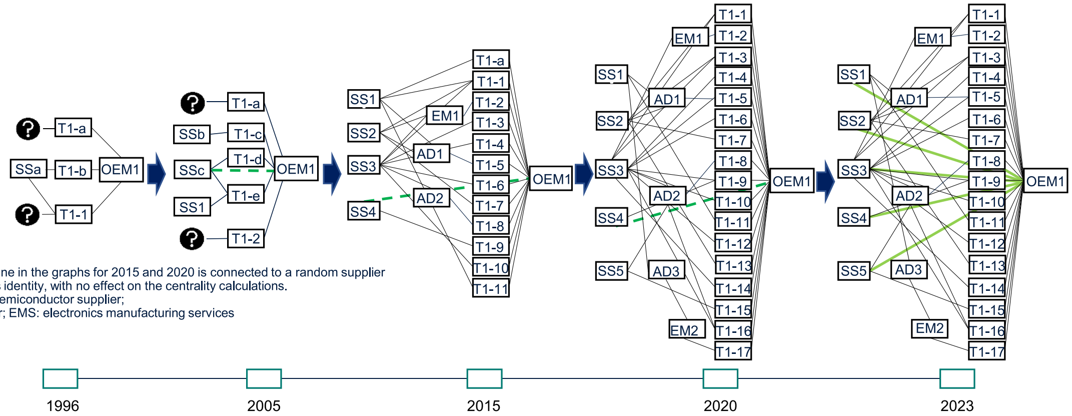
Thereafter, transcriptions and other data were coded inductively using NVivo software. Joint discussions were conducted among the researchers to reach consensus and identify suitable concepts from the literature (Eisenhardt, 1989) directly related to procurement focus (i.e. on cost, innovation, and securing supply), changes in the supply network, influences of supply network structure, and relevant external and internal environmental factors.

Graphs of OEM1's supply network over the studied years were generated based on E/E architecture maps and component lists. In addition to the starting and ending years of each analyzed period (1996, 2005, 2020, and 2023), we included the network map for 2015, since the supply network changed considerably in that year. In each network map, connections between two nodes represented the existence of a contractual relationship between the two actors and an established transactional relationship. The only exception was the connections between OEM1 and semiconductor suppliers, which were not regulated by contracts.

We used Pajek software (De Nooy *et al.*, 2018) to plot network maps and calculate the network metrics in Table 1. We analyzed the relationships between the procurement focus, supply network structure, and external and internal environmental factors. All observations were clustered into themes that supported the same interaction as measured between procurement focus and supply network structure.

4. Findings

For the OEMs studied, the procurement focus can be divided into two periods. In the period 1996–2020 procurement's predominant focus was on cost and a limited focus was on innovation and supply assurance. In contrast, the period 2020–2023 was characterized by a shift to a predominant focus on supply assurance. Figure 1 presents the evolution of OEM1's supply network through maps of OEM1's supply network for SECs in the years 1996, 2005, 2015, 2020, and 2023 as well as the main SNA metrics measured for the network (see Appendix 2 for a table with all network metrics for all network nodes). The network maps show a constant growth of the network, from seven actors to 28, which can be associated with the increasing number of electronics in vehicles, that is, from five ECUs in 1996 to more than 30 in 2020 for OEM1. One consequence of the growing number of ECUs was OEM1's



Notes: the green dotted line in the graphs for 2015 and 2020 is connected to a random supplier to preserve the supplier's identity, with no effect on the centrality calculations.
T1: Tier 1 supplier; SS: semiconductor supplier;
AD: authorized distributor; EMS: electronics manufacturing services

Supply network metrics

	1996	2005	2015	2020	2023
OEM 1 centrality					
Degree	3	6	13	18	23
Betweenness	0.600	0.822	0.59	0.56	0.67
Closeness	0.111	0.071	0.040	0.027	0.031
Tier 1 centrality (average)					
Degree	2.33	2.2	2.33	2.35	2.34
Betweenness	0.29	0.16	0.03	0.02	0.01
Closeness	0.089	0.048	0.026	0.017	0.018
Semiconductor Supplier centrality (highest)					
Degree	2	3	10	14	14
Betweenness	0.067	0.022	0.21	0.26	0.17
Closeness	0.077	0.050	0.033	0.024	0.024
Network-level metrics					
Size	7	11	20	28	28
Density	0.33	0.22	0.18	0.13	0.14
Degree centralization	0.23	0.47	0.56	0.58	0.72

Procurement focus and decisions

Cost

-1996 – 2020: Sustained cost focus at sourcing, all OEMs

Adoption of a cost-efficient Tier 1-centered sourcing model

Innovation

-1996: selection of MCUs, OEM1

-2004: Beginning of semiconductor focus at R&D, OEM3

-2005: Decision to use one MCU family, OEM1

-2005 – 2020: Sustained direct contact between OEMs' R&D and semiconductor suppliers, all OEMs

Limited procurement contact with semiconductor suppliers (e.g., signing non-disclosure agreements for R&D's discussions regarding MCUs)

Access to innovation happened mostly through Tier 1 suppliers

Supply assurance

1996 – 2020: Supply assurance through the Tier 1 suppliers. Stable suppliers, taken as a "given"

OEMs' R&D ensured that MCU would be produced for as many years as OEMs needed

-2020 – 2023: Supply assurance focus

-2021: Creation of semiconductor taskforces

Direct contact with semiconductor suppliers

Source(s): Created by the authors

Figure 1.
Summary of findings

increasing degree centrality, mostly due to new direct connections with Tier 1 suppliers to procure the new ECUs needed. On the other hand, we observed a decrease in OEM1's closeness centrality, with the exception of the period 2020–2023.

Besides the increase in network size, we observed an increased network centralization, which can be attributed to an increasing number of OEM1's connections with Tier 1 suppliers and the consequent overload on OEM1. On the other hand, the network's density decreased in the period 1996–2020, as a result of the predominance of connections going through Tier 1 suppliers and the lack of connections between OEM1 and semiconductor suppliers in this period.

4.1 OEMs' continuous focus on cost and Tier 1 suppliers (1996–2020)

For the studied OEMs, as electronics design was not recognized as a core competence, they adopted an overall focus on cost efficiency and based on reliance on Tier 1 suppliers: OEMs specified the required functionality of the ECUs but did not oversee the ECU design and its subcomponents. "*We were looking for a system supplier that is able to deliver the complete system*" (OEM2-P2). Consequently, the responsibility for the selection of subcomponents and the assurance of supply was given to Tier 1 suppliers. The result of this practice was what is referred to in the industry as the "black box approach." This outsourcing to Tier 1 suppliers was a cost-efficient model in which the OEM had the Tier 1 supplier as a single point of contact to coordinate the rest of the SC for a given ECU.

It is important to highlight that a cost focus does not mean a complete absence of procurement activities oriented toward innovation and supply assurance during this period. In fact, some OEMs' purchasers mentioned the existence of supply assurance activities in the early 2000s, and their earlier involvement in the product development process in the late 2000s. However, these activities were occasional and dependent on the purchaser's own interest in technical discussions. In the period 1996–2020, cost was identified as the OEMs' main procurement objective and their main motivations for a sourcing model reying on Tier 1 suppliers.

The OEMs' cost focus had important consequences for the supply network. Cost pressure from OEMs prompted Tier 1 suppliers to establish cost-efficient SCs, production in low-cost countries, and it encouraged the emergence of new actors such as authorized distributors and EMS companies. Adding new actors increased the length of paths between OEMs and semiconductor suppliers, which caused OEMs' low closeness centrality. "*And we didn't really know before this 2020–2021 crisis. We were not sure, and we didn't ask the suppliers, how they do the procurement of components or who is delivering the components to them. We don't know if they use a distributor or if they have a direct relation with (the semiconductor supplier)*" (OEM1-PSQM2). In the case of OEM1, the longest distance from OEM1 to a semiconductor supplier increased from two in 1996 to four in 2020.

The focus on Tier 1 suppliers and cost efficiency prevented OEMs from connecting with semiconductor suppliers. Besides an overall sentiment of "*staying away from semiconductor suppliers*," focusing resources on cost-reduction activities constrained the availability of resources to cultivate connections with semiconductor suppliers. This happened despite the increased amount and cost of semiconductors in vehicles.

4.2 Need for and challenges of capturing innovation (1996–2020)

The supply network forged by the OEMs' continuous focus on cost and Tier 1 suppliers created a lack of transparency in the network and affected their access to market innovation. Already in the period 1996–2020, the lack of OEMs' connection to semiconductor suppliers constrained their access to innovation and new semiconductor technologies in the supply network. Faced by increasing demands from vehicle emission regulations that required the latest technologies and increasing performance in its ECUs, OEM1 found itself dependent on its Tier 1 suppliers to access new semiconductor technologies. This motivated OEM1's R&D department to increase its involvement in software development and establish a direct yet informal connection to semiconductor suppliers to select MCUs for powertrain ECUs. "*We had learned that we need to bring software in … then we took a really big and important decision, and we did look at different suppliers, but we ended up in a new development component CPU from [semiconductor supplier]*" (OEM1-T1).

In OEM3's case, a connection to semiconductor suppliers was needed to secure timely access to new technologies for infotainment and driver assistance systems, which the OEM could not obtain from Tier 1 suppliers. As a result, in 2004, OEM3 started to investigate semiconductors in its ECUs and established informal connections to semiconductor suppliers through its R&D department.

Hence, in the cases of OEM1 and OEM3, the low closeness centrality and lack of connections to semiconductor suppliers hindered the OEMs' access to innovation. The OEMs identified the need to follow the technological developments in the semiconductor industry and increase their closeness centrality to capture innovation and meet the demands from the external environment. Their efforts included gaining knowledge about semiconductors through their R&D departments, with no involvement from procurement.

In the period 2005–2020, the connections between the OEMs and semiconductor suppliers were maintained, driven by the need to obtain synergies in software development for the growing number of ECUs, as the OEMs decided to choose a semiconductor supplier and a family of MCU chips to use across different ECUs. "*Because we had the control of the software by ourselves, it was not that important to talk with the Tier 1s how to handle this. It was more important to have, already at that time, a discussion about what is the next step in the chip development*" (OEM1-T1).

The direct connection with the semiconductor suppliers made the OEMs less dependent on Tier 1 suppliers and helped them overcome Tier 1s′ difficulty in following all developments in the semiconductor industry. "*Because these devices are so complex, you must know a lot of things. And the Tier 1s, they're not able to, with their resources, to understand every device. So, the knowledge you must know is at the semiconductor supplier and not at the Tier 1*" (OEM3-T1).

On the other side of the equation, semiconductor suppliers needed information on the demands of OEMs to develop new technologies, and they faced difficulties obtaining this information through Tier 1 suppliers. "*It's been hard to define the new technologies based on the information from the Tier 1*" (SS). Consequently, semiconductor suppliers also sought to maintain direct relationships with OEMs.

These relationships only had a technical character, and once the semiconductors were selected, all commercial aspects of supplying the semiconductors were handed over to Tier 1 suppliers. Other reasons for procurement's limited involvement with semiconductors were a lack of knowledge about semiconductors and R&D's power in making decisions for technology selection.

4.3 Securing supply and the unforeseen disruption (2020–2023)

The OEMs' procurement focus suffered a dramatic change with the semiconductor shortage crisis that started in late 2020. Prior to 2020, the predominantly stable external environment in this period allowed the OEMs' procurement to focus on cost savings with limited concerns about component supply, despite minor previous supply disruptions. The OEMs relied predonminantly on Tier 1 suppliers to secure supply, as deliveries were taken as a given. "*At that time, we had never discussed certain stocks for us or to secure the deliveries. At that time, it was for us, it was a given*" (OEM3-P1). By relying on Tier 1 suppliers to secure semiconductor supply, the OEMs did not connect with the semiconductor suppliers until 2020, lowering their closeness centrality (see Figure 1). In addition, the lack of supply assurance focus prevented the OEMs from identifying and understanding the consequences of long supply chains.

After this long period of stable supplies, natural disasters and component shortages in the period 2020–2023 prompted the OEMs' procurement to better secure component supply. Largely due to changes in demand patterns due to the COVID-19 pandemic and other events such as a snowstorm, a fire incident, and specific COVID-19 outbreaks, the semiconductor crisis of this period affected the automotive industry in many ways. As a result of the OEMs' low closeness centrality and lack of connection to semiconductor suppliers, the OEMs did not receive early warnings of shortages, and access to information and transparency of deliveries was dependent on Tier 1 suppliers. This limited the OEMs' ability to react to the shortages.

Missing semiconductor supplies and the high cost of lost production made the OEMs' focus shift from cost to securing supply. They created cross-functional taskforces and dedicated semiconductor procurement positions to establish connections with semiconductor suppliers. This was done to address their low closeness centrality and lack of visibility in the supply network. For OEM1, the new connections increased its closeness centrality and helped it access information from semiconductor suppliers. "*It's easier to talk to the source. We have access to the source, that is the semiconductor manufacturer. And then we can ask them so we don't have to rely on our tier 1 to tell us everything*" (OEM1-P3).

The impacts of the shortages also affected the collaboration between procurement and R&D departments internally at the OEMs due to the realization of the importance of supply assurance when a semiconductor component is chosen.

4.4 Evolution of the supply network across time periods

Table 3 summarizes the network characteristics and their implications for procurement across the years of our study. In terms of node centrality, the quantitative data indicate a decrease in the betweenness and closeness centrality of the Tier 1s and increased degree centrality of the semiconductor suppliers. This contradicts the central position of the Tier 1 suppliers in connecting the objectives of the OEMs with the semiconductor suppliers, which resulted in a detachment between upstream and downstream in innovation/developments, and supply planning. The direct communication links created between the OEM and one semiconductor supplier in 2023 contributed to better sharing of information, but the Tier 1 contracts still restricted the type and amount of information sharable.

In respect to network complexity, the size of the network increased significantly, but the density decreased. Aside from a larger number of semiconductor suppliers, new Tier 1 suppliers also entered the network. Increasingly disconnected nodes appeared in the network in 2005, such as authorized distributors and EMS companies, thus lowering network density. The network's increasing centralization highlighted the increasing number of connections of the OEM, but our contextual data revealed that each ECU had one responsible Tier 1 supplier, which had a central position connecting the other nodes in the chain for that ECU.

In contrast to the decreasing betweenness centrality shown by SNA metrics, Tier 1 suppliers maintained a central position because information flows were often specific to a certain ECU in its supply chain. In each of these unique information paths, the Tier 1 supplier was positioned in the path between the OEM and the semiconductor supplier, having the task and power to control the flow of information and materials. The centrality of Tier 1 suppliers was also observed in the cases of OEM2 and OEM3: "*I always told my management: 'Hey, there we get 20% more [semiconductor cost]. We have now, I don't know, €500 in the car, in five years we will have €2,000 in the car of semiconductors', but nobody was saying 'OK, we have to really put more focus on it.' It was still the point that it was done by the Tier 1s*" (OEM3-P1).

Table 3. Cross-year analysis of network characteristics

	1996	2005	2015	2020	2023
Node centrality	- The OEM's degree centrality increases from 1996 to 2023 (3–22) and closeness centrality decreases (0.111–0.031); betweenness remains the highest in the network (0.6) - Tier 1 suppliers' average degree centrality does not change (~2.33) but closeness centrality (0.089–0.018) and betweenness centrality decrease strongly (0.2–0.01) from 1996 to 2023 - The semiconductor suppliers' highest degree centrality increases (SS3, from 2 in 1996 to 14 in 2023), but closeness centrality decreases considerably (0.077–0.024); the highest betweenness centrality decreases (0.067–0.17) while many semiconductor suppliers have betweenness centrality close to 0				
	- Lack of connections between OEM and semiconductor suppliers - Tier 1 suppliers have central position to control and connect upstream and downstream	- OEM's decision to use one semiconductor family across its ECUs enables SS3's growing degree centrality starting from 2005 - Stronger links are created with specific semiconductor suppliers (OEM1 - SS3)	- Degree centrality of OEM and semiconductor suppliers increase due to new connections with Tier 1 suppliers - Emergence of new, disconnected nodes (ADs, EMs) - A gap is created in linking innovation needs and possibilities between OEMs and semiconductor suppliers	- Tier 1 suppliers cannot coordinate supply and demand for semiconductors due to demand fluctuations and semiconductor shortages	- OEMs make direct connections with semiconductor suppliers connections aiming to secure supply by increasing information sharing - Information flows are still restricted by confidentiality terms of contracts with Tier 1 suppliers

(*continued*)

	1996	2005	2015	2020	2023
Network complexity	- Network size increases from 7 to 28, and density decreases from 0.33 to 0.14 - Continuous network growth due to the need for new ECUs - The entrance of new Tier 1 suppliers outweighs mergers and acquisitions between Tier 1 suppliers - Addition of new, increasingly disconnected nodes - During all years except 2023, all connections passed through Tier 1 suppliers - No cooperation between nodes of the same type: each ECU has one responsible Tier 1 supplier, which is connected to other nodes needed for that ECU				
	- Small number of ECUs in vehicles - Few Tier 1 suppliers are able to meet ECU vibration test requirements - Monopoly-like position of those few Tier 1 suppliers	- High network density	- Entrance of Tier 1 suppliers previously specialized in mechanical parts - First appearance of ADs and EMS companies in the network	- The network achieves its peak size with the entrance of new nodes in all node types	- Network density slightly increases due to new connections across the network
Network centralization	- Degree centralization of the network increases from 0.23 to 0.72 - Unique information paths for each ECU makes the Tier 1 supplier the central actor in each ECU's supply chain - Increasing centralization represents the high centrality of the OEM, while in reality, power is centered around Tier 1 suppliers				
	OEMs' active decision not to design ECUs but rather rely on Tier 1 suppliers for that task	–	Lack of resources and semiconductor knowledge stopped OEMs from involvement with semiconductor suppliers, despite growing value of semiconductors in vehicles	–	–

Source(s): Created by the authors

Table 3.

In Table 3, the most central semiconductor supplier is highlighted. OEM1's decision to use SS3's MCUs across different ECUs made it the most central supplier in its network, which is visible by SS3's increasing degree centrality. We observed a similar trend for all three OEMs. These direct connections only covered innovation aspects and did not affect cost and supply assurance, which was coordinated by Tier 1 suppliers. "*We didn't think that much about the rest of the supply chain. From the semiconductor perspective, you need to know who is taking the decision to put your part on the PCB [printed circuit board]. And then you focus on that party in the supply chain to put your part on the BOM [bill of material] or on the PCB. And then, if that causes a problem or not to the rest of the supply chain, I don't think we took that into consideration. Or not, at least on the sales side I would say*" (SE2).

On a network level, the increasing network size points to an increasing network complexity and reflects the OEMs' difficulty in being connected to relevant suppliers due to limited resources: "*With the manpower we had, we could not communicate to different players in the game*" (OEM3-P1). After 2020, to address previous insufficiency of resources, OEMs allocated semiconductor procurement teams with a focus on innovation, cost, and supply assurance. On the other hand, a decreasing network density over the years until 2020 reveals a declining network complexity due to an increasing number of suppliers that are disconnected from one another (see Figure 1). Every ECU had a supply chain that was managed by a Tier 1 supplier, with no cooperation between actors of the same type or across the network. The detachment between OEMs and lower tier suppliers hindered the OEMs' ability to recognize changes happening in the semiconductor industry, such as the changes in demand and supply that caused the semiconductor crisis in late 2020: "*At that time, we didn't know much about semiconductor industry and for us, it was more the focus on the price and the setup, do we have the right product and how we get the price down, 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*." (OEM3-P1).

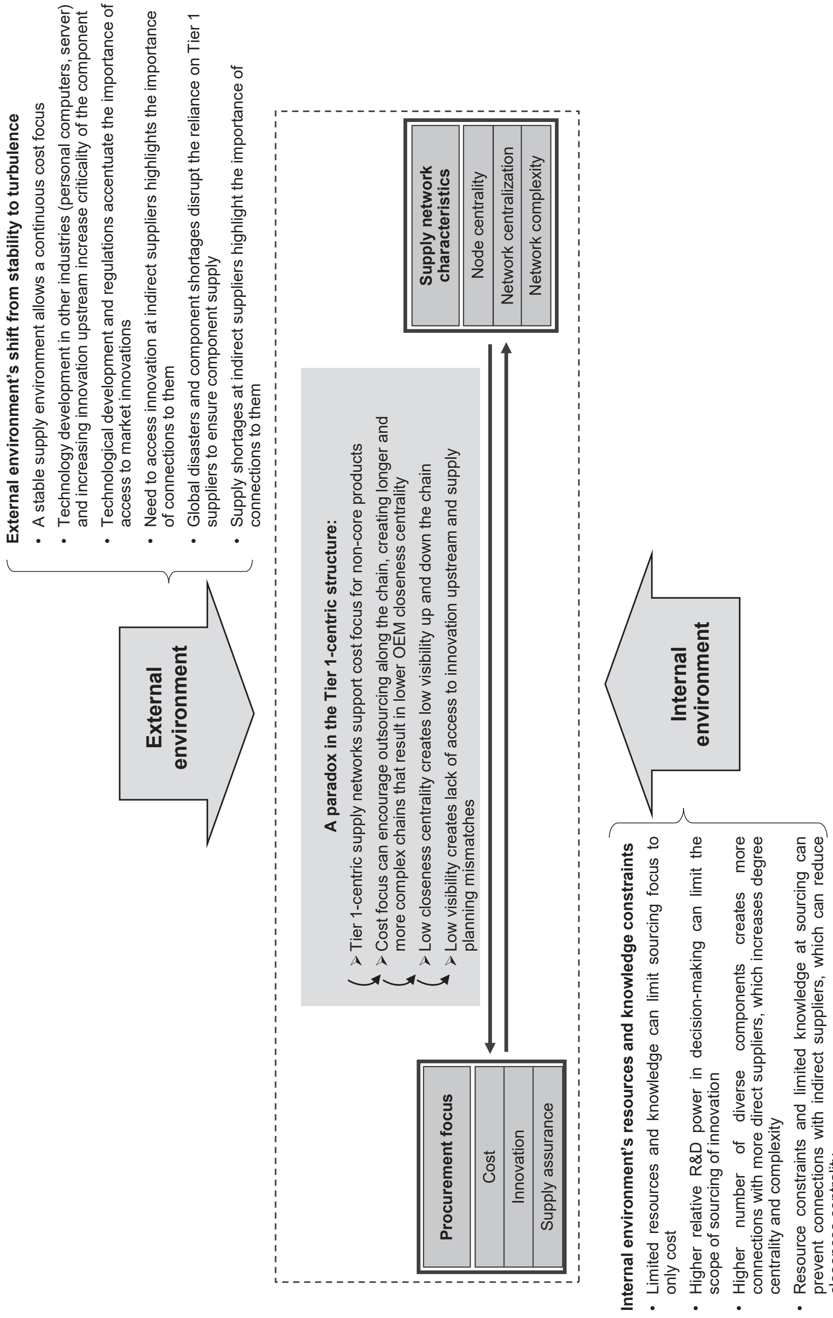
5. Discussion

In this paper, we aimed to investigate how the SEC network and the automotive industry have interrelated over time, and what the implications of the supply network structure were for the OEMs procurement of SEC. As summarized in Figure 2, our findings indicate (1) a change in the Tier 1-centric supply network of the OEMs (represented in the center of Figure 2 and further discussed in Section 5.1), and (2) triggers or restrictions posed by the stability or turbulence of the decision-making environment (internal and external) (summarized on the top and bottom of Figure 2 and elaborated in Section 5.2).

5.1 The change of a Tier 1-centric supply network

As summarized in the mid-section of Figure 2, our findings indicate a paradox in the formation of the Tier 1 centric supply network to support cost objectives in the context of our study. The focus on the cost objectives contributed to a network structure that resulted in low visibility and mismatches in planning upstream and downstream, which not only did not support the cost objectives in recent years, but also sacrificed innovation and supply assurance. In the automotive SEC context of our study, the products have been categorized as non-core competences, and the industry has historically been very dependent on Tier 1 suppliers as hubs in the network (Han *et al.*, 2020; Choi and Linton, 2011).

OEMs had centered their procurement through Tier 1 suppliers to achieve all procurement objectives (Choi and Linton, 2011) and relied on the Tier 1 suppliers to access and coordinate innovation and supply in a cost-effective manner. The Tier 1 suppliers were placed in the center of each product's supply chain, took on a "broker role" and the control of information



Source(s): Created by the authors

Figure 2.
Implications of the supply network structure and decision-making environment on procurement of technological components

(Borgatti and Li, 2009; Kim *et al.*, 2011), and the OEMs became unaware of technological developments and supply planning in the semiconductor domain. The OEMs had a "coordinator role" in the network (as defined by Kim *et al.*, 2011), which enabled them to access innovation from Tier 1 suppliers and implement them in their products to meet their technological needs. This was also evident in their high degree centrality and the high network centralization.

The implications of these measures and the coordinator's role were twofold. First, contrary to the expectation that OEMs' cost focus would reduce the number of direct suppliers (Kim and Narasimhan, 2019; Hesping and Schiele, 2015), this was not possible due to the growing number of ECUs, and the OEMs did not reduce the number of Tier 1 suppliers, creating high coordination costs for the OEMs' procurement. Second, new Tier 1 connections reduced the OEMs' visibility to lower tier suppliers, who were a crucial source of innovation and capacity, which was made evident by a decreasing closeness centrality (Kim *et al.*, 2011, 2020; Borgatti and Li, 2009; Legenvre and Gualandris, 2018).

After 2020, the OEMs' focus shifted to supply assurance, and there was a visible increase in degree and closeness centrality (Li *et al.*, 2020; Kim *et al.*, 2015; Pereira *et al.*, 2020). The new connections here contributed to a better flow of supply and information. The increased importance of SEC, in turn, increased the need for alignment between the OEMs and semiconductor suppliers. At the same time, the OEMs aimed to control a number of tasks that were previously entrusted to Tier 1 suppliers.

Our study reveals a case of hubs becoming overloaded in their task in the network to link the offerings from upstream with the demands from downstream (Hearnshaw and Wilson, 2013; Kim *et al.*, 2011). As a reaction, direct connections between OEMs and indirect suppliers were formed. This moved the network structure away from the linear supply chain that has often been studied in SNA research (Han *et al.*, 2020) and into an interconnected, and arguably complex, structure that should be the subject of further research. While some scholars have suggested that reduction of complexity can "simplify supply chains" (Bode and Wagner, 2015), others have argued that greater complexity in terms of number of actors and network density relates to better procurement performance in cost savings, supply assurance, and innovation (Ateş and Memiş, 2021; Choi and Krause, 2006). In our study we found, in line with these latter arguments, that after 2020, to access innovation and secure supply, OEMs' created new connections across the network that have increased network density and complexity. Yet, it is not possible to say that the network has become more complex from 1996 to today, as it has become larger in size but with lower density. The decrease in density is due to the lack of connections across the network, which also explains the low supply chain visibility between the OEMs and the semiconductor producers.

5.2 Role of the external and internal environments

Theoretically, in a stable supply environment, a firm's inclination toward a cost focus is rational (Ghobadian *et al.*, 2007; Patrucco *et al.*, 2023). Changes in the environment or the focus should be adjusted accordingly (Choi *et al.*, 2001; Kim and Narasimhan, 2019). These adjustments did not happen as expected in the context of our study, because procurement did not increase its innovation and supply assurance focus to match the network changes, while the network changed regardless of the OEM directives.

Over the past decades, the importance of semiconductors for innovation has increased, and R&D increased its focus on semiconductor components, but not procurement. In an environment marked by technological uncertainty, procurement is expected to increase its innovation focus (Luzzini and Ronchi, 2011; Patrucco *et al.*, 2023) technical product knowledge, and internal resources to engage with indirect suppliers (Luzzini and Ronchi, 2011; Johnsen, 2011; Mena *et al.*, 2013), and collaborate with R&D (Schiele, 2010; Arvidsson *et al.*, 2022). In our study, we found that limitations in internal resources, knowledge, and alignment with R&D resulted in low procurement capability to identify and absorb innovation from indirect suppliers and to adjust to the external environment. Additionally, procurement is expected to increase its supply assurance capabilities when it lacks SC visibility (Pereira *et al.*, 2020). In the context of the OEMs we researched, reliance on Tier 1's to manage the supply, limited market knowledge, and limited understanding of the production process of semiconductors resulted in low capabilities to assure supply after 2020.

In both the situations of supply instability and technological uncertainty, new connections along the network can increase information transparency (Bellamy *et al.*, 2014; Küffner *et al.*, 2022; Choi and Linton, 2011), but these connections require additional resources and investment in technical skills at procurement (Mena *et al.*, 2013; Luzzini and Ronchi, 2011). We also found that moving from a hub-centric network to distributed connections with various nodes across the network can benefit from dedicated procurement teams that connect with indirect suppliers and increase technical knowledge about their products. Such a move requires procurement to shift the focus from Tier 1 suppliers to a holistic view of the value chain (Choi and Linton, 2011; Ramírez *et al.*, 2020), which we observed in the links that OEMs were making with semiconductor suppliers in 2023.

6. Conclusion

The findings of this study add to our understanding of supply chain management in distinct ways. First, increasing technological relevance and supply uncertainty of indirect suppliers' products can outpace the supplier hubs' coordination capability in the network and hinder innovation and supply assurance. In recent years, these hinderances have motivated OEMs to skip their Tier 1 supplier hubs and establish connections across the supply network, but ideally, this should not only happen after a global shortage crisis. Hence, firms in a supply network that is centered around hub nodes need to maintain the ability to sense developments in their external environment and adapt their procurement focus and internal environment. In this regard, similar to the suggestions of Choi and Linton (2011), we believe that OEMs should not overly delegate responsibilities to direct suppliers, such as the coordination of innovation and supply assurance for critical components.

Second, by taking a longitudinal retrospective perspective of the supply network structure using SNA, we add to the existing literature that otherwise consists of studies investigating the network at a given point in time (Kim *et al.*, 2011, 2020; Bellamy *et al.*, 2014; Li *et al.*, 2020). This longitudinal view reveals how network and firm strategies co-evolve, or fail to, over time.

Third, we extend our knowledge of the automotive SEC supply network, an increasingly critical context. Our main contribution here is to the call for more studies mapping the supply network (Congress.gov, 2022; European Commission, 2023), by providing a map of the automotive SEC supply network and its interactions over 3 decades. We also expand the existing knowledge on the importance of the internal (Luzzini and Ronchi, 2011; Ateş *et al.*, 2018) and external environments (González-Benito *et al.*, 2010; Ghobadian *et al.*, 2007) by shedding light on the role of regulatory, technological, and supply uncertainties in this network and the increased resources and technical knowledge needed by OEMs' procurement to counterbalance these uncertainties.

Fourth, in this study, the use of SNA and its metrics furthers our understanding of the roles of nodes in the supply network. We highlight the consequences of OEMs' centrality and of the perceived overload on the central Tier 1 suppliers and show the implications of these characteristics on the network over time (Borgatti and Li, 2009; Kim *et al.*, 2011). By only using SNA metrics, it would not be possible to capture the nature of the relationships, in terms of strength, content, and the relevance of the actors. Hence, it is beneficial to combine SNA metrics with qualitative insights in the SCM context (Kim *et al.*, 2011). In our study, contextual data on OEMs' strategic decisions and motivations for their procurement focus aided our understanding of the connections established and changes in the network over time.

For practitioners, the understanding of the circumstances that formed today's supply network structure can aid in the development of procurement strategies to attain objectives of cost, innovation, and supply assurance in the future. Based on the case of the automotive SECs, our findings can contribute to the procurement of similar types of products, especially those sourced through supplier networks that extend into multi-tiers upstream and have some kind of criticality. Our findings suggest that strategies that account for external and internal factors can help companies better manage supply disruptions and secure innovation. Specifically, monitoring legal regulations and developments beyond the first supplier tier as well as investing in resources and knowledge are initiatives that can strengthen firms' procurement's ability to deal with future challenges.

This study was limited by taking the OEMs' perspective in the automotive industry, which further studies could extend to more firms and in other industries. Furthermore, while measures were taken to ensure the accuracy and completeness of the findings from the retrospective study, these findings are reported as accounts of the most relevant developments in the studied time and are not intended as an exhaustive narrative of this period. The findings of this paper reveal periods of OEMs' focus on cost or supply assurance, but no focus on innovation of semiconductors. Future research can focus on how procurement can strengthen required internal factors (e.g. technical knowledge, collaboration with R&D) to access supplier innovation. The findings also reveal opportunities for future research to extend our findings related to the procurement's role in shaping the supply network to secure procurement objectives. For example, future research can explore the perspective of Tier 1 suppliers and other actors in the automotive supply network and other sector networks. Another possibility for future research is to investigate the applicability of the model presented in Figure 2 to other types of components or in other industries to understand what internal and external factors influence the supply network for other types of components. Finally, future research can investigate the role of procurement in securing access to innovation in an environment of intense technological development of semiconductors.

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Appendix 1

#	Type of network change	Topic	Link
1	Semiconductor supplier: entrance in the automotive market	Entrance of Intel in the automotive industry	https://timeline.intel.com/1988/on-the-road
2	Semiconductor supplier: entrance in the automotive market	Entrance of Intel in the automotive industry	https://www.intel.com/content/www/us/en/history/virtual-vault/articles/book-ford.html
3	Tier 1 supplier: mergers, acquisitions, spin-offs	Split of SAAB combitech	https://www.saab.com/globalassets/cision/documents/1999/19990506-saab-omstrukturerar-combitech-sv-1-7170.pdf
4	Tier 1 supplier: mergers, acquisitions, spin-offs	Split of SAAB combitech	https://etn.se/index.php/11317
5	Semiconductor supplier: mergers, acquisitions, spin-offs	Infineon's spin off from Siemens semiconductors	https://www.eetimes.com/siemens-names-chip-spinoff-infineon/
6	Semiconductor supplier: entrance in the automotive market	Motorola semiconductors in the automotive industry	https://www.radiolocman.com/news/new.html?di=913
7	Semiconductor supplier: entrance in the automotive market	Motorola semiconductors in the automotive industry	https://europe.autonews.com/article/20000424/ANE/4240836/motorola-enjoys-long-term-deals
8	Semiconductor supplier: mergers, acquisitions, spin-offs	Motorola semiconductors becomes Freescale	https://www.motorolasolutions.com/newsroom/press-releases/motorola-completes-separation-freescale-semiconductor.html
9	Semiconductor supplier: mergers, acquisitions, spin-offs	Freescale's take over by NXP	https://www.reuters.com/article/us-autos-semiconductors-nxp-semicondtrs-idUSKBN0TQ1IK20151207
10	Tier 1 supplier: mergers, acquisitions, spin-offs	Motorola's take over by Continental	https://www.continental.com/en/investors/ir-news/ad-hoc-news/continental-ag-continental-to-acquire-motorolas-automotive-electronics-business/
11	Tier 1 supplier: mergers, acquisitions, spin-offs	Siemens VDO acquired by Continental	https://www.continental.com/en/investors/ir-news/ad-hoc-news/continental-agcontinental-acquires-siemens-vdo-for-eur114-billion/
12	Tier 1 supplier: mergers, acquisitions, spin-offs	Split of Aptiv from Deplhi	https://ir.aptiv.com/investors/press-releases/press-release-details/2017/Delphi-Automotive-Announces-Post-Spin-Off-Names/default.aspx
13	Tier 1 supplier: mergers, acquisitions, spin-offs	BorgWarner acquires Delphi	https://www.forbes.com/sites/greggardner/2020/01/28/borgwarner-to-buy-delphi-technologies-in-33-billion-deal/
14	External factors: emission regulations	European vehicle emission regulations	https://single-market-economy.ec.europa.eu/sectors/automotive-industry/environmental-protection/emissions-automotive-sector_en
15	External factors: natural disasters	Impact of earthquake in Japan 2018	https://www.reuters.com/article/us-japan-quake/magnitude-6-1-quake-kills-three-stops-factories-in-japans-osaka-area-idUSKBN1JD13F/?il=0

Table A1.
List of news articles

Appendix 2

		Degree centrality					Closeness centrality					Betweenness centrality				
		1996	2005	2015	2020	2023	1996	2005	2015	2020	2023	1996	2005	2015	2020	2023
	OEM 1	3	6	13	18	22	0.111	0.071	0.040	0.027	0.031	0.600	0.822	0.59	0.56	0.67
Tier 1 suppliers	T1-a	2	2	2			0.083	0.048	0.025			0.333	0.200	0.03		
	T1-b	2					0.083					0.100				
	T1-1	3		3	3	3	0.100		0.027	0.018	0.019	0.433		0.01	0.01	0.00
	T1-2		2	4	4	4		0.048	0.028	0.018	0.019		0.200	0.06	0.02	0.01
	T1-c		2					0.048					0.200			
	T1-d		2					0.045					0.000			
	T1-e		3					0.050					0.200			
	T1-3			2	3	3			0.025	0.018	0.019			0.00	0.05	0.00
	T1-4			2	2	2			0.025	0.017	0.019			0.00	0.00	0.00
	T1-5			2	2	2			0.026	0.017	0.018			0.03	0.01	0.00
	T1-6			2	2	2			0.025	0.017	0.019			0.00	0.00	0.00
	T1-7			2	2	2			0.026	0.017	0.018			0.01	0.01	0.00
	T1-8			3	3	3			0.026	0.018	0.019			0.02	0.01	0.01
	T1-9			2	3	3			0.024	0.018	0.019			0.11	0.07	0.00
	T1-10			2	2	2			0.025	0.017	0.019			0.00	0.00	0.00
	T1-11			2	2	2			0.025	0.017	0.018			0.03	0.03	0.00
	T1-12				2	2				0.017	0.019				0.00	0.00
	T1-13				2	2				0.017	0.018				0.01	0.00
	T1-14				2	2				0.017	0.019				0.00	0.00
	T1-15				2	2				0.017	0.018				0.04	0.00
	T1-16				2	2				0.017	0.018				0.01	0.01
	T1-17				2	2				0.017	0.018				0.07	0.06
SS	SSa	2					0.077					0.067				
	** SS_1	1	1				0.059	0.033				0.000	0.000			
	** SS_2	1					0.067					0.000				
	** SS_3		1					0.033					0.000			
	SSb		1					0.033					0.000			
	SSc		3					0.050					0.022			
	SS1		1	3	4	5		0.034	0.020	0.014	0.020		0.000	0.02	0.07	0.08
	SS2			6	6	7			0.027	0.015	0.020			0.11	0.03	0.04
	SS3			10	14	14			0.033	0.024	0.024			0.21	0.26	0.17
	SS4			1	1	2			0.017	0.012	0.018			0.00	0.00	0.00
	SS5				2	3				0.013	0.018				0.00	0.01
EMS	EM1			2	3	3			0.020	0.016	0.016			0.00	0.00	0.00
	EM2				2	2				0.013	0.013				0.01	0.00
ADs	AD1			3	4	4			0.023	0.018	0.018			0.04	0.05	0.02
	AD2			2	4	4			0.021	0.016	0.016			0.00	0.04	0.01
	AD3				2	2				0.011	0.014				0.01	0.01

Table A2. Network metrics for all nodes